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(12) **Reissued Patent**

Mitsunaga et al.

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(54) **IMAGE PROCESSING APPARATUS AND METHOD FOR GENERATING A RESTORATION IMAGE**

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(73) Assignee: **SONY SEMICONDUCTOR SOLUTIONS CORPORATION**, Kanagawa (JP)

(21) Appl. No.: **14/968,441**

(22) Filed: **Dec. 14, 2015**

Related U.S. Patent Documents

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Issued: **Jul. 26, 2011**
Appl. No.: **12/112,778**
Filed: **Apr. 30, 2008**

U.S. Applications:

(60) Division of application No. 13/951,178, filed on Jul. 25, 2013, now Pat. No. Re. 46,557, which is an (Continued)

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Jan. 9, 2001 (JP) 2001-000980

(51) **Int. Cl.**
H04N 5/355 (2011.01)
H04N 9/04 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04N 5/35563*** (2013.01); ***H04N 5/367*** (2013.01); ***H04N 5/3651*** (2013.01); ***H04N 5/372*** (2013.01); ***H04N 9/045*** (2013.01)

(58) **Field of Classification Search**
CPC H04N 9/045; H04N 5/335; H04N 5/35563; H04N 5/367; H04N 5/3651; H04N 5/372; G06T 3/4015
See application file for complete search history.

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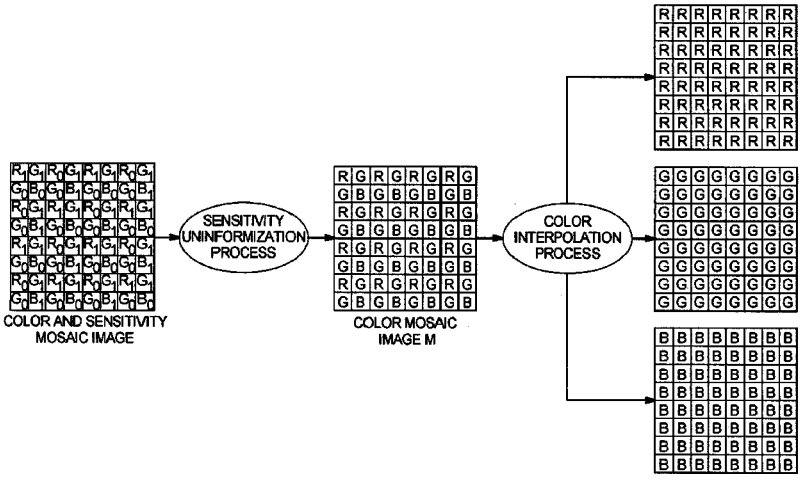
Primary Examiner — Stephen J Ralis
(74) *Attorney, Agent, or Firm* — K&L Gates LLP

(57) **ABSTRACT**

The present invention relates to an image processing apparatus which can restore, from a color and sensitivity mosaic image acquired using a CCD image sensor of the single plate type or the like, a color image signal of a wide dynamic range wherein the sensitivity characteristics of pixels are uniformized and each of the pixels has all of a plurality of color components. A sensitivity uniformization section uniformizes the sensitivities of pixels of a color and sensitivity mosaic image to produce a color mosaic image, and a color interpolation section interpolates color components of the pixels of the color mosaic image M to produce output images R, G and B. The present invention can be applied to a digital camera which converts a picked up optical image into a color image signal of a wide dynamic range.

36 Claims, 90 Drawing Sheets



Related U.S. Application Data

application for the reissue of Pat. No. 7,986,360, which is a continuation of application No. 10/466,015, filed as application No. PCT/JP02/00036 on Jan. 9, 2002, now Pat. No. 7,847,829.

(51) **Int. Cl.**

H04N 5/372	(2011.01)
H04N 5/365	(2011.01)
H04N 5/367	(2011.01)

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FIG. 1

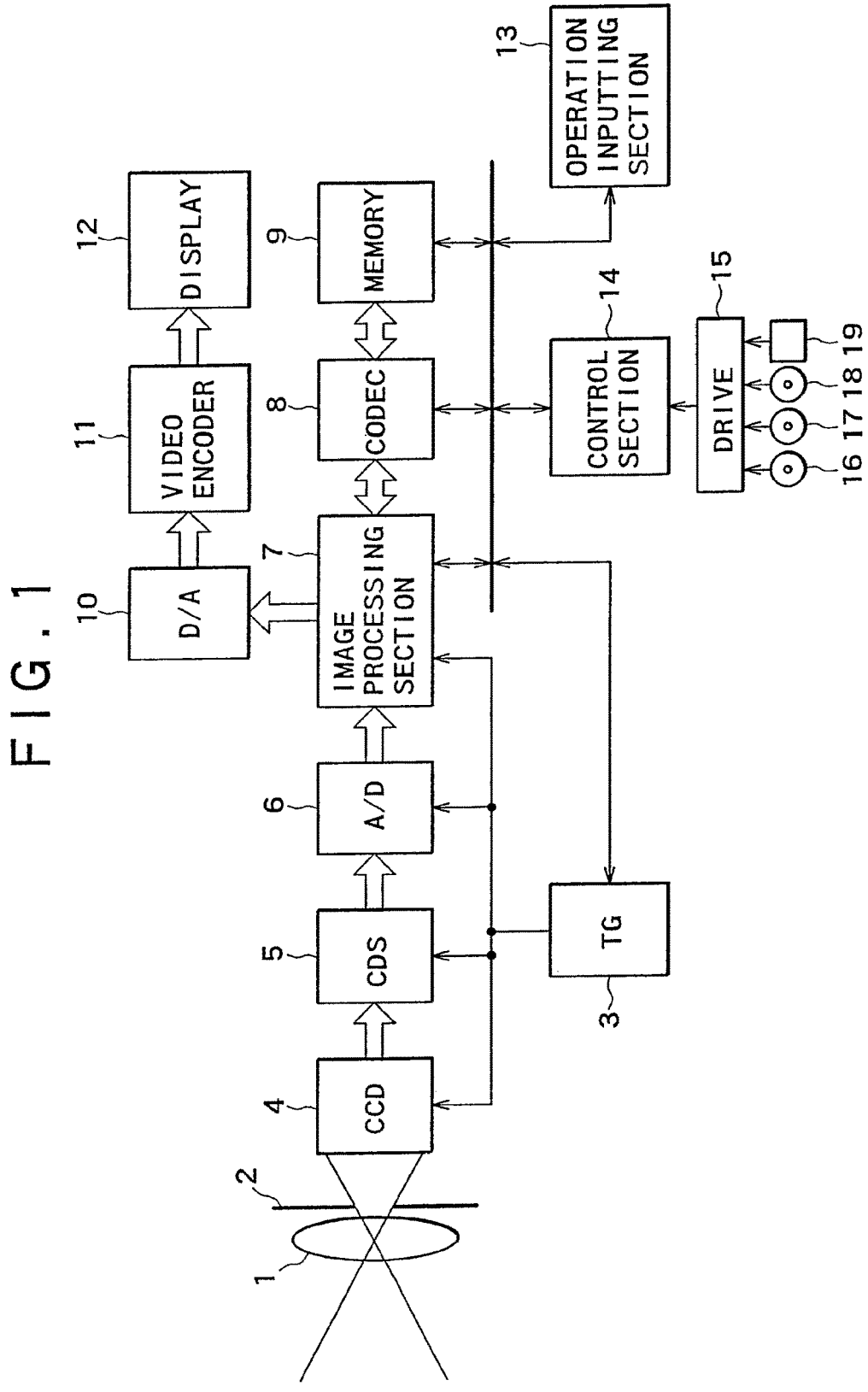

1
2
CCD
4
CDS
5
A/D
6
IMAGE PROCESSING SECTION
7
CODEC
8
MEMORY
9
D/A
10
VIDEO ENCODER
11
DISPLAY
12
TG
3
OPERATION INPUTTING SECTION
13
CONTROL SECTION
14
DRIVE
15
16 17 18 19

FIG. 2

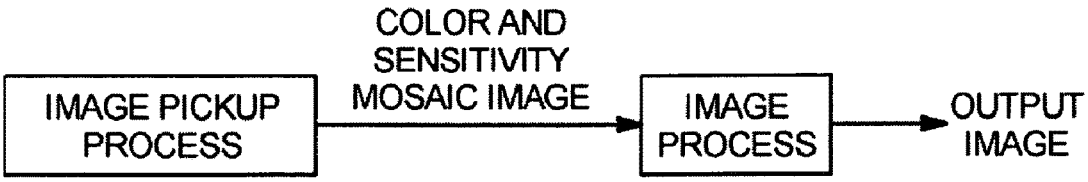


IMAGE PICKUP PROCESS
COLOR AND SENSITIVITY MOSAIC IMAGE
IMAGE PROCESS
OUTPUT IMAGE

FIG. 3

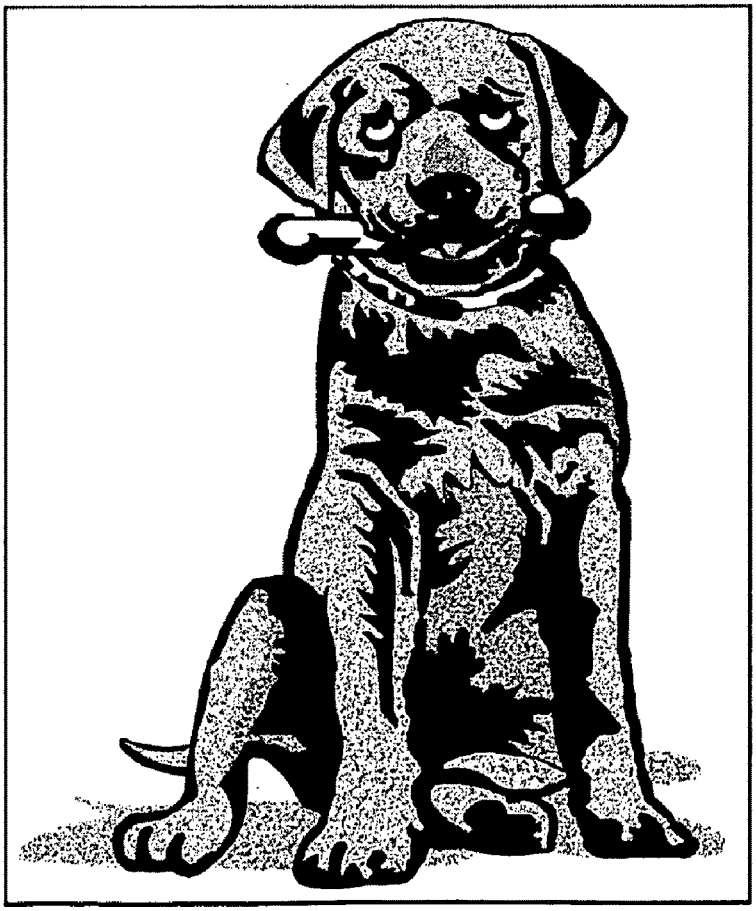


FIG. 4

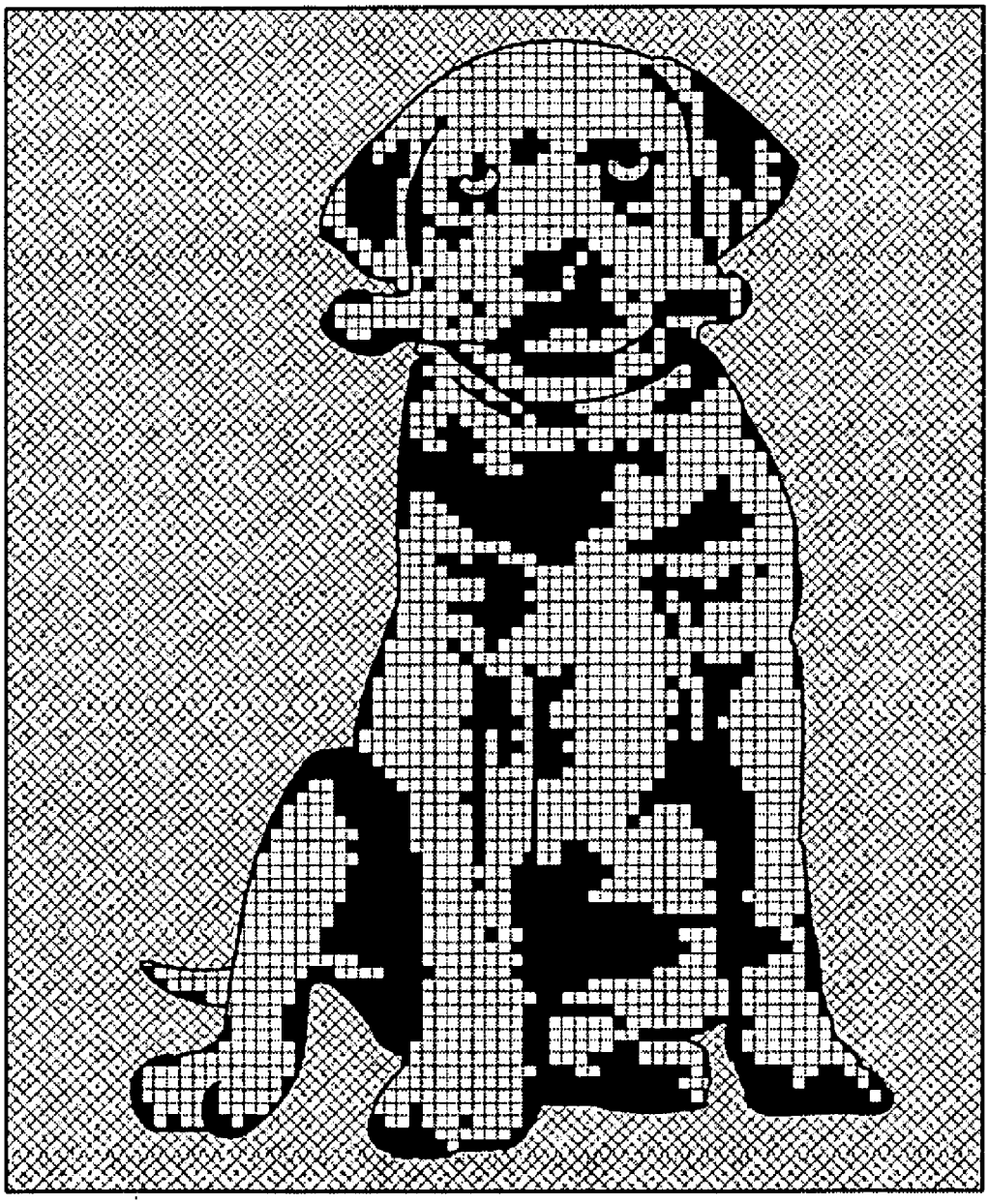


FIG. 5

R_1	G_1	B_1	G_1	R_1	G_1	B_1	G_1
G_0	B_0	G_0	R_0	G_0	B_0	G_0	R_0
B_1	G_1	R_1	G_1	B_1	G_1	R_1	G_1
G_0	R_0	G_0	B_0	G_0	R_0	G_0	B_0
R_1	G_1	B_1	G_1	R_1	G_1	B_1	G_1
G_0	B_0	G_0	R_0	G_0	B_0	G_0	R_0
B_1	G_1	R_1	G_1	B_1	G_1	R_1	G_1
G_0	R_0	G_0	B_0	G_0	R_0	G_0	B_0

FIG. 6

R_1	G_1	R_0	G_1	R_1	G_1	R_0	G_1
G_0	B_0	G_0	B_1	G_0	B_0	G_0	B_1
R_0	G_1	R_1	G_1	R_0	G_1	R_1	G_1
G_0	B_1	G_0	B_0	G_0	B_1	G_0	B_0
R_1	G_1	R_0	G_1	R_1	G_1	R_0	G_1
G_0	B_0	G_0	B_1	G_0	B_0	G_0	B_1
R_0	G_1	R_1	G_1	R_0	G_1	R_1	G_1
G_0	B_1	G_0	B_0	G_0	B_1	G_0	B_0

FIG. 7

G_1	B_0	G_1	R_0	G_1	B_0	G_1	R_0
G_0	R_1	G_0	B_1	G_0	R_1	G_0	B_1
G_1	R_0	G_1	B_0	G_1	R_0	G_1	B_0
G_0	B_1	G_0	R_1	G_0	B_1	G_0	R_1
G_1	B_0	G_1	R_0	G_1	B_0	G_1	R_0
G_0	R_1	G_0	B_1	G_0	R_1	G_0	B_1
G_1	R_0	G_1	B_0	G_1	R_0	G_1	B_0
G_0	B_1	G_0	R_1	G_0	B_1	G_0	R_1

FIG. 8

G_1	B_1	G_1	B_0	G_1	B_1	G_1	B_0
G_0	R_1	G_0	R_0	G_0	R_1	G_0	R_0
G_1	B_0	G_1	B_1	G_1	B_0	G_1	B_1
G_0	R_0	G_0	R_1	G_0	R_0	G_0	R_1
G_1	B_1	G_1	B_0	G_1	B_1	G_1	B_0
G_0	R_1	G_0	R_0	G_0	R_1	G_0	R_0
G_1	B_0	G_1	B_1	G_1	B_0	G_1	B_1
G_0	R_0	G_0	R_1	G_0	R_0	G_0	R_1

FIG. 9

G_1	B_1	G_1	R_1	G_1	B_1	G_1	R_1
G_0	B_0	G_0	R_0	G_0	B_0	G_0	R_0
G_1	R_1	G_1	B_1	G_1	R_1	G_1	B_1
G_0	R_0	G_0	B_0	G_0	R_0	G_0	B_0
G_1	B_1	G_1	R_1	G_1	B_1	G_1	R_1
G_0	B_0	G_0	R_0	G_0	B_0	G_0	R_0
G_1	R_1	G_1	B_1	G_1	R_1	G_1	B_1
G_0	R_0	G_0	B_0	G_0	R_0	G_0	B_0

FIG. 10

M_1	Y_1	M_0	Y_0	M_1	Y_1	M_0	Y_0
G_1	C_1	G_0	C_0	G_1	C_1	G_0	C_0
M_0	Y_0	M_1	Y_1	M_0	Y_0	M_1	Y_1
G_0	C_0	G_1	C_1	G_0	C_0	G_1	C_1
M_1	Y_1	M_0	Y_0	M_1	Y_1	M_0	Y_0
G_1	C_1	G_0	C_0	G_1	C_1	G_0	C_0
M_0	Y_0	M_1	Y_1	M_0	Y_0	M_1	Y_1
G_0	C_0	G_1	C_1	G_0	C_0	G_1	C_1

FIG. 11

Y_1	M_0	G_1	C_0	Y_1	M_0	G_1	C_0
Y_0	C_1	G_0	M_1	Y_0	C_1	G_0	M_1
G_1	C_0	Y_1	M_0	G_1	C_0	Y_1	M_0
G_0	M_1	Y_0	C_1	G_0	M_1	Y_0	C_1
Y_1	M_0	G_1	C_0	Y_1	M_0	G_1	C_0
Y_0	C_1	G_0	M_1	Y_0	C_1	G_0	M_1
G_1	C_0	Y_1	M_0	G_1	C_0	Y_1	M_0
G_0	M_1	Y_0	C_1	G_0	M_1	Y_0	C_1

FIG. 12

G_2	R_2	B_2	G_2	R_2	B_2
G_1	R_1	B_1	G_1	R_1	B_1
G_0	R_0	B_0	G_0	R_0	B_0
G_2	R_2	B_2	G_2	R_2	B_2
G_1	R_1	B_1	G_1	R_1	B_1
G_0	R_0	B_0	G_0	R_0	B_0

FIG. 13

B_2	R_0	G_1	B_2	R_0	G_1
R_1	G_2	B_0	R_1	G_2	B_0
G_0	B_1	R_2	G_0	B_1	R_2
B_2	R_0	G_1	B_2	R_0	G_1
R_1	G_2	B_0	R_1	G_2	B_0
G_0	B_1	R_2	G_0	B_1	R_2

FIG. 14

B_3	G_2	B_0	G_3	B_3	G_2	B_0	G_3
G_1	R_2	G_0	R_1	G_1	R_2	G_0	R_1
B_1	G_3	B_2	G_2	B_1	G_3	B_2	G_2
G_0	R_0	G_1	R_3	G_0	R_0	G_1	R_3
B_3	G_2	B_0	G_3	B_3	G_2	B_0	G_3
G_1	R_2	G_0	R_1	G_1	R_2	G_0	R_1
B_1	G_3	B_2	G_2	B_1	G_3	B_2	G_2
G_0	R_0	G_1	R_3	G_0	R_0	G_1	R_3

FIG. 15

B_3	G_1	B_0	G_2	B_3	G_1	B_0	G_2
G_2	R_2	G_1	R_1	G_2	R_2	G_1	R_1
B_1	G_3	B_2	G_0	B_1	G_3	B_2	G_0
G_0	R_0	G_3	R_3	G_0	R_0	G_3	R_3
B_3	G_1	B_0	G_2	B_3	G_1	B_0	G_2
G_2	R_2	G_1	R_1	G_2	R_2	G_1	R_1
B_1	G_3	B_2	G_0	B_1	G_3	B_2	G_0
G_0	R_0	G_3	R_3	G_0	R_0	G_3	R_3

FIG. 16

G_3	G_1	R_3	B_1	G_3	G_1	R_3	B_1
R_0	B_2	G_0	G_2	R_0	B_2	G_0	G_2
B_3	R_1	G_3	G_1	B_3	R_1	G_3	G_1
G_0	G_2	B_0	R_2	G_0	G_2	B_0	R_2
G_3	G_1	R_3	B_1	G_3	G_1	R_3	B_1
R_0	B_2	G_0	G_2	R_0	B_2	G_0	G_2
B_3	R_1	G_3	G_1	B_3	R_1	G_3	G_1
G_0	G_2	B_0	R_2	G_0	G_2	B_0	R_2

FIG. 17

M_2	Y_1	M_3	Y_0	M_2	Y_1	M_3	Y_0
G_2	C_1	G_3	C_0	G_2	C_1	G_3	C_0
M_0	Y_3	M_1	Y_2	M_0	Y_3	M_1	Y_2
G_0	C_3	G_1	C_2	G_0	C_3	G_1	C_2
M_2	Y_1	M_3	Y_0	M_2	Y_1	M_3	Y_0
G_2	C_1	G_3	C_0	G_2	C_1	G_3	C_0
M_0	Y_3	M_1	Y_2	M_0	Y_3	M_1	Y_2
G_0	C_3	G_1	C_2	G_0	C_3	G_1	C_2

FIG. 18

C_2	M_1	G_2	Y_1	C_2	M_1	G_2	Y_1
M_0	C_3	Y_0	G_3	M_0	C_3	Y_0	G_3
Y_2	G_1	M_2	C_1	Y_2	G_1	M_2	C_1
G_0	Y_3	C_0	M_3	G_0	Y_3	C_0	M_3
C_2	M_1	G_2	Y_1	C_2	M_1	G_2	Y_1
M_0	C_3	Y_0	G_3	M_0	C_3	Y_0	G_3
Y_2	G_1	M_2	C_1	Y_2	G_1	M_2	C_1
G_0	Y_3	C_0	M_3	G_0	Y_3	C_0	M_3

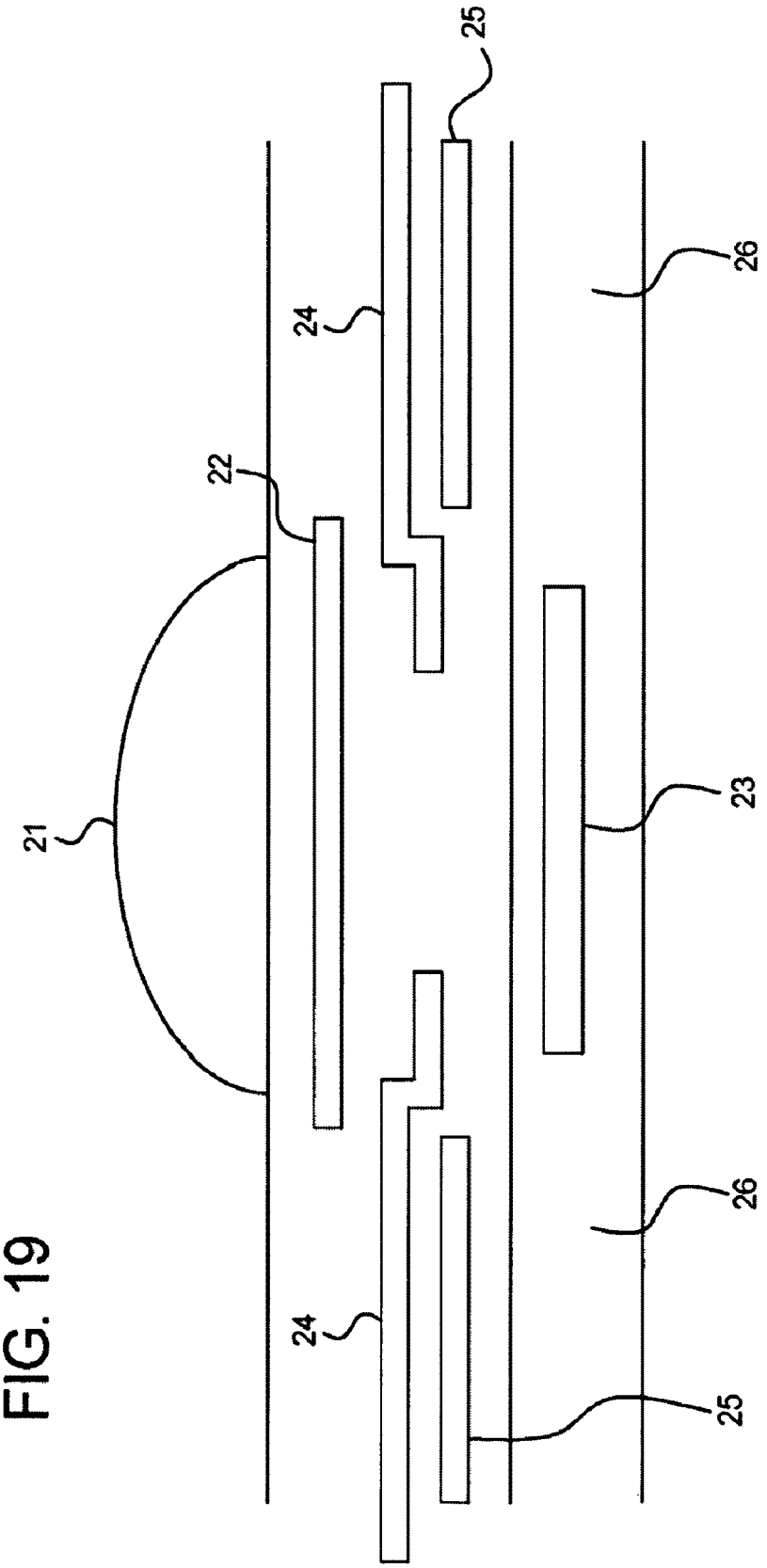


FIG. 19

FIG. 20

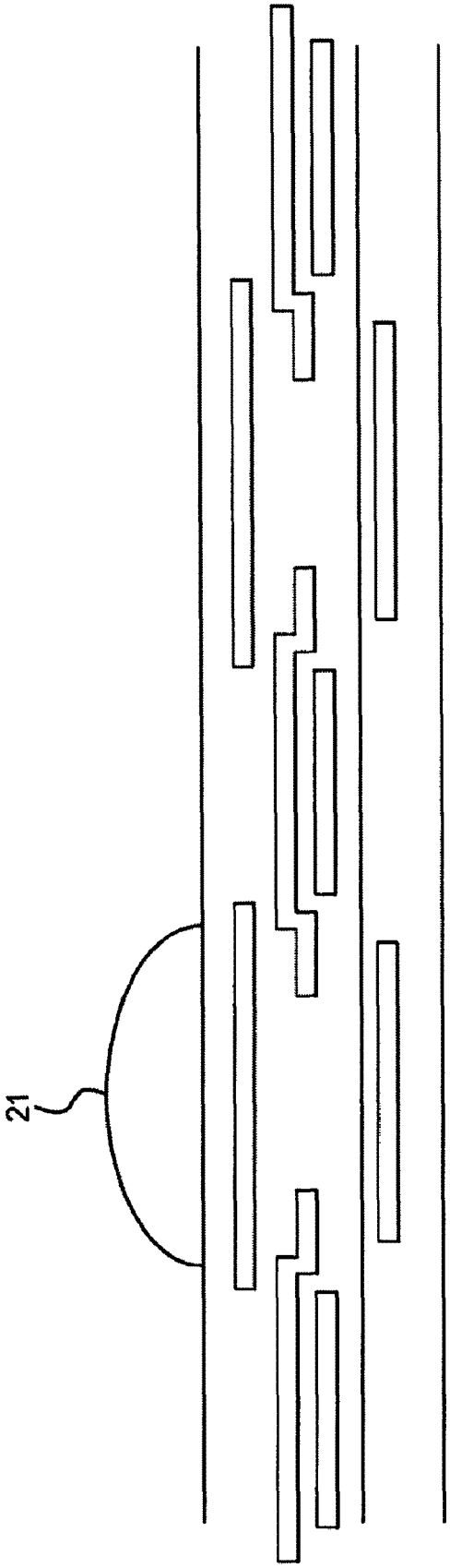


FIG. 21

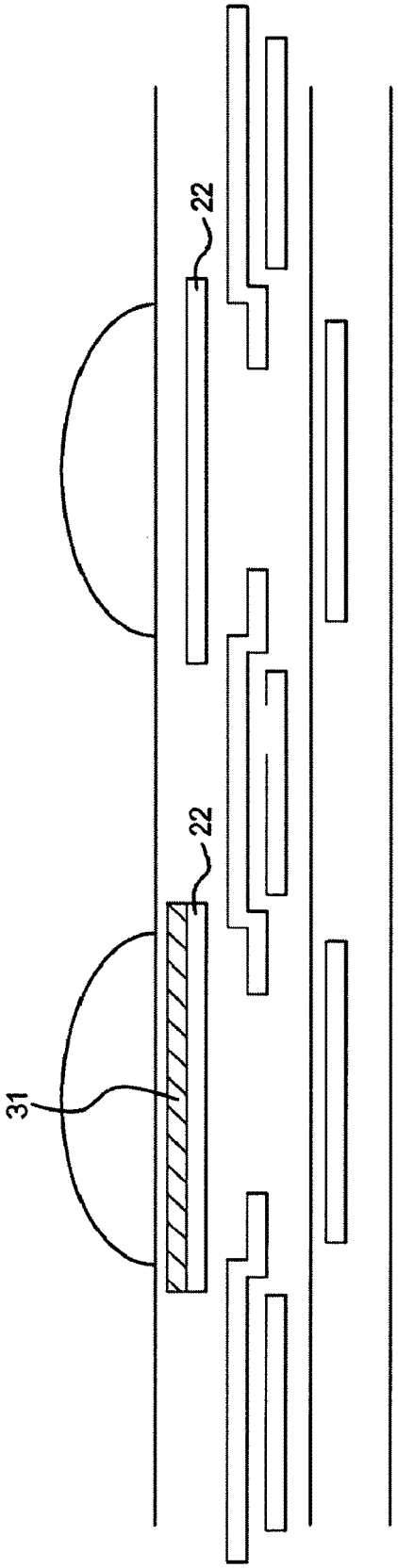


FIG. 22

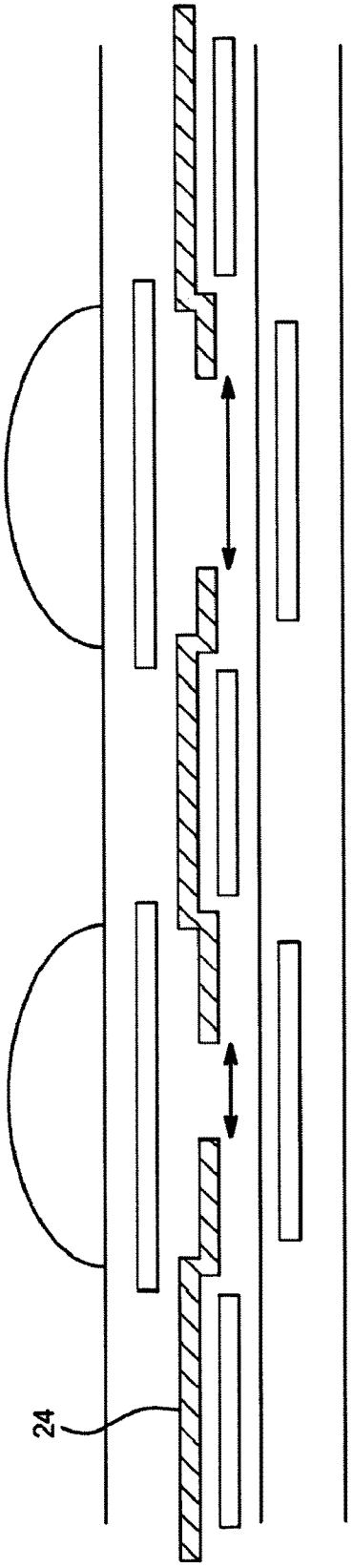


FIG. 23

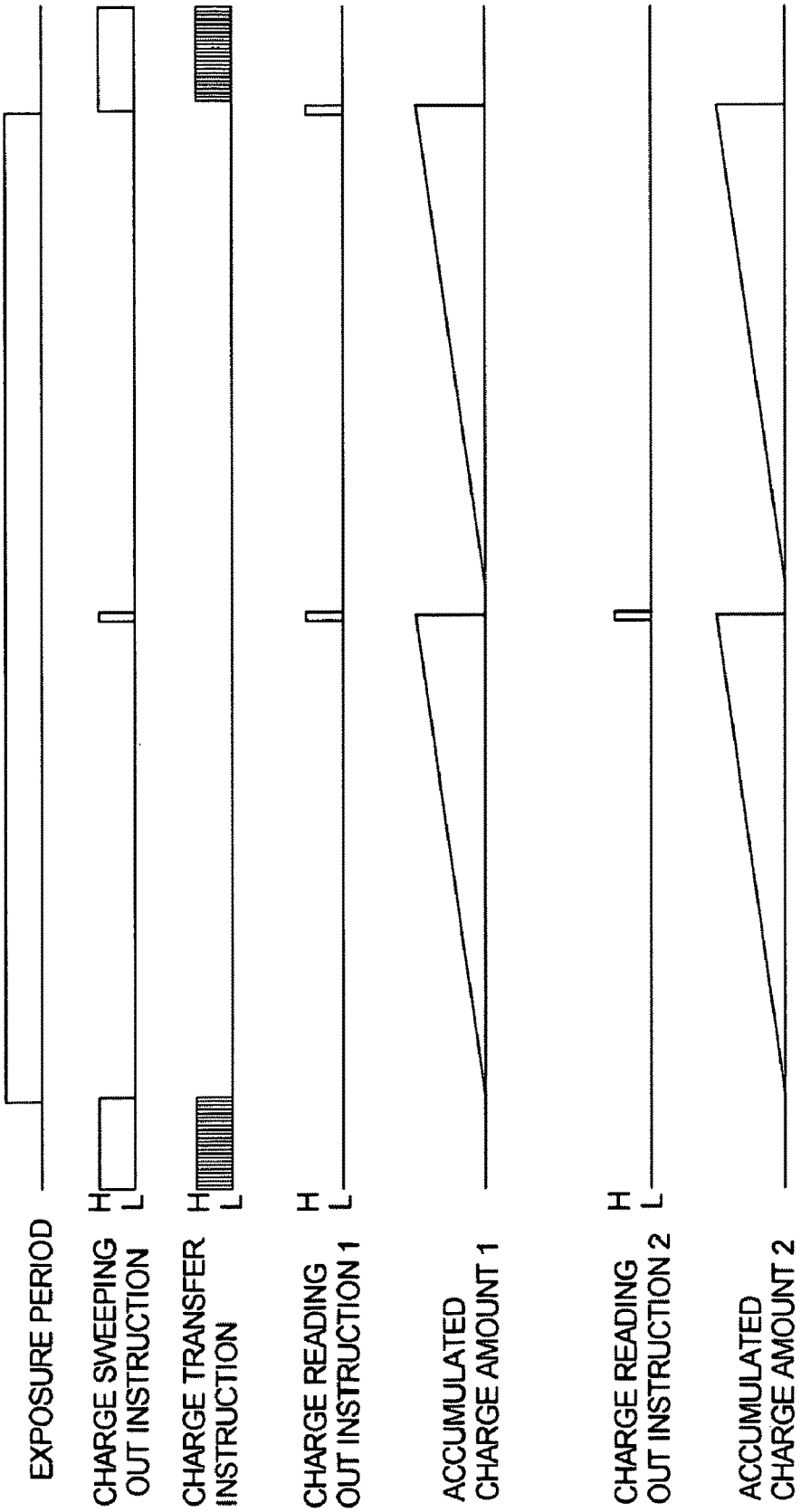

EXPOSURE PERIOD
CHARGE SWEEPING OUT INSTRUCTION
H
L
CHARGE TRANSFER INSTRUCTION
H
L
CHARGE READING OUT INSTRUCTION 1
H
L
ACCUMULATED CHARGE AMOUNT 1
CHARGE READING OUT INSTRUCTION 2
H
L
ACCUMULATED CHARGE AMOUNT 2

FIG. 24

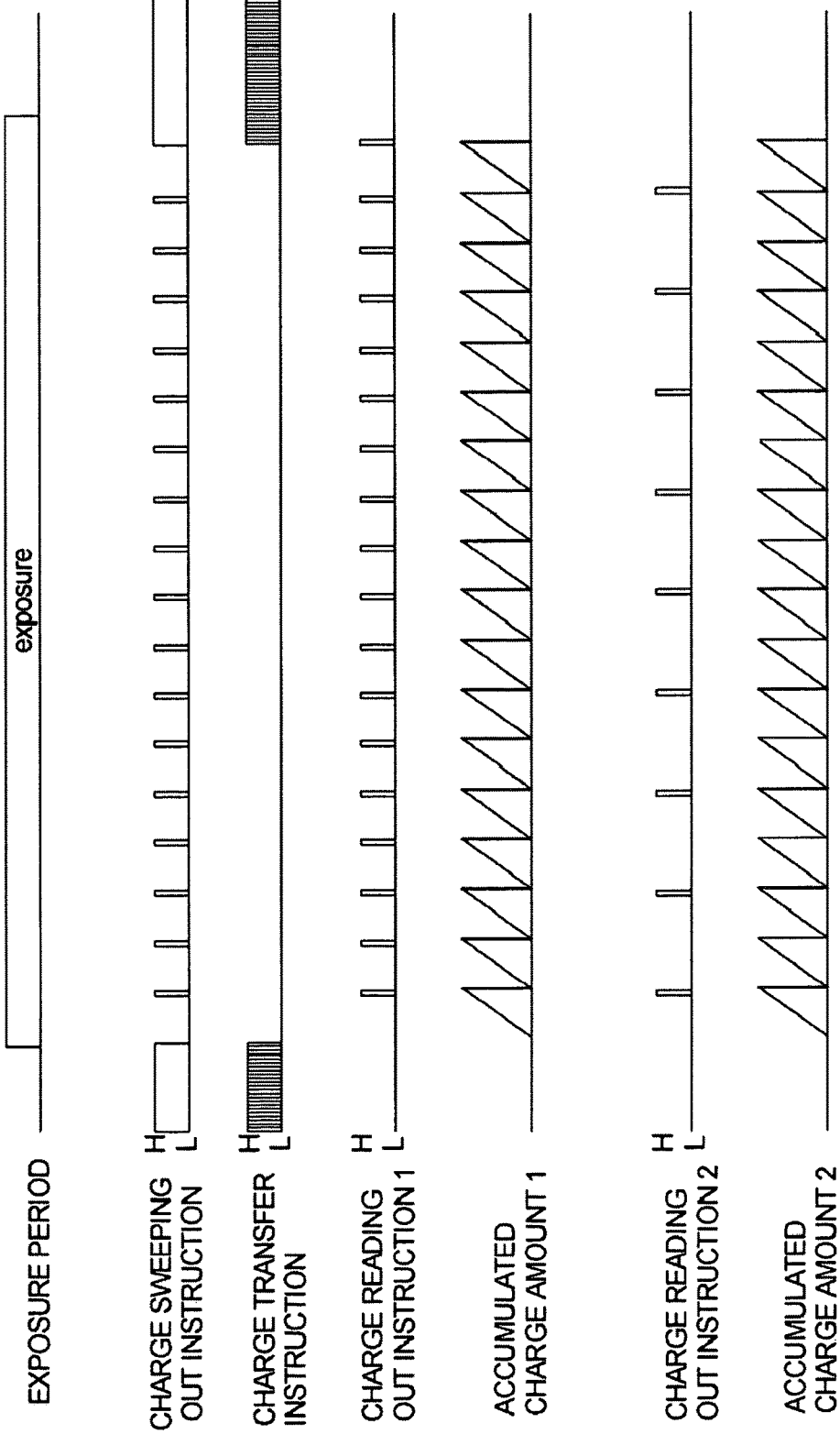

EXPOSURE PERIOD
exposure
CHARGE SWEEPING OUT INSTRUCTION
H
L
CHARGE TRANSFER INSTRUCTION
H
L
CHARGE READING OUT INSTRUCTION 1
H
L
ACCUMULATED CHARGE AMOUNT 1
CHARGE READING OUT INSTRUCTION 2
H
L
ACCUMULATED CHARGE AMOUNT 2

FIG. 25

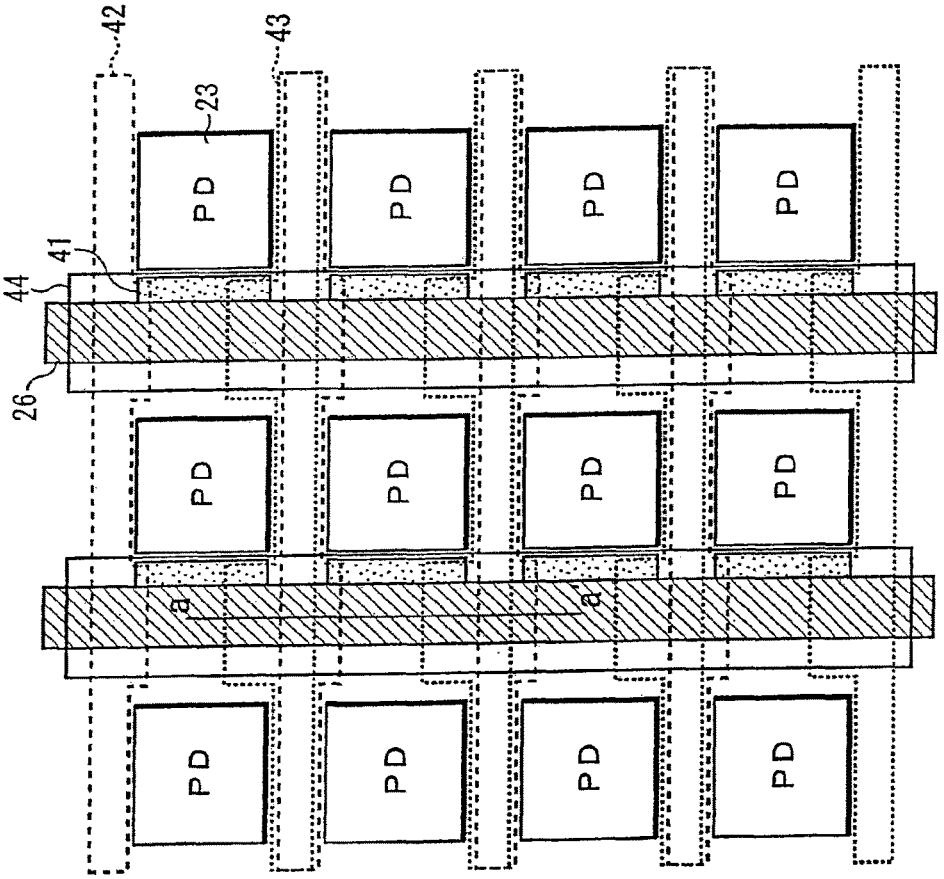


FIG. 26

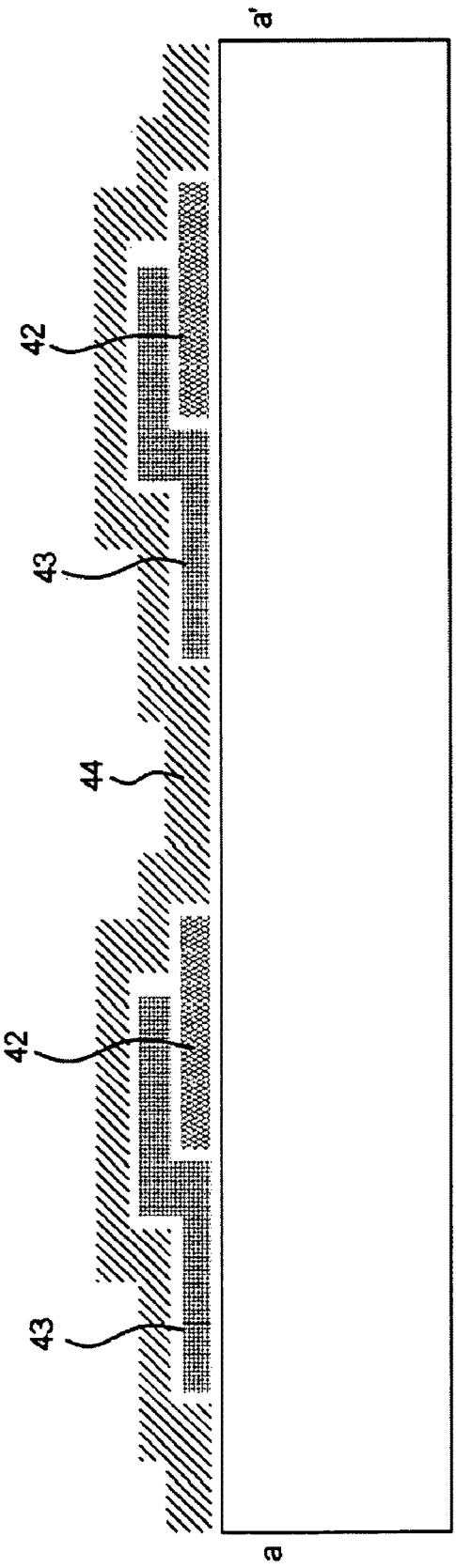


FIG. 27

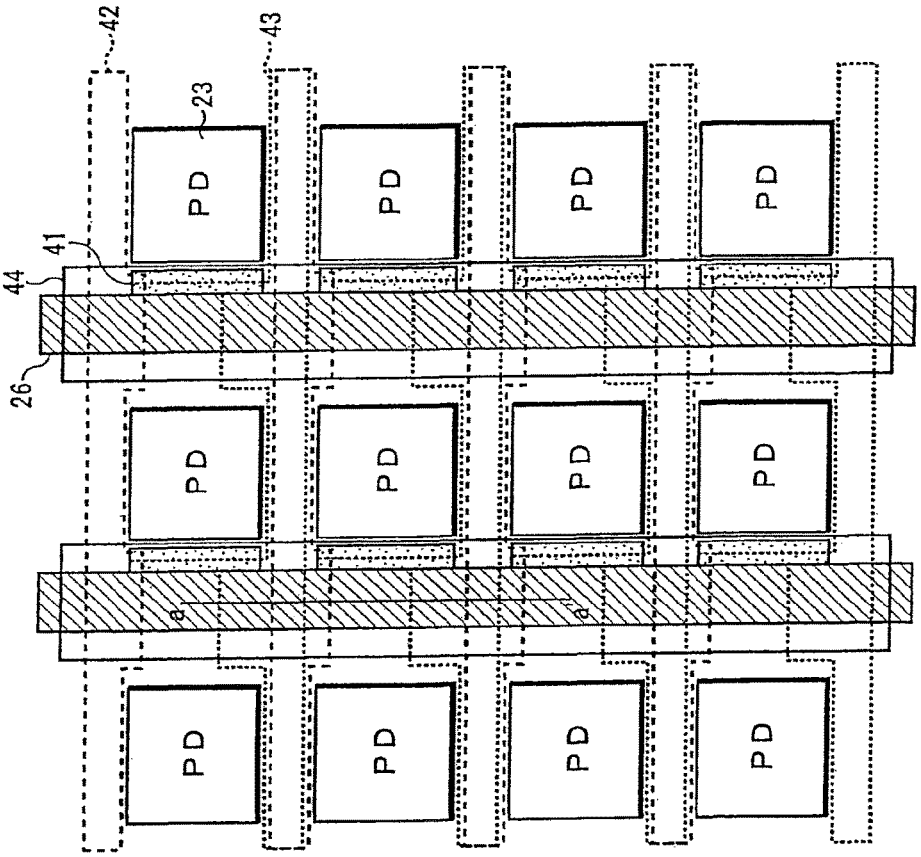


FIG.28

OR	OR	OR	OR	OR	OR	OR	OR
AND	AND	AND	AND	AND	AND	AND	AND
OR	OR	OR	OR	OR	OR	OR	OR
AND	AND	AND	AND	AND	AND	AND	AND
OR	OR	OR	OR	OR	OR	OR	OR
AND	AND	AND	AND	AND	AND	AND	AND
OR	OR	OR	OR	OR	OR	OR	OR
AND	AND	AND	AND	AND	AND	AND	AND

FIG.29

OR	OR	AND	OR	OR	OR	AND	OR
AND	AND	AND	OR	AND	AND	AND	OR
AND	OR	OR	OR	AND	OR	OR	OR
AND	OR	AND	AND	AND	OR	AND	AND
OR	OR	AND	OR	OR	OR	AND	OR
AND	AND	AND	OR	AND	AND	AND	OR
AND	OR	OR	OR	AND	OR	OR	OR
AND	OR	AND	AND	AND	OR	AND	AND

FIG.30

OR	AND	OR	AND	OR	AND	OR	AND
AND	OR	AND	OR	AND	OR	AND	OR
OR	AND	OR	AND	OR	AND	OR	AND
AND	OR	AND	OR	AND	OR	AND	OR
OR	AND	OR	AND	OR	AND	OR	AND
AND	OR	AND	OR	AND	OR	AND	OR
OR	AND	OR	AND	OR	AND	OR	AND
AND	OR	AND	OR	AND	OR	AND	OR

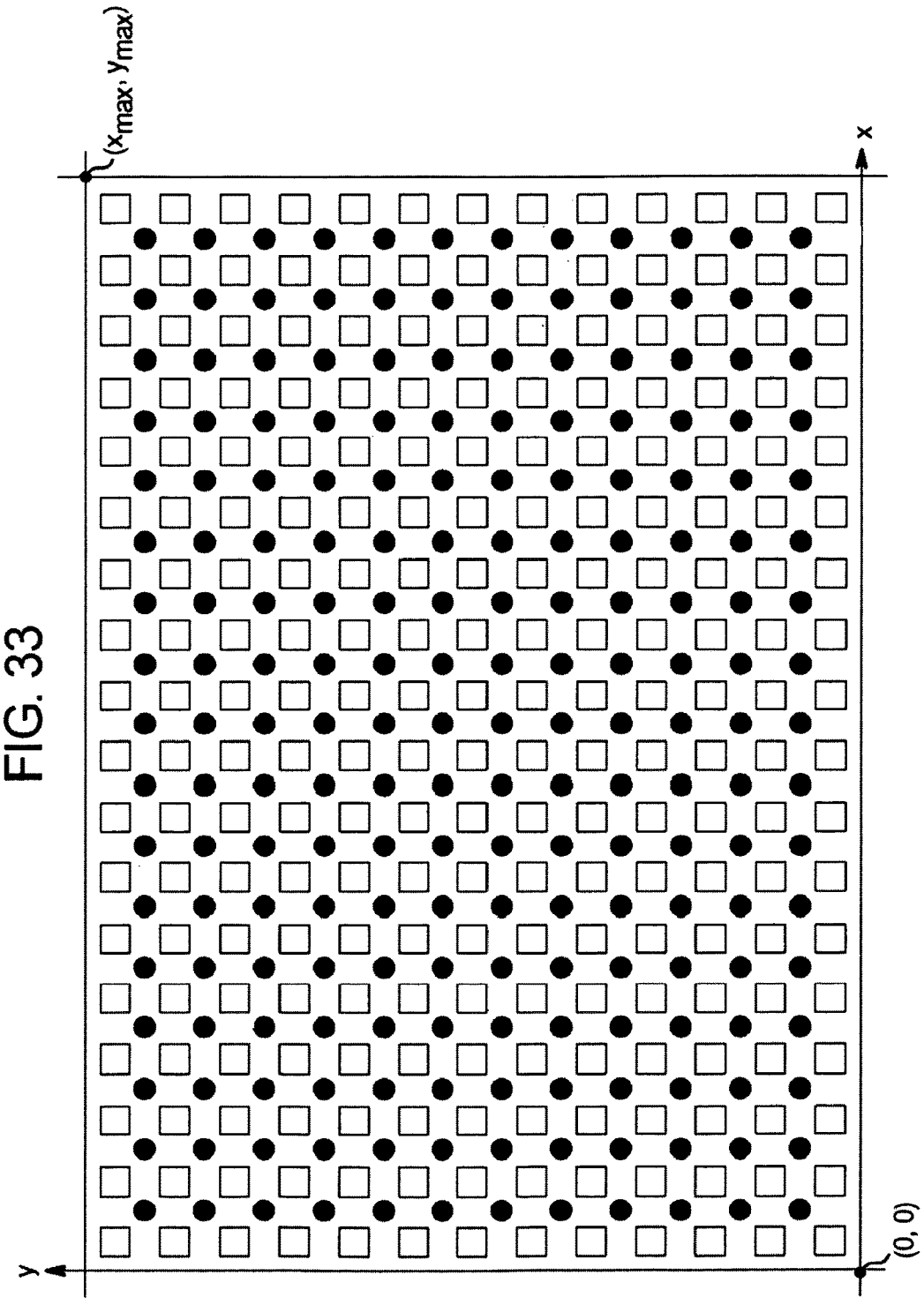
FIG.31

OR	OR	OR	AND	OR	OR	OR	AND
AND	OR	AND	AND	AND	OR	AND	AND
OR	AND	OR	OR	OR	AND	OR	OR
AND	AND	AND	OR	AND	AND	AND	OR
OR	OR	OR	AND	OR	OR	OR	AND
AND	OR	AND	AND	AND	OR	AND	AND
OR	AND	OR	OR	OR	AND	OR	OR
AND	AND	AND	OR	AND	AND	AND	OR

FIG.32

OR	OR	OR	OR	OR	OR	OR	OR
AND	AND	AND	AND	AND	AND	AND	AND
OR	OR	OR	OR	OR	OR	OR	OR
AND	AND	AND	AND	AND	AND	AND	AND
OR	OR	OR	OR	OR	OR	OR	OR
AND	AND	AND	AND	AND	AND	AND	AND
OR	OR	OR	OR	OR	OR	OR	OR
AND	AND	AND	AND	AND	AND	AND	AND

FIG. 33



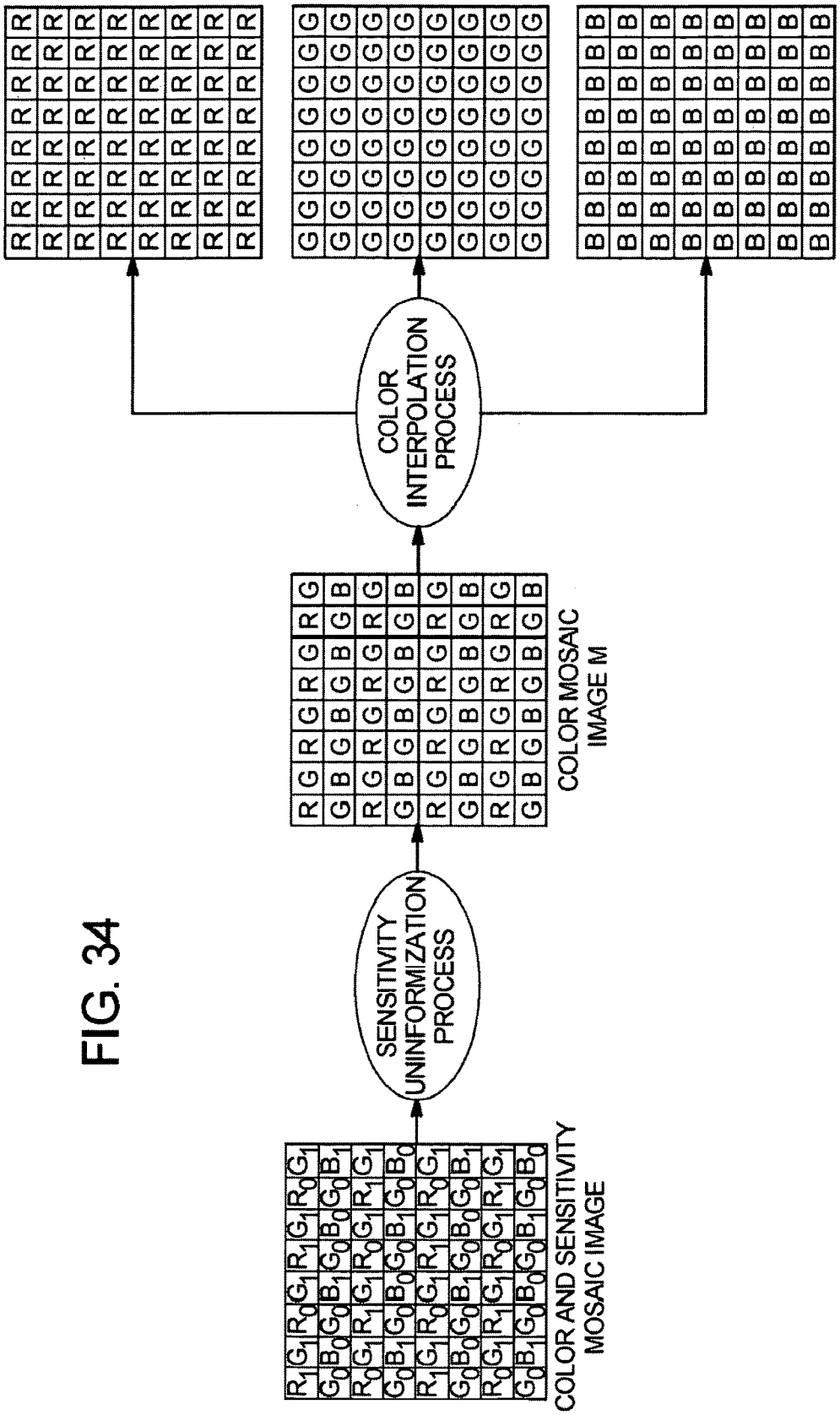

COLOR AND SENSITIVITY MOSAIC IMAGE
SENSITIVITY UNINFORMIZATION PROCESS
COLOR MOSAIC IMAGE M
COLOR INTERPOLATION PROCESS

FIG. 34

FIG. 35

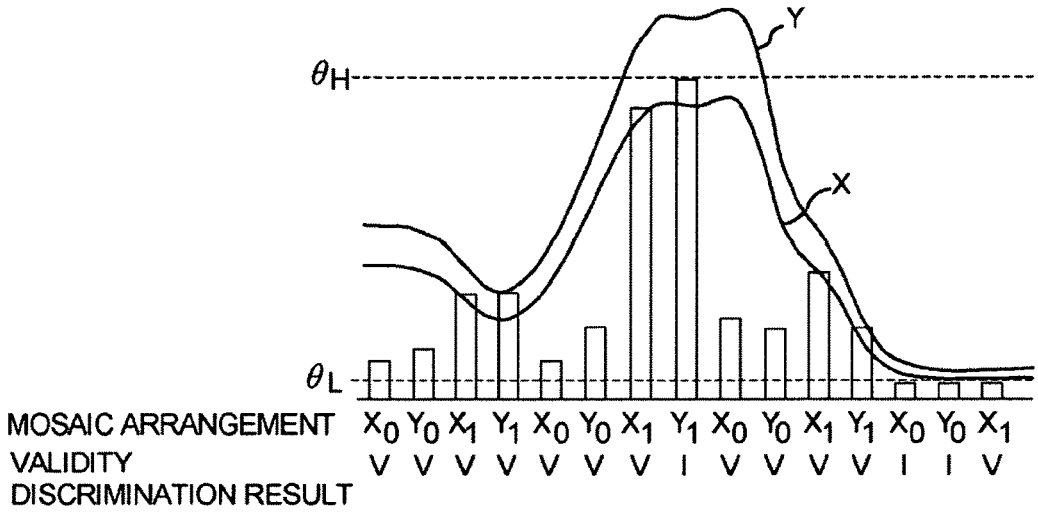

Y
θH
X
θL
MOSAIC ARRANGEMENT X0 Y0 X1 Y1 X0 Y0 X1 Y1 X0 Y0 X1 Y1 X0 Y0 X1
VALIDITY V V V V V V V I V V V V I I V
DISCRIMINATION RESULT

FIG. 36

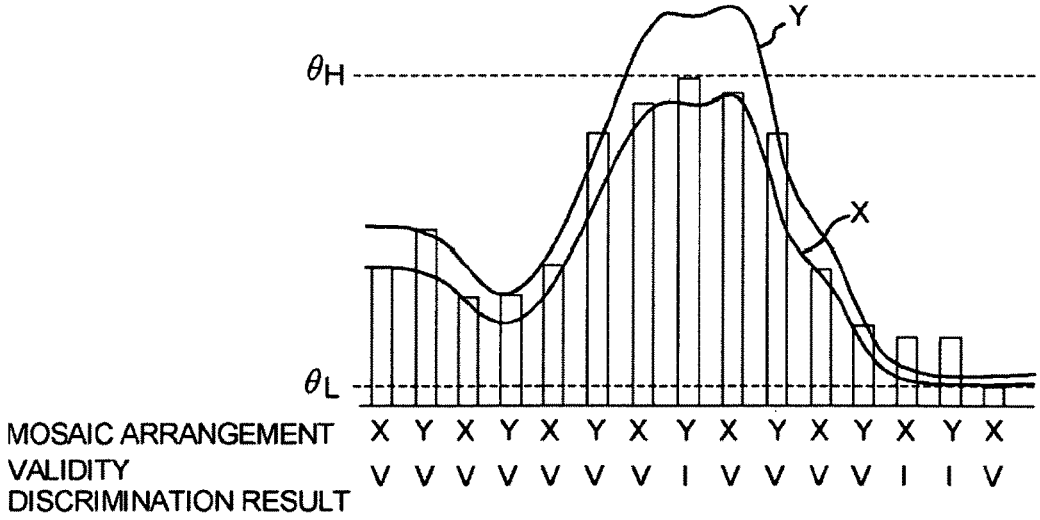

Y
θH
X
θL
MOSAIC ARRANGEMENT X Y X Y X Y X Y X Y X Y X Y X
VALIDITY V V V V V V V I V V V V I I V
DISCRIMINATION RESULT

FIG. 37

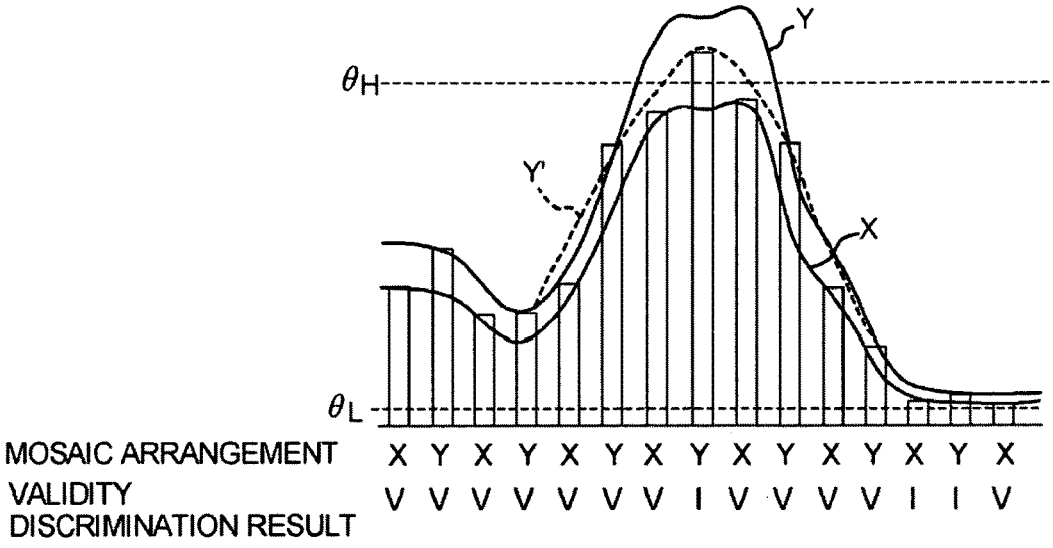

Y
θH
Y'
X
θL
MOSAIC ARRANGEMENT X Y X Y X Y X Y X Y X Y X Y X
VALIDITY DISCRIMINATION RESULT V V V V V V V I V V V V I I V

FIG. 38

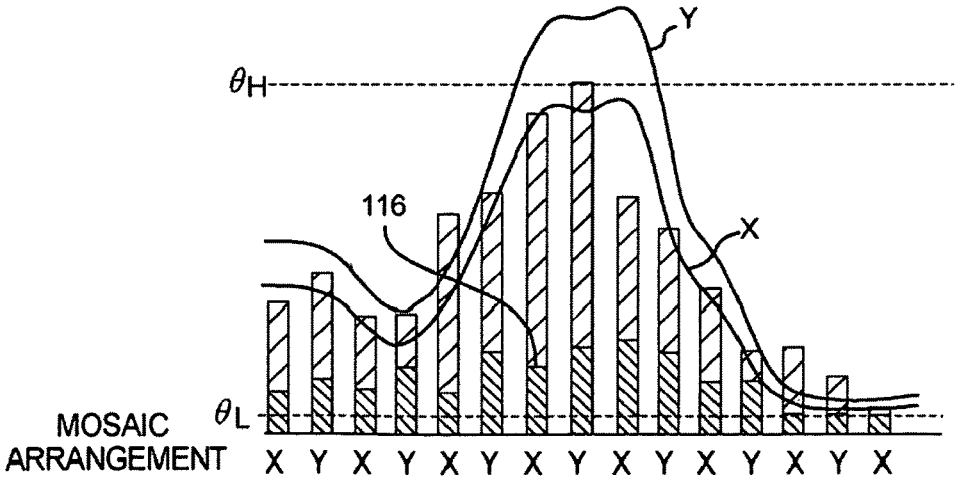
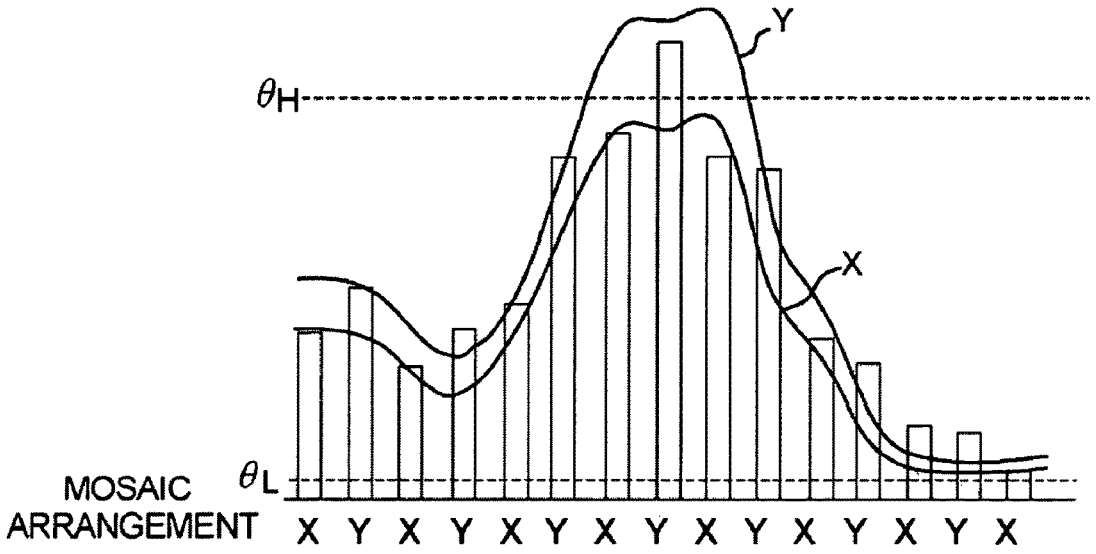

Y
θH
116
X
θL
MOSAIC ARRANGEMENT X Y X Y X Y X Y X Y X Y X Y X

FIG. 39



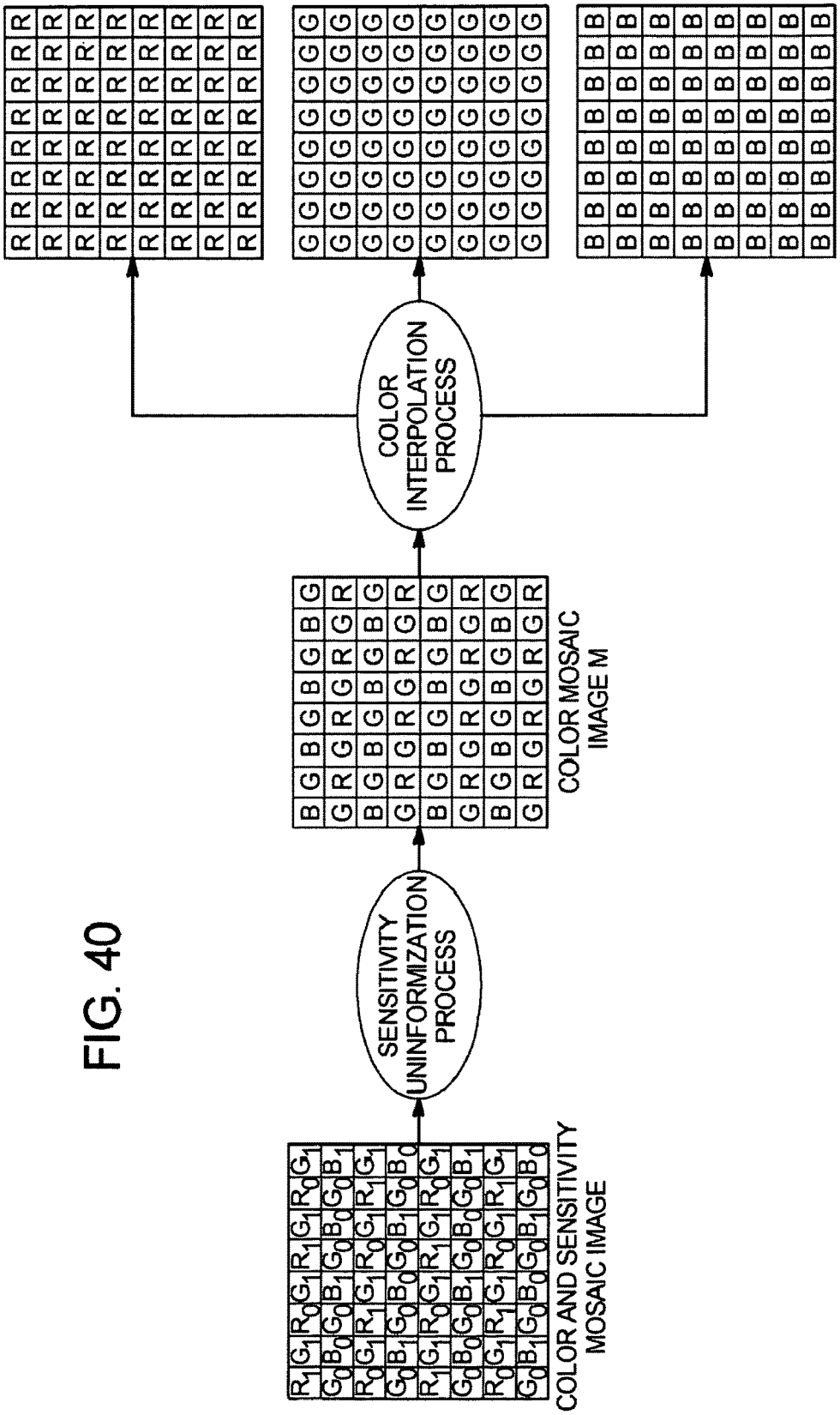

COLOR AND SENSITIVITY MOSAIC IMAGE
SENSITIVITY UNINFORMIZATION PROCESS
COLOR MOSAIC IMAGE M
COLOR INTERPOLATION PROCESS

FIG. 40

FIG. 41

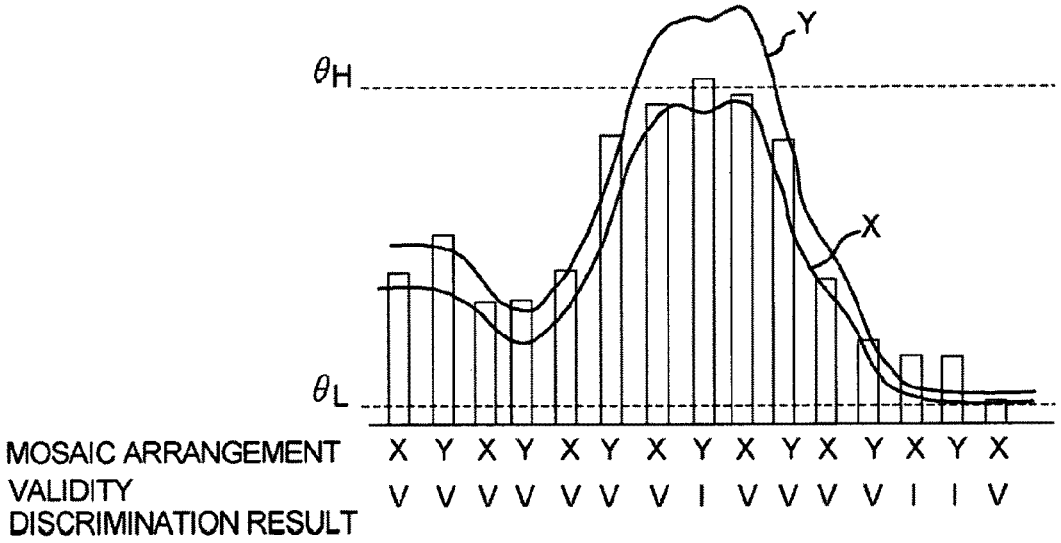

θH
θL
Y
X
MOSAIC ARRANGEMENT
X Y X Y X Y X Y X Y X Y X Y X
VALIDITY
DISCRIMINATION RESULT
V V V V V V V I V V V V I I V

FIG. 42

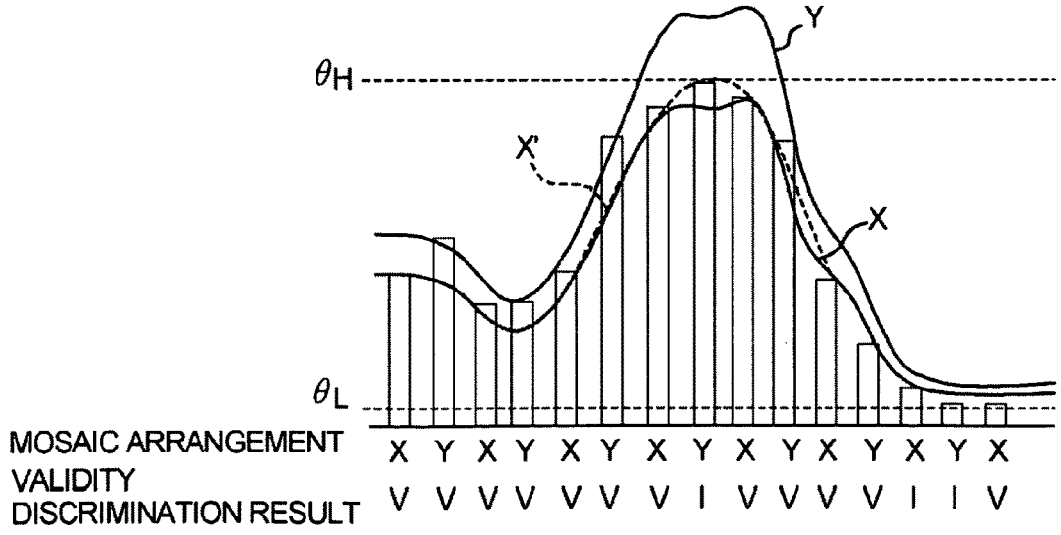

θH
θL
Y
X'
X
MOSAIC ARRANGEMENT
X Y X Y X Y X Y X Y X Y X Y X
VALIDITY
DISCRIMINATION RESULT
V V V V V V V I V V V V I I V

FIG. 43

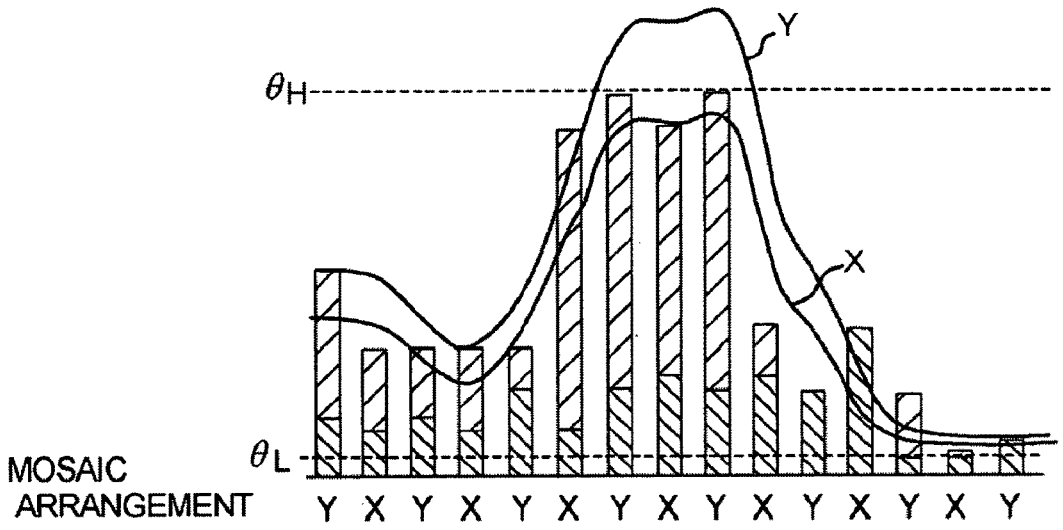

Y
θH
X
θL
MOSAIC ARRANGEMENT
Y X Y X Y X Y X Y X Y X Y X Y

FIG. 44

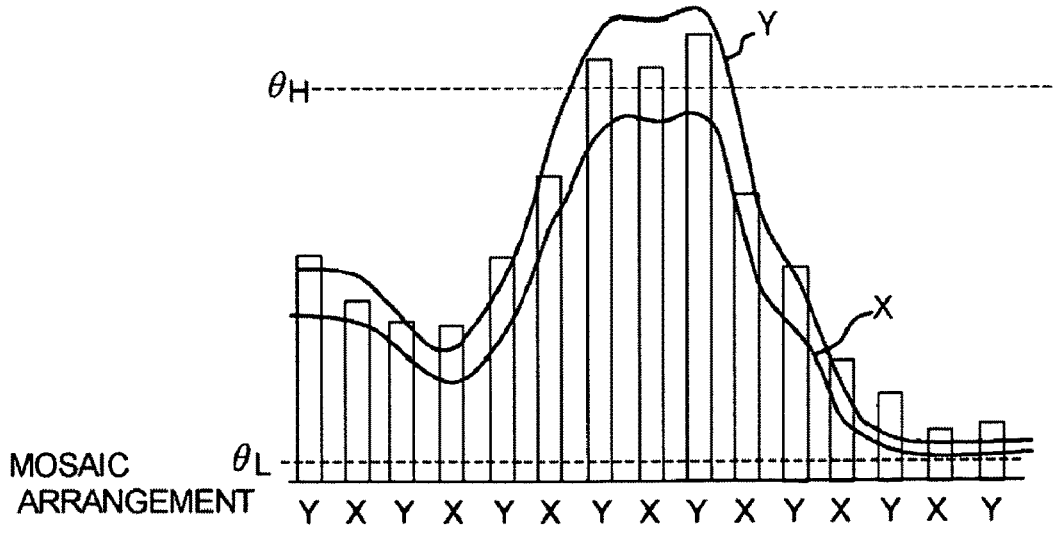

Y
θH
X
θL
MOSAIC ARRANGEMENT
Y X Y X Y X Y X Y X Y X Y X Y

FIG. 45

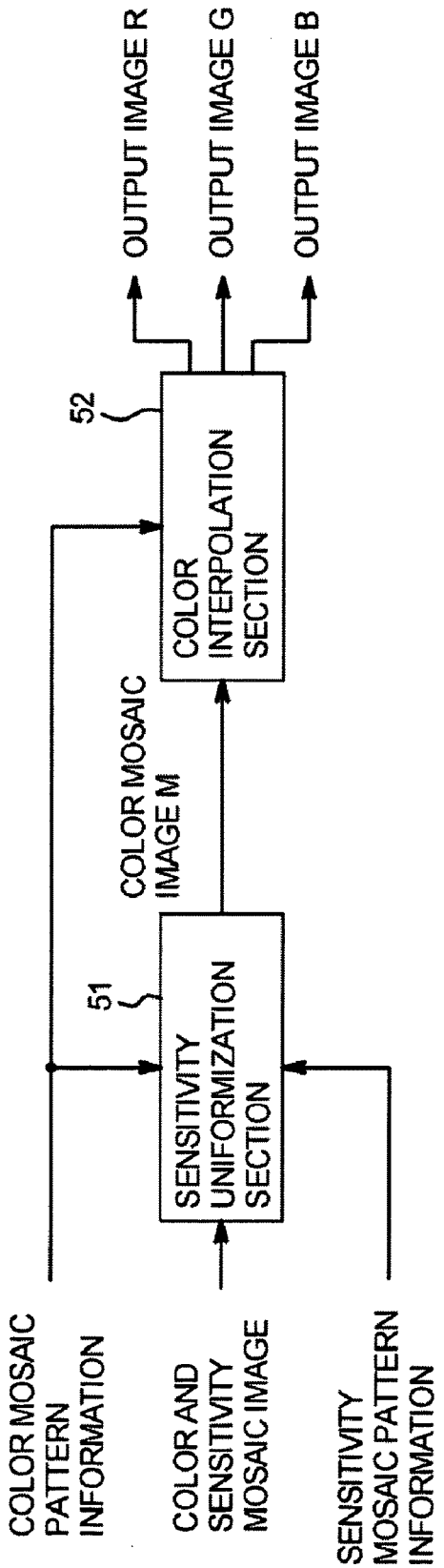

COLOR MOSAIC PATTERN INFORMATION
COLOR AND SENSITIVITY MOSAIC IMAGE
SENSITIVITY MOSAIC PATTERN INFORMATION
51
SENSITIVITY UNIFORMIZATION SECTION
COLOR MOSAIC IMAGE M
52
COLOR INTERPOLATION SECTION
OUTPUT IMAGE R
OUTPUT IMAGE G
OUTPUT IMAGE B

FIG. 46

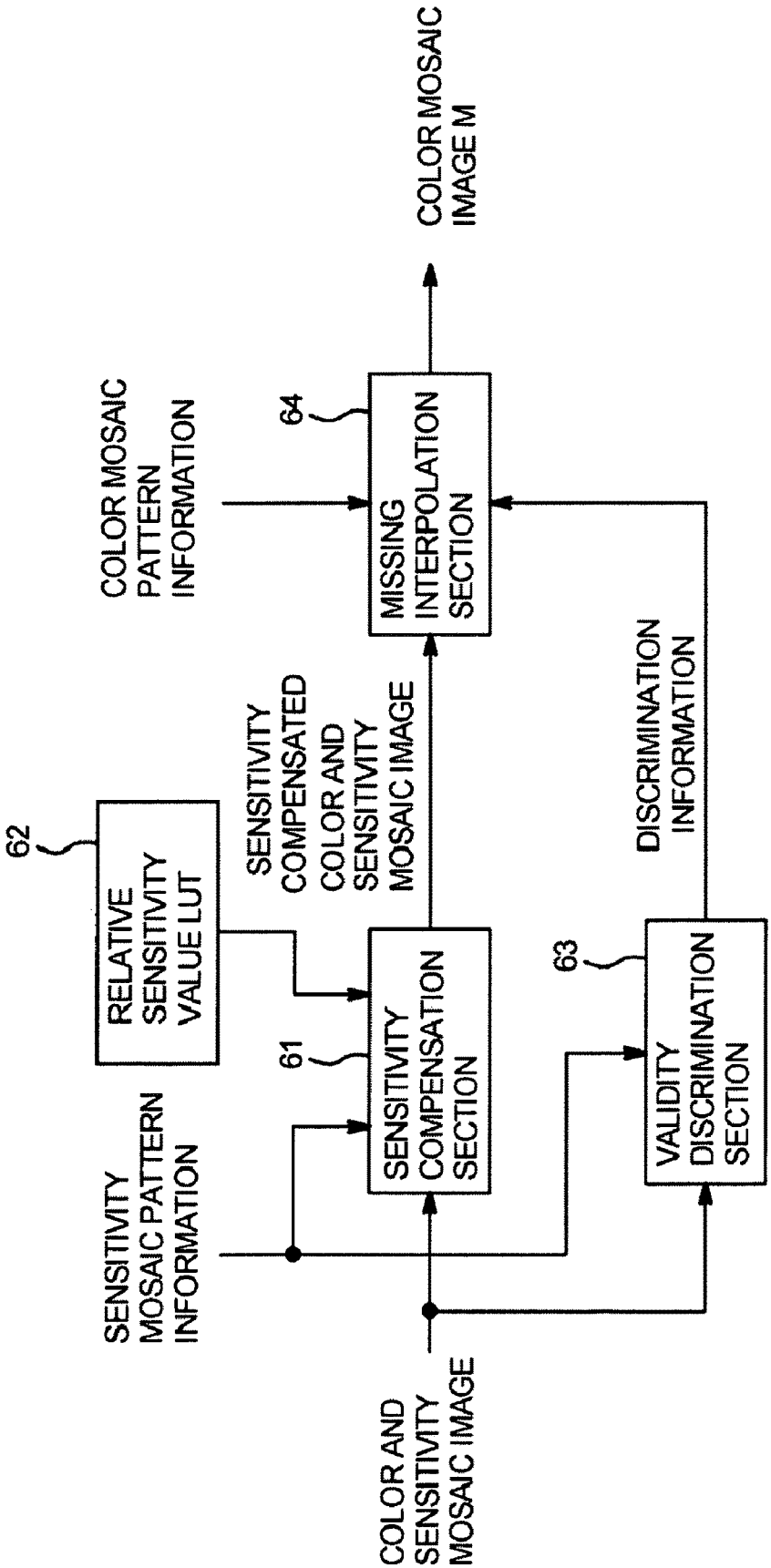

COLOR AND SENSITIVITY MOSAIC IMAGE
SENSITIVITY MOSAIC PATTERN INFORMATION
COLOR MOSAIC PATTERN INFORMATION
62
RELATIVE SENSITIVITY VALUE LUT
61
SENSITIVITY COMPENSATION SECTION
SENSITIVITY COMPENSATED COLOR AND SENSITIVITY MOSAIC IMAGE
63
VALIDITY DISCRIMINATION SECTION
DISCRIMINATION INFORMATION
64
MISSING INTERPOLATION SECTION
COLOR MOSAIC IMAGE M

FIG. 47

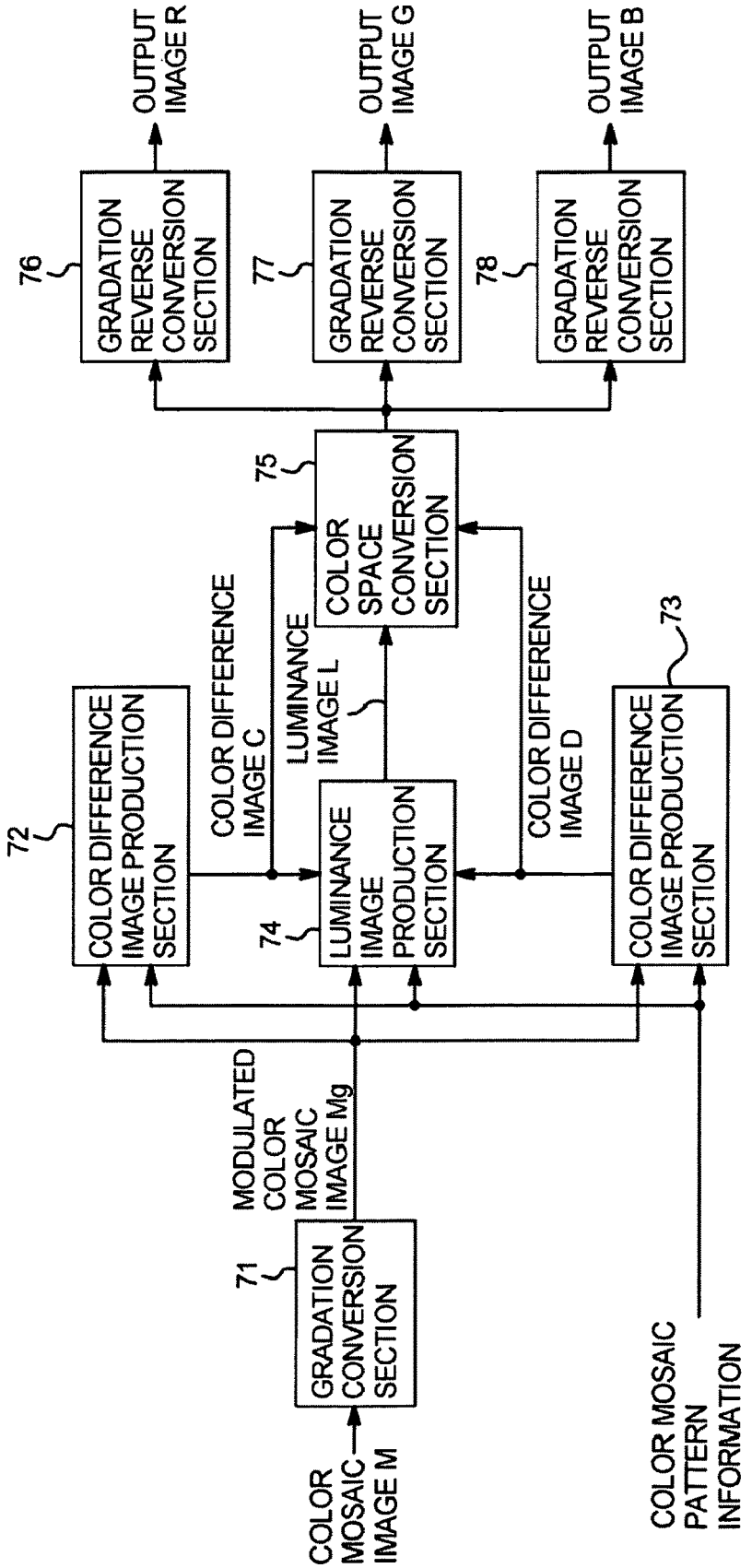

COLOR MOSAIC IMAGE M
GRADATION CONVERSION SECTION
71
MODULATED COLOR MOSAIC IMAGE Mg
COLOR MOSAIC PATTERN INFORMATION
COLOR DIFFERENCE IMAGE PRODUCTION SECTION
72
LUMINANCE IMAGE PRODUCTION SECTION
74
COLOR DIFFERENCE IMAGE PRODUCTION SECTION
73
COLOR DIFFERENCE IMAGE C
LUMINANCE IMAGE L
COLOR DIFFERENCE IMAGE D
COLOR SPACE CONVERSION SECTION
75
GRADATION REVERSE CONVERSION SECTION
76
GRADATION REVERSE CONVERSION SECTION
77
GRADATION REVERSE CONVERSION SECTION
78
OUTPUT IMAGE R
OUTPUT IMAGE G
OUTPUT IMAGE B

FIG. 48

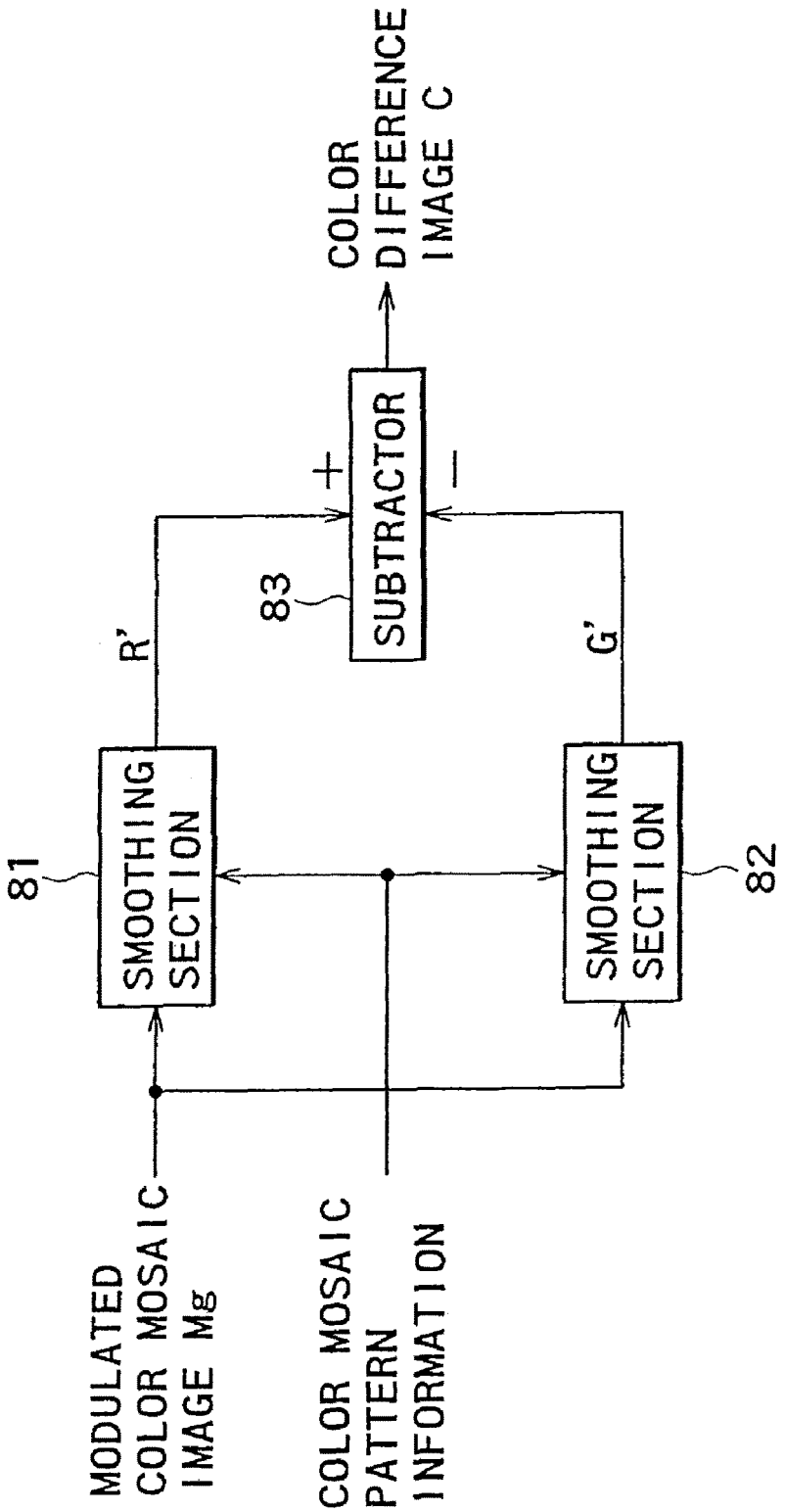

MODULATED COLOR MOSAIC IMAGE Mg
COLOR MOSAIC PATTERN INFORMATION
81
SMOOTHING SECTION
82
SMOOTHING SECTION
R'
G'
83
SUBTRACTOR
+
−
COLOR DIFFERENCE IMAGE C

FIG. 49

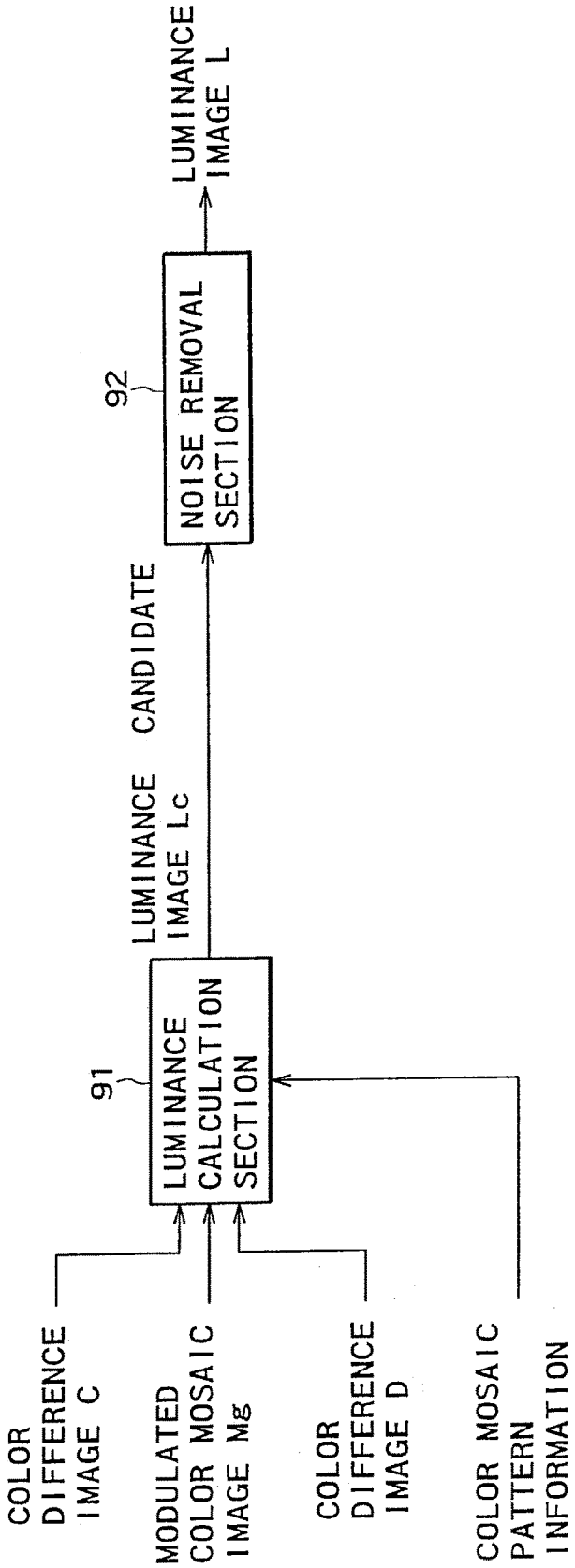

COLOR DIFFERENCE IMAGE C
MODULATED COLOR MOSAIC IMAGE Mg
COLOR DIFFERENCE IMAGE D
COLOR MOSAIC PATTERN INFORMATION
91
LUMINANCE CALCULATION SECTION
LUMINANCE IMAGE Lc
CANDIDATE
92
NOISE REMOVAL SECTION
LUMINANCE IMAGE L

FIG. 50

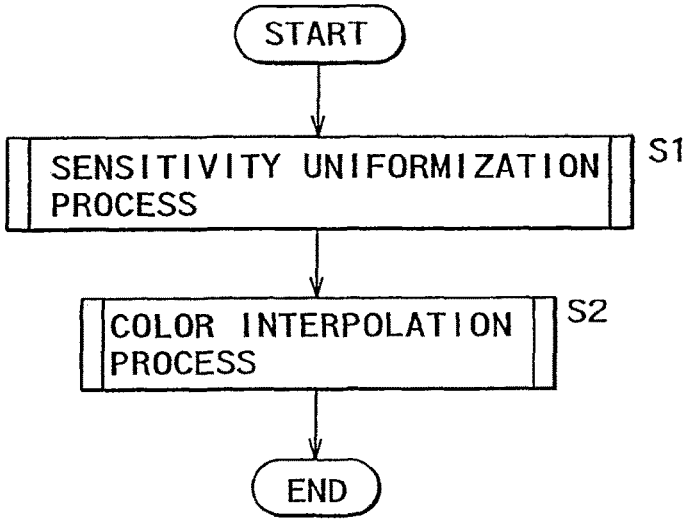

START
SENSITIVITY UNIFORMIZATION PROCESS
S1
COLOR INTERPOLATION PROCESS
S2
END

FIG. 51

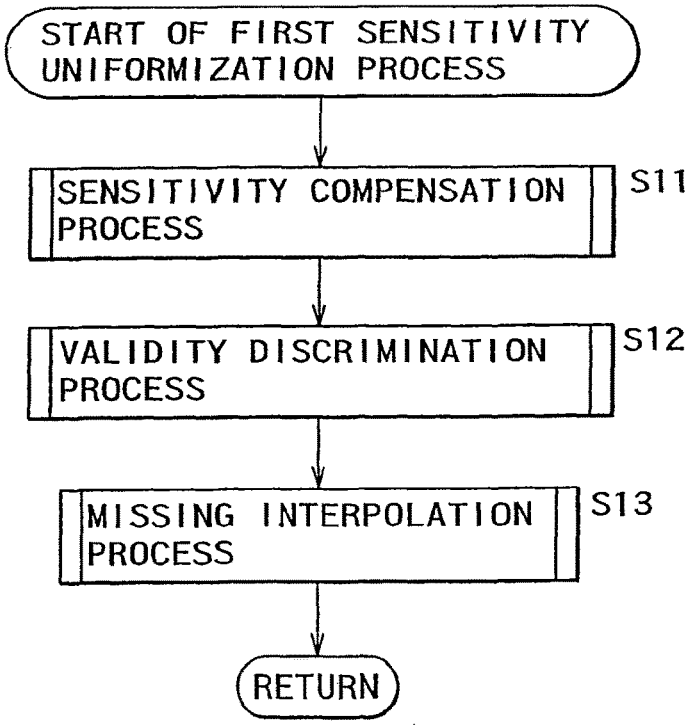

START OF FIRST SENSITIVITY UNIFORMIZATION PROCESS
SENSITIVITY COMPENSATION PROCESS
S11
VALIDITY DISCRIMINATION PROCESS
S12
MISSING INTERPOLATION PROCESS
S13
RETURN

FIG. 52

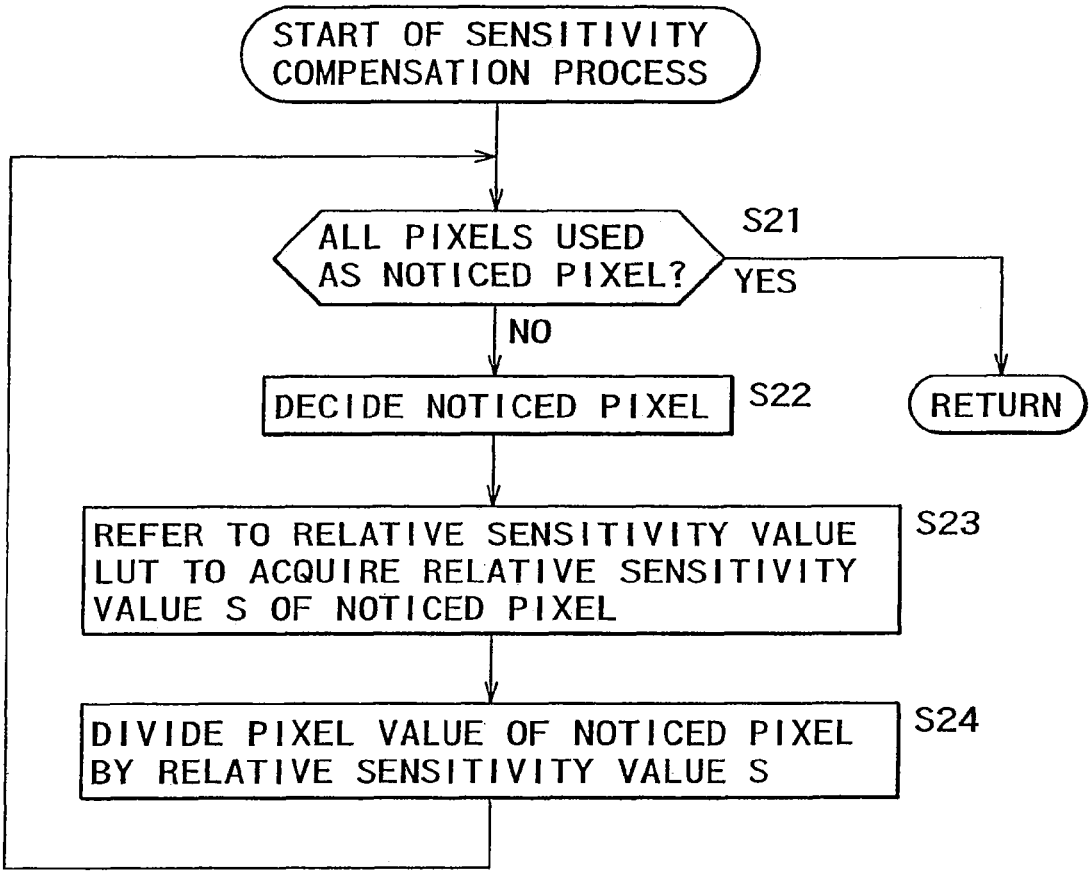

START OF SENSITIVITY COMPENSATION PROCESS
ALL PIXELS USED AS NOTICED PIXEL?
S21
YES
NO
RETURN
DECIDE NOTICED PIXEL
S22
REFER TO RELATIVE SENSITIVITY VALUE LUT TO ACQUIRE RELATIVE SENSITIVITY VALUE S OF NOTICED PIXEL
S23
DIVIDE PIXEL VALUE OF NOTICED PIXEL BY RELATIVE SENSITIVITY VALUE S
S24

FIG. 53

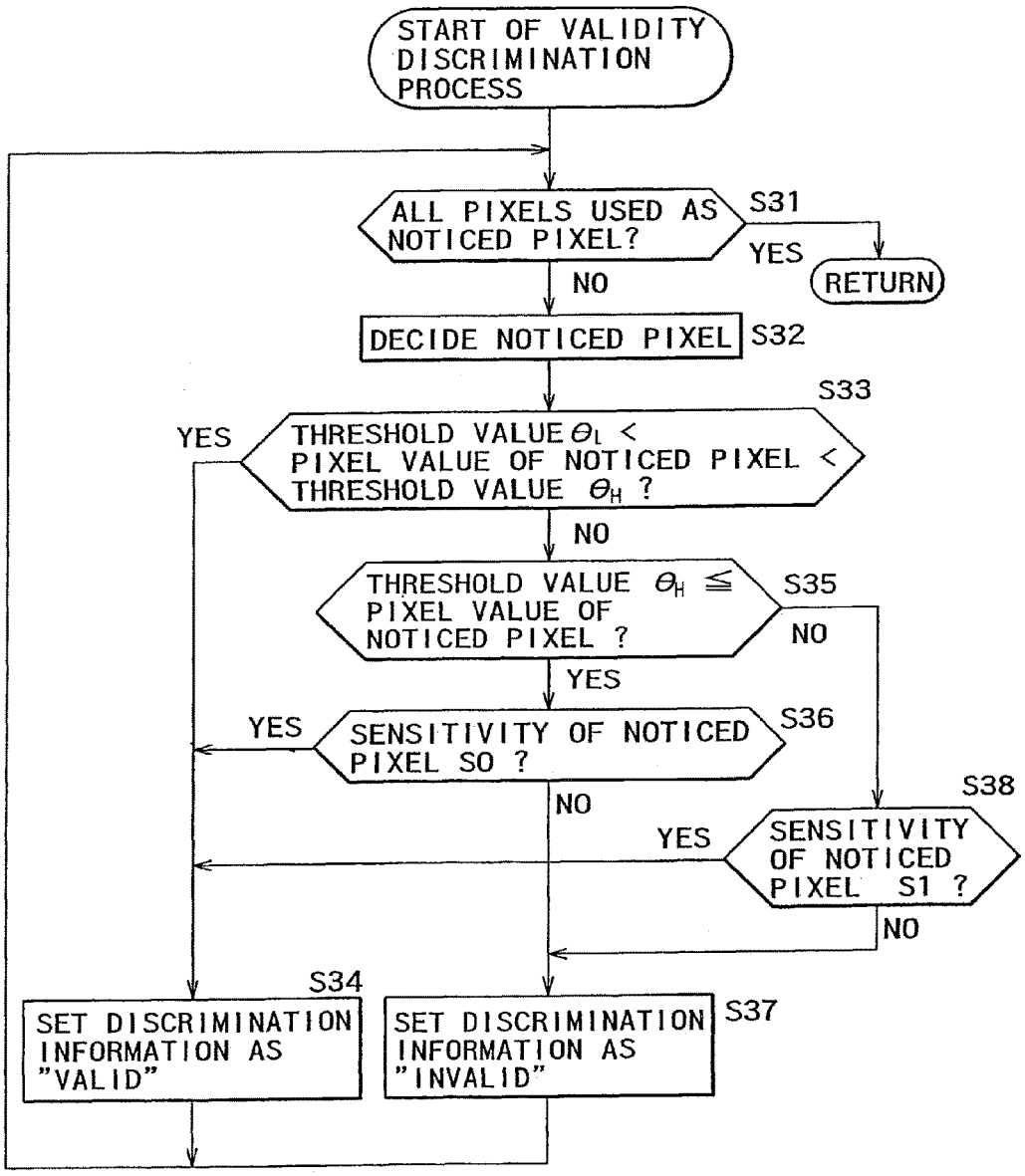

START OF VALIDITY DISCRIMINATION PROCESS
ALL PIXELS USED AS NOTICED PIXEL?
S31
YES
RETURN
NO
DECIDE NOTICED PIXEL
S32
S33
YES
THRESHOLD VALUE θ_L < PIXEL VALUE OF NOTICED PIXEL < THRESHOLD VALUE θ_H ?
NO
THRESHOLD VALUE θ_H ≦ PIXEL VALUE OF NOTICED PIXEL ?
S35
NO
YES
YES
SENSITIVITY OF NOTICED PIXEL SO ?
S36
NO
S38
YES
SENSITIVITY OF NOTICED PIXEL S1 ?
NO
S34
SET DISCRIMINATION INFORMATION AS "VALID"
SET DISCRIMINATION INFORMATION AS "INVALID"
S37

FIG. 54

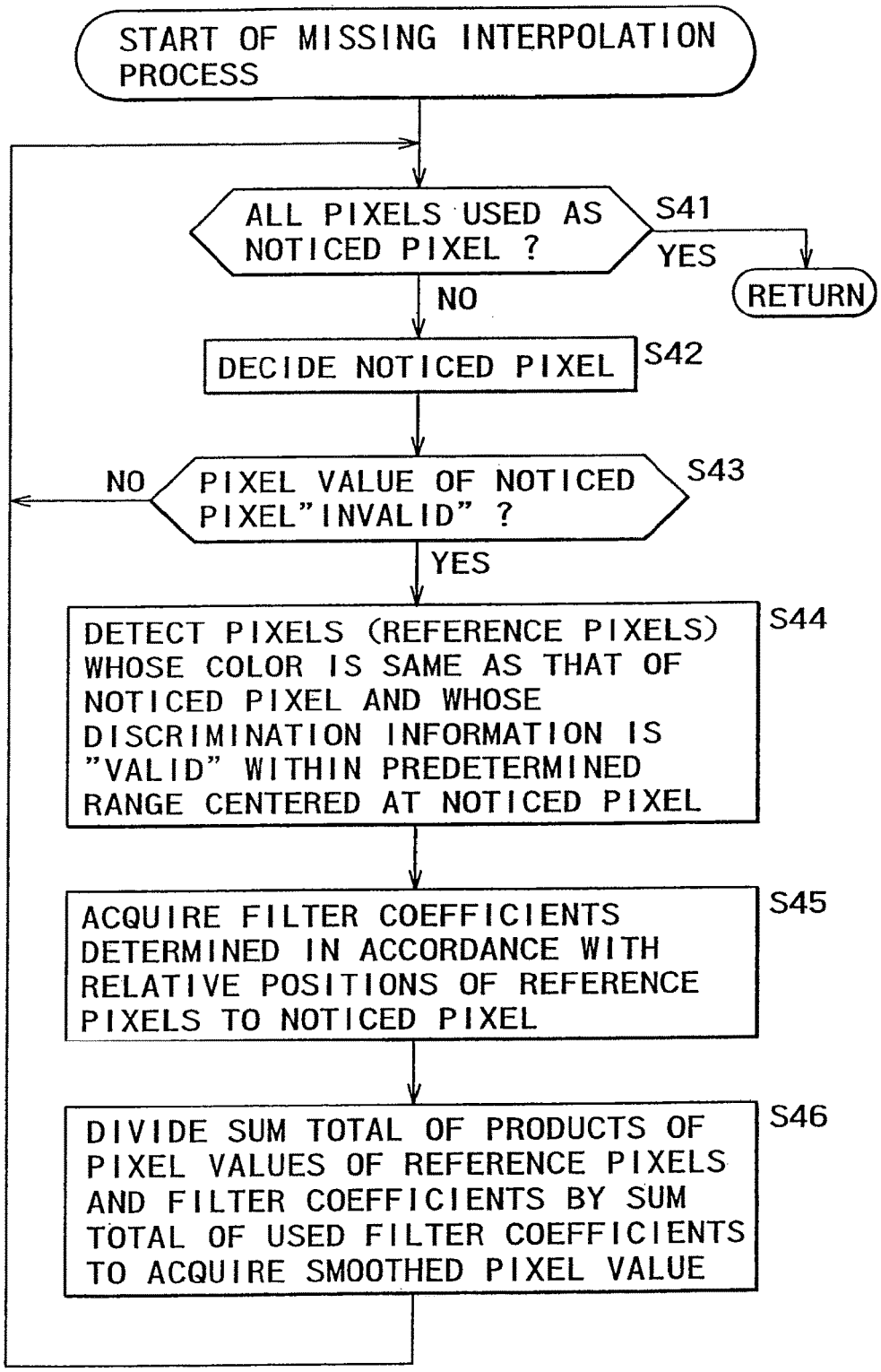

START OF MISSING INTERPOLATION PROCESS
ALL PIXELS USED AS NOTICED PIXEL ?
S41
YES
RETURN
NO
DECIDE NOTICED PIXEL
S42
NO
PIXEL VALUE OF NOTICED PIXEL"INVALID" ?
S43
YES
DETECT PIXELS (REFERENCE PIXELS) WHOSE COLOR IS SAME AS THAT OF NOTICED PIXEL AND WHOSE DISCRIMINATION INFORMATION IS "VALID" WITHIN PREDETERMINED RANGE CENTERED AT NOTICED PIXEL
S44
ACQUIRE FILTER COEFFICIENTS DETERMINED IN ACCORDANCE WITH RELATIVE POSITIONS OF REFERENCE PIXELS TO NOTICED PIXEL
S45
DIVIDE SUM TOTAL OF PRODUCTS OF PIXEL VALUES OF REFERENCE PIXELS AND FILTER COEFFICIENTS BY SUM TOTAL OF USED FILTER COEFFICIENTS TO ACQUIRE SMOOTHED PIXEL VALUE
S46

FIG. 55

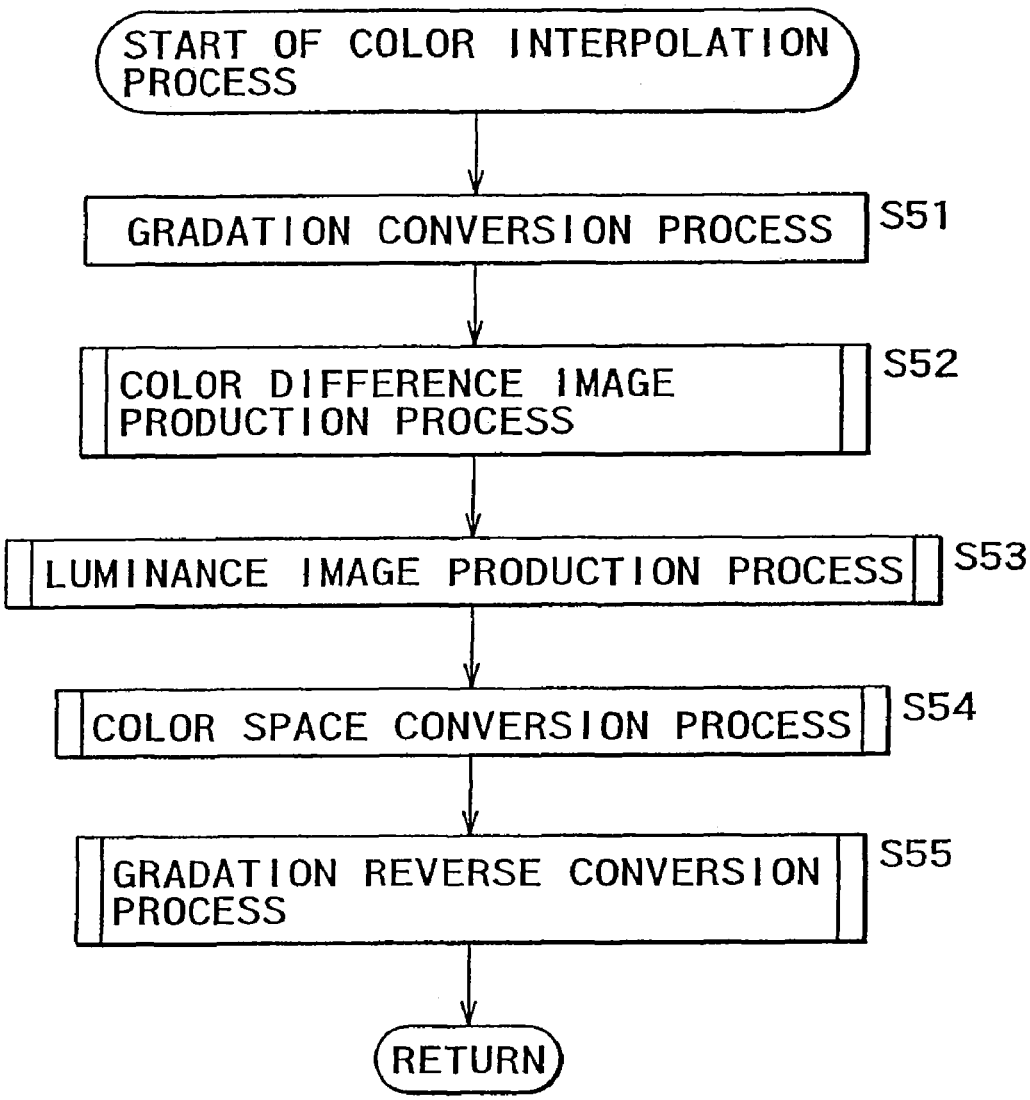

START OF COLOR INTERPOLATION PROCESS
GRADATION CONVERSION PROCESS
S51
COLOR DIFFERENCE IMAGE PRODUCTION PROCESS
S52
LUMINANCE IMAGE PRODUCTION PROCESS
S53
COLOR SPACE CONVERSION PROCESS
S54
GRADATION REVERSE CONVERSION PROCESS
S55
RETURN

FIG. 56

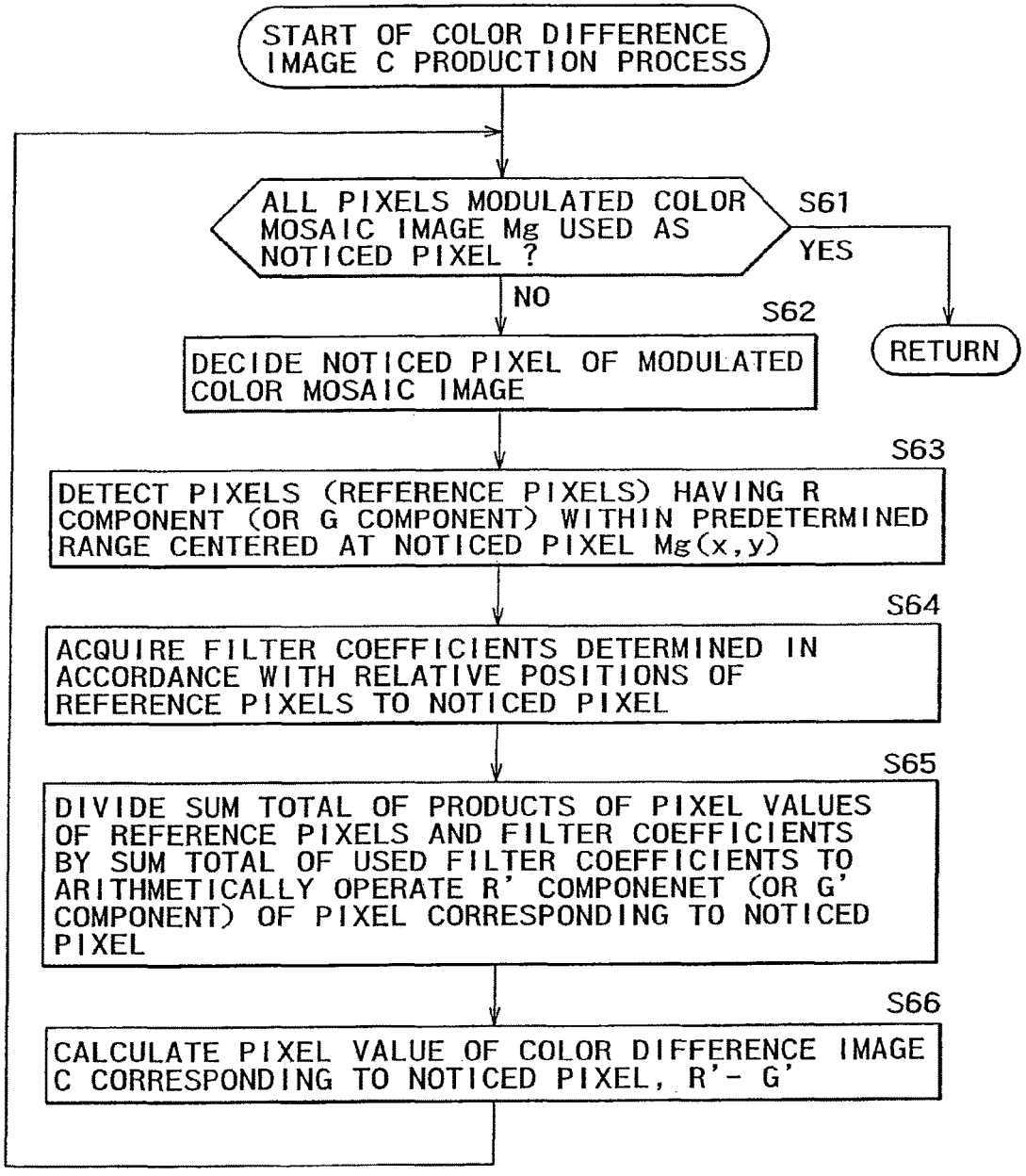

START OF COLOR DIFFERENCE IMAGE C PRODUCTION PROCESS
ALL PIXELS MODULATED COLOR MOSAIC IMAGE Mg USED AS NOTICED PIXEL ?
S61
YES
NO
RETURN
S62
DECIDE NOTICED PIXEL OF MODULATED COLOR MOSAIC IMAGE
S63
DETECT PIXELS (REFERENCE PIXELS) HAVING R COMPONENT (OR G COMPONENT) WITHIN PREDETERMINED RANGE CENTERED AT NOTICED PIXEL Mg(x,y)
S64
ACQUIRE FILTER COEFFICIENTS DETERMINED IN ACCORDANCE WITH RELATIVE POSITIONS OF REFERENCE PIXELS TO NOTICED PIXEL
S65
DIVIDE SUM TOTAL OF PRODUCTS OF PIXEL VALUES OF REFERENCE PIXELS AND FILTER COEFFICIENTS BY SUM TOTAL OF USED FILTER COEFFICIENTS TO ARITHMETICALLY OPERATE R' COMPONENET (OR G' COMPONENT) OF PIXEL CORRESPONDING TO NOTICED PIXEL
S66
CALCULATE PIXEL VALUE OF COLOR DIFFERENCE IMAGE C CORRESPONDING TO NOTICED PIXEL, R'- G'

FIG. 57

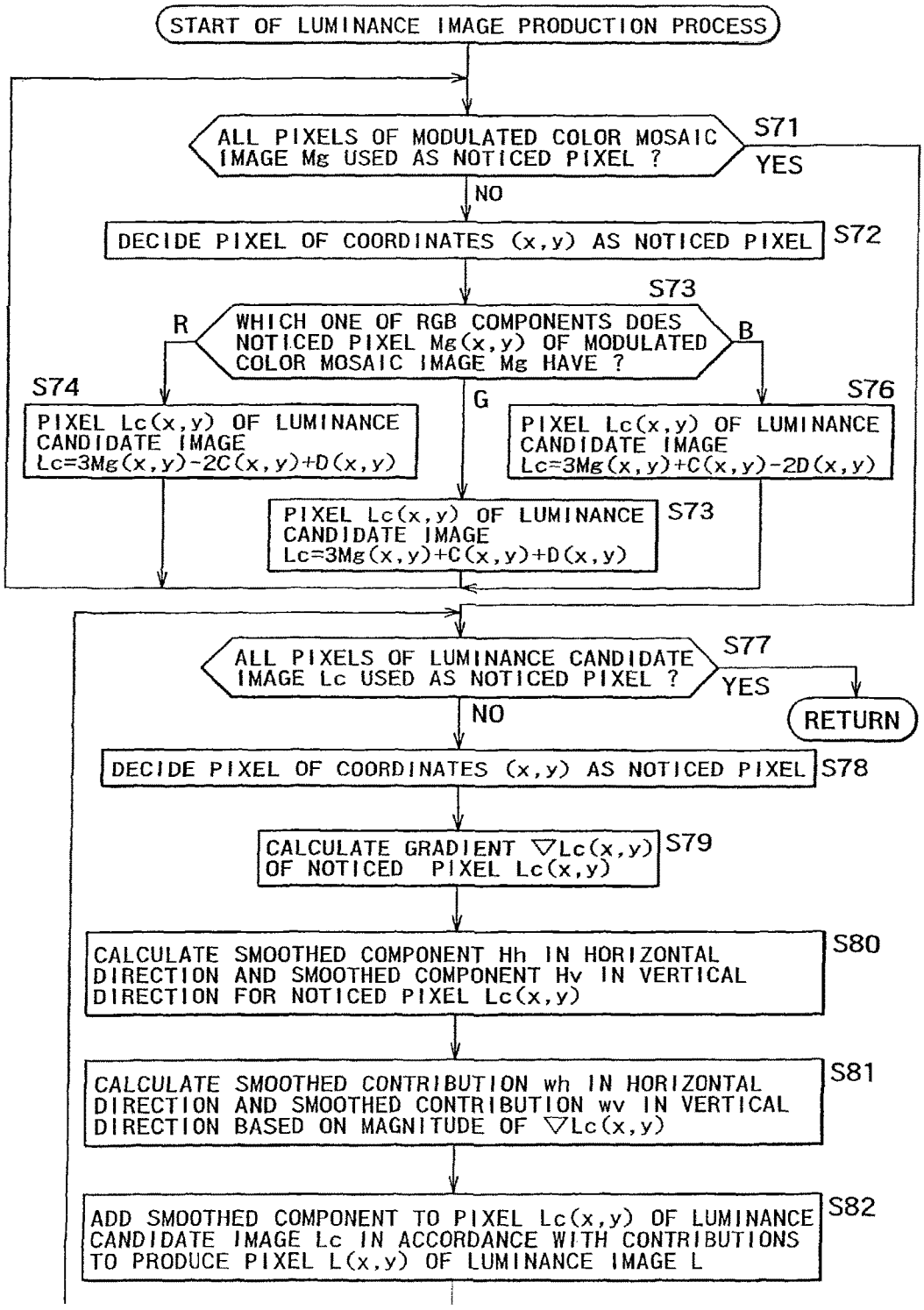

START OF LUMINANCE IMAGE PRODUCTION PROCESS
ALL PIXELS OF MODULATED COLOR MOSAIC IMAGE Mg USED AS NOTICED PIXEL ?
S71
YES
NO
DECIDE PIXEL OF COORDINATES (x,y) AS NOTICED PIXEL
S72
S73
WHICH ONE OF RGB COMPONENTS DOES NOTICED PIXEL Mg(x,y) OF MODULATED COLOR MOSAIC IMAGE Mg HAVE ?
R
G
B
S74
PIXEL Lc(x,y) OF LUMINANCE CANDIDATE IMAGE Lc=3Mg(x,y)-2C(x,y)+D(x,y)
PIXEL Lc(x,y) OF LUMINANCE CANDIDATE IMAGE Lc=3Mg(x,y)+C(x,y)-2D(x,y)
S76
PIXEL Lc(x,y) OF LUMINANCE CANDIDATE IMAGE Lc=3Mg(x,y)+C(x,y)+D(x,y)
S73
ALL PIXELS OF LUMINANCE CANDIDATE IMAGE Lc USED AS NOTICED PIXEL ?
S77
YES
NO
RETURN
DECIDE PIXEL OF COORDINATES (x,y) AS NOTICED PIXEL
S78
CALCULATE GRADIENT ▽Lc(x,y) OF NOTICED PIXEL Lc(x,y)
S79
CALCULATE SMOOTHED COMPONENT Hh IN HORIZONTAL DIRECTION AND SMOOTHED COMPONENT Hv IN VERTICAL DIRECTION FOR NOTICED PIXEL Lc(x,y)
S80
CALCULATE SMOOTHED CONTRIBUTION wh IN HORIZONTAL DIRECTION AND SMOOTHED CONTRIBUTION wv IN VERTICAL DIRECTION BASED ON MAGNITUDE OF ▽Lc(x,y)
S81
ADD SMOOTHED COMPONENT TO PIXEL Lc(x,y) OF LUMINANCE CANDIDATE IMAGE Lc IN ACCORDANCE WITH CONTRIBUTIONS TO PRODUCE PIXEL L(x,y) OF LUMINANCE IMAGE L
S82

FIG. 58

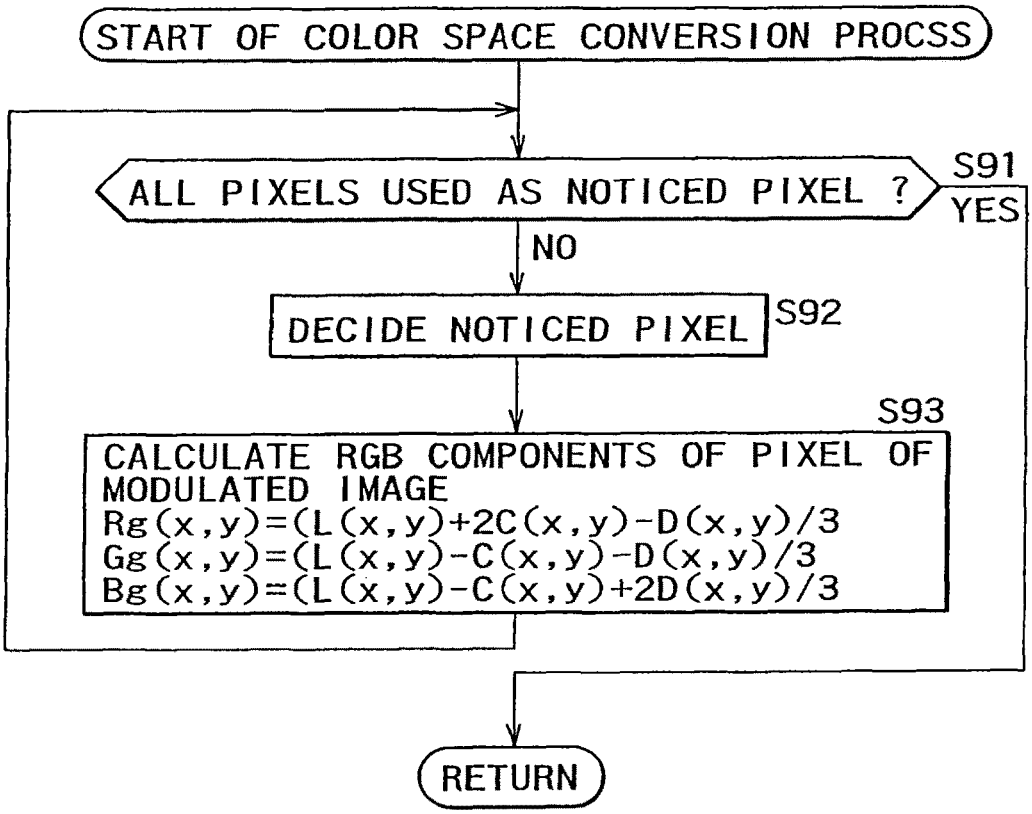

START OF COLOR SPACE CONVERSION PROCSS
ALL PIXELS USED AS NOTICED PIXEL ?
S91
YES
NO
DECIDE NOTICED PIXEL
S92
S93
CALCULATE RGB COMPONENTS OF PIXEL OF MODULATED IMAGE
Rg(x,y)=(L(x,y)+2C(x,y)-D(x,y)/3
Gg(x,y)=(L(x,y)-C(x,y)-D(x,y)/3
Bg(x,y)=(L(x,y)-C(x,y)+2D(x,y)/3
RETURN

FIG. 59

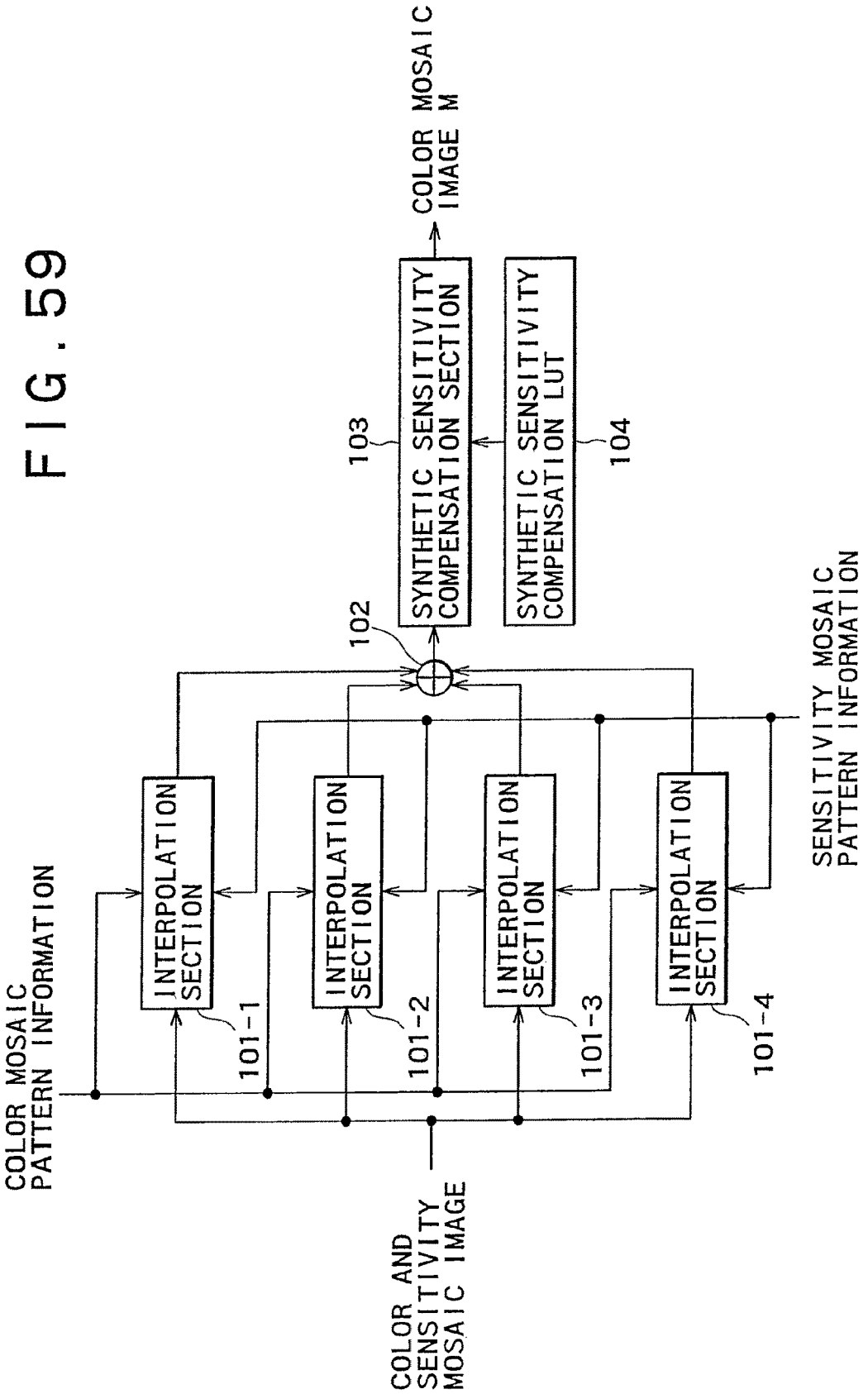

COLOR MOSAIC IMAGE M
SYNTHETIC SENSITIVITY COMPENSATION SECTION
SYNTHETIC SENSITIVITY COMPENSATION LUT
103
104
102
INTERPOLATION SECTION
101-1
101-2
101-3
101-4
COLOR MOSAIC PATTERN INFORMATION
SENSITIVITY MOSAIC PATTERN INFORMATION
COLOR AND SENSITIVITY MOSAIC IMAGE

FIG. 60

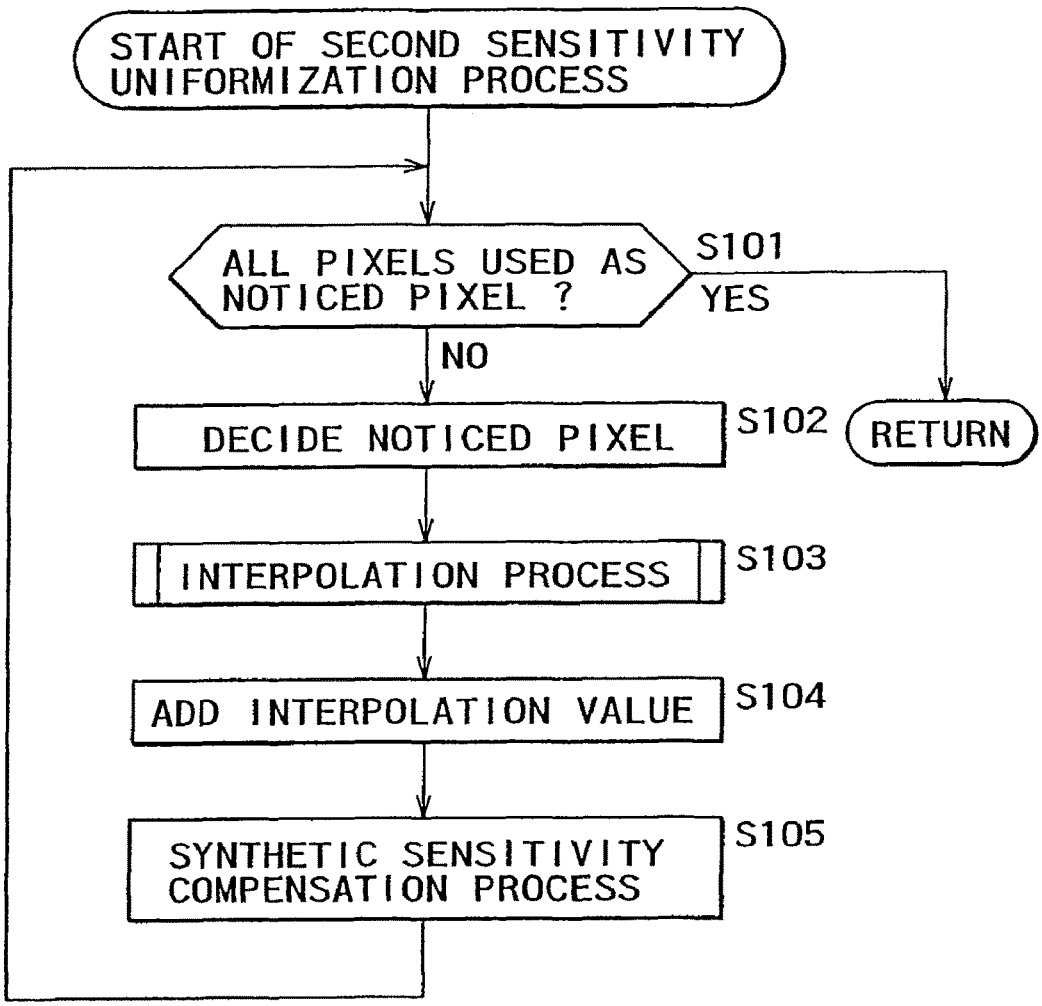

START OF SECOND SENSITIVITY UNIFORMIZATION PROCESS
ALL PIXELS USED AS NOTICED PIXEL ?
S101
YES
NO
RETURN
DECIDE NOTICED PIXEL
S102
INTERPOLATION PROCESS
S103
ADD INTERPOLATION VALUE
S104
SYNTHETIC SENSITIVITY COMPENSATION PROCESS
S105

FIG. 61

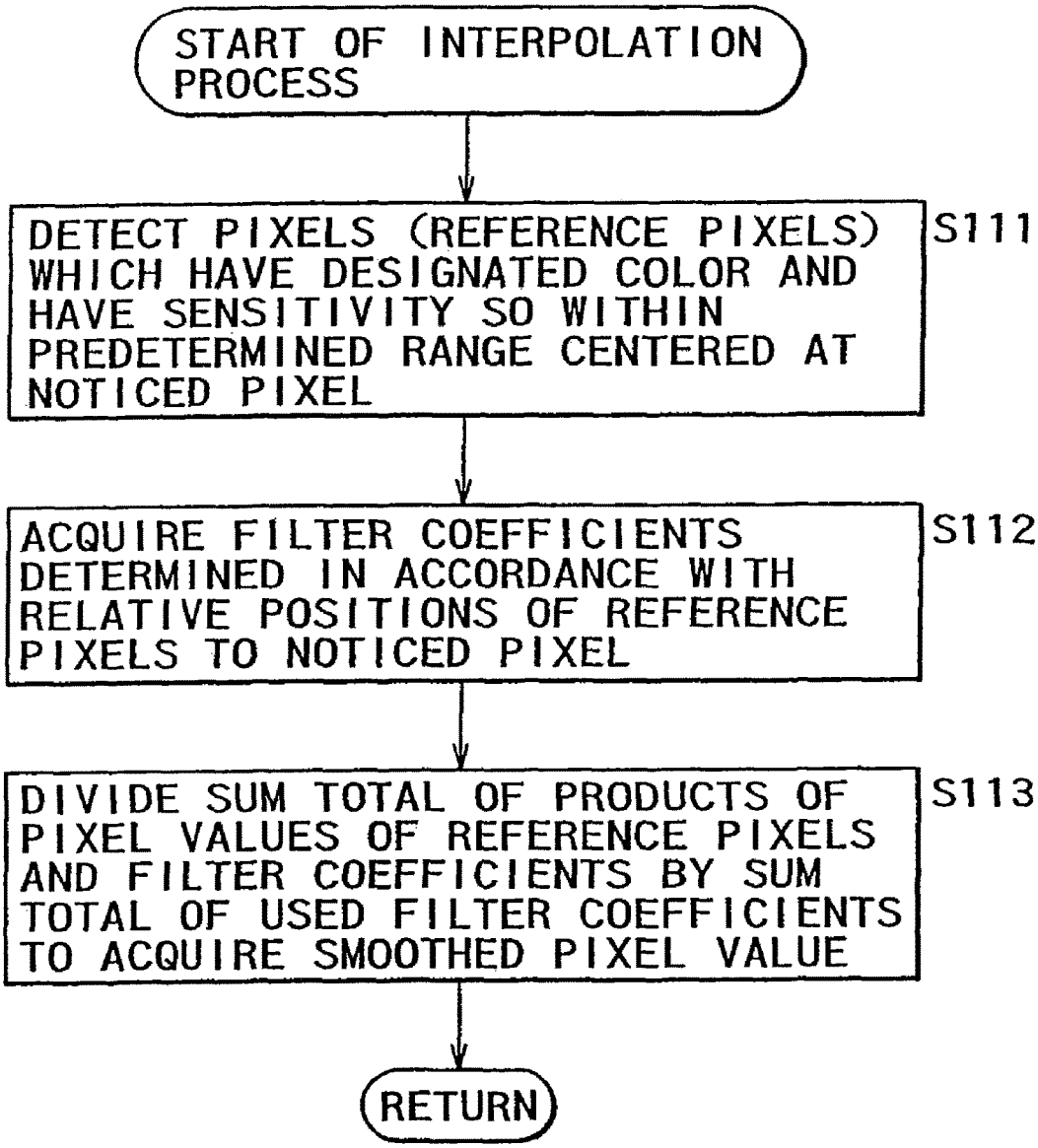

START OF INTERPOLATION PROCESS
DETECT PIXELS (REFERENCE PIXELS) WHICH HAVE DESIGNATED COLOR AND HAVE SENSITIVITY SO WITHIN PREDETERMINED RANGE CENTERED AT NOTICED PIXEL
S111
ACQUIRE FILTER COEFFICIENTS DETERMINED IN ACCORDANCE WITH RELATIVE POSITIONS OF REFERENCE PIXELS TO NOTICED PIXEL
S112
DIVIDE SUM TOTAL OF PRODUCTS OF PIXEL VALUES OF REFERENCE PIXELS AND FILTER COEFFICIENTS BY SUM TOTAL OF USED FILTER COEFFICIENTS TO ACQUIRE SMOOTHED PIXEL VALUE
S113
RETURN

FIG. 62

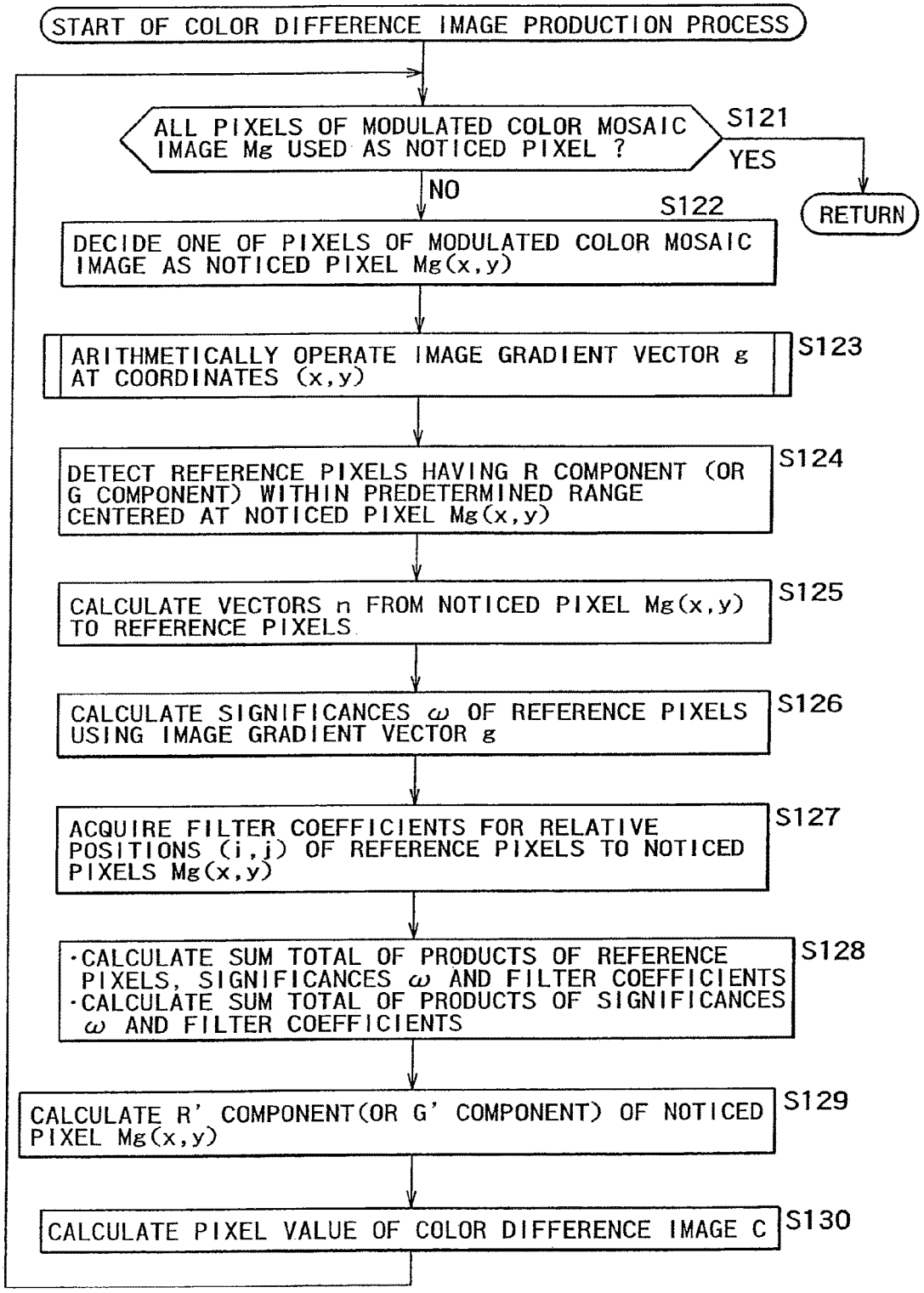

START OF COLOR DIFFERENCE IMAGE PRODUCTION PROCESS
ALL PIXELS OF MODULATED COLOR MOSAIC IMAGE Mg USED AS NOTICED PIXEL ?
S121
YES
NO
RETURN
S122
DECIDE ONE OF PIXELS OF MODULATED COLOR MOSAIC IMAGE AS NOTICED PIXEL Mg(x,y)
ARITHMETICALLY OPERATE IMAGE GRADIENT VECTOR g AT COORDINATES (x,y)
S123
DETECT REFERENCE PIXELS HAVING R COMPONENT (OR G COMPONENT) WITHIN PREDETERMINED RANGE CENTERED AT NOTICED PIXEL Mg(x,y)
S124
CALCULATE VECTORS n FROM NOTICED PIXEL Mg(x,y) TO REFERENCE PIXELS
S125
CALCULATE SIGNIFICANCES ω OF REFERENCE PIXELS USING IMAGE GRADIENT VECTOR g
S126
ACQUIRE FILTER COEFFICIENTS FOR RELATIVE POSITIONS (i,j) OF REFERENCE PIXELS TO NOTICED PIXELS Mg(x,y)
S127
·CALCULATE SUM TOTAL OF PRODUCTS OF REFERENCE PIXELS, SIGNIFICANCES ω AND FILTER COEFFICIENTS
·CALCULATE SUM TOTAL OF PRODUCTS OF SIGNIFICANCES ω AND FILTER COEFFICIENTS
S128
CALCULATE R' COMPONENT(OR G' COMPONENT) OF NOTICED PIXEL Mg(x,y)
S129
CALCULATE PIXEL VALUE OF COLOR DIFFERENCE IMAGE C
S130

FIG. 63

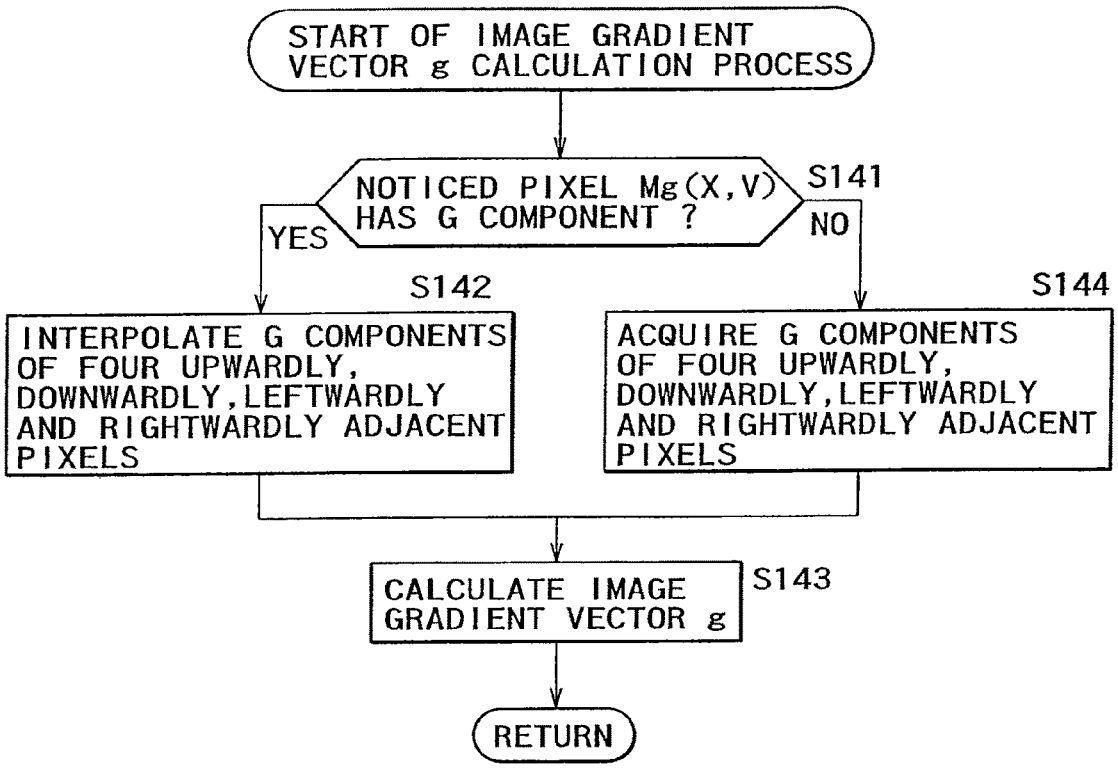

START OF IMAGE GRADIENT VECTOR g CALCULATION PROCESS
NOTICED PIXEL Mg(X,V) HAS G COMPONENT ?
S141
YES
NO
S142
INTERPOLATE G COMPONENTS OF FOUR UPWARDLY, DOWNWARDLY, LEFTWARDLY AND RIGHTWARDLY ADJACENT PIXELS
S144
ACQUIRE G COMPONENTS OF FOUR UPWARDLY, DOWNWARDLY, LEFTWARDLY AND RIGHTWARDLY ADJACENT PIXELS
CALCULATE IMAGE GRADIENT VECTOR g
S143
RETURN

FIG. 64

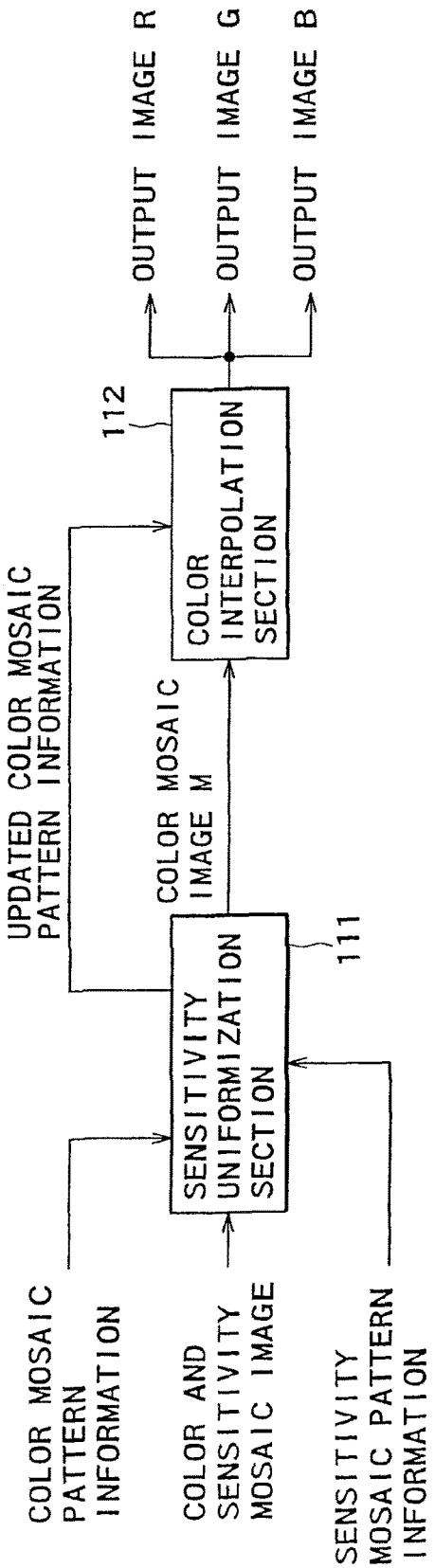

COLOR MOSAIC PATTERN INFORMATION
COLOR AND SENSITIVITY MOSAIC IMAGE
SENSITIVITY MOSAIC PATTERN INFORMATION
SENSITIVITY UNIFORMIZATION SECTION
111
UPDATED COLOR MOSAIC PATTERN INFORMATION
COLOR MOSAIC IMAGE M
COLOR INTERPOLATION SECTION
112
OUTPUT IMAGE R
OUTPUT IMAGE G
OUTPUT IMAGE B

FIG. 65

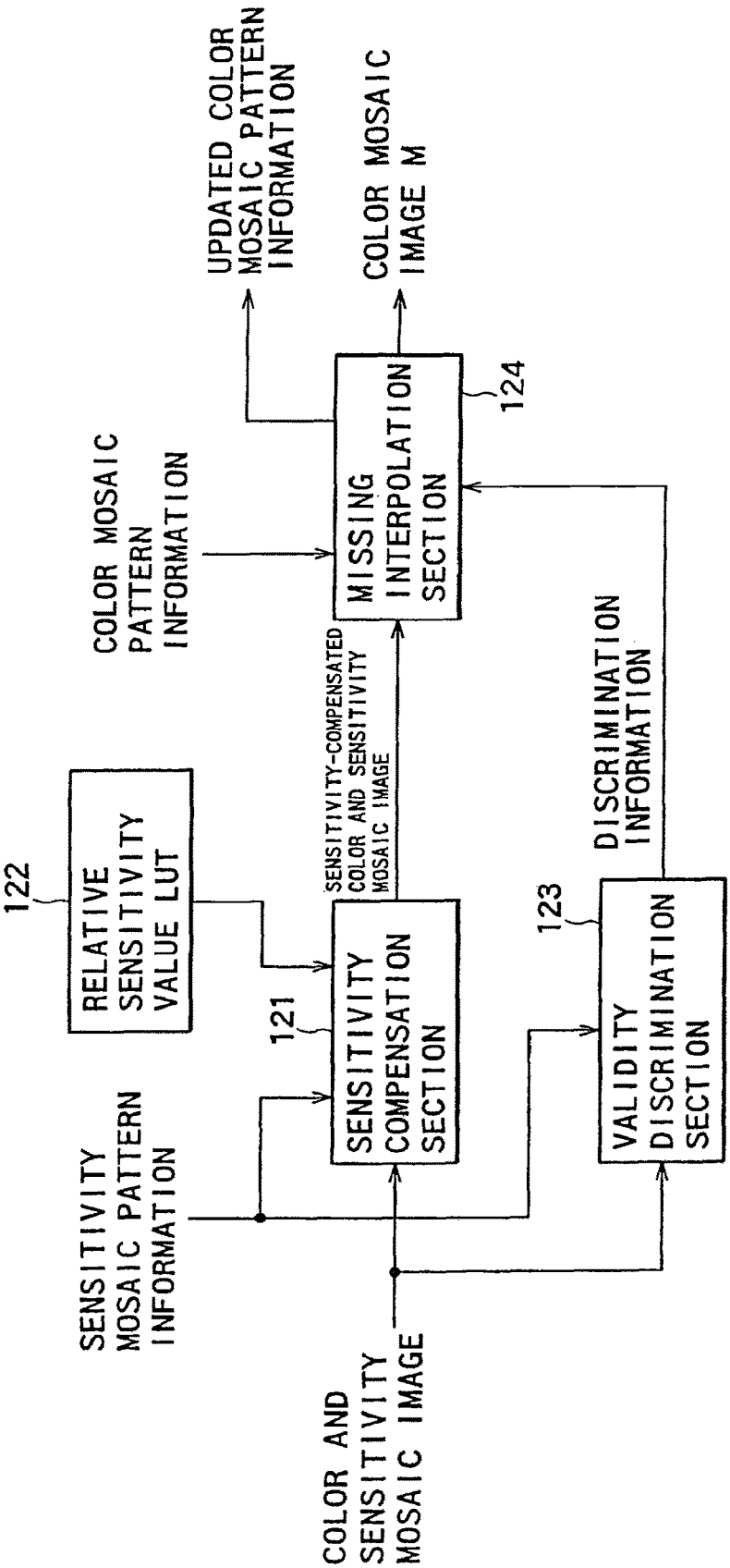

UPDATED COLOR MOSAIC PATTERN INFORMATION
COLOR MOSAIC IMAGE M
COLOR MOSAIC PATTERN INFORMATION
MISSING INTERPOLATION SECTION
124
SENSITIVITY-COMPENSATED COLOR AND SENSITIVITY MOSAIC IMAGE
DISCRIMINATION INFORMATION
122
RELATIVE SENSITIVITY VALUE LUT
123
121
SENSITIVITY COMPENSATION SECTION
VALIDITY DISCRIMINATION SECTION
SENSITIVITY MOSAIC PATTERN INFORMATION
COLOR AND SENSITIVITY MOSAIC IMAGE

FIG. 66

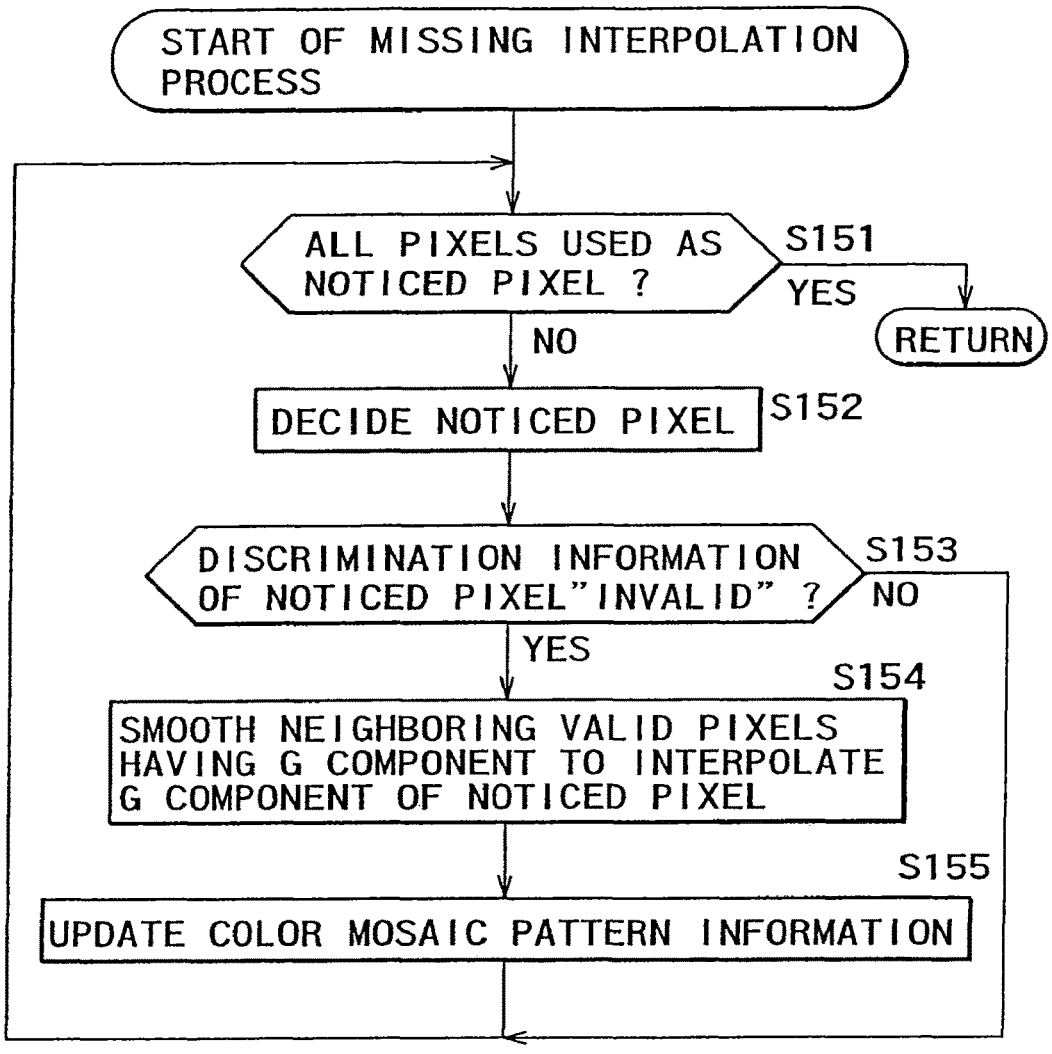

START OF MISSING INTERPOLATION PROCESS
ALL PIXELS USED AS NOTICED PIXEL ?
S151
YES
RETURN
NO
DECIDE NOTICED PIXEL
S152
DISCRIMINATION INFORMATION OF NOTICED PIXEL "INVALID" ?
S153
NO
YES
S154
SMOOTH NEIGHBORING VALID PIXELS HAVING G COMPONENT TO INTERPOLATE G COMPONENT OF NOTICED PIXEL
S155
UPDATE COLOR MOSAIC PATTERN INFORMATION

FIG. 67

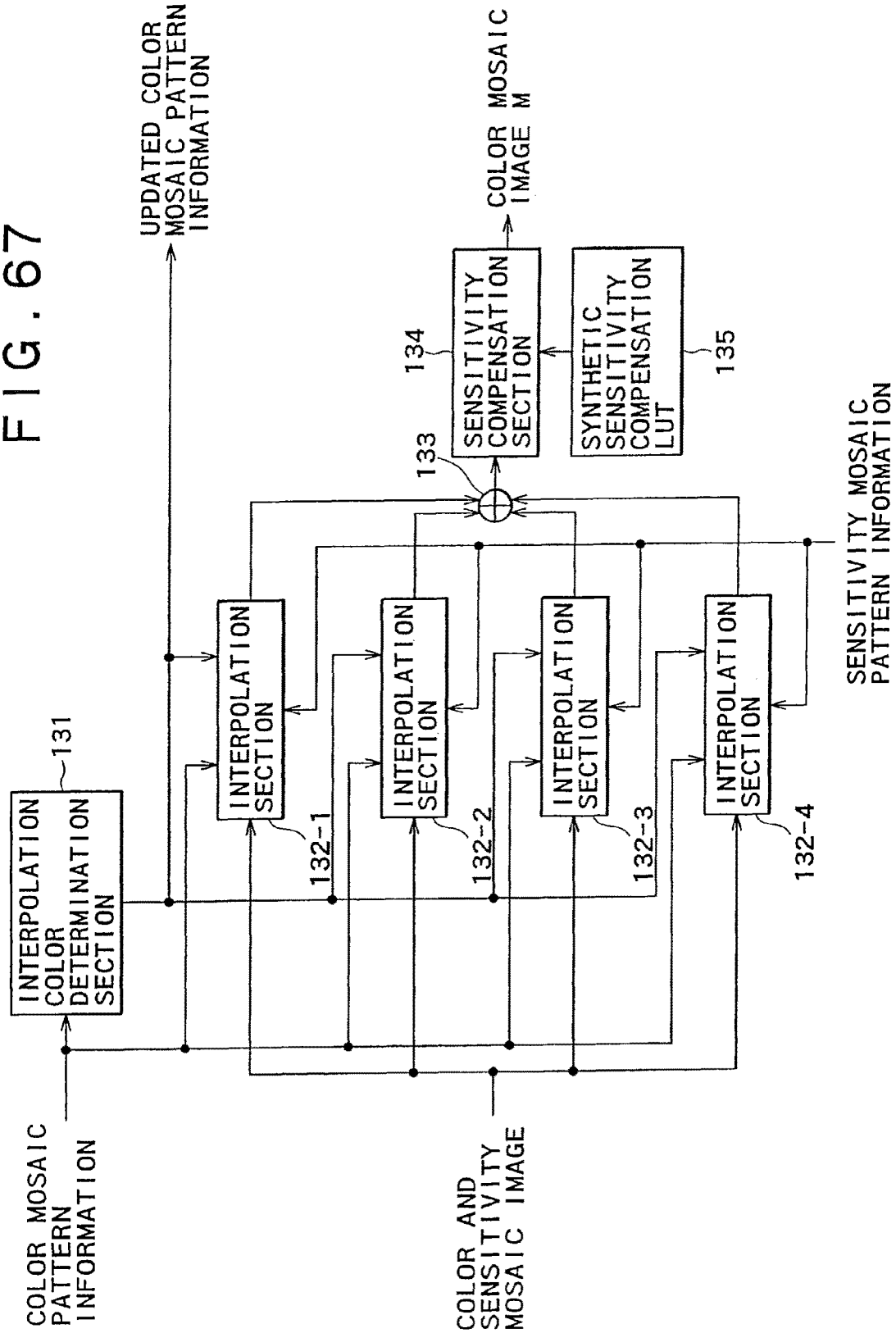

COLOR MOSAIC PATTERN INFORMATION
COLOR AND SENSITIVITY MOSAIC IMAGE
INTERPOLATION COLOR DETERMINATION SECTION
131
INTERPOLATION SECTION
132-1
INTERPOLATION SECTION
132-2
INTERPOLATION SECTION
132-3
INTERPOLATION SECTION
132-4
UPDATED COLOR MOSAIC PATTERN INFORMATION
SENSITIVITY MOSAIC PATTERN INFORMATION
133
SENSITIVITY COMPENSATION SECTION
134
SYNTHETIC SENSITIVITY COMPENSATION LUT
135
COLOR MOSAIC IMAGE M

FIG. 68

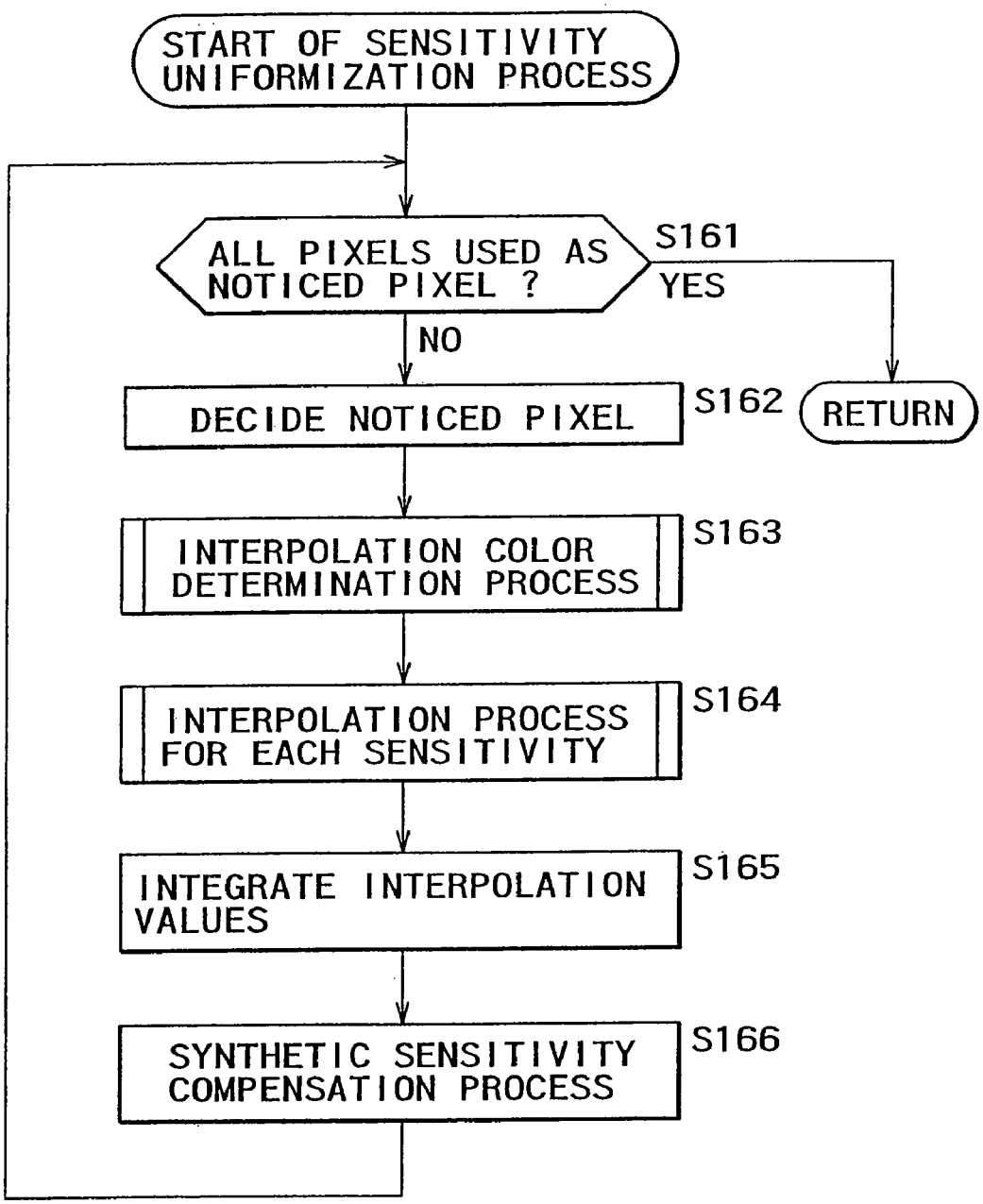
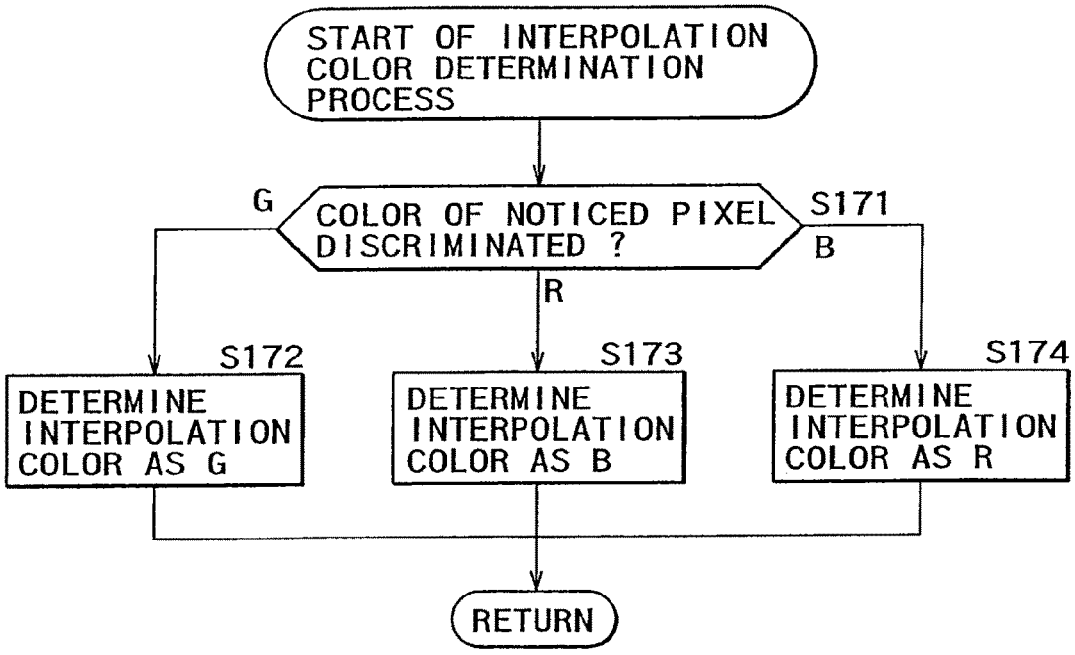

START OF SENSITIVITY UNIFORMIZATION PROCESS
ALL PIXELS USED AS NOTICED PIXEL ?
S161
YES
NO
RETURN
DECIDE NOTICED PIXEL
S162
INTERPOLATION COLOR DETERMINATION PROCESS
S163
INTERPOLATION PROCESS FOR EACH SENSITIVITY
S164
INTEGRATE INTERPOLATION VALUES
S165
SYNTHETIC SENSITIVITY COMPENSATION PROCESS
S166

FIG. 69


START OF INTERPOLATION COLOR DETERMINATION PROCESS
COLOR OF NOTICED PIXEL DISCRIMINATED ?
S171
G
R
B
S172
DETERMINE INTERPOLATION COLOR AS G
S173
DETERMINE INTERPOLATION COLOR AS B
S174
DETERMINE INTERPOLATION COLOR AS R
RETURN

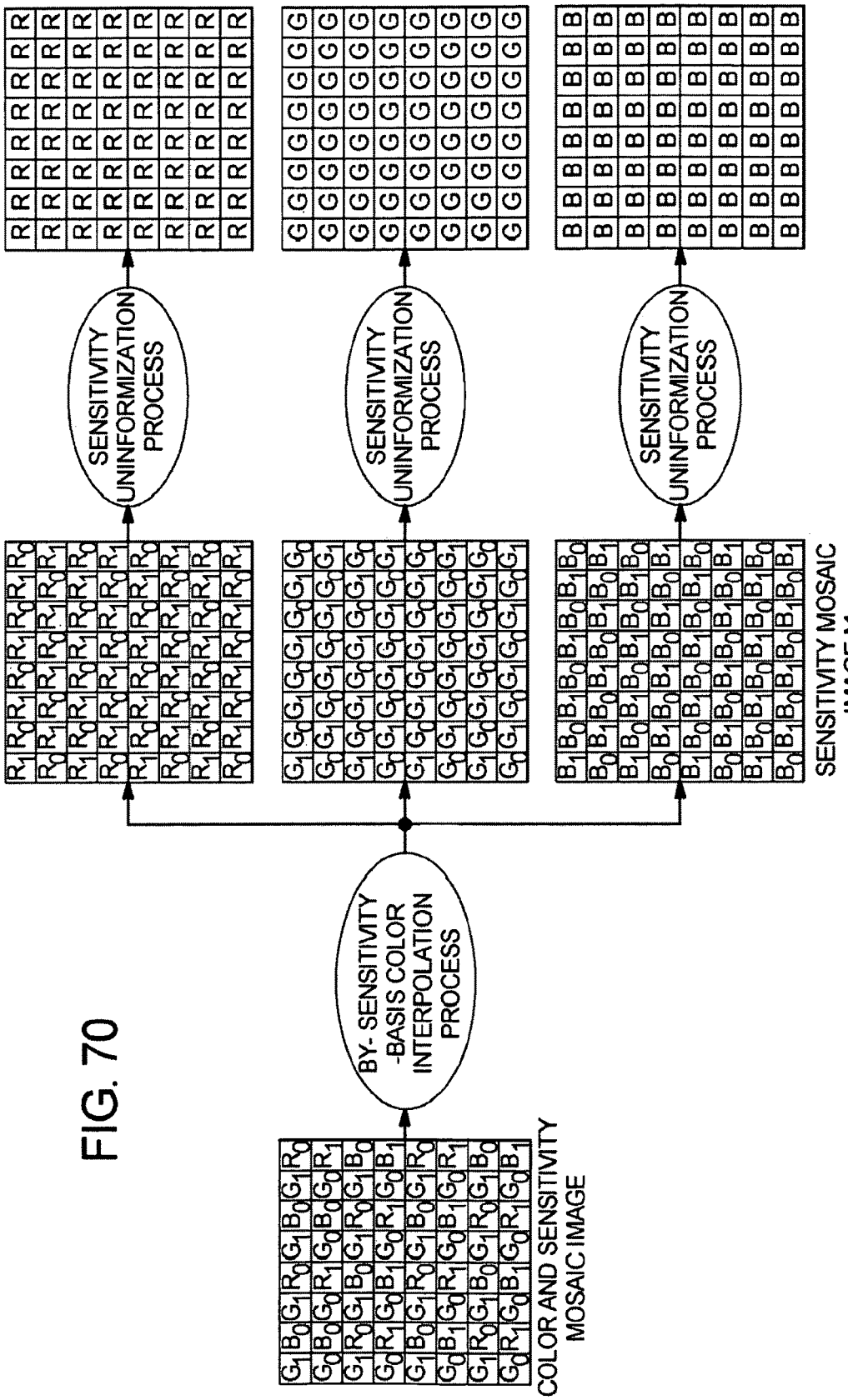

COLOR AND SENSITIVITY MOSAIC IMAGE
BY- SENSITIVITY -BASIS COLOR INTERPOLATION PROCESS
SENSITIVITY UNINFORMIZATION PROCESS
SENSITIVITY UNINFORMIZATION PROCESS
SENSITIVITY UNINFORMIZATION PROCESS
SENSITIVITY MOSAIC IMAGE Ms

FIG. 70

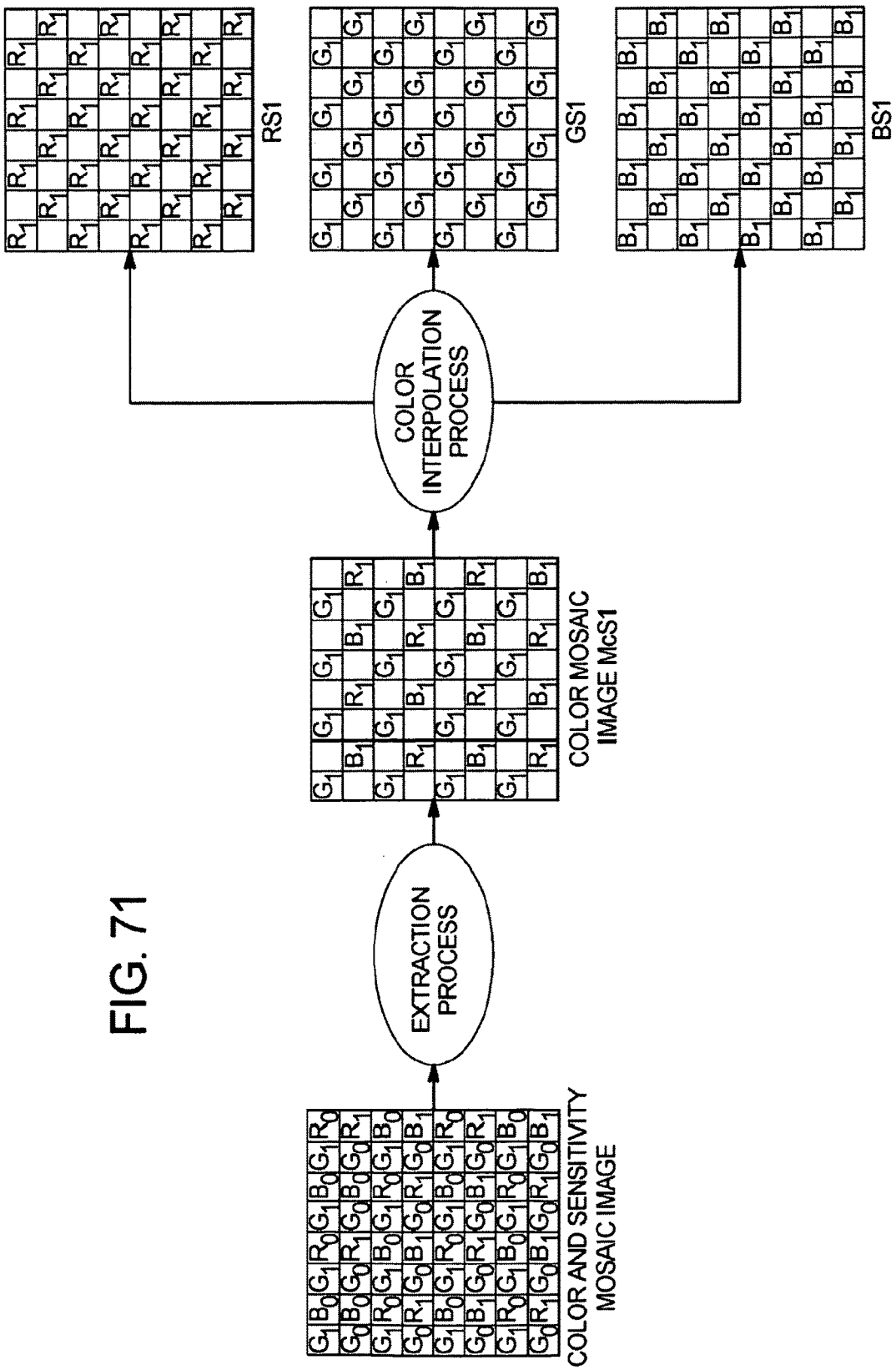

COLOR AND SENSITIVITY MOSAIC IMAGE
EXTRACTION PROCESS
COLOR MOSAIC IMAGE McS1
COLOR INTERPOLATION PROCESS
RS1
GS1
BS1

FIG. 71

FIG. 72

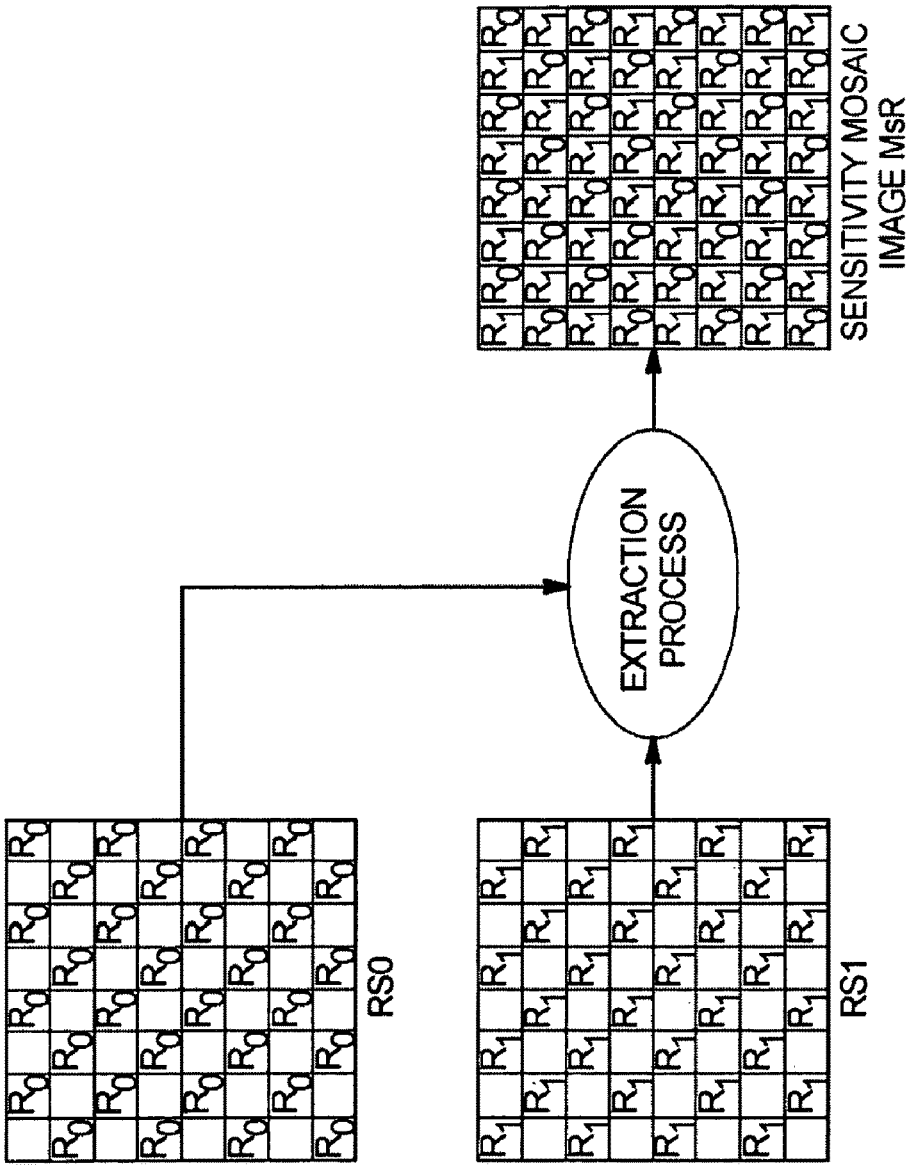


FIG. 73

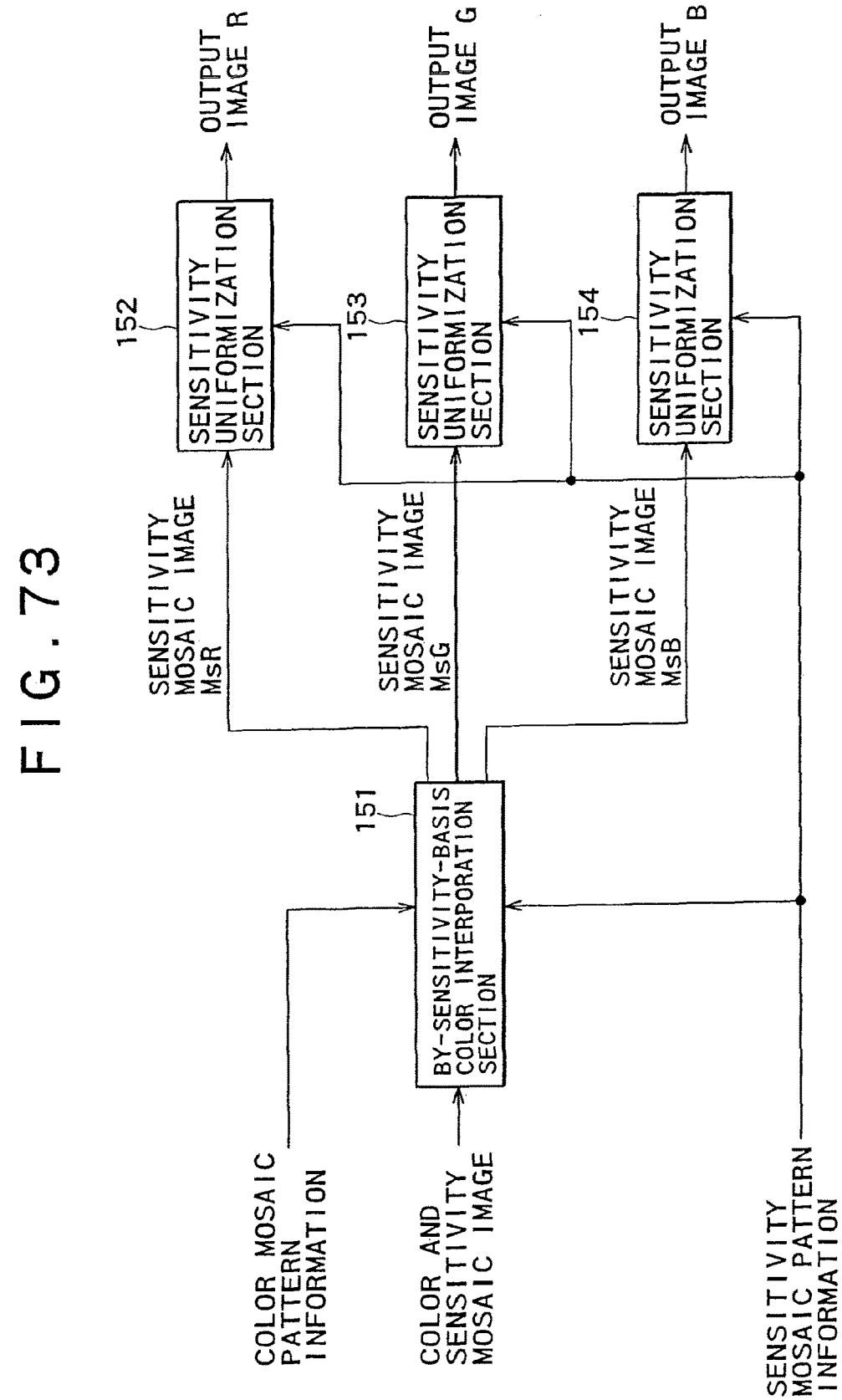

OUTPUT IMAGE R
OUTPUT IMAGE G
OUTPUT IMAGE B
152
153
154
SENSITIVITY UNIFORMIZATION SECTION
SENSITIVITY UNIFORMIZATION SECTION
SENSITIVITY UNIFORMIZATION SECTION
SENSITIVITY MOSAIC IMAGE MsR
SENSITIVITY MOSAIC IMAGE MsG
SENSITIVITY MOSAIC IMAGE MsB
151
BY-SENSITIVITY-BASIS COLOR INTERPORATION SECTION
COLOR MOSAIC PATTERN INFORMATION
COLOR AND SENSITIVITY MOSAIC IMAGE
SENSITIVITY MOSAIC PATTERN INFORMATION

FIG. 74

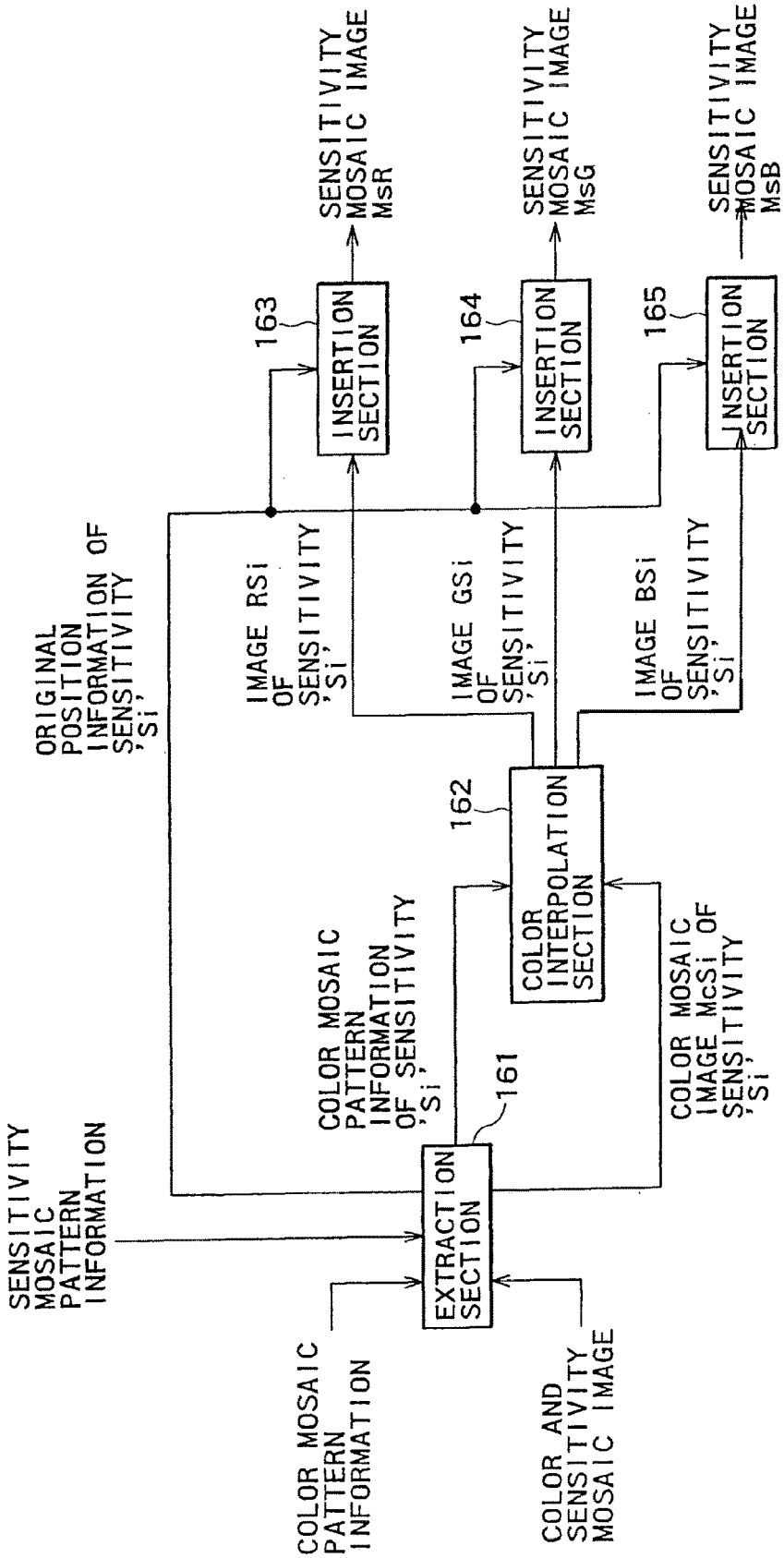

SENSITIVITY MOSAIC PATTERN INFORMATION
COLOR MOSAIC PATTERN INFORMATION
COLOR AND SENSITIVITY MOSAIC IMAGE
EXTRACTION SECTION
161
COLOR MOSAIC PATTERN INFORMATION OF SENSITIVITY 'Si'
ORIGINAL POSITION INFORMATION OF SENSITIVITY 'Si'
COLOR MOSAIC IMAGE McSi OF SENSITIVITY 'Si'
COLOR INTERPOLATION SECTION
162
IMAGE RSi OF SENSITIVITY 'Si'
IMAGE GSi OF SENSITIVITY 'Si'
IMAGE BSi OF SENSITIVITY 'Si'
163
164
165
INSERTION SECTION
INSERTION SECTION
INSERTION SECTION
SENSITIVITY MOSAIC IMAGE MsR
SENSITIVITY MOSAIC IMAGE MsG
SENSITIVITY MOSAIC IMAGE MsB

FIG. 75

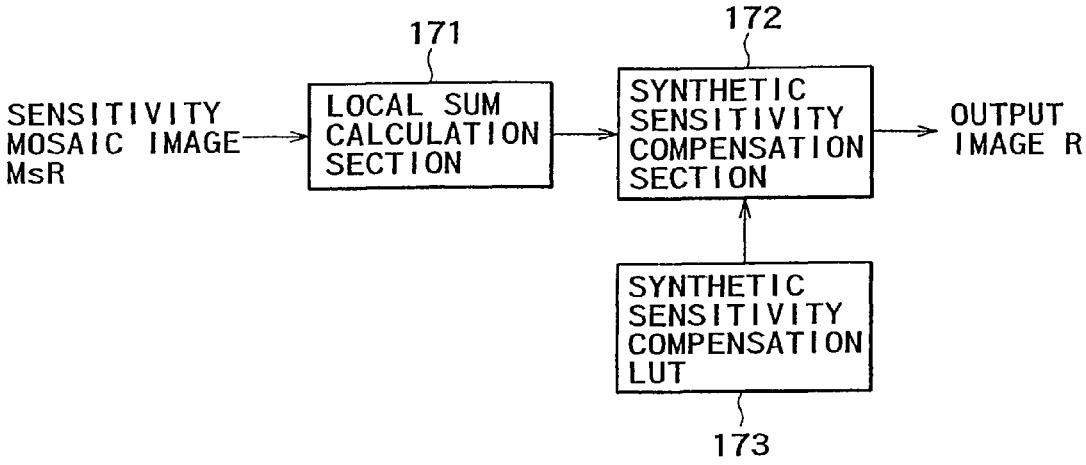

171
172
SENSITIVITY MOSAIC IMAGE MsR
LOCAL SUM CALCULATION SECTION
SYNTHETIC SENSITIVITY COMPENSATION SECTION
OUTPUT IMAGE R
SYNTHETIC SENSITIVITY COMPENSATION LUT
173

FIG. 76

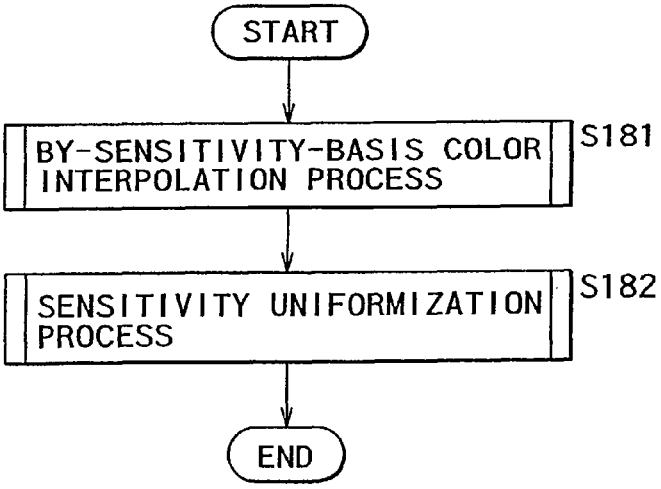

START
BY-SENSITIVITY-BASIS COLOR INTERPOLATION PROCESS
S181
SENSITIVITY UNIFORMIZATION PROCESS
S182
END

FIG. 77

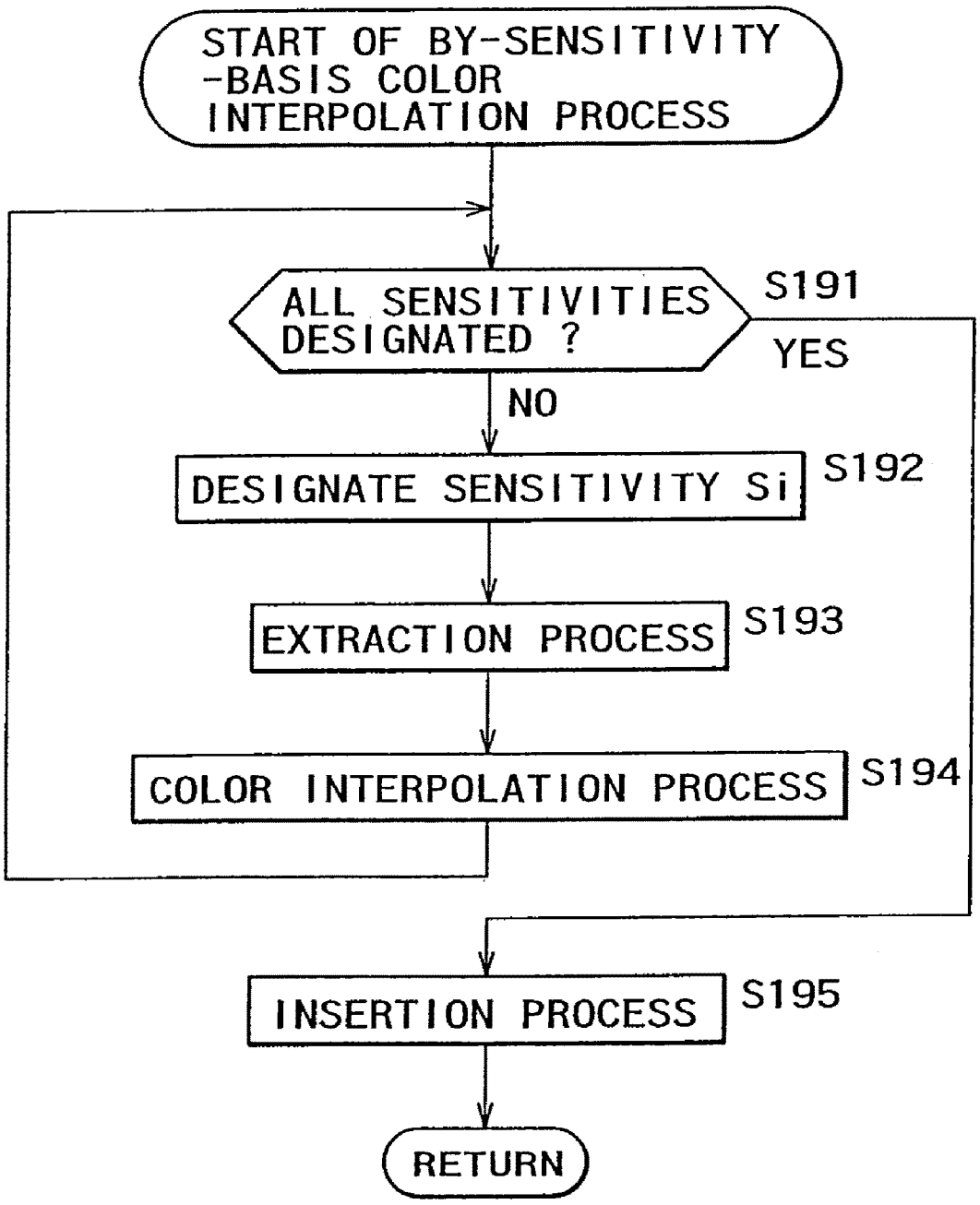

START OF BY-SENSITIVITY -BASIS COLOR INTERPOLATION PROCESS
ALL SENSITIVITIES DESIGNATED ?
S191
YES
NO
DESIGNATE SENSITIVITY Si
S192
EXTRACTION PROCESS
S193
COLOR INTERPOLATION PROCESS
S194
INSERTION PROCESS
S195
RETURN

FIG. 78

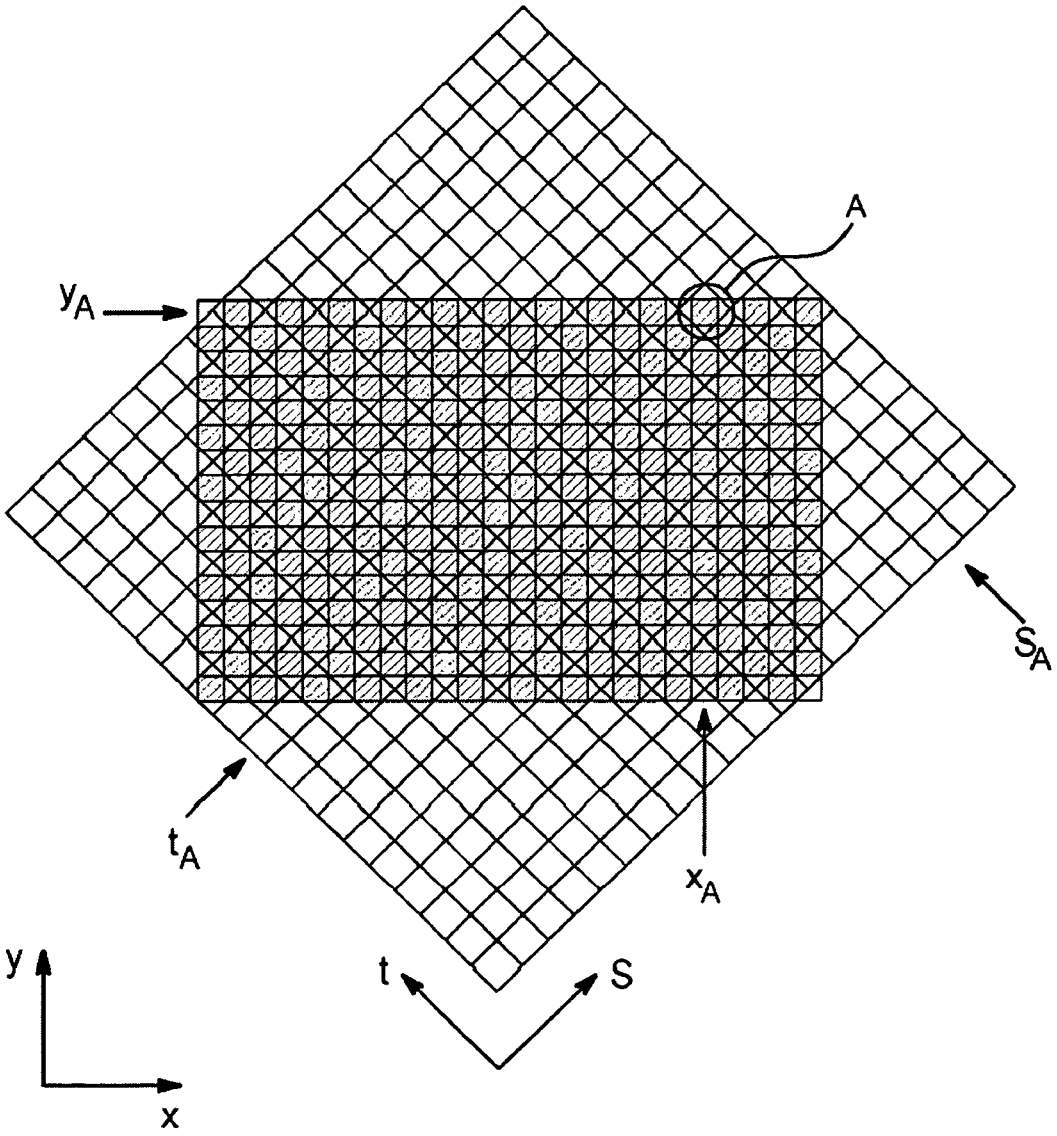


FIG. 79

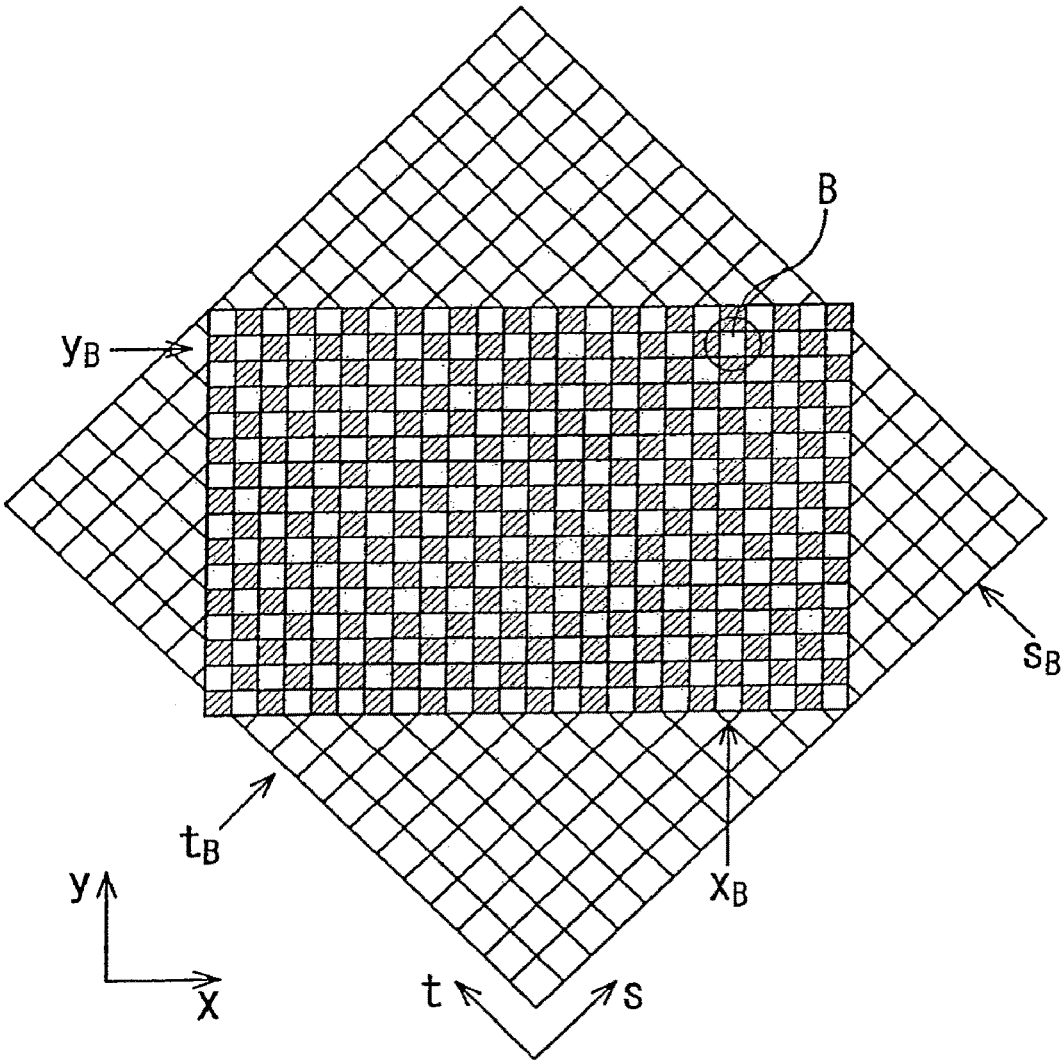


FIG. 80

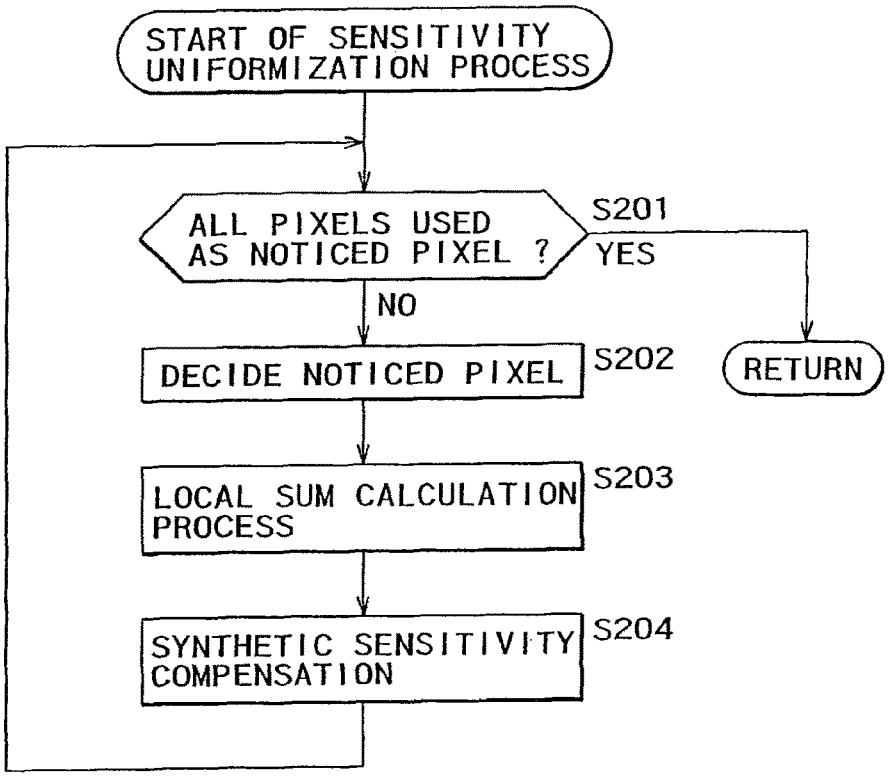


FIG. 81

0.043	-0.618	-1.322	-0.618	0.043
-0.618	9.001	19.238	9.001	-0.618
-1.322	19.238	41.12	19.238	-1.322
-0.618	9.001	19.238	9.001	-0.618
0.043	-0.618	-1.322	-0.618	0.043

FIG. 82

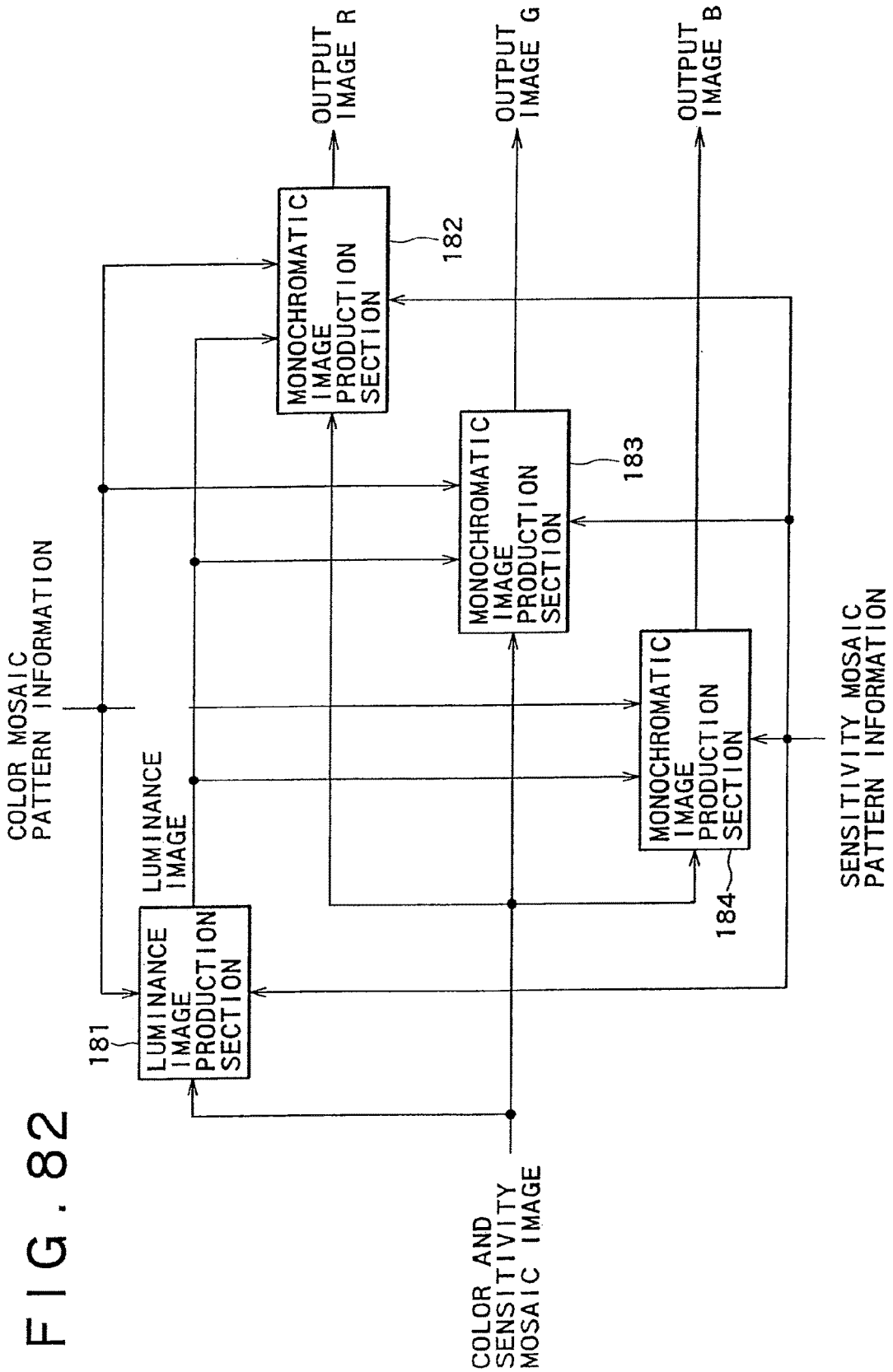

COLOR AND SENSITIVITY MOSAIC IMAGE
LUMINANCE IMAGE PRODUCTION SECTION
181
LUMINANCE IMAGE
COLOR MOSAIC PATTERN INFORMATION
MONOCHROMATIC IMAGE PRODUCTION SECTION
182
MONOCHROMATIC IMAGE PRODUCTION SECTION
183
MONOCHROMATIC IMAGE PRODUCTION SECTION
184
SENSITIVITY MOSAIC PATTERN INFORMATION
OUTPUT IMAGE R
OUTPUT IMAGE G
OUTPUT IMAGE B

FIG. 83

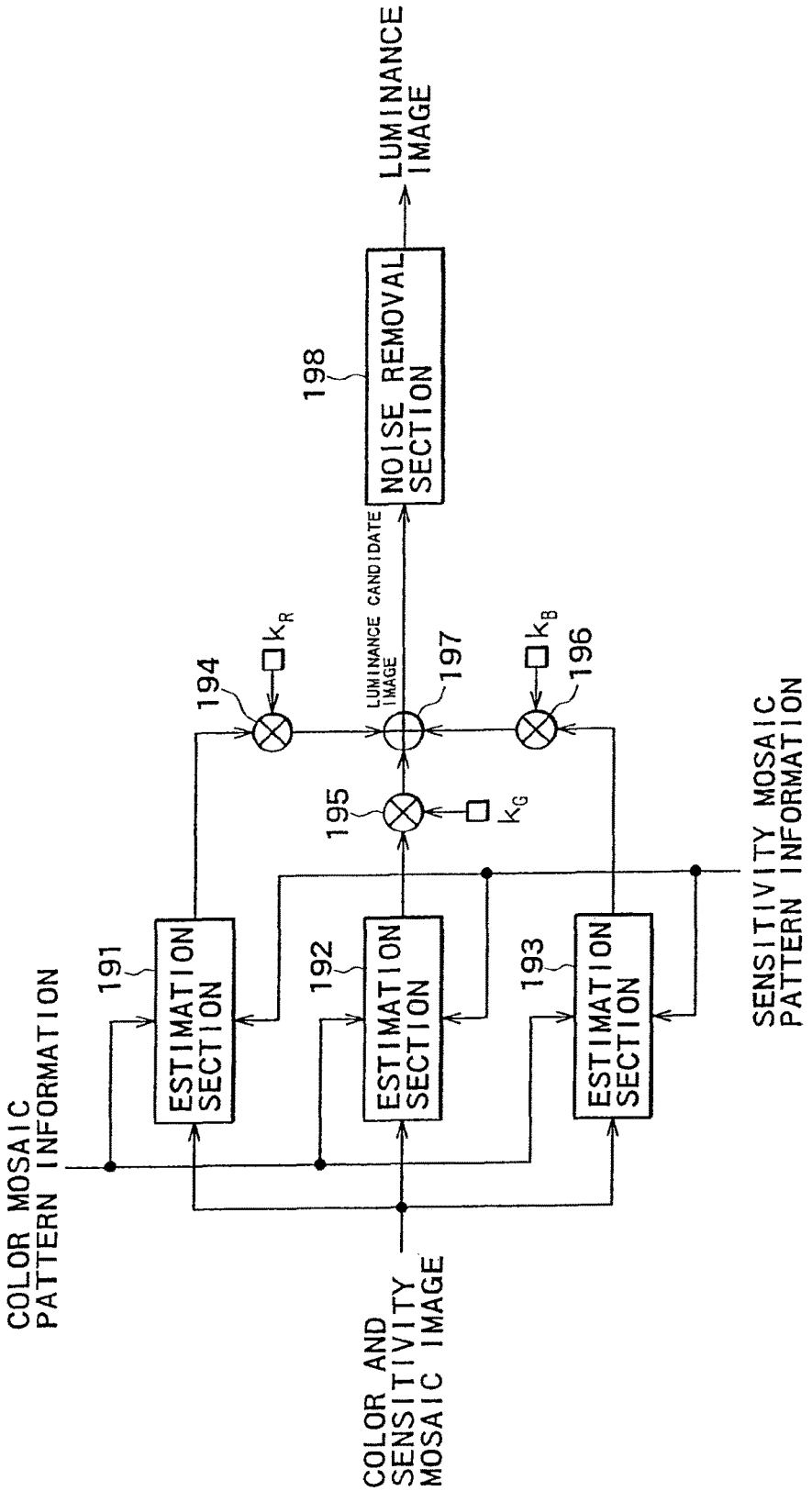

COLOR AND SENSITIVITY MOSAIC IMAGE
COLOR MOSAIC PATTERN INFORMATION
SENSITIVITY MOSAIC PATTERN INFORMATION
191
192
193
ESTIMATION SECTION
ESTIMATION SECTION
ESTIMATION SECTION
195
194
196
197
k_G
k_R
k_B
LUMINANCE CANDIDATE IMAGE
198
NOISE REMOVAL SECTION
LUMINANCE IMAGE

FIG. 84

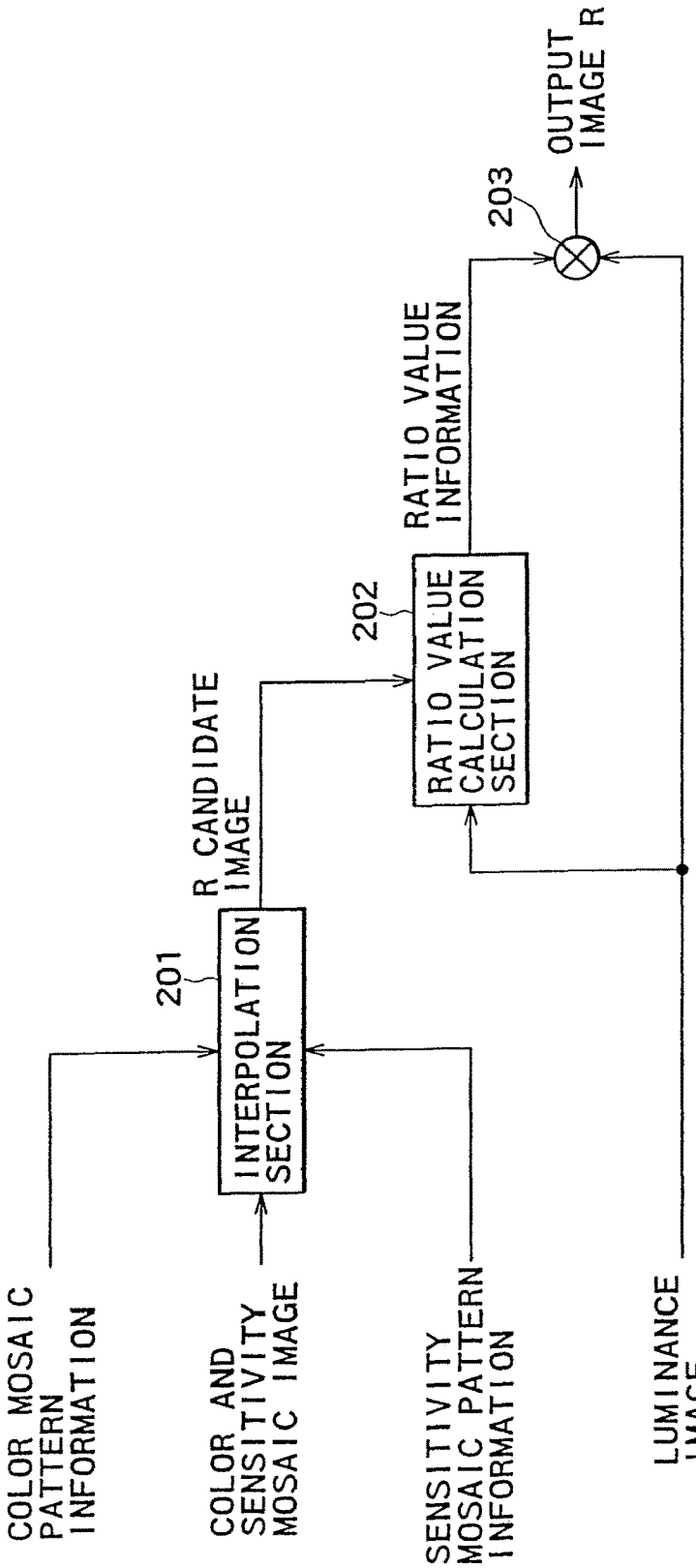

COLOR MOSAIC PATTERN INFORMATION
COLOR AND SENSITIVITY MOSAIC IMAGE
SENSITIVITY MOSAIC PATTERN INFORMATION
LUMINANCE IMAGE
201
INTERPOLATION SECTION
R CANDIDATE IMAGE
202
RATIO VALUE CALCULATION SECTION
RATIO VALUE INFORMATION
203
OUTPUT IMAGE R

FIG. 85

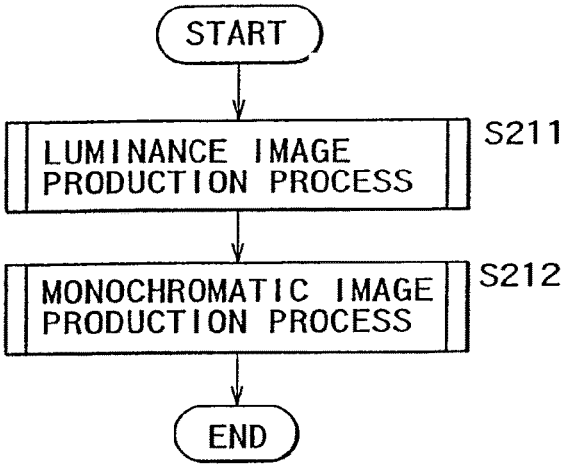

START
LUMINANCE IMAGE PRODUCTION PROCESS
S211
MONOCHROMATIC IMAGE PRODUCTION PROCESS
S212
END

FIG. 86

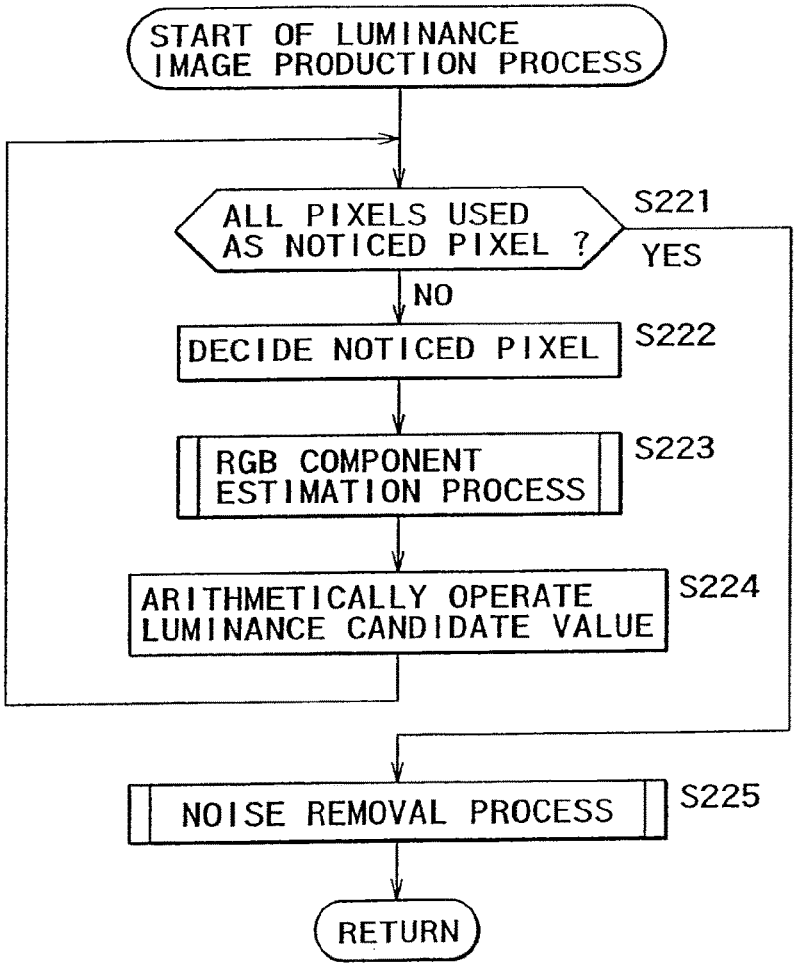

START OF LUMINANCE IMAGE PRODUCTION PROCESS
ALL PIXELS USED AS NOTICED PIXEL ?
S221
YES
NO
DECIDE NOTICED PIXEL
S222
RGB COMPONENT ESTIMATION PROCESS
S223
ARITHMETICALLY OPERATE LUMINANCE CANDIDATE VALUE
S224
NOISE REMOVAL PROCESS
S225
RETURN

FIG. 87

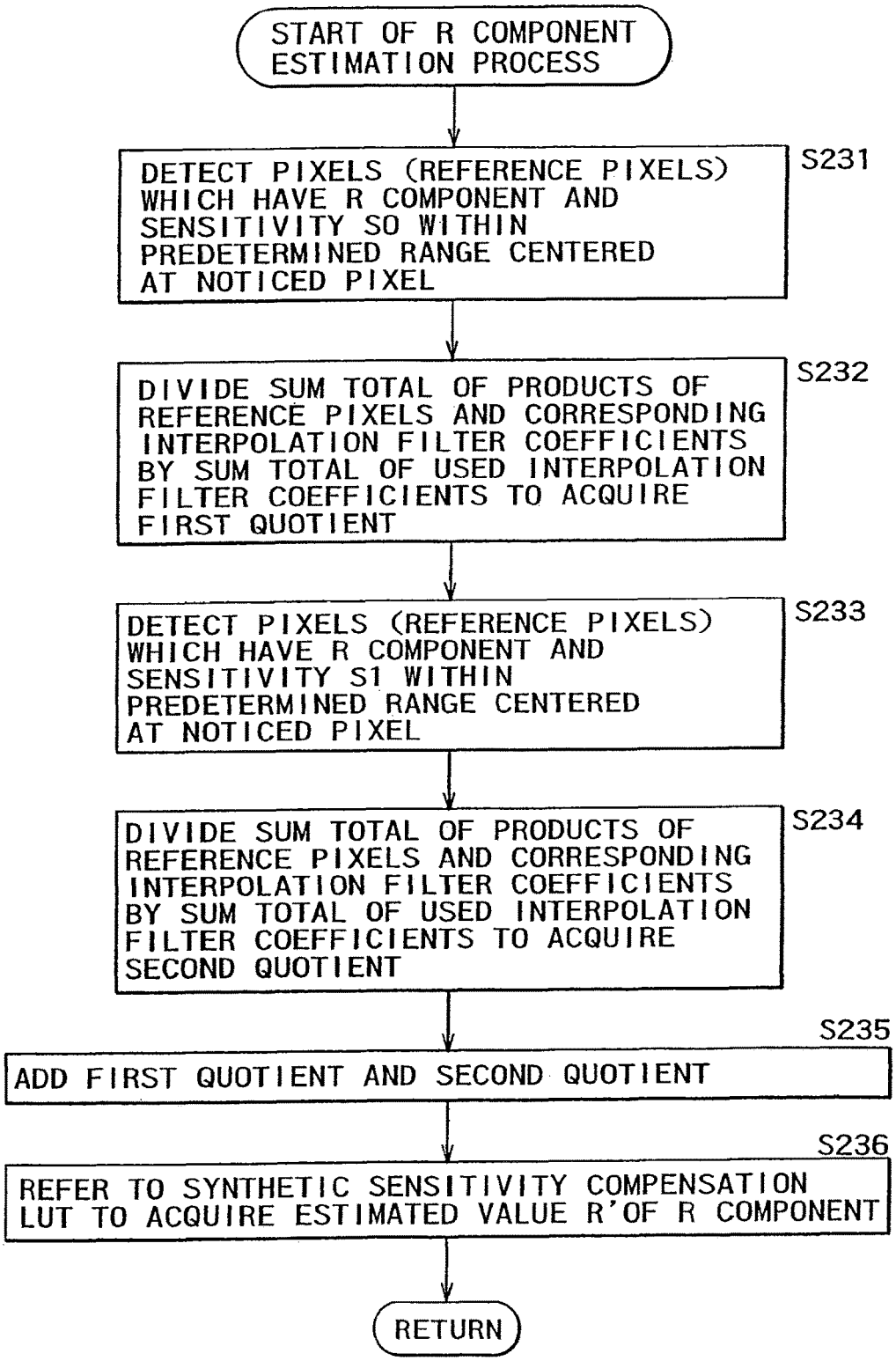

START OF R COMPONENT ESTIMATION PROCESS
DETECT PIXELS (REFERENCE PIXELS) WHICH HAVE R COMPONENT AND SENSITIVITY SO WITHIN PREDETERMINED RANGE CENTERED AT NOTICED PIXEL
S231
DIVIDE SUM TOTAL OF PRODUCTS OF REFERENCE PIXELS AND CORRESPONDING INTERPOLATION FILTER COEFFICIENTS BY SUM TOTAL OF USED INTERPOLATION FILTER COEFFICIENTS TO ACQUIRE FIRST QUOTIENT
S232
DETECT PIXELS (REFERENCE PIXELS) WHICH HAVE R COMPONENT AND SENSITIVITY S1 WITHIN PREDETERMINED RANGE CENTERED AT NOTICED PIXEL
S233
DIVIDE SUM TOTAL OF PRODUCTS OF REFERENCE PIXELS AND CORRESPONDING INTERPOLATION FILTER COEFFICIENTS BY SUM TOTAL OF USED INTERPOLATION FILTER COEFFICIENTS TO ACQUIRE SECOND QUOTIENT
S234
ADD FIRST QUOTIENT AND SECOND QUOTIENT
S235
REFER TO SYNTHETIC SENSITIVITY COMPENSATION LUT TO ACQUIRE ESTIMATED VALUE R'OF R COMPONENT
S236
RETURN

FIG. 88

0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.002	0.004	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	−0.005	0.000	0.005	0.000	−0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	−0.020	−0.035	−0.016	0.000	−0.016	−0.035	−0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	−0.020	−0.063	−0.061	0.000	0.051	0.000	−0.061	−0.063	−0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	−0.005	−0.035	−0.061	0.000	0.196	0.316	0.196	0.000	−0.061	−0.035	−0.005	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.002	0.000	−0.016	0.000	0.196	0.563	0.752	0.563	0.196	0.000	−0.016	0.000	0.002	0.002	0.000	0.000	0.000	0.000
0.001	0.004	0.005	0.000	0.051	0.316	0.752	0.000	0.752	0.316	0.051	0.000	0.005	0.004	0.001	0.000	0.000	0.000	0.000
0.000	0.002	0.000	−0.016	0.000	0.196	0.563	0.752	0.563	0.196	0.000	−0.016	0.000	0.002	0.000	0.000	0.000	0.000	0.000
0.000	0.000	−0.005	−0.035	−0.061	0.000	0.196	0.316	0.196	0.000	−0.061	−0.035	−0.005	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	−0.020	−0.063	−0.061	0.000	0.051	0.000	−0.061	−0.063	−0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	−0.020	−0.035	−0.016	0.000	−0.016	−0.035	−0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	−0.005	0.000	0.005	0.000	−0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.004	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

FIG. 89

0. 004	0. 000	−0. 035	−0. 063	−0. 035	0. 000	0. 004
0. 000	0. 000	0. 000	0. 000	0. 000	0. 000	0. 000
0. 035	0. 000	0. 316	0. 563	0. 316	0. 000	−0. 035
0. 063	0 000	0. 563	1. 000	0. 563	0. 000	−0. 063
0. 035	0. 000	0. 316	0. 563	0. 316	0. 000	−0. 035
0. 000	0. 000	0. 000	0. 000	0. 000	0. 000	0. 000
0. 004	0. 000	−0. 035	−0. 063	−0. 035	0. 000	0. 004

FIG. 90

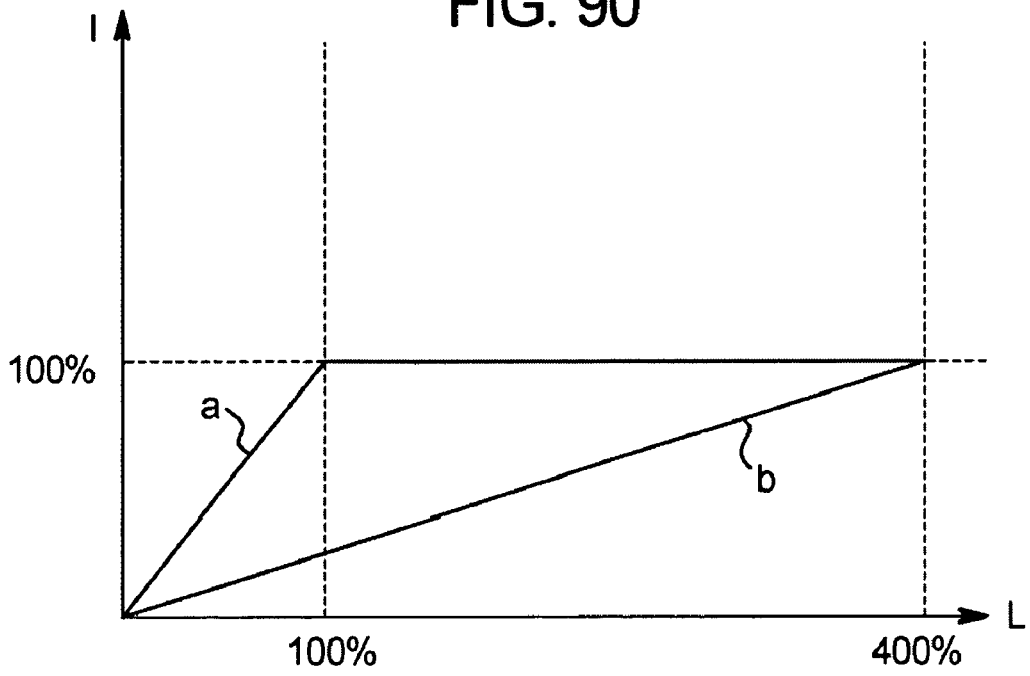


FIG. 91

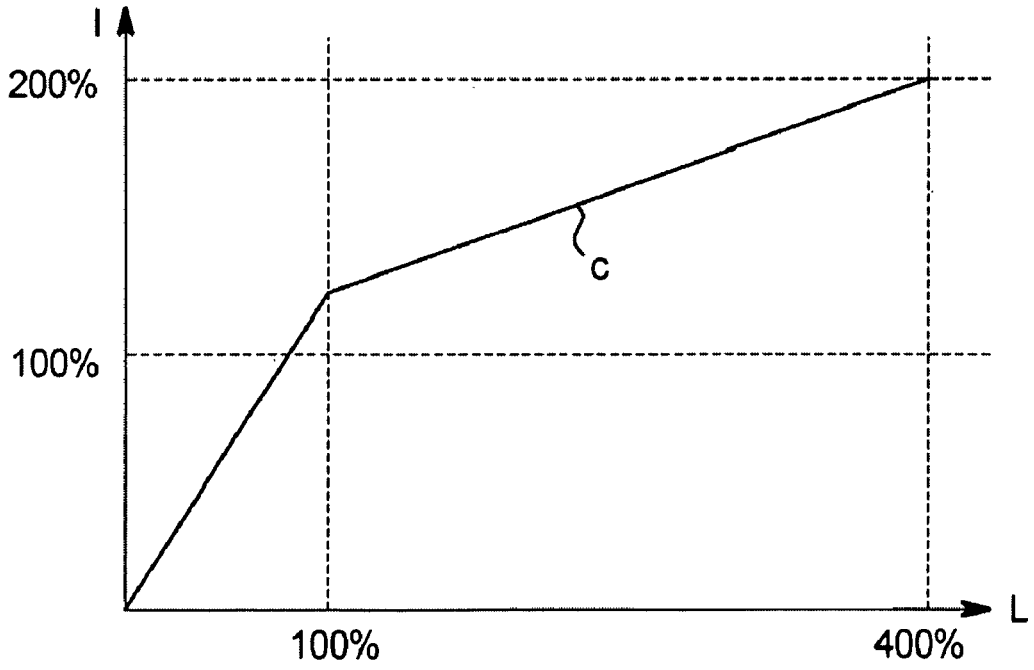


FIG. 92

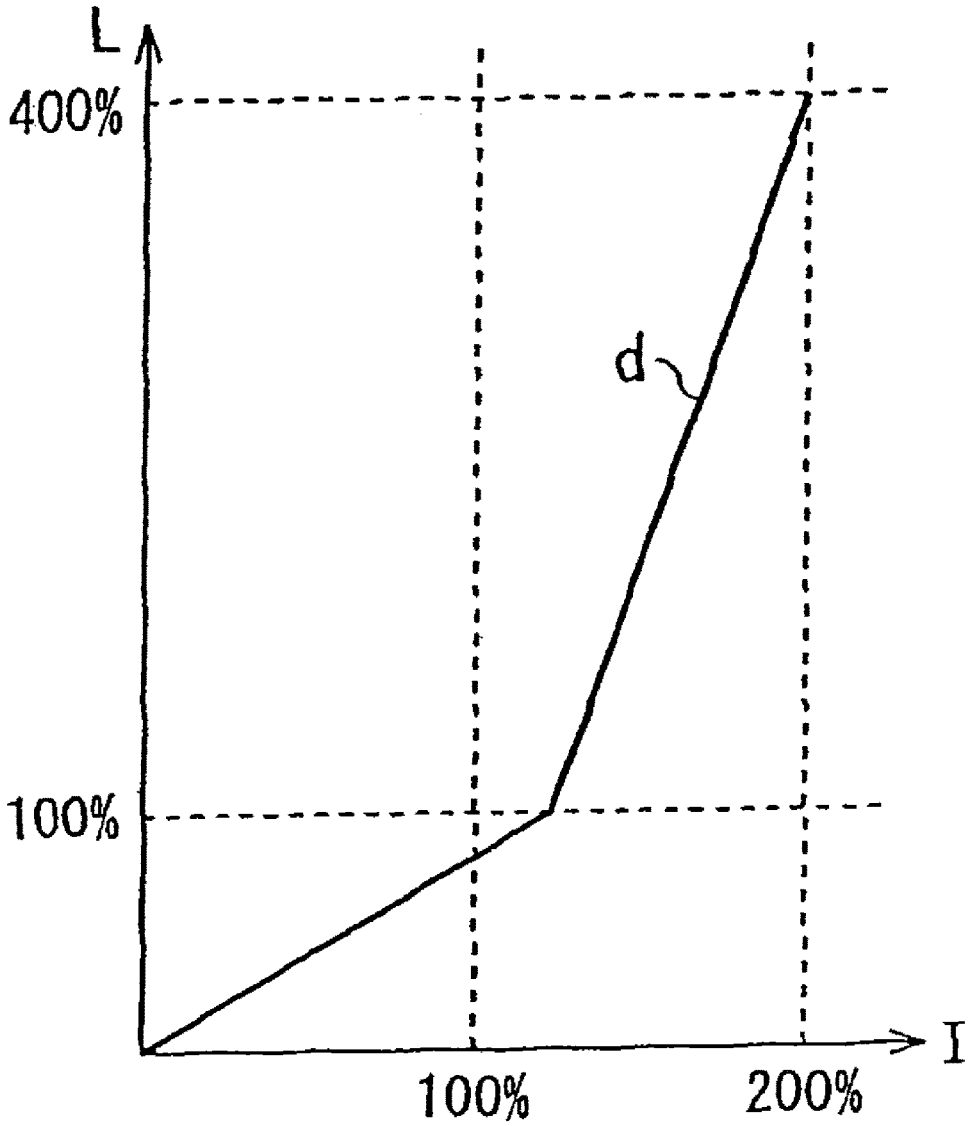


FIG. 93

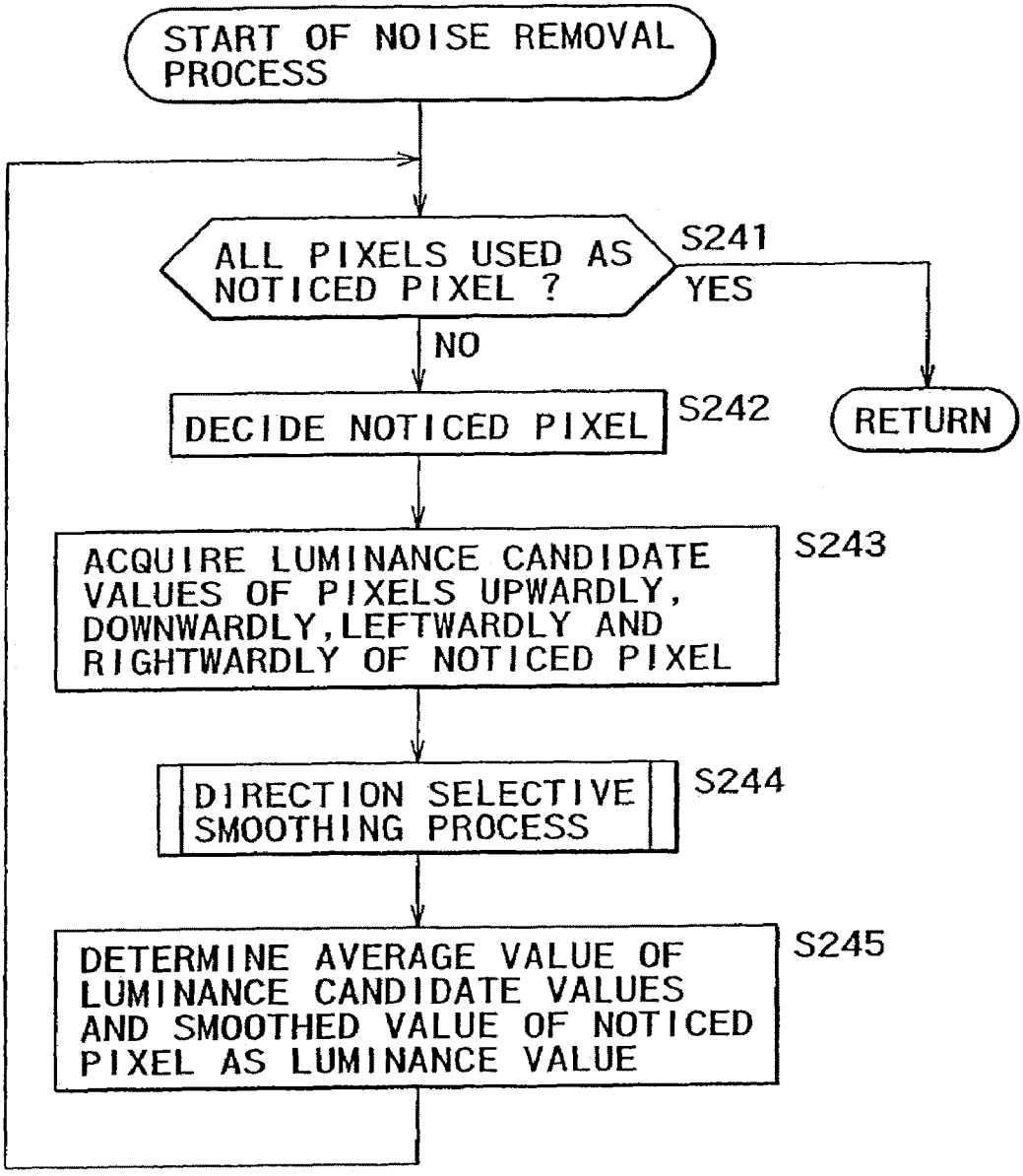

START OF NOISE REMOVAL PROCESS
ALL PIXELS USED AS NOTICED PIXEL ?
S241
YES
NO
RETURN
DECIDE NOTICED PIXEL
S242
ACQUIRE LUMINANCE CANDIDATE VALUES OF PIXELS UPWARDLY, DOWNWARDLY, LEFTWARDLY AND RIGHTWARDLY OF NOTICED PIXEL
S243
DIRECTION SELECTIVE SMOOTHING PROCESS
S244
DETERMINE AVERAGE VALUE OF LUMINANCE CANDIDATE VALUES AND SMOOTHED VALUE OF NOTICED PIXEL AS LUMINANCE VALUE
S245

FIG. 94

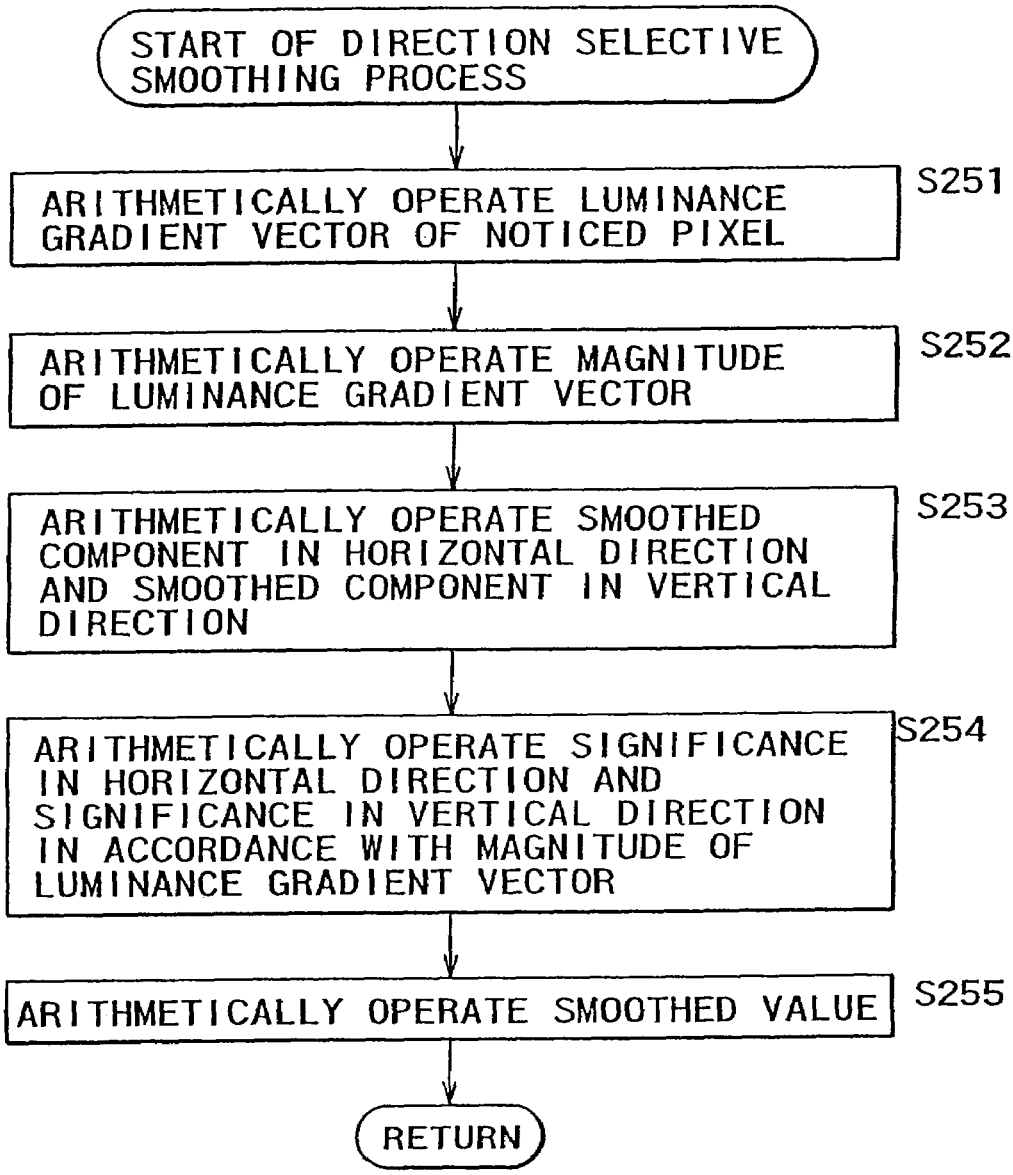

START OF DIRECTION SELECTIVE SMOOTHING PROCESS
ARITHMETICALLY OPERATE LUMINANCE GRADIENT VECTOR OF NOTICED PIXEL
S251
ARITHMETICALLY OPERATE MAGNITUDE OF LUMINANCE GRADIENT VECTOR
S252
ARITHMETICALLY OPERATE SMOOTHED COMPONENT IN HORIZONTAL DIRECTION AND SMOOTHED COMPONENT IN VERTICAL DIRECTION
S253
ARITHMETICALLY OPERATE SIGNIFICANCE IN HORIZONTAL DIRECTION AND SIGNIFICANCE IN VERTICAL DIRECTION IN ACCORDANCE WITH MAGNITUDE OF LUMINANCE GRADIENT VECTOR
S254
ARITHMETICALLY OPERATE SMOOTHED VALUE
S255
RETURN

FIG. 95

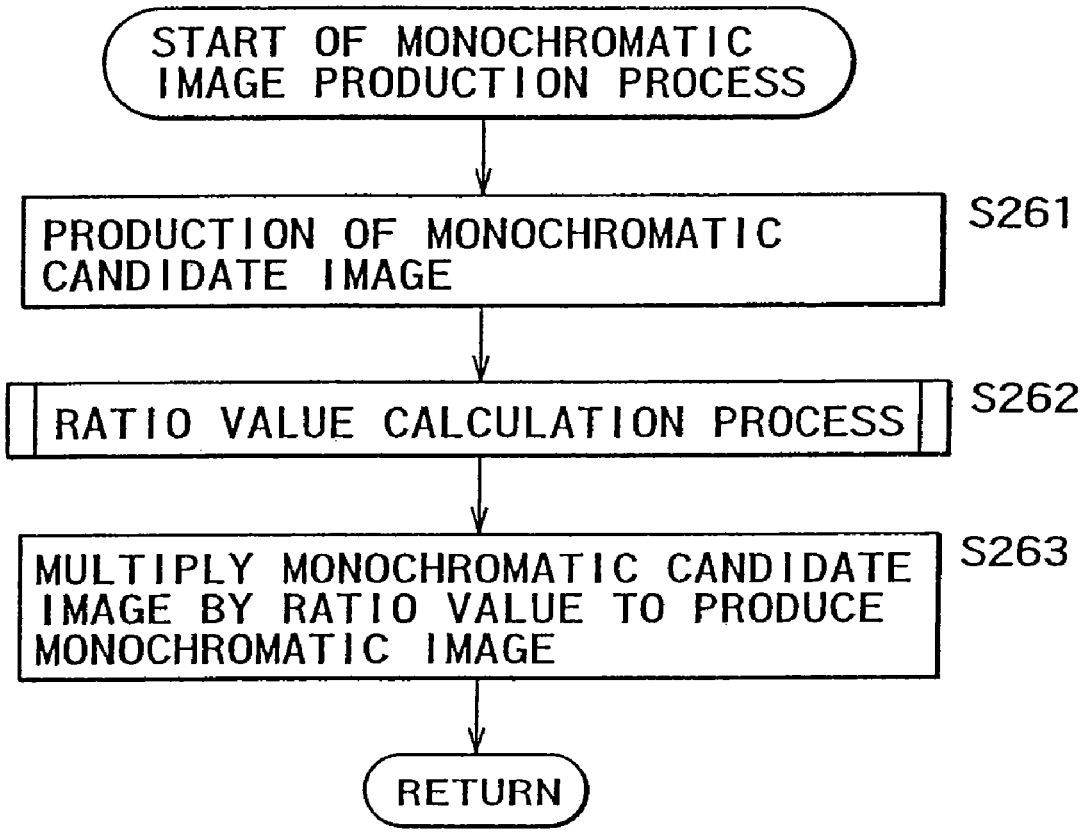

START OF MONOCHROMATIC IMAGE PRODUCTION PROCESS
PRODUCTION OF MONOCHROMATIC CANDIDATE IMAGE
S261
RATIO VALUE CALCULATION PROCESS
S262
MULTIPLY MONOCHROMATIC CANDIDATE IMAGE BY RATIO VALUE TO PRODUCE MONOCHROMATIC IMAGE
S263
RETURN

FIG. 96

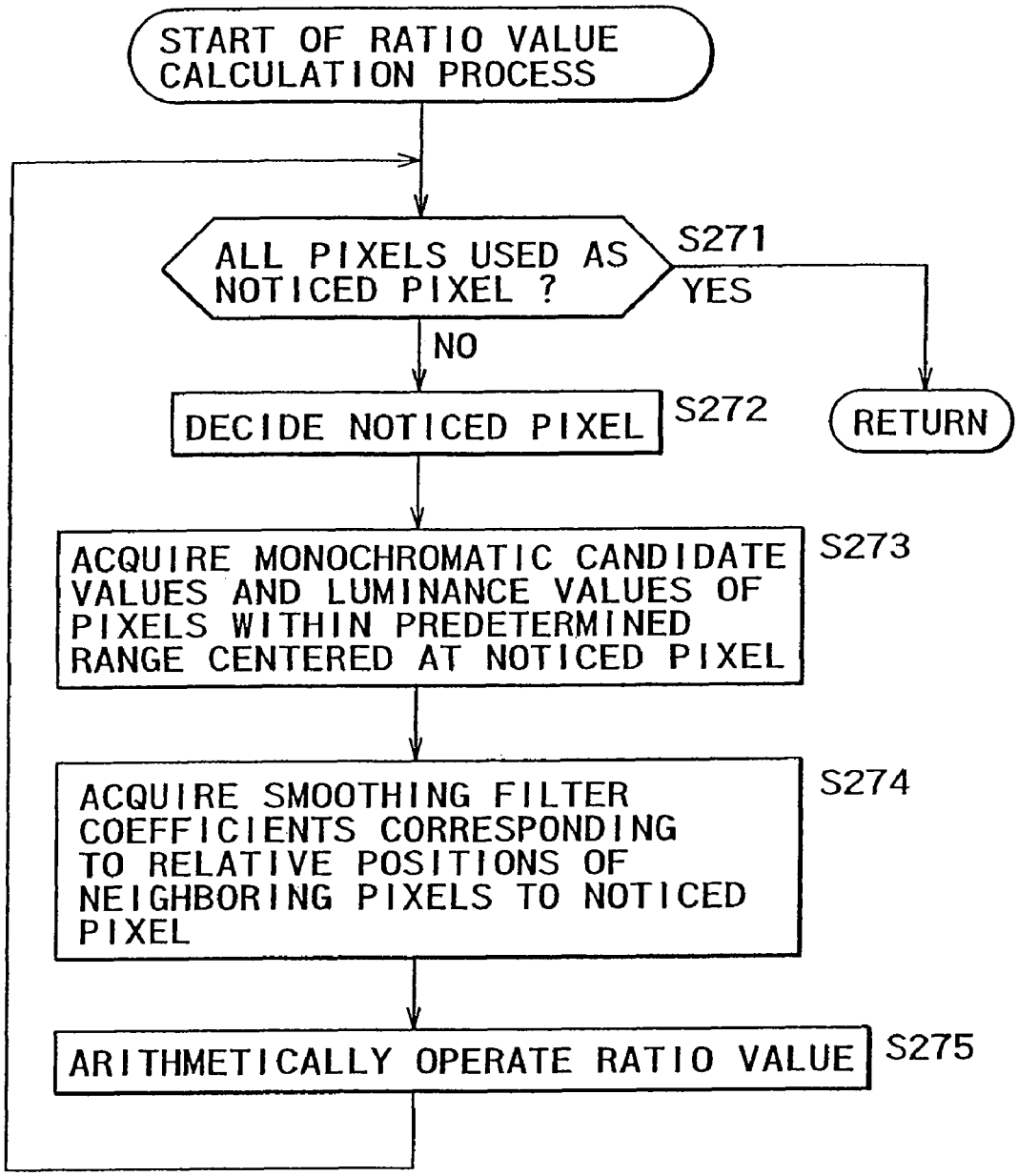

START OF RATIO VALUE CALCULATION PROCESS
ALL PIXELS USED AS NOTICED PIXEL ?
S271
YES
NO
RETURN
DECIDE NOTICED PIXEL
S272
ACQUIRE MONOCHROMATIC CANDIDATE VALUES AND LUMINANCE VALUES OF PIXELS WITHIN PREDETERMINED RANGE CENTERED AT NOTICED PIXEL
S273
ACQUIRE SMOOTHING FILTER COEFFICIENTS CORRESPONDING TO RELATIVE POSITIONS OF NEIGHBORING PIXELS TO NOTICED PIXEL
S274
ARITHMETICALLY OPERATE RATIO VALUE
S275

FIG. 97

0.000	0.003	0.010	0.014	0.010	0.003	0.000
0.003	0.028	0.080	0.111	0.080	0.028	0.003
0.010	0.080	0.230	0.319	0.230	0.080	0.010
0.014	0.111	0.319	0.444	0.319	0.111	0.014
0.010	0.080	0.230	0.319	0.230	0.080	0.010
0.003	0.028	0.080	0.111	0.080	0.028	0.003
0.000	0.003	0.010	0.014	0.010	0.003	0.000

FIG. 98

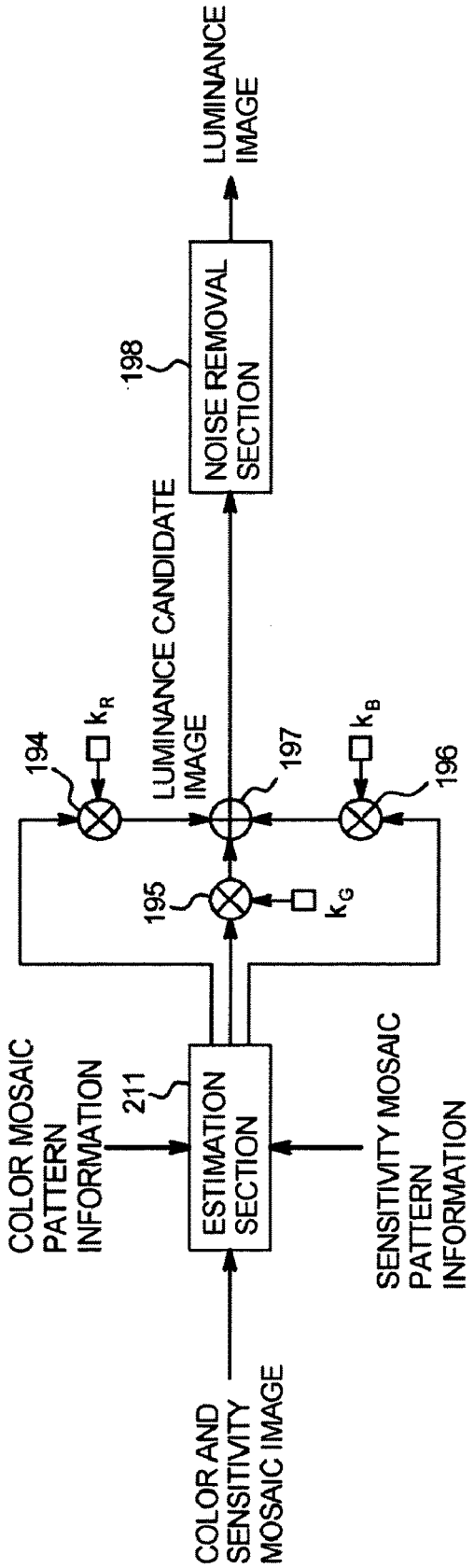

COLOR AND SENSITIVITY MOSAIC IMAGE
COLOR MOSAIC PATTERN INFORMATION
211
ESTIMATION SECTION
SENSITIVITY MOSAIC PATTERN INFORMATION
195
k_G
194
k_R
LUMINANCE CANDIDATE IMAGE
197
k_B
196
198
NOISE REMOVAL SECTION
LUMINANCE IMAGE

FIG. 99

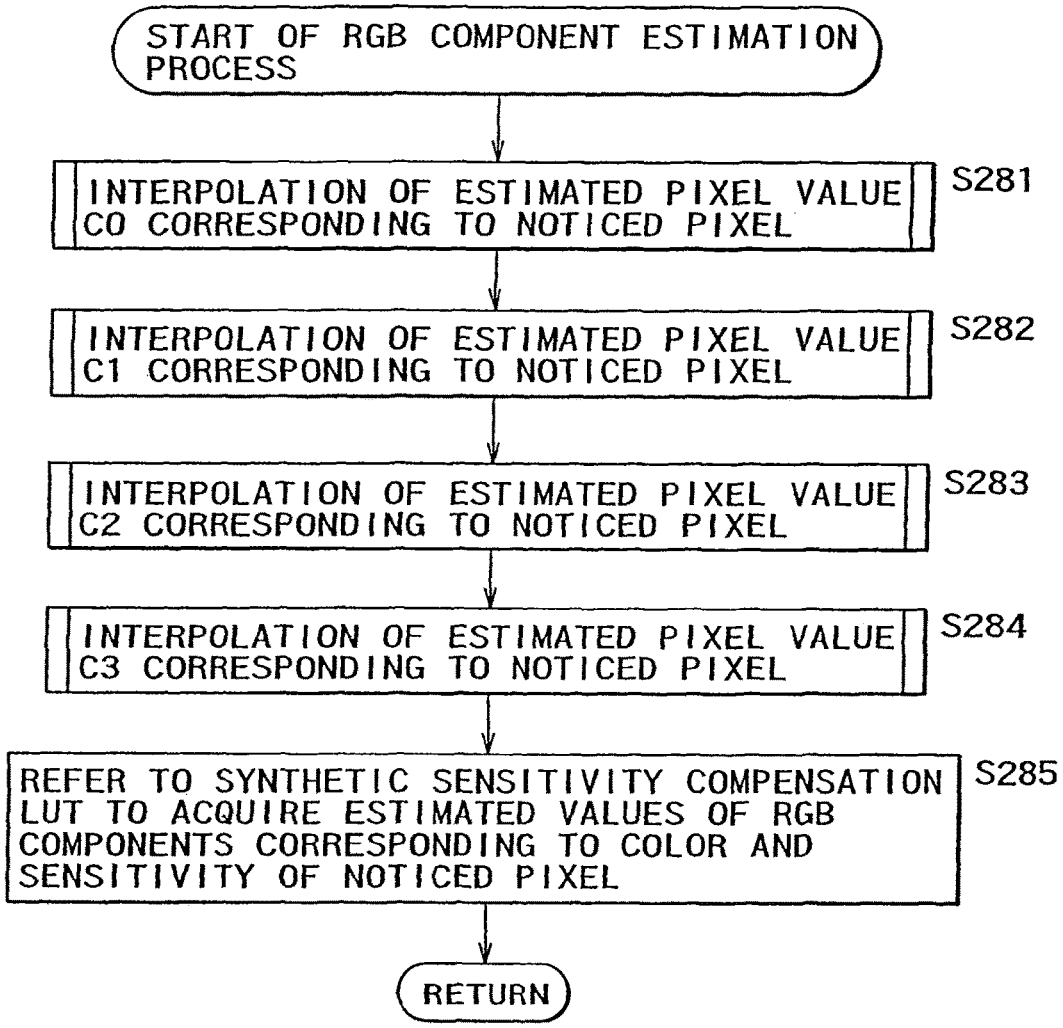

START OF RGB COMPONENT ESTIMATION PROCESS
INTERPOLATION OF ESTIMATED PIXEL VALUE C0 CORRESPONDING TO NOTICED PIXEL
S281
INTERPOLATION OF ESTIMATED PIXEL VALUE C1 CORRESPONDING TO NOTICED PIXEL
S282
INTERPOLATION OF ESTIMATED PIXEL VALUE C2 CORRESPONDING TO NOTICED PIXEL
S283
INTERPOLATION OF ESTIMATED PIXEL VALUE C3 CORRESPONDING TO NOTICED PIXEL
S284
REFER TO SYNTHETIC SENSITIVITY COMPENSATION LUT TO ACQUIRE ESTIMATED VALUES OF RGB COMPONENTS CORRESPONDING TO COLOR AND SENSITIVITY OF NOTICED PIXEL
S285
RETURN

FIG. 100

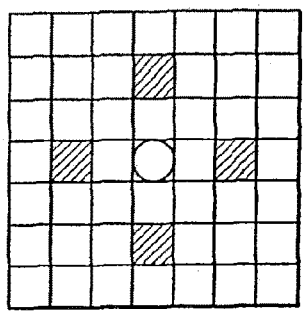


FIG. 101

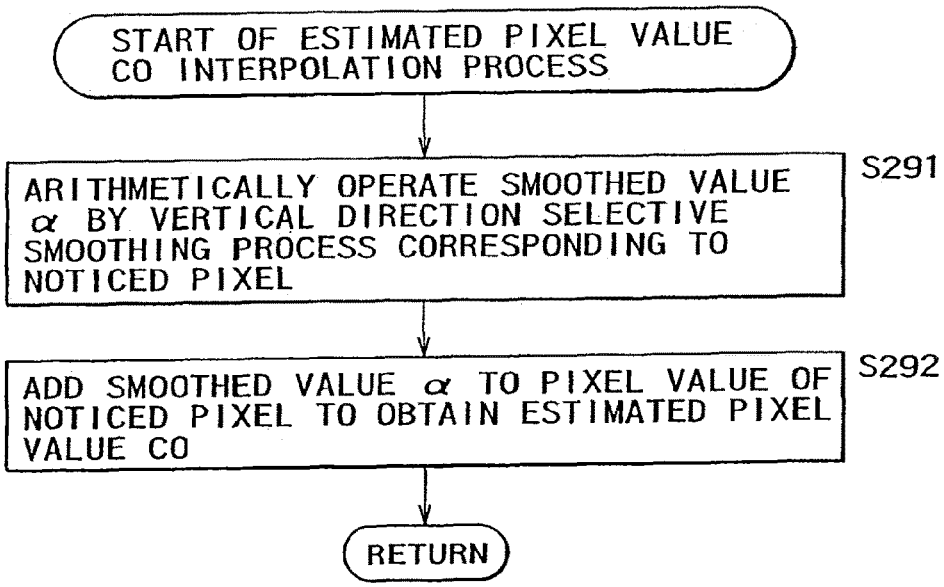


FIG. 102

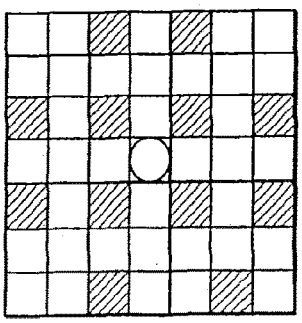


FIG. 103

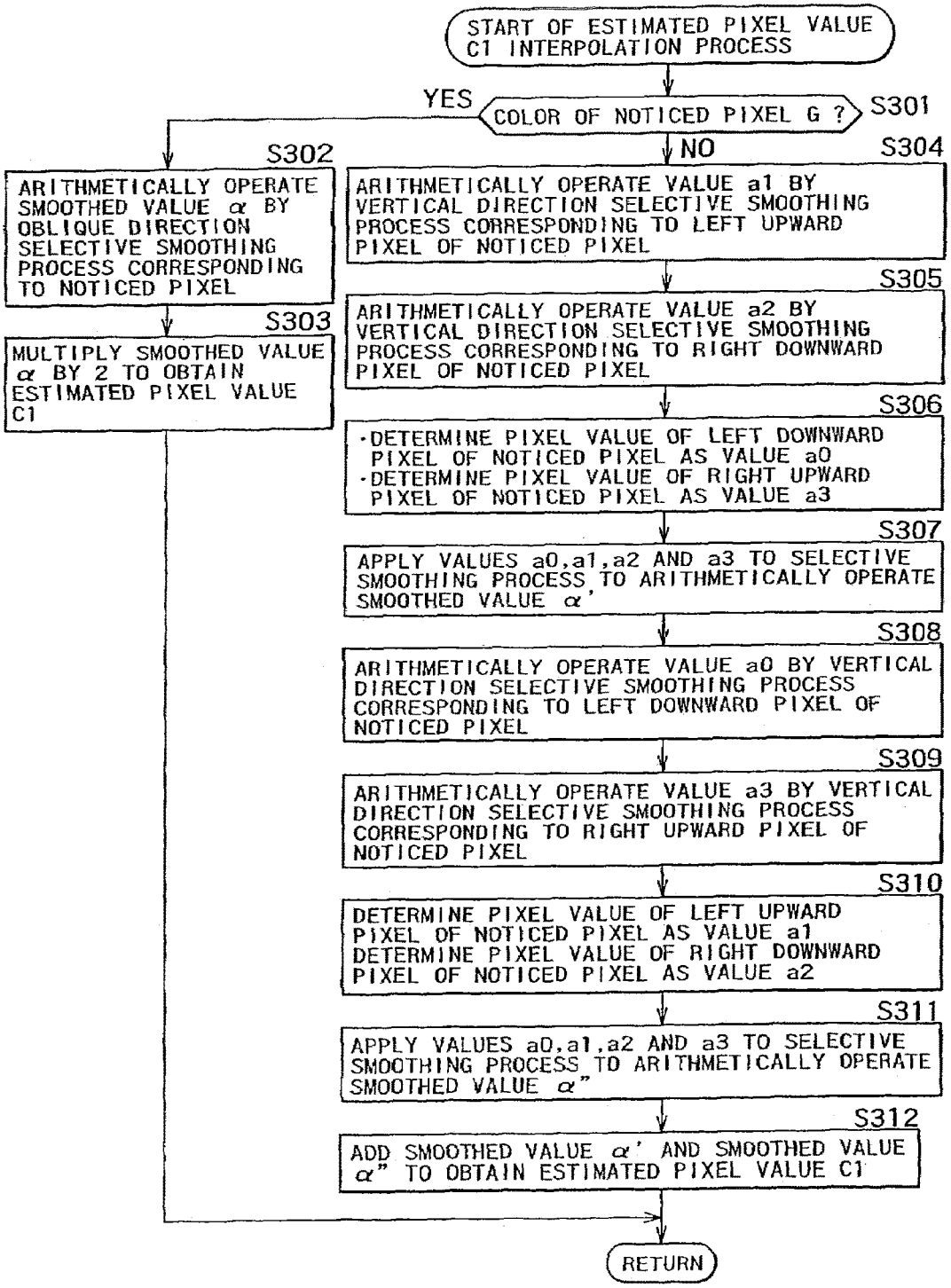

START OF ESTIMATED PIXEL VALUE C1 INTERPOLATION PROCESS
COLOR OF NOTICED PIXEL G ?
S301
YES
NO
S302
ARITHMETICALLY OPERATE SMOOTHED VALUE α BY OBLIQUE DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO NOTICED PIXEL
S303
MULTIPLY SMOOTHED VALUE α BY 2 TO OBTAIN ESTIMATED PIXEL VALUE C1
S304
ARITHMETICALLY OPERATE VALUE a1 BY VERTICAL DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO LEFT UPWARD PIXEL OF NOTICED PIXEL
S305
ARITHMETICALLY OPERATE VALUE a2 BY VERTICAL DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO RIGHT DOWNWARD PIXEL OF NOTICED PIXEL
S306
·DETERMINE PIXEL VALUE OF LEFT DOWNWARD PIXEL OF NOTICED PIXEL AS VALUE a0
·DETERMINE PIXEL VALUE OF RIGHT UPWARD PIXEL OF NOTICED PIXEL AS VALUE a3
S307
APPLY VALUES a0,a1,a2 AND a3 TO SELECTIVE SMOOTHING PROCESS TO ARITHMETICALLY OPERATE SMOOTHED VALUE α'
S308
ARITHMETICALLY OPERATE VALUE a0 BY VERTICAL DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO LEFT DOWNWARD PIXEL OF NOTICED PIXEL
S309
ARITHMETICALLY OPERATE VALUE a3 BY VERTICAL DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO RIGHT UPWARD PIXEL OF NOTICED PIXEL
S310
DETERMINE PIXEL VALUE OF LEFT UPWARD PIXEL OF NOTICED PIXEL AS VALUE a1
DETERMINE PIXEL VALUE OF RIGHT DOWNWARD PIXEL OF NOTICED PIXEL AS VALUE a2
S311
APPLY VALUES a0,a1,a2 AND a3 TO SELECTIVE SMOOTHING PROCESS TO ARITHMETICALLY OPERATE SMOOTHED VALUE α"
S312
ADD SMOOTHED VALUE α' AND SMOOTHED VALUE α" TO OBTAIN ESTIMATED PIXEL VALUE C1
RETURN

FIG. 104A

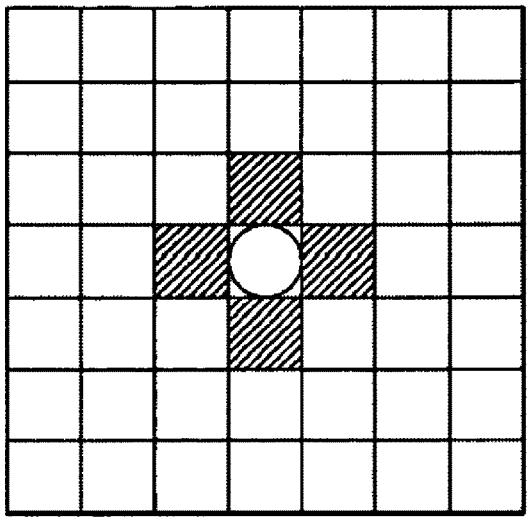


FIG. 104B

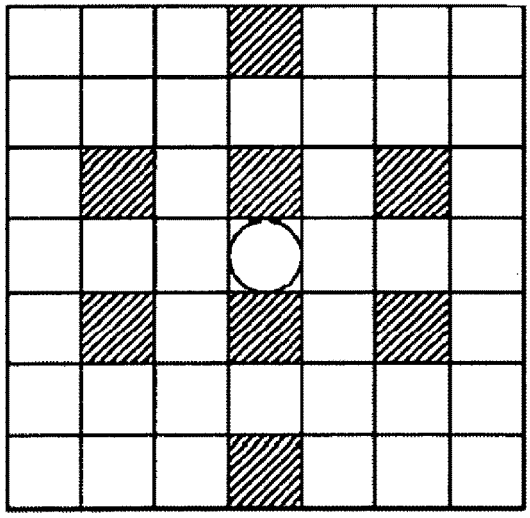


FIG. 105

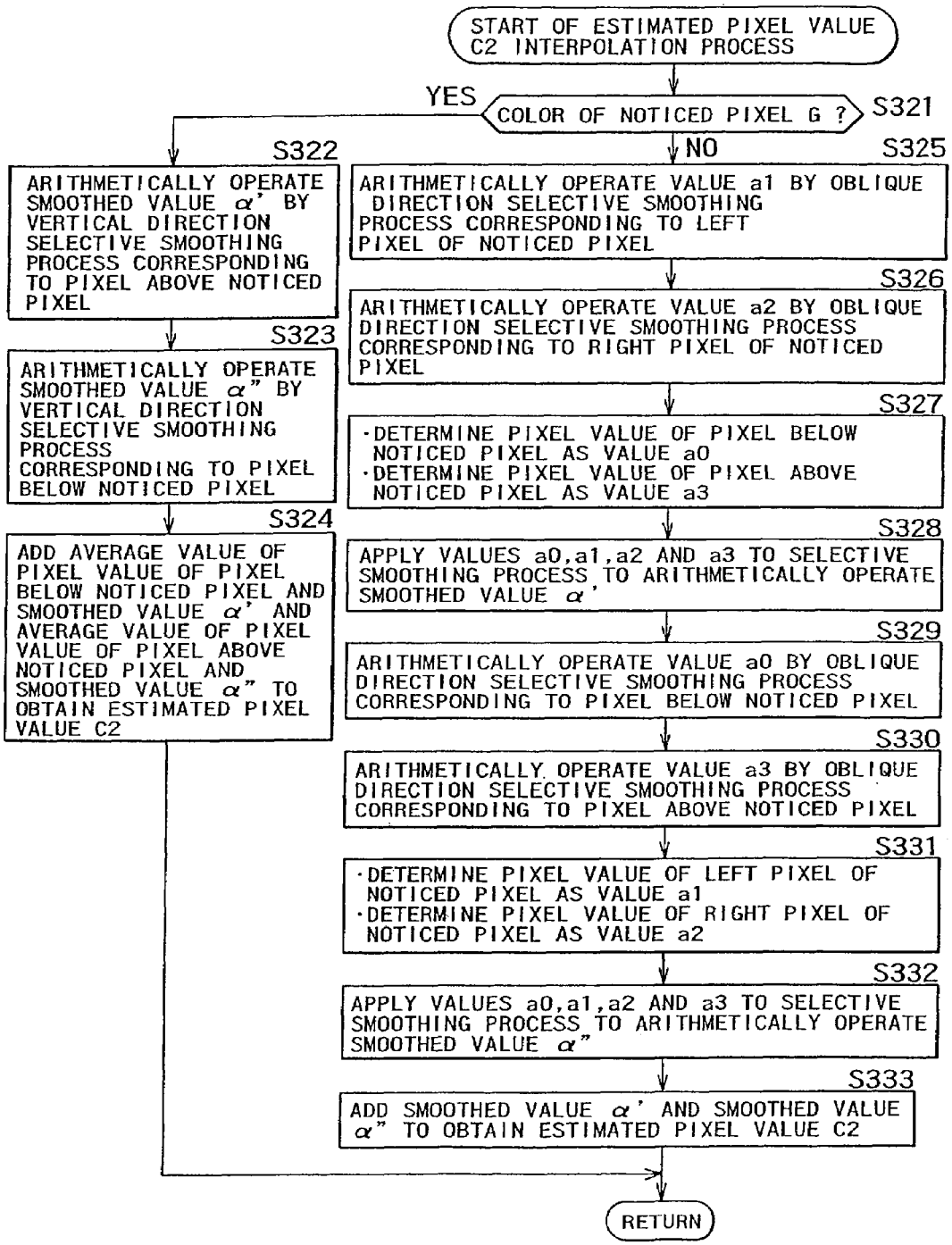

START OF ESTIMATED PIXEL VALUE C2 INTERPOLATION PROCESS
COLOR OF NOTICED PIXEL G ?
YES
NO
S321
S322
ARITHMETICALLY OPERATE SMOOTHED VALUE α' BY VERTICAL DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO PIXEL ABOVE NOTICED PIXEL
S323
ARITHMETICALLY OPERATE SMOOTHED VALUE α" BY VERTICAL DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO PIXEL BELOW NOTICED PIXEL
S324
ADD AVERAGE VALUE OF PIXEL VALUE OF PIXEL BELOW NOTICED PIXEL AND SMOOTHED VALUE α' AND AVERAGE VALUE OF PIXEL VALUE OF PIXEL ABOVE NOTICED PIXEL AND SMOOTHED VALUE α" TO OBTAIN ESTIMATED PIXEL VALUE C2
S325
ARITHMETICALLY OPERATE VALUE a1 BY OBLIQUE DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO LEFT PIXEL OF NOTICED PIXEL
S326
ARITHMETICALLY OPERATE VALUE a2 BY OBLIQUE DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO RIGHT PIXEL OF NOTICED PIXEL
S327
·DETERMINE PIXEL VALUE OF PIXEL BELOW NOTICED PIXEL AS VALUE a0
·DETERMINE PIXEL VALUE OF PIXEL ABOVE NOTICED PIXEL AS VALUE a3
S328
APPLY VALUES a0,a1,a2 AND a3 TO SELECTIVE SMOOTHING PROCESS TO ARITHMETICALLY OPERATE SMOOTHED VALUE α'
S329
ARITHMETICALLY OPERATE VALUE a0 BY OBLIQUE DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO PIXEL BELOW NOTICED PIXEL
S330
ARITHMETICALLY OPERATE VALUE a3 BY OBLIQUE DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO PIXEL ABOVE NOTICED PIXEL
S331
·DETERMINE PIXEL VALUE OF LEFT PIXEL OF NOTICED PIXEL AS VALUE a1
·DETERMINE PIXEL VALUE OF RIGHT PIXEL OF NOTICED PIXEL AS VALUE a2
S332
APPLY VALUES a0,a1,a2 AND a3 TO SELECTIVE SMOOTHING PROCESS TO ARITHMETICALLY OPERATE SMOOTHED VALUE α"
S333
ADD SMOOTHED VALUE α' AND SMOOTHED VALUE α" TO OBTAIN ESTIMATED PIXEL VALUE C2
RETURN

FIG. 106

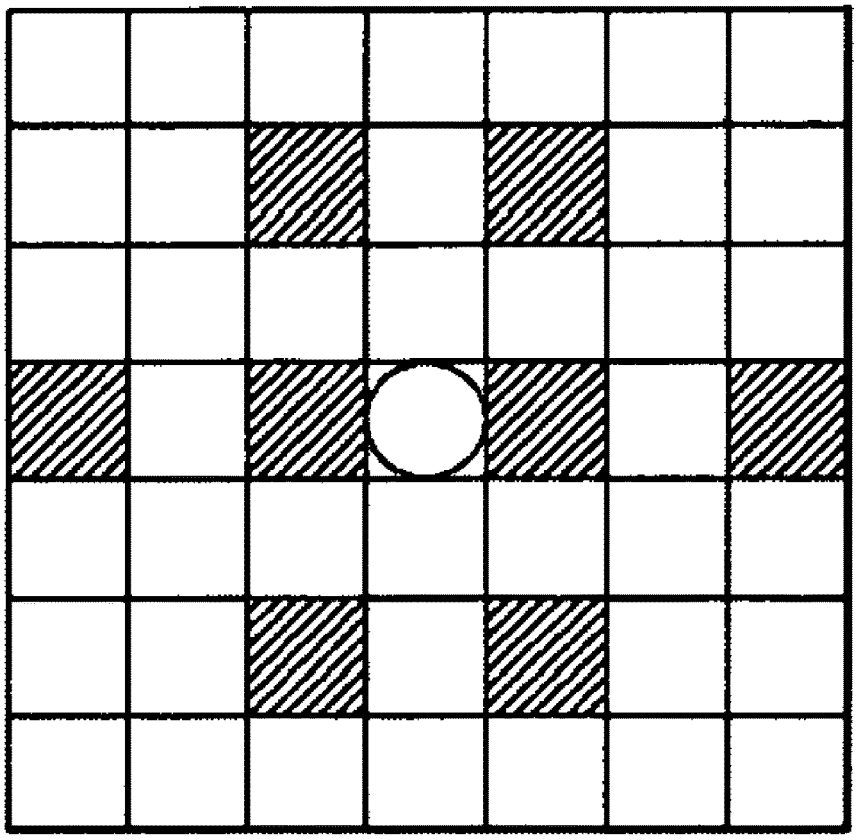


FIG. 107

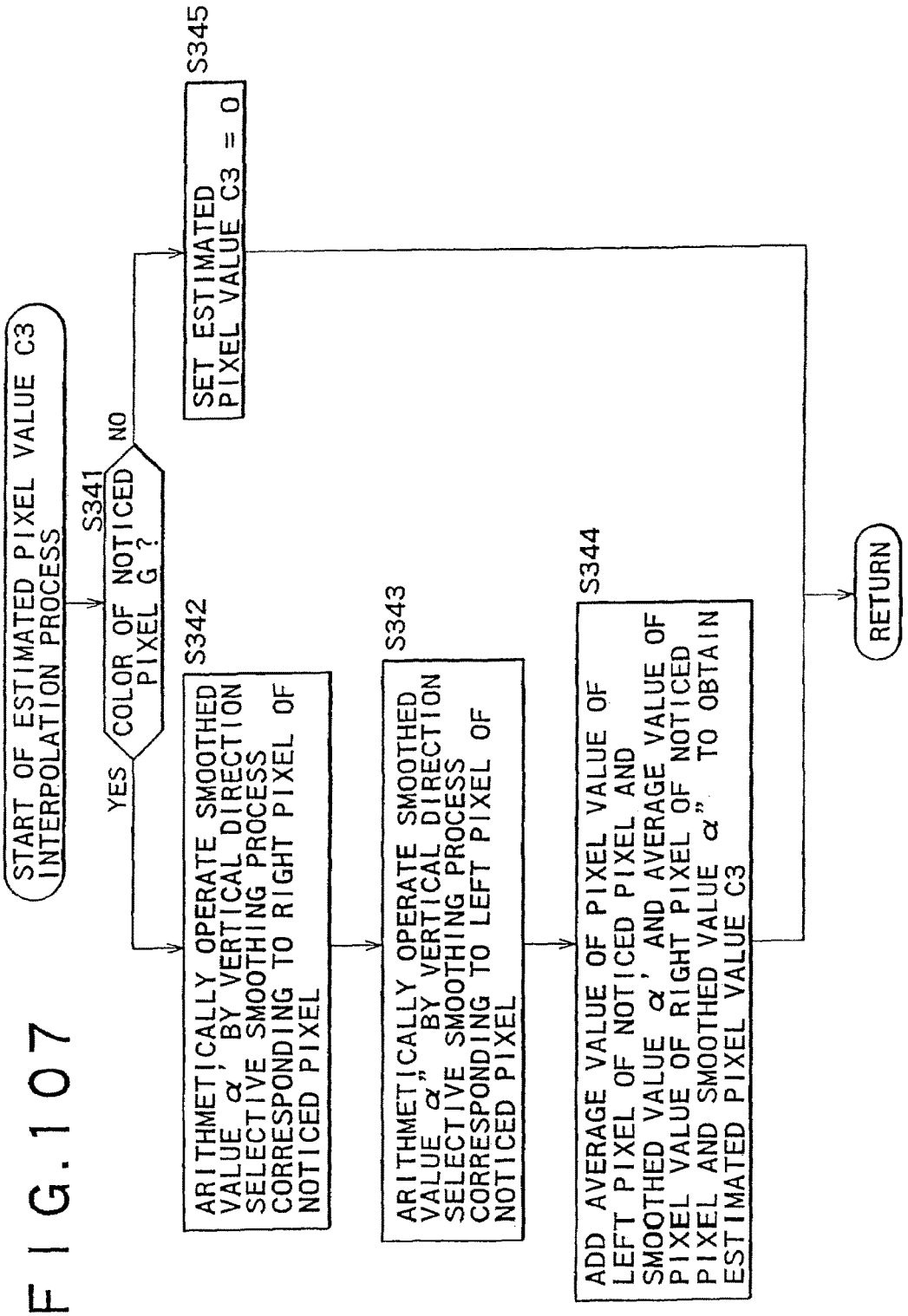

START OF ESTIMATED PIXEL VALUE C3 INTERPOLATION PROCESS
S341
COLOR OF NOTICED PIXEL G ?
YES
NO
S342
ARITHMETICALLY OPERATE SMOOTHED VALUE α' BY VERTICAL DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO RIGHT PIXEL OF NOTICED PIXEL
S343
ARITHMETICALLY OPERATE SMOOTHED VALUE α" BY VERTICAL DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO LEFT PIXEL OF NOTICED PIXEL
S344
ADD AVERAGE VALUE OF PIXEL VALUE OF LEFT PIXEL OF NOTICED PIXEL AND SMOOTHED VALUE α' AND AVERAGE VALUE OF PIXEL VALUE OF RIGHT PIXEL OF NOTICED PIXEL AND SMOOTHED VALUE α" TO OBTAIN ESTIMATED PIXEL VALUE C3
S345
SET ESTIMATED PIXEL VALUE C3 = 0
RETURN

FIG. 108

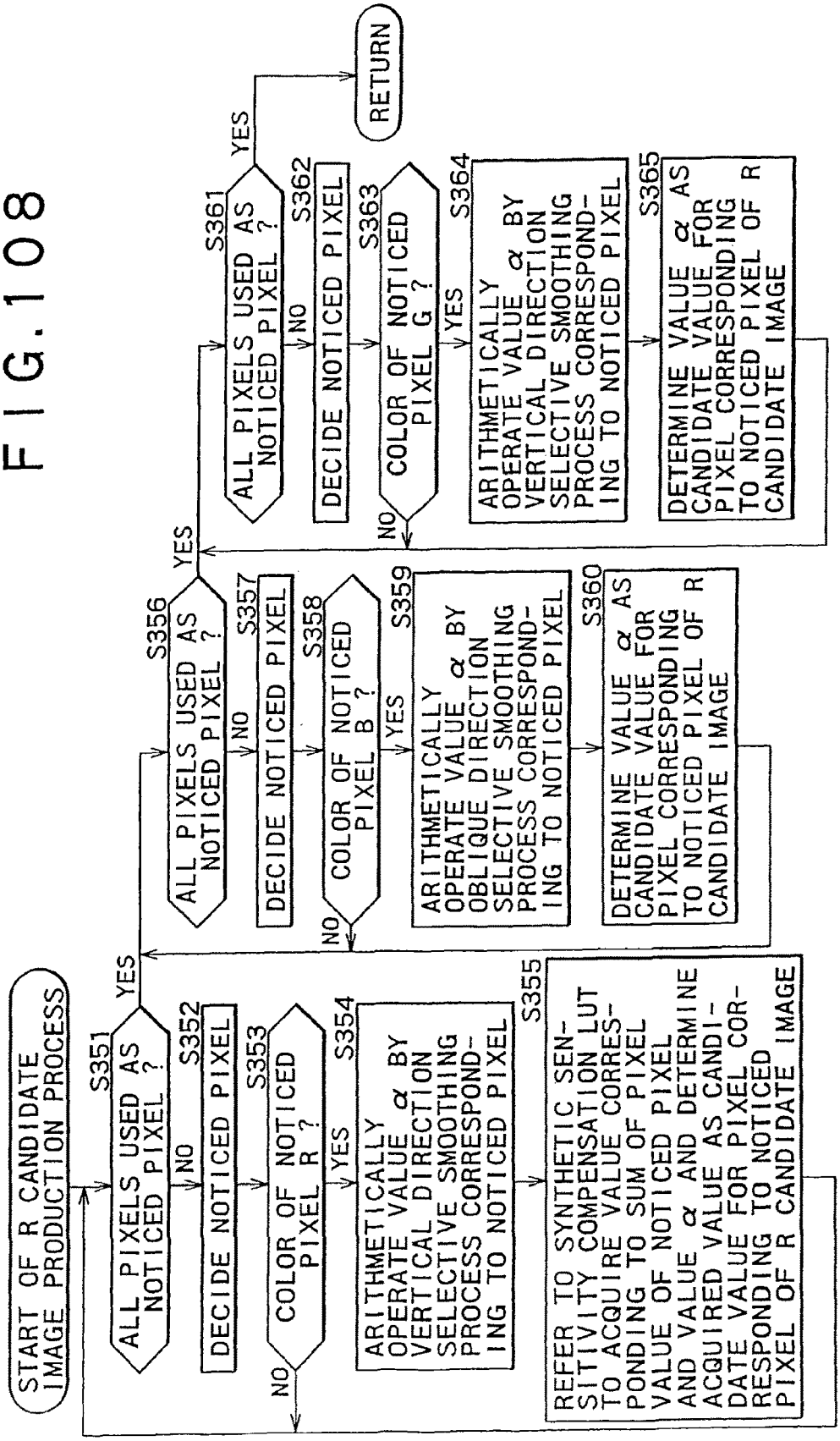

START OF R CANDIDATE IMAGE PRODUCTION PROCESS
S351
ALL PIXELS USED AS NOTICED PIXEL ?
YES
NO
S352
DECIDE NOTICED PIXEL
S353
COLOR OF NOTICED PIXEL R ?
YES
NO
S354
ARITHMETICALLY OPERATE VALUE α BY VERTICAL DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO NOTICED PIXEL
S355
REFER TO SYNTHETIC SENSITIVITY COMPENSATION LUT TO ACQUIRE VALUE CORRESPONDING TO SUM OF PIXEL VALUE OF NOTICED PIXEL AND VALUE α AND DETERMINE ACQUIRED VALUE AS CANDIDATE VALUE FOR PIXEL CORRESPONDING TO NOTICED PIXEL OF R CANDIDATE IMAGE
S356
ALL PIXELS USED AS NOTICED PIXEL ?
YES
NO
S357
DECIDE NOTICED PIXEL
S358
COLOR OF NOTICED PIXEL B ?
YES
NO
S359
ARITHMETICALLY OPERATE VALUE α BY OBLIQUE DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO NOTICED PIXEL
S360
DETERMINE VALUE α AS CANDIDATE VALUE FOR PIXEL CORRESPONDING TO NOTICED PIXEL OF R CANDIDATE IMAGE
S361
ALL PIXELS USED AS NOTICED PIXEL ?
YES
NO
S362
DECIDE NOTICED PIXEL
S363
COLOR OF NOTICED PIXEL G ?
YES
NO
S364
ARITHMETICALLY OPERATE VALUE α BY VERTICAL DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO NOTICED PIXEL
S365
DETERMINE VALUE α AS CANDIDATE VALUE FOR PIXEL CORRESPONDING TO NOTICED PIXEL OF R CANDIDATE IMAGE
RETURN

FIG. 109

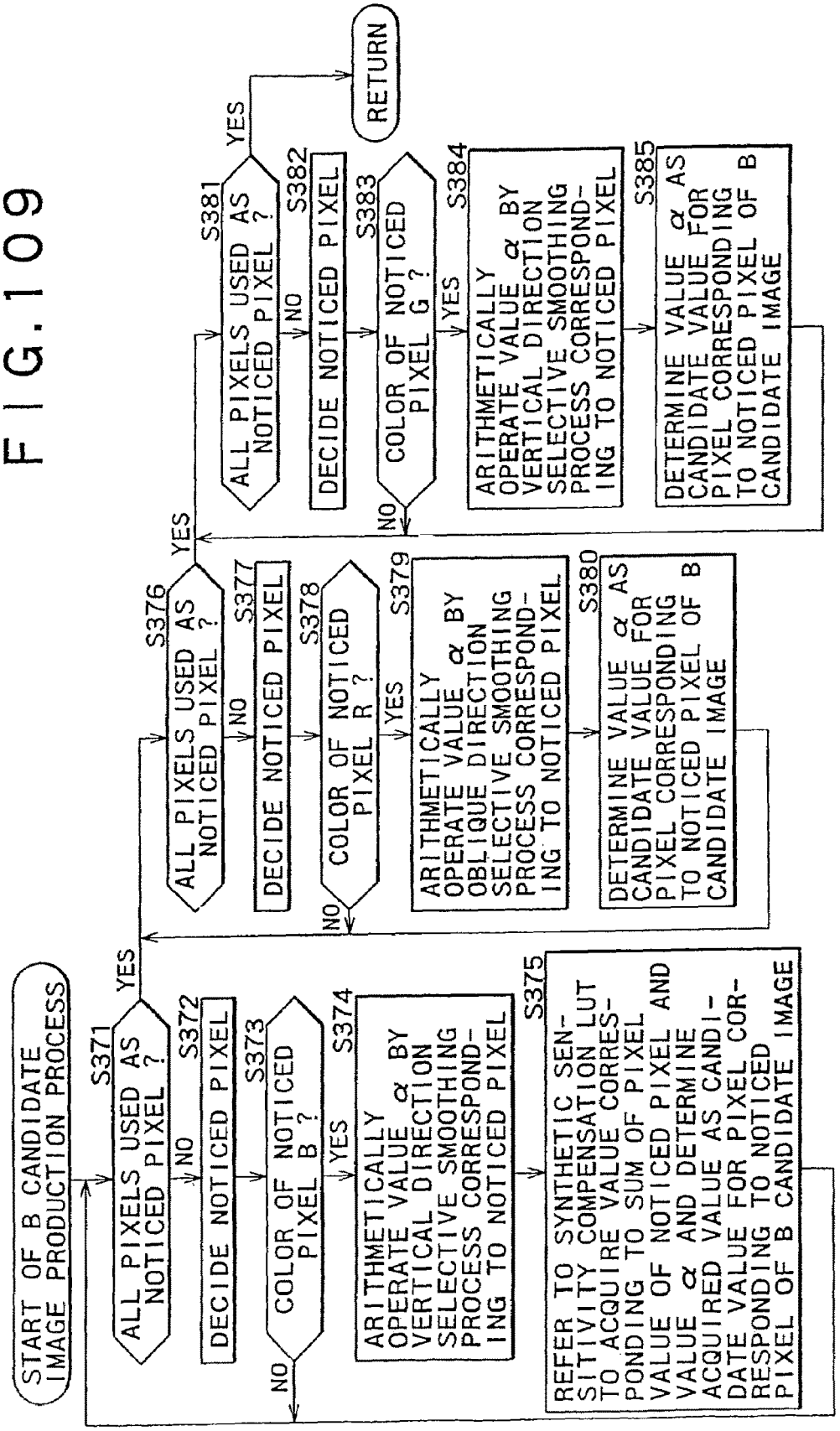

START OF B CANDIDATE IMAGE PRODUCTION PROCESS
S371
ALL PIXELS USED AS NOTICED PIXEL ?
YES
NO
S372
DECIDE NOTICED PIXEL
S373
COLOR OF NOTICED PIXEL B ?
YES
NO
S374
ARITHMETICALLY OPERATE VALUE α BY VERTICAL DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO NOTICED PIXEL
S375
REFER TO SYNTHETIC SENSITIVITY COMPENSATION LUT TO ACQUIRE VALUE CORRESPONDING TO SUM OF PIXEL VALUE OF NOTICED PIXEL AND VALUE α AND DETERMINE ACQUIRED VALUE AS CANDIDATE VALUE FOR PIXEL CORRESPONDING TO NOTICED PIXEL OF B CANDIDATE IMAGE
S376
ALL PIXELS USED AS NOTICED PIXEL ?
YES
NO
S377
DECIDE NOTICED PIXEL
S378
COLOR OF NOTICED PIXEL R ?
YES
NO
S379
ARITHMETICALLY OPERATE VALUE α BY OBLIQUE DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO NOTICED PIXEL
S380
DETERMINE VALUE α AS CANDIDATE VALUE FOR PIXEL CORRESPONDING TO NOTICED PIXEL OF B CANDIDATE IMAGE
S381
ALL PIXELS USED AS NOTICED PIXEL ?
YES
NO
S382
DECIDE NOTICED PIXEL
S383
COLOR OF NOTICED PIXEL G ?
YES
NO
S384
ARITHMETICALLY OPERATE VALUE α BY VERTICAL DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO NOTICED PIXEL
S385
DETERMINE VALUE α AS CANDIDATE VALUE FOR PIXEL CORRESPONDING TO NOTICED PIXEL OF B CANDIDATE IMAGE
RETURN

FIG. 110

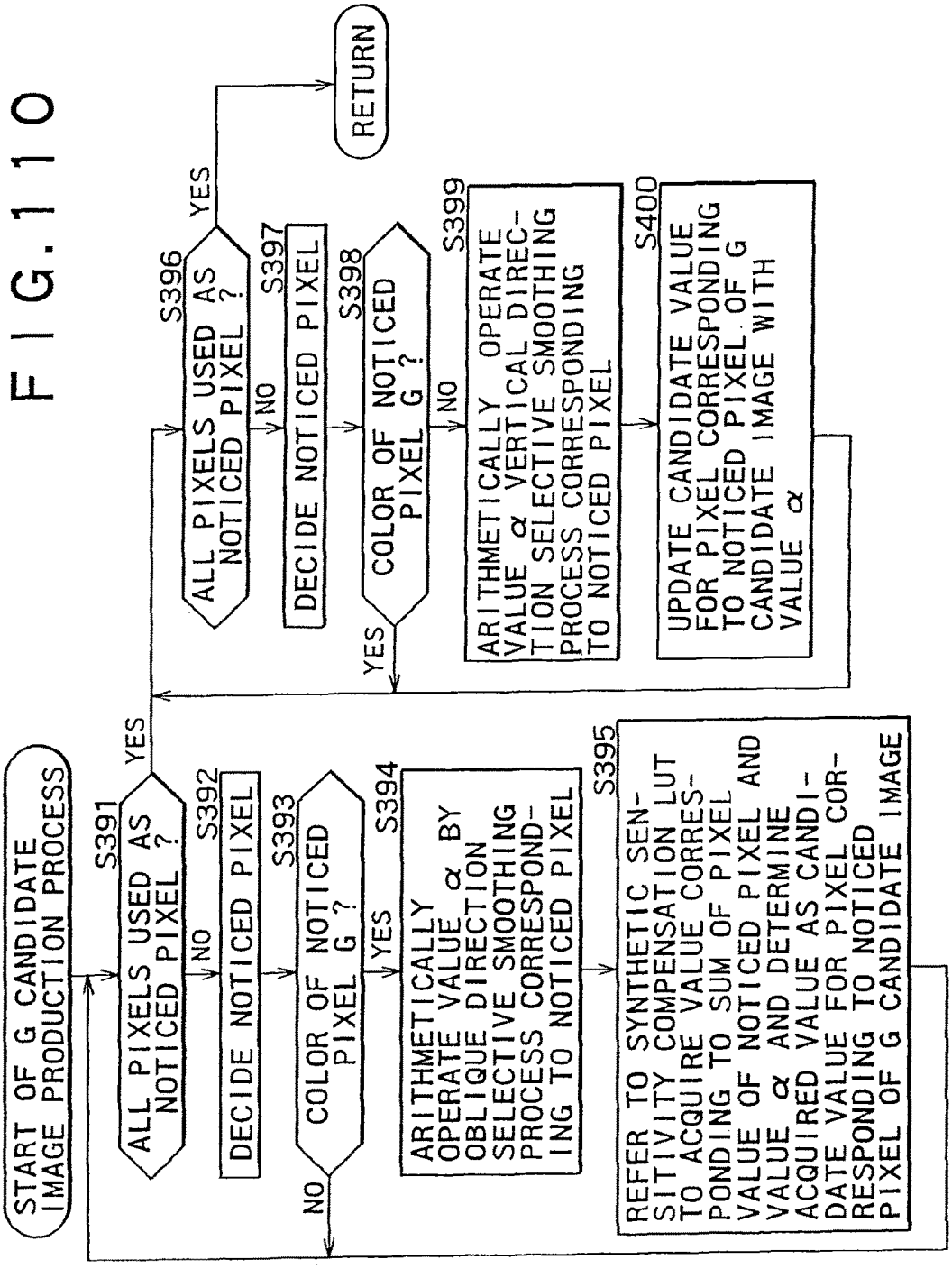

START OF G CANDIDATE IMAGE PRODUCTION PROCESS
S391
ALL PIXELS USED AS NOTICED PIXEL ?
YES
NO
S392
DECIDE NOTICED PIXEL
S393
COLOR OF NOTICED PIXEL G ?
YES
NO
S394
ARITHMETICALLY OPERATE VALUE α BY OBLIQUE DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO NOTICED PIXEL
S395
REFER TO SYNTHETIC SENSITIVITY COMPENSATION LUT TO ACQUIRE VALUE CORRESPONDING TO SUM OF PIXEL VALUE OF NOTICED PIXEL AND VALUE α AND DETERMINE ACQUIRED VALUE AS CANDIDATE VALUE FOR PIXEL CORRESPONDING TO NOTICED PIXEL OF G CANDIDATE IMAGE
S396
ALL PIXELS USED AS NOTICED PIXEL ?
YES
NO
S397
DECIDE NOTICED PIXEL
S398
COLOR OF NOTICED PIXEL G ?
YES
NO
S399
ARITHMETICALLY OPERATE VALUE α VERTICAL DIRECTION SELECTIVE SMOOTHING PROCESS CORRESPONDING TO NOTICED PIXEL
S400
UPDATE CANDIDATE VALUE FOR PIXEL CORRESPONDING TO NOTICED PIXEL OF G CANDIDATE IMAGE WITH VALUE α
RETURN

FIG. 111

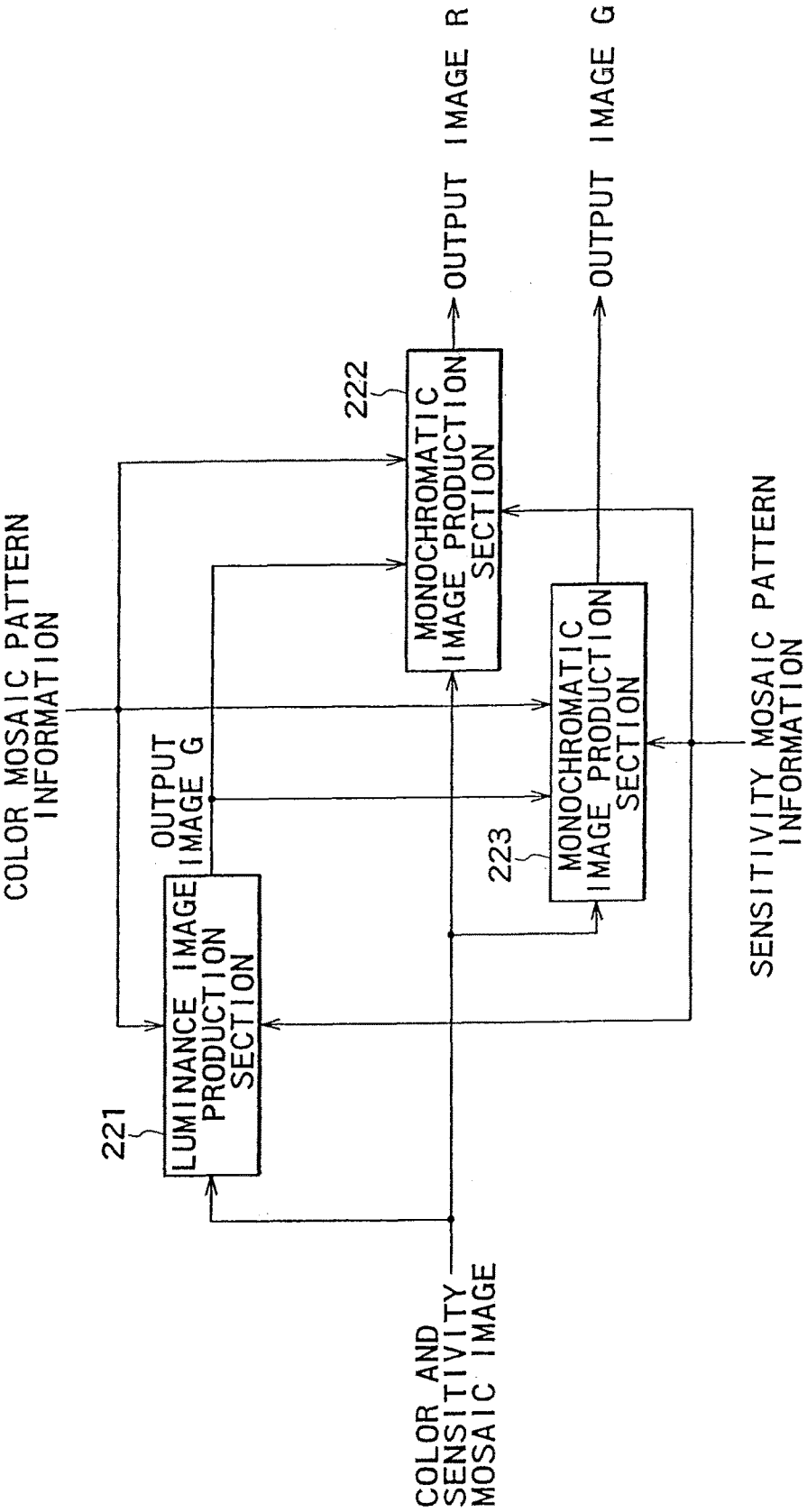

COLOR MOSAIC PATTERN INFORMATION
OUTPUT IMAGE G
LUMINANCE IMAGE PRODUCTION SECTION
221
MONOCHROMATIC IMAGE PRODUCTION SECTION
222
MONOCHROMATIC IMAGE PRODUCTION SECTION
223
OUTPUT IMAGE R
OUTPUT IMAGE G
SENSITIVITY MOSAIC PATTERN INFORMATION
COLOR AND SENSITIVITY MOSAIC IMAGE

IMAGE PROCESSING APPARATUS AND METHOD FOR GENERATING A RESTORATION IMAGE

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.

CROSS REFERENCE TO RELATED APPLICATIONS

More than one reissue application has been filed for the reissue of U.S. Pat. No. 7,986,360. The present application is [a continuation of U.S. patent application Ser. No. 10,466,015 filed on Jan. 14, 2004 which was the National Stage of International Application No. PCT/JP02/00036, filed on Jan. 9, 2002, and which claims priority to Japanese Patent Document Nos. P2001-000979 filed on Jan. 9, 2001; and P2001-000980 filed on Jan. 9, 2001, the disclosures of which are herein incorporated by reference] *a reissue divisional application of U.S. application Ser. No. 13/951,178, which is a reissue application of U.S. Pat. No. 7,986,360, which is a continuation of U.S. patent application Ser. No. 10/466,015, filed on Jan. 14, 2004, now U.S. Pat. No. 7,847,829, issued Dec. 7, 2010, which was the National Stage of International Application No. PCT/JP02/00036, filed on Jan. 9, 2002, and which claims priority to Japanese Patent Document Nos. P2001-000979 filed on Jan. 9, 2001; and P2001-000980 filed on Jan. 9, 2001, the disclosures of which are herein incorporated by reference.*

BACKGROUND

This invention relates to an image processing apparatus, and more particularly to an image processing apparatus suitable for use for production of a color image signal of a wide dynamic range from an image signal acquired, for example, using a CCD image sensor of the single plate type or the like.

A solid-state image pickup device such as a CCD (Charge Coupled Device) or a CMOS (Complementary Mental-Oxide Semiconductor) is utilized widely in image pickup apparatus such as a video camera and a digital still camera, part inspection apparatus in the field of the FA (Factory Automation) and optical measuring instruments such as an electronic endoscope in the field of the ME (Medical Electronics).

Conventionally, a method is known wherein light intensity signals measured with different sensitivities among different pixels are synthesized in order to increase the dynamic range of image pickup apparatus and optical measuring instruments in which a solid-state image pickup device is used. In the following, first to fourth related-art methods of the type mentioned are described.

As the first related-art method, a method can be listed wherein incoming light beams branched to a plurality of optical axes having different optical transmission factors are measured by solid-state image pickup devices disposed on the individual optical axes. This method is disclosed in the official gazette of Japanese Patent Laid-Open No. Hei 8-223491 and so forth. However, the first method has a problem in that it is disadvantageous in terms of the reduction of the cost or the reduction of the space because it requires a plurality of solid-state image pickup devices and a complicated optical system for branching light.

As the second related-art method, a method can be listed wherein a single solid-state image pickup device is used such that the exposure time thereof is divided into a plurality of time periods to pick up a plurality of images and then the images are synthesized. This method is disclosed in the official gazette of Japanese Patent Laid-Open No. Hei 8-331461 and so forth. However, the second method has a problem in that an image of a dynamic scene in which the intensity of light varies every moment cannot be picked up properly because the information measured with the different sensitivities are picked up at different points of time and with different time widths.

As the third related-art method, a method can be listed wherein a single solid-state image pickup device is used such that a plurality of light receiving elements adjacent each other on an image pickup face thereof form a set which corresponds to one pixel of an output image and have sensitivities different from each other to pick up an image. This method is disclosed in the official gazette of U.S. Pat. No. 5,789,737. As a method for making the sensitivities of light receiving elements which form a solid-state image pickup device different from each other, a method is available wherein the light receiving elements are covered with filters having transmission factors different from each other. Further, a technique which adapts the third related-art method to a color image is disclosed in the official gazette of Japanese Patent Laid-Open No. 2000-69491.

The third related-art method is advantageous in terms of the reduction of the cost and the reduction of the space in terms of which the first related-art method is disadvantageous. Further, the third related-art method can solve the problem of the second related-art method that an image of a dynamic scene cannot be picked up properly. However, with the third related-art method, since a plurality of light receiving elements adjacent each other form a set and correspond to one pixel of an output image, in order to secure a resolution of output pixels, a number of image pickup devices including a number of light receiving elements equal to several times the number of pixels of the output image, resulting in a subject that a large unit cell size is required.

As the fourth related-art method, a method can be listed wherein an image pickup device having an ordinary dynamic range is used to pick up an image with a mechanism applied thereto which makes the exposure different for each light receiving element corresponding to one pixel of an output image and the resulting image signals are subject to predetermined image processing to produce an image signal of a wide dynamic range. The mechanism for making the exposure different among different light receiving elements is implemented by producing a spatial sensitivity pattern by changing the light transmission factor or the numerical aperture for each light receiving element. This method is disclosed in a document 'S. K. Nayar and T. Mitsunaga, "High Dynamic Range Imaging: Spatially Varying Pixel Exposures", Proc. of Computer Vision and Pattern Recognition 2000, Vol. 1, pp. 472-479, June, 2000'.

In the fourth related-art method, each of the light receiving elements has only one kind of sensitivity. Consequently, each of pixels of an image picked up can acquire information of a dynamic range which the image pickup device originally has. However, by applying predetermined image processing to resulting image signals so that the sensitivities of all of the pixels may become equal to one another, an image having a wide dynamic range can be produced. Further, since all of the light receiving elements are exposed to light

at the same time, an image of a subject having some movement can be picked up properly. Furthermore, since one light receiving element corresponds to one pixel of output image, the problem that a great unit size is required does not occur with the fourth related-art method.

As described above, the fourth related-art method can solve the problems of the first to third related-art methods. However, the fourth related-art method has a premise that a monochromatic image is produced, and has a subject that a technique for producing a color image has not been established. More particularly, the fourth related-art method has a subject that a technique of producing image signals of all color components for all pixels from an image having different colors and/or different sensitivities among different pixels and making the sensitivity uniform has not conventionally been established.

SUMMARY

The present invention has been made in such a situation as described above, and it is an object of the present invention to make it possible to use a color and sensitivity mosaic image wherein the color and/or the sensitivity are different among different pixels to produce a restored image wherein the pixels have a uniformed sensitivity characteristic and each pixel has all of a plurality of color components.

A first image processing apparatus of the present invention is characterized in that it includes restoration means for restoring, based on a color and sensitivity mosaic image wherein each of a plurality of pixels has one of a plurality of color components and one of a plurality of sensitivity characteristics with respect to the intensity of light and a plurality of ones of the pixels which have the same color component and the same sensitivity characteristic are arranged in a grating-like arrangement and besides a plurality of ones of the pixels which have the same color component irrespective of the sensitivity characteristic are arranged in a grating-like arrangement, a restoration image wherein the sensitivities of the pixels are uniformized and each of the pixels has all of the plurality of color components.

The restoration means may include luminance image production means for producing a luminance image corresponding to the color and sensitivity mosaic image based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image and color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image, and a plurality of monochromatic image production means each for producing a monochromatic image corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, the color mosaic pattern information and the luminance image.

The luminance image production means may include a plurality of estimation means each for calculating an estimated value of a color component corresponding to each of the pixels of the color and sensitivity mosaic image, and luminance candidate value calculation means for calculating a luminance candidate value corresponding to each of the pixels of the color and sensitivity mosaic image using a plurality of the estimated values calculated individually by the plurality of estimation means.

Each of the estimation means may calculate a plurality of estimated value candidates individually corresponding to the plurality of sensitivity characteristics, add the plurality of estimated value candidates and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of estimated value candidates.

The luminance image production means may further include noise removal means for removing noise components of the luminance candidate value to produce a luminance value.

Each of the monochromatic image production means may include monochromatic image candidate production means for producing a monochromatic image candidate corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information, and modification means for modifying the monochromatic image candidate based on the luminance image to produce the monochromatic image.

The monochromatic image candidate production means may calculate a plurality of monochromatic candidate values individually corresponding to the plurality of sensitivity characteristics, add the plurality of monochromatic candidate values and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of monochromatic candidate values to calculate pixel values of the monochromatic image candidate to produce the monochromatic image candidate.

The monochromatic image candidate production means may use a direction selective smoothing process to produce the monochromatic image candidate corresponding to the color and sensitivity mosaic image.

The first image processing apparatus of the present invention may further include image pickup means for picking up an image of a subject to produce the color and sensitivity mosaic image.

The restoration means may include sensitivity characteristic uniformization means for uniformizing the sensitivity characteristics of the pixels based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image, and color interpolation means for interpolating color components of the pixels based on color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image.

The sensitivity characteristic uniformization means may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a color mosaic image, and the color interpolation means may interpolate the color components of the pixels of the color mosaic image based on the color mosaic pattern information to produce the restoration image.

The sensitivity characteristic uniformization means may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image without changing the kinds of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image.

The sensitivity characteristic uniformization means may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image and update the color mosaic pattern information.

The sensitivity uniformization means may include compensation means for compensating for the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, discrimination means for discriminating the validity of the color compo-

nents of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and modification means for modifying the color components of the pixels compensated for by the compensation means through an interpolation process in response to a result of the discrimination of the discrimination means.

The sensitivity uniformization means may include calculation means for calculating estimated pixel values of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and correction means for correcting the estimated pixel values calculated by the calculation means.

The color interpolation means may interpolate all of the color components of the pixels of the color and sensitivity mosaic image without changing the sensitivity characteristics of the pixels based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a sensitivity mosaic image of the color components, and the sensitivity characteristic uniformization means may uniformize the sensitivity characteristics of the pixels of the sensitivity mosaic image based on the sensitivity mosaic pattern information to produce the restoration image.

The color interpolation means may include extraction means for extracting those of the pixels which have the same sensitivity characteristic from the color and sensitivity mosaic image, all color component interpolation means for interpolating all of the color components of the pixels extracted by the extraction means, and synthesis means for synthesizing those of the pixels having all of the color components interpolated by the all color component interpolation means which have the same color component and have the different sensitivity characteristics to produce the sensitivity mosaic image.

A first image processing method of the present invention is characterized in that it includes a restoration step of restoring, based on a color and sensitivity mosaic image wherein each of a plurality of pixels has one of a plurality of color components and one of a plurality of sensitivity characteristics with respect to the intensity of light and a plurality of ones of the pixels which have the same color component and the same sensitivity characteristic are arranged in a grating-like arrangement and besides a plurality of ones of the pixels which have the same color component irrespective of the sensitivity characteristic are arranged in a grating-like arrangement, a restoration image wherein the sensitivities of the pixels are uniformized and each of the pixels has all of the plurality of color components.

The restoration step may include a luminance image production step of producing a luminance image corresponding to the color and sensitivity mosaic image based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image and color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image, and a plurality of monochromatic image production steps each of producing a monochromatic image corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, the color mosaic pattern information and the luminance image.

The luminance image production step may include a plurality of estimation steps each of calculating an estimated value of a color component corresponding to each of the pixels of the color and sensitivity mosaic image, and a luminance candidate value calculation step of calculating a luminance candidate value corresponding to each of the pixels of the color and sensitivity mosaic image using a plurality of the estimated values calculated individually by the processing of the plurality of estimation steps.

The processing of each of the estimation steps may calculate a plurality of estimated value candidate individually corresponding to the plurality of sensitivity characteristics, add the plurality of estimated value candidates and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of estimated value candidates.

The luminance image production step may further include a noise removal step of removing noise components of the luminance candidate value to produce a luminance value.

Each of the monochromatic image production steps may include a monochromatic image candidate production step of producing a monochromatic image candidate corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information, and a modification step of modifying the monochromatic image candidate based on the luminance image to produce the monochromatic image.

The processing of the monochromatic image candidate production step may calculate a plurality of monochromatic candidate values individually corresponding to the plurality of sensitivity characteristics, add the plurality of monochromatic candidate values and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of monochromatic candidate values to calculate pixel values of the monochromatic image candidate to produce the monochromatic image candidate.

The processing of the monochromatic image candidate production step may use a direction selective smoothing process to produce the monochromatic image candidate corresponding to the color and sensitivity mosaic image.

The first image processing method of the present invention may further include an image pickup step of picking up an image of a subject to produce the color and sensitivity mosaic image.

The restoration step may include a sensitivity characteristic uniformization step of uniformizing the sensitivity characteristics of the pixels based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image, and a color interpolation step of interpolating color components of the pixels based on color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a color mosaic image, and the processing of the color interpolation step may interpolate the color components of the pixels of the color mosaic image based on the color mosaic pattern information to produce the restoration image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image without changing the kinds of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the

color mosaic pattern information to produce the color mosaic image and update the color mosaic pattern information.

The sensitivity uniformization step may include a compensation step of compensating for the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, a discrimination step of discriminating the validity of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a modification step of modifying the color components of the pixels compensated for by the processing of the compensation step through an interpolation process in response to a result of the discrimination of the discrimination means.

The sensitivity uniformization step may include a calculation step of calculating estimated pixel values of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a correction step of correcting the estimated pixel values calculated by the processing of the calculation step.

The processing of the color interpolation step may interpolate all of the color components of the pixels of the color and sensitivity mosaic image without changing the sensitivity characteristics of the pixels based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a sensitivity mosaic image of the color components, and the processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the sensitivity mosaic image based on the sensitivity mosaic pattern information to produce the restoration image.

The color interpolation step may include an extraction step of extracting those of the pixels which have the same sensitivity characteristic from the color and sensitivity mosaic image, an all color component interpolation step of interpolating all of the color components of the pixels extracted by the processing of the extraction step, and a synthesis step of synthesizing those of the pixels having all of the color components interpolated by the processing of the all color component interpolation step which have the same color component and have the different sensitivity characteristics to produce the sensitivity mosaic image.

A program of a first recording medium of the present invention is characterized in that the program includes a restoration step of restoring, based on a color and sensitivity mosaic image wherein each of a plurality of pixels has one of a plurality of color components and one of a plurality of sensitivity characteristics with respect to the intensity of light and a plurality of ones of the pixels which have the same color component and the same sensitivity characteristic are arranged in a grating-like arrangement and besides a plurality of ones of the pixels which have the same color component irrespective of the sensitivity characteristic are arranged in a grating-like arrangement, a restoration image wherein the sensitivities of the pixels are uniformized and each of the pixels has all of the plurality of color components.

The restoration step may include a luminance image production step of producing a luminance image corresponding to the color and sensitivity mosaic image based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image and color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image, and a plurality of monochromatic image production steps each of producing a monochromatic image corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, the color mosaic pattern information and the luminance image.

The luminance image production step may include a plurality of estimation steps each of calculating an estimated value of a color component corresponding to each of the pixels of the color and sensitivity mosaic image, and a luminance candidate value calculation step of calculating a luminance candidate value corresponding to each of the pixels of the color and sensitivity mosaic image using a plurality of the estimated values calculated individually by the processing of the plurality of estimation steps.

The processing of each of the estimation steps may calculate a plurality of estimated value candidates individually corresponding to the plurality of sensitivity characteristics, add the plurality of estimated value candidates and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of estimated value candidates.

The luminance image production step may further include a noise removal step of removing noise components of the luminance candidate value to produce a luminance value.

Each of the monochromatic image production steps may include a monochromatic image candidate production step of producing a monochromatic image candidate corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information, and a modification step of modifying the monochromatic image candidate based on the luminance image to produce the monochromatic image.

The processing of the monochromatic image candidate production step may calculate a plurality of monochromatic candidate values individually corresponding to the plurality of sensitivity characteristics, add the plurality of monochromatic candidate values and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of monochromatic candidate values to calculate pixel values of the monochromatic image candidate to produce the monochromatic image candidate.

The processing of the monochromatic image candidate production step may use a direction selective smoothing process to produce the monochromatic image candidate corresponding to the color and sensitivity mosaic image.

The program of the first recording medium of the present invention may further include an image pickup controlling step of controlling a process of picking up an image of a subject to produce the color and sensitivity mosaic image.

The restoration step may include a sensitivity characteristic uniformization step of uniformizing the sensitivity characteristics of the pixels based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image, and a color interpolation step of interpolating color components of the pixels based on color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a color mosaic image, and the processing of the color interpolation step may interpolate the color components of the pixels of the color mosaic image based on the color mosaic pattern information to produce the restoration image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity character-

istics of the pixels of the color and sensitivity mosaic image without changing the kinds of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image and update the color mosaic pattern information.

The sensitivity uniformization step may include a compensation step of compensating for the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, a discrimination step of discriminating the validity of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a modification step of modifying the color components of the pixels compensated for by the processing of the compensation step through an interpolation process in response to a result of the discrimination of the discrimination means.

The sensitivity uniformization step may include a calculation step of calculating estimated pixel values of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a correction step of correcting the estimated pixel values calculated by the processing of the calculation step.

The processing of the color interpolation step may interpolate all of the color components of the pixels of the color and sensitivity mosaic image without changing the sensitivity characteristics of the pixels based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a sensitivity mosaic image of the color components, and the processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the sensitivity mosaic image based on the sensitivity mosaic pattern information to produce the restoration image.

The color interpolation step may include an extraction step of extracting those of the pixels which have the same sensitivity characteristic from the color and sensitivity mosaic image, an all color component interpolation step of interpolating all of the color components of the pixels extracted by the processing of the extraction step, and a synthesis step of synthesizing those of the pixels having all of the color components interpolated by the processing of the all color component interpolation step which have the same color component and have the different sensitivity characteristics to produce the sensitivity mosaic image.

A first program of the present invention is characterized in that it causes a computer to execute a restoration step of restoring, based on a color and sensitivity mosaic image wherein each of a plurality of pixels has one of a plurality of color components and one of a plurality of sensitivity characteristics with respect to the intensity of light and a plurality of ones of the pixels which have the same color component and the same sensitivity characteristic are arranged in a grating-like arrangement and besides a plurality of ones of the pixels which have the same color component irrespective of the sensitivity characteristic are arranged in a grating-like arrangement, a restoration image wherein the sensitivities of the pixels are uniformized and each of the pixels has all of the plurality of color components.

The restoration step may include a luminance image production step of producing a luminance image corresponding to the color and sensitivity mosaic image based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image and color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image, and a plurality of monochromatic image production steps each of producing a monochromatic image corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, the color mosaic pattern information and the luminance image.

The luminance image production step may include a plurality of estimation steps each of calculating an estimated value of a color component corresponding to each of the pixels of the color and sensitivity mosaic image, and a luminance candidate value calculation step of calculating a luminance candidate value corresponding to each of the pixels of the color and sensitivity mosaic image using a plurality of the estimated values calculated individually by the processing of the plurality of estimation steps.

The processing of each of the estimation steps may calculate a plurality of estimated value candidates individually corresponding to the plurality of sensitivity characteristics, add the plurality of estimated value candidates and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of estimated value candidates.

The luminance image production step may further include a noise removal step of removing noise components of the luminance candidate value to produce a luminance value.

Each of the monochromatic image production steps may include a monochromatic image candidate production step of producing a monochromatic image candidate corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information, and a modification step of modifying the monochromatic image candidate based on the luminance image to produce the monochromatic image.

The processing of the monochromatic image candidate production step may calculate a plurality of monochromatic candidate values individually corresponding to the plurality of sensitivity characteristics, add the plurality of monochromatic candidate values and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of monochromatic candidate values to calculate pixel values of the monochromatic image candidate to produce the monochromatic image candidate.

The processing of the monochromatic image candidate production step may use a direction selective smoothing process to produce the monochromatic image candidate corresponding to the color and sensitivity mosaic image.

The first program of the present invention may further include an image pickup controlling step of controlling a process of picking up an image of a subject to produce the color and sensitivity mosaic image.

The restoration step may include a sensitivity characteristic uniformization step of uniformizing the sensitivity characteristics of the pixels based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image, and a color interpolation step of interpolating color components of the pixels based on color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a color mosaic image, and the processing of the color interpolation step may interpolate the color components of the pixels of the color mosaic image based on the color mosaic pattern information to produce the restoration image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image without changing the kinds of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image and update the color mosaic pattern information.

The sensitivity uniformization step may include a compensation step of compensating for the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, a discrimination step of discriminating the validity of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a modification step of modifying the color components of the pixels compensated for by the processing of the compensation step through an interpolation process in response to a result of the discrimination of the discrimination means.

The sensitivity uniformization step may include a calculation step of calculating estimated pixel values of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a correction step of correcting the estimated pixel values calculated by the processing of the calculation step.

The processing of the color interpolation step may interpolate all of the color components of the pixels of the color and sensitivity mosaic image without changing the sensitivity characteristics of the pixels based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a sensitivity mosaic image of the color components, and the processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the sensitivity mosaic image based on the sensitivity mosaic pattern information to produce the restoration image.

The color interpolation step may include an extraction step of extracting those of the pixels which have the same sensitivity characteristic from the color and sensitivity mosaic image, an all color component interpolation step of interpolating all of the color components of the pixels extracted by the processing of the extraction step, and a synthesis step of synthesizing those of the pixels having all of the color components interpolated by the processing of the all color component interpolation step which have the same color component and have the different sensitivity characteristics to produce the sensitivity mosaic image.

A second image processing apparatus of the present invention is characterized in that it includes restoration means for restoring, based on a color and sensitivity mosaic image wherein each of a plurality of pixels has one of a plurality of color components and one of a plurality of sensitivity characteristics with respect to the intensity of light and a plurality of ones of the pixels which have the same color component and the same sensitivity characteristic are arranged in a grating-like arrangement and besides a plurality of ones of the pixels which have the same sensitivity characteristic irrespective of the color component are arranged in a grating-like arrangement such that totaling 5 pixels including an arbitrary pixel and four pixels neighboring upwardly, downwardly, leftwardly and rightwardly of the arbitrary pixel include all of the color components, a restoration image wherein the sensitivities of the pixels are uniformized and each of the pixels has all of the plurality of color components.

The restoration means may includes luminance image production means for producing a luminance image corresponding to the color and sensitivity mosaic image based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image and color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image, and a plurality of monochromatic image production means each for producing a monochromatic image corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, the color mosaic pattern information and the luminance image.

The luminance image production means may include a plurality of estimation means each for calculating an estimated value of a color component corresponding to each of the pixels of the color and sensitivity mosaic image, and luminance candidate value calculation means for calculating a luminance candidate value corresponding to each of the pixels of the color and sensitivity mosaic image using a plurality of the estimated values calculated individually by the plurality of estimation means.

Each of the estimation means may calculate a plurality of estimated value candidates individually corresponding to the plurality of sensitivity characteristics, add the plurality of estimated value candidates and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of estimated value candidates.

The luminance image production means may further include noise removal means for removing noise components of the luminance candidate value to produce a luminance value.

Each of the monochromatic image production means may include monochromatic image candidate production means for producing a monochromatic image candidate corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information, and modification means for modifying the monochromatic image candidate based on the luminance image to produce the monochromatic image.

The monochromatic image candidate production means may calculate a plurality of monochromatic candidate values individually corresponding to the plurality of sensitivity characteristics, add the plurality of monochromatic candidate values and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of monochromatic candidate values to calculate pixel values of the monochromatic image candidate to produce the monochromatic image candidate.

The monochromatic image candidate production means may use a direction selective smoothing process to produce the monochromatic image candidate corresponding to the color and sensitivity mosaic image.

The second image processing apparatus of the present invention may further include image pickup means for picking up an image of a subject to produce the color and sensitivity mosaic image.

The restoration means may include sensitivity characteristic uniformization means for uniformizing the sensitivity characteristics of the pixels based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image, and color interpolation means for interpolating color components of the pixels based on color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image.

The sensitivity characteristic uniformization means may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a color mosaic image, and the color interpolation means may interpolate the color components of the pixels of the color mosaic image based on the color mosaic pattern information to produce the restoration image.

The sensitivity characteristic uniformization means may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image without changing the kinds of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image.

The sensitivity characteristic uniformization means may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image and update the color mosaic pattern information.

The sensitivity uniformization means may include compensation means for compensating for the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, discrimination means for discriminating the validity of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and modification means for modifying the color components of the pixels compensated for by the compensation means through an interpolation process in response to a result of the discrimination of the discrimination means.

The sensitivity uniformization means may include calculation means for calculating estimated pixel values of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and correction means for correcting the estimated pixel values calculated by the calculation means.

The color interpolation means may interpolate all of the color components of the pixels of the color and sensitivity mosaic image without changing the sensitivity characteristics of the pixels based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a sensitivity mosaic image of the color components, and the sensitivity characteristic uniformization means may uniformize the sensitivity characteristics of the pixels of the sensitivity mosaic image based on the sensitivity mosaic pattern information to produce the restoration image.

The color interpolation means may include extraction means for extracting those of the pixels which have the same sensitivity characteristic from the color and sensitivity mosaic image, all color component interpolation means for interpolating all of the color components of the pixels extracted by the extraction means, and synthesis means for synthesizing those of the pixels having all of the color components interpolated by the all color component interpolation means which have the same color component and have the different sensitivity characteristics to produce the sensitivity mosaic image.

A second image processing method of the present invention is characterized in that it includes a restoration step of restoring, based on a color and sensitivity mosaic image wherein each of a plurality of pixels has one of a plurality of color components and one of a plurality of sensitivity characteristics with respect to the intensity of light and a plurality of ones of the pixels which have the same color component and the same sensitivity characteristic are arranged in a grating-like arrangement and besides a plurality of ones of the pixels which have the same sensitivity characteristic irrespective of the color component are arranged in a grating-like arrangement such that totaling 5 pixels including an arbitrary pixel and four pixels neighboring upwardly, downwardly, leftwardly and rightwardly of the arbitrary pixel include all of the color components, a restoration image wherein the sensitivities of the pixels are uniformized and each of the pixels has all of the plurality of color components.

The restoration step may include a luminance image production step of producing a luminance image corresponding to the color and sensitivity mosaic image based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image and color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image, and a plurality of monochromatic image production steps each of producing a monochromatic image corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, the color mosaic pattern information and the luminance image.

The luminance image production step may include a plurality of estimation steps each of calculating an estimated value of a color component corresponding to each of the pixels of the color and sensitivity mosaic image, and a luminance candidate value calculation step of calculating a luminance candidate value corresponding to each of the pixels of the color and sensitivity mosaic image using a plurality of the estimated values calculated individually by the processing of the plurality of estimation steps.

The processing of each of the estimation steps may calculate a plurality of estimated value candidates individually corresponding to the plurality of sensitivity characteristics, add the plurality of estimated value candidates and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of estimated value candidates.

The luminance image production step may further include a noise removal step of removing noise components of the luminance candidate value to produce a luminance value.

Each of the monochromatic image production steps may include a monochromatic image candidate production step of producing a monochromatic image candidate corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information, and a modification step of modifying the monochromatic image candidate based on the luminance image to produce the monochromatic image.

The processing of the monochromatic image candidate production step may calculate a plurality of monochromatic candidate values individually corresponding to the plurality of sensitivity characteristics, add the plurality of monochro-

matic candidate values and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of monochromatic candidate values to calculate pixel values of the monochromatic image candidate to produce the monochromatic image candidate.

The processing of the monochromatic image candidate production step may use a direction selective smoothing process to produce the monochromatic image candidate corresponding to the color and sensitivity mosaic image.

The second image processing method of the present invention may further include an image pickup step of picking up an image of a subject to produce the color and sensitivity mosaic image.

The restoration step may include a sensitivity characteristic uniformization step of uniformizing the sensitivity characteristics of the pixels based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image, and a color interpolation step of interpolating color components of the pixels based on color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a color mosaic image, and the processing of the color interpolation step may interpolate the color components of the pixels of the color mosaic image based on the color mosaic pattern information to produce the restoration image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image without changing the kinds of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image and update the color mosaic pattern information.

The sensitivity uniformization step may include a compensation step of compensating for the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, a discrimination step of discriminating the validity of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a modification step of modifying the color components of the pixels compensated for by the processing of the compensation step through an interpolation process in response to a result of the discrimination of the discrimination means.

The sensitivity uniformization step may include a calculation step of calculating estimated pixel values of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a correction step of correcting the estimated pixel values calculated by the processing of the calculation step.

The processing of the color interpolation step may interpolate all of the color components of the pixels of the color and sensitivity mosaic image without changing the sensitivity characteristics of the pixels based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a sensitivity mosaic image of the color components, and the processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the sensitivity mosaic image based on the sensitivity mosaic pattern information to produce the restoration image.

The color interpolation step may include an extraction step of extracting those of the pixels which have the same sensitivity characteristic from the color and sensitivity mosaic image, an all color component interpolation step of interpolating all of the color components of the pixels extracted by the processing of the extraction step, and a synthesis step of synthesizing those of the pixels having all of the color components interpolated by the processing of the all color component interpolation step which have the same color component and have the different sensitivity characteristics to produce the sensitivity mosaic image.

A program of a second recording medium of the present invention is characterized in that the program includes a restoration step of restoring, based on a color and sensitivity mosaic image wherein each of a plurality of pixels has one of a plurality of color components and one of a plurality of sensitivity characteristics with respect to the intensity of light and a plurality of ones of the pixels which have the same color component and the same sensitivity characteristic are arranged in a grating-like arrangement and besides a plurality of ones of the pixels which have the same sensitivity characteristic irrespective of the color component are arranged in a grating-like arrangement such that totaling 5 pixels including an arbitrary pixel and four pixels neighboring upwardly, downwardly, leftwardly and rightwardly of the arbitrary pixel include all of the color components, a restoration image wherein the sensitivities of the pixels are uniformized and each of the pixels has all of the plurality of color components.

The restoration step may include a luminance image production step of producing a luminance image corresponding to the color and sensitivity mosaic image based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image and color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image, and a plurality of monochromatic image production steps each of producing a monochromatic image corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, the color mosaic pattern information and the luminance image.

The luminance image production step may include a plurality of estimation steps each of calculating an estimated value of a color component corresponding to each of the pixels of the color and sensitivity mosaic image, and a luminance candidate value calculation step of calculating a luminance candidate value corresponding to each of the pixels of the color and sensitivity mosaic image using a plurality of the estimated values calculated individually by the processing of the plurality of estimation steps.

The processing of each of the estimation steps may calculate a plurality of estimated value candidates individually corresponding to the plurality of sensitivity characteristics, add the plurality of estimated value candidates and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of estimated value candidates.

The luminance image production step may further include a noise removal step of removing noise components of the luminance candidate value to produce a luminance value.

Each of the monochromatic image production steps may include a monochromatic image candidate production step of producing a monochromatic image candidate corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information, and a modification step of modifying the monochromatic image candidate based on the luminance image to produce the monochromatic image.

The processing of the monochromatic image candidate production step may calculate a plurality of monochromatic candidate values individually corresponding to the plurality of sensitivity characteristics, add the plurality of monochromatic candidate values and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of monochromatic candidate values to calculate pixel values of the monochromatic image candidate to produce the monochromatic image candidate.

The processing of the monochromatic image candidate production step may use a direction selective smoothing process to produce the monochromatic image candidate corresponding to the color and sensitivity mosaic image.

The program of the second recording medium of the present invention may further include an image pickup controlling step of controlling a process of picking up an image of a subject to produce the color and sensitivity mosaic image.

The restoration step may include a sensitivity characteristic uniformization step of uniformizing the sensitivity characteristics of the pixels based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image, and a color interpolation step of interpolating color components of the pixels based on color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a color mosaic image, and the processing of the color interpolation step may interpolate the color components of the pixels of the color mosaic image based on the color mosaic pattern information to produce the restoration image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image without changing the kinds of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image and update the color mosaic pattern information.

The sensitivity uniformization step may include a compensation step of compensating for the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, a discrimination step of discriminating the validity of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a modification step of modifying the color components of the pixels compensated for by the processing of the compensation step through an interpolation process in response to a result of the discrimination of the discrimination means.

The sensitivity uniformization step may include a calculation step of calculating estimated pixel values of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a correction step of correcting the estimated pixel values calculated by the processing of the calculation step.

The processing of the color interpolation step may interpolate all of the color components of the pixels of the color and sensitivity mosaic image without changing the sensitivity characteristics of the pixels based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a sensitivity mosaic image of the color components, and the processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the sensitivity mosaic image based on the sensitivity mosaic pattern information to produce the restoration image.

The color interpolation step may include an extraction step of extracting those of the pixels which have the same sensitivity characteristic from the color and sensitivity mosaic image, an all color component interpolation step of interpolating all of the color components of the pixels extracted by the processing of the extraction step, and a synthesis step of synthesizing those of the pixels having all of the color components interpolated by the processing of the all color component interpolation step which have the same color component and have the different sensitivity characteristics to produce the sensitivity mosaic image.

A second program of the present invention is characterized in that it causes a computer to execute a restoration step of restoring, based on a color and sensitivity mosaic image wherein each of a plurality of pixels has one of a plurality of color components and one of a plurality of sensitivity characteristics with respect to the intensity of light and a plurality of ones of the pixels which have the same color component and the same sensitivity characteristic are arranged in a grating-like arrangement and besides a plurality of ones of the pixels which have the same sensitivity characteristic irrespective of the color component are arranged in a grating-like arrangement such that totaling 5 pixels including an arbitrary pixel and four pixels neighboring upwardly, downwardly, leftwardly and rightwardly of the arbitrary pixel include all of the color components, a restoration image wherein the sensitivities of the pixels are uniformized and each of the pixels has all of the plurality of color components.

The restoration step may include a luminance image production step of producing a luminance image corresponding to the color and sensitivity mosaic image based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image and color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image, and a plurality of monochromatic image production steps each of producing a monochromatic image corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, the color mosaic pattern information and the luminance image.

The luminance image production step may include a plurality of estimation steps each of calculating an estimated value of a color component corresponding to each of the pixels of the color and sensitivity mosaic image, and a luminance candidate value calculation step of calculating a luminance candidate value corresponding to each of the

pixels of the color and sensitivity mosaic image using a plurality of the estimated values calculated individually by the processing of the plurality of estimation steps.

The processing of each of the estimation steps may calculate a plurality of estimated value candidates individually corresponding to the plurality of sensitivity characteristics, add the plurality of estimated value candidates and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of estimated value candidates.

The luminance image production step may further include a noise removal step of removing noise components of the luminance candidate value to produce a luminance value.

Each of the monochromatic image production steps may include a monochromatic image candidate production step of producing a monochromatic image candidate corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information, and a modification step of modifying the monochromatic image candidate based on the luminance image to produce the monochromatic image.

The processing of the monochromatic image candidate production step may calculate a plurality of monochromatic candidate values individually corresponding to the plurality of sensitivity characteristics, add the plurality of monochromatic candidate values and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of monochromatic candidate values to calculate pixel values of the monochromatic image candidate to produce the monochromatic image candidate.

The processing of the monochromatic image candidate production step may use a direction selective smoothing process to produce the monochromatic image candidate corresponding to the color and sensitivity mosaic image.

The second program of the present invention may further include an image pickup controlling step of controlling a process of picking up an image of a subject to produce the color and sensitivity mosaic image.

The restoration step may include a sensitivity characteristic uniformization step of uniformizing the sensitivity characteristics of the pixels based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image, and a color interpolation step of interpolating color components of the pixels based on color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a color mosaic image, and the processing of the color interpolation step may interpolate the color components of the pixels of the color mosaic image based on the color mosaic pattern information to produce the restoration image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image without changing the kinds of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image and update the color mosaic pattern information.

The sensitivity uniformization step may include a compensation step of compensating for the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, a discrimination step of discriminating the validity of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a modification step of modifying the color components of the pixels compensated for by the processing of the compensation step through an interpolation process in response to a result of the discrimination of the discrimination means.

The sensitivity uniformization step may include a calculation step of calculating estimated pixel values of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a correction step of correcting the estimated pixel values calculated by the processing of the calculation step.

The processing of the color interpolation step may interpolate all of the color components of the pixels of the color and sensitivity mosaic image without changing the sensitivity characteristics of the pixels based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a sensitivity mosaic image of the color components, and the processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the sensitivity mosaic image based on the sensitivity mosaic pattern information to produce the restoration image.

The color interpolation step may include an extraction step of extracting those of the pixels which have the same sensitivity characteristic from the color and sensitivity mosaic image, an all color component interpolation step of interpolating all of the color components of the pixels extracted by the processing of the extraction step, and a synthesis step of synthesizing those of the pixels having all of the color components interpolated by the processing of the all color component interpolation step which have the same color component and have the different sensitivity characteristics to produce the sensitivity mosaic image.

A third image processing apparatus of the present invention is characterized in that it includes sensitivity characteristic uniformization means for uniformizing the sensitivity characteristics of the pixels based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image, and color interpolation means for interpolating color components of the pixels based on color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image.

The sensitivity characteristic uniformization means may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a color mosaic image, and the color interpolation means may interpolate the color components of the pixels of the color mosaic image based on the color mosaic pattern information to produce the restoration image.

The sensitivity characteristic uniformization means may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image without changing the kinds of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image.

The sensitivity characteristic uniformization means may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image and update the color mosaic pattern information.

The sensitivity uniformization means may include compensation means for compensating for the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, discrimination means for discriminating the validity of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and modification means for modifying the color components of the pixels compensated for by the compensation means through an interpolation process in response to a result of the discrimination of the discrimination means.

The sensitivity uniformization means may include calculation means for calculating estimated pixel values of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and correction means for correcting the estimated pixel values calculated by the calculation means.

The color interpolation means may interpolate all of the color components of the pixels of the color and sensitivity mosaic image without changing the sensitivity characteristics of the pixels based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a sensitivity mosaic image of the color components, and the sensitivity characteristic uniformization means may uniformize the sensitivity characteristics of the pixels of the sensitivity mosaic image based on the sensitivity mosaic pattern information to produce the restoration image.

The color interpolation means may include extraction means for extracting those of the pixels which have the same sensitivity characteristic from the color and sensitivity mosaic image, all color component interpolation means for interpolating all of the color components of the pixels extracted by the extraction means, and synthesis means for synthesizing those of the pixels having all of the color components interpolated by the all color component interpolation means which have the same color component and have the different sensitivity characteristics to produce the sensitivity mosaic image.

The third image processing apparatus of the present invention may further include image pickup means for picking up an image of a subject to produce the color and sensitivity mosaic image.

A third image processing method of the present invention is characterized in that it includes a sensitivity characteristic uniformization step of uniformizing the sensitivity characteristics of the pixels based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image, and a color interpolation step of interpolating color components of the pixels based on color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a color mosaic image, and the processing of the color interpolation step may interpolate the color components of the pixels of the color mosaic image based on the color mosaic pattern information to produce the restoration image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image without changing the kinds of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image and update the color mosaic pattern information.

The sensitivity uniformization step may include a compensation step of compensating for the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, a discrimination step of discriminating the validity of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a modification step of modifying the color components of the pixels compensated for by the processing of the compensation step through an interpolation process in response to a result of the processing at the discrimination step.

The sensitivity uniformization step may include a calculation step of calculating estimated pixel values of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a correction step of correcting the estimated pixel values calculated by the processing of the calculation step.

The processing of the color interpolation step may interpolate all of the color components of the pixels of the color and sensitivity mosaic image without changing the sensitivity characteristics of the pixels based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a sensitivity mosaic image of the color components, and the processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the sensitivity mosaic image based on the sensitivity mosaic pattern information to produce the restoration image.

The color interpolation step may include an extraction step of extracting those of the pixels which have the same sensitivity characteristic from the color and sensitivity mosaic image, an all color component interpolation step of interpolating all of the color components of the pixels extracted by the processing of the extraction step, and a synthesis step of synthesizing those of the pixels having all of the color components interpolated by the processing of the all color component interpolation step which have the same color component and have the different sensitivity characteristics to produce the sensitivity mosaic image.

The third image processing method of the present invention may further include an image pickup step of picking up an image of a subject to produce the color and sensitivity mosaic image.

A program of a third recording medium of the present invention is characterized in that the program includes a sensitivity characteristic uniformization step of uniformizing the sensitivity characteristics of the pixels based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image, and a color interpolation step of interpolating color components of the pixels based on

color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a color mosaic image, and the processing of the color interpolation step may interpolate the color components of the pixels of the color mosaic image based on the color mosaic pattern information to produce the restoration image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image without changing the kinds of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image and update the color mosaic pattern information.

The sensitivity uniformization step may include a compensation step of compensating for the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, a discrimination step of discriminating the validity of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a modification step of modifying the color components of the pixels compensated for by the processing of the compensation step through an interpolation process in response to a result of the processing at the discrimination step.

The sensitivity uniformization step may include a calculation step of calculating estimated pixel values of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a correction step of correcting the estimated pixel values calculated by the processing of the calculation step.

The processing of the color interpolation step may interpolate all of the color components of the pixels of the color and sensitivity mosaic image without changing the sensitivity characteristics of the pixels based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a sensitivity mosaic image of the color components, and the processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the sensitivity mosaic image based on the sensitivity mosaic pattern information to produce the restoration image.

The color interpolation step may include an extraction step of extracting those of the pixels which have the same sensitivity characteristic from the color and sensitivity mosaic image, an all color component interpolation step of interpolating all of the color components of the pixels extracted by the processing of the extraction step, and a synthesis step of synthesizing those of the pixels having all of the color components interpolated by the processing of the all color component interpolation step which have the same color component and have the different sensitivity characteristics to produce the sensitivity mosaic image.

The program of the third recording medium of the present invention may further include an image pickup controlling step of controlling a process of picking up an image of a subject to produce the color and sensitivity mosaic image.

A third program of the present invention is characterized in that it causes a computer to execute a sensitivity characteristic uniformization step of uniformizing the sensitivity characteristics of the pixels based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image, and a color interpolation step of interpolating color components of the pixels based on color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a color mosaic image, and the processing of the color interpolation step may interpolate the color components of the pixels of the color mosaic image based on the color mosaic pattern information to produce the restoration image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image without changing the kinds of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image.

The processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce the color mosaic image and update the color mosaic pattern information.

The sensitivity uniformization step may include a compensation step of compensating for the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, a discrimination step of discriminating the validity of the color components of the pixels of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a modification step of modifying the color components of the pixels compensated for by the processing of the compensation step through an interpolation process in response to a result of the processing at the discrimination step.

The sensitivity uniformization step may include a calculation step of calculating estimated pixel values of the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, and a correction step of correcting the estimated pixel values calculated by the processing of the calculation step.

The processing of the color interpolation step may interpolate all of the color components of the pixels of the color and sensitivity mosaic image without changing the sensitivity characteristics of the pixels based on the sensitivity mosaic pattern information and the color mosaic pattern information to produce a sensitivity mosaic image of the color components, and the processing of the sensitivity characteristic uniformization step may uniformize the sensitivity characteristics of the pixels of the sensitivity mosaic image based on the sensitivity mosaic pattern information to produce the restoration image.

The color interpolation step may include an extraction step of extracting those of the pixels which have the same sensitivity characteristic from the color and sensitivity mosaic image, an all color component interpolation step of

interpolating all of the color components of the pixels extracted by the processing of the extraction step, and a synthesis step of synthesizing those of the pixels having all of the color components interpolated by the processing of the all color component interpolation step which have the same color component and have the different sensitivity characteristics to produce the sensitivity mosaic image.

The third program of the present invention may further include an image pickup controlling step of controlling a process of picking up an image of a subject to produce the color and sensitivity mosaic image.

A fourth image processing apparatus of the present invention is characterized in that it includes luminance image production means for producing a luminance image corresponding to the color and sensitivity mosaic image based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image and color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image, and a plurality of monochromatic image production means each for producing a monochromatic image corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, the color mosaic pattern information and the luminance image.

The luminance image production means may include a plurality of estimation means each for calculating an estimated value of a color component corresponding to each of the pixels of the color and sensitivity mosaic image, and luminance candidate value calculation means for calculating a luminance candidate value corresponding to each of the pixels of the color and sensitivity mosaic image using a plurality of the estimated values calculated individually by the plurality of estimation means.

Each of the estimation means may calculate a plurality of estimated value candidates individually corresponding to the plurality of sensitivity characteristics, add the plurality of estimated value candidates and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of estimated value candidates.

The luminance image production means may further include noise removal means for removing noise components of the luminance candidate value to produce a luminance value.

Each of the monochromatic image production means may include monochromatic image candidate production means for producing a monochromatic image candidate corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information, and modification means for modifying the monochromatic image candidate based on the luminance image to produce the monochromatic image.

The monochromatic image candidate production means may calculate a plurality of monochromatic candidate values individually corresponding to the plurality of sensitivity characteristics, add the plurality of monochromatic candidate values and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of monochromatic candidate values to calculate pixel values of the monochromatic image candidate to produce the monochromatic image candidate.

The monochromatic image candidate production means may use a direction selective smoothing process to produce the monochromatic image candidate corresponding to the color and sensitivity mosaic image.

The fourth image processing apparatus of the present invention may further include image pickup means for picking up an image of a subject to produce the color and sensitivity mosaic image.

A fourth image processing method of the present invention is characterized in that it includes a luminance image production step of producing a luminance image corresponding to the color and sensitivity mosaic image based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image and color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image, and a plurality of monochromatic image production steps each of producing a monochromatic image corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, the color mosaic pattern information and the luminance image.

The luminance image production step may include a plurality of estimation steps each of calculating an estimated value of a color component corresponding to each of the pixels of the color and sensitivity mosaic image, and a luminance candidate value calculation step of calculating a luminance candidate value corresponding to each of the pixels of the color and sensitivity mosaic image using a plurality of the estimated values calculated individually by the processing of the plurality of estimation steps.

The processing of each of the estimation steps may calculate a plurality of estimated value candidates individually corresponding to the plurality of sensitivity characteristics, add the plurality of estimated value candidates and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of estimated value candidates.

The luminance image production step may further include a noise removal step of removing noise components of the luminance candidate value to produce a luminance value.

Each of the monochromatic image production steps may include a monochromatic image candidate production step of producing a monochromatic image candidate corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information, and a modification step of modifying the monochromatic image candidate based on the luminance image to produce the monochromatic image.

The processing of the monochromatic image candidate production step may calculate a plurality of monochromatic candidate values individually corresponding to the plurality of sensitivity characteristics, add the plurality of monochromatic candidate values and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of monochromatic candidate values to calculate pixel values of the monochromatic image candidate to produce the monochromatic image candidate.

The processing of the monochromatic image candidate production step may use a direction selective smoothing process to produce the monochromatic image candidate corresponding to the color and sensitivity mosaic image.

The fourth image processing method of the present invention may further include an image pickup step of picking up an image of a subject to produce the color and sensitivity mosaic image.

A program of a fourth recording medium of the present invention is characterized in that the program includes a luminance image production step of producing a luminance image corresponding to the color and sensitivity mosaic image based on sensitivity mosaic pattern information rep-

resentative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image and color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image, and a plurality of monochromatic image production steps each of producing a monochromatic image corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, the color mosaic pattern information and the luminance image.

The luminance image production step may include a plurality of estimation steps each of calculating an estimated value of a color component corresponding to each of the pixels of the color and sensitivity mosaic image, and a luminance candidate value calculation step of calculating a luminance candidate value corresponding to each of the pixels of the color and sensitivity mosaic image using a plurality of the estimated values calculated individually by the processing of the plurality of estimation steps.

The processing of each of the estimation steps may calculate a plurality of estimated value candidates individually corresponding to the plurality of sensitivity characteristics, add the plurality of estimated value candidates and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of estimated value candidates.

The luminance image production step may further include a noise removal step of removing noise components of the luminance candidate value to produce a luminance value.

Each of the monochromatic image production steps may include a monochromatic image candidate production step of producing a monochromatic image candidate corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information, and a modification step of modifying the monochromatic image candidate based on the luminance image to produce the monochromatic image.

The processing of the monochromatic image candidate production step may calculate a plurality of monochromatic candidate values individually corresponding to the plurality of sensitivity characteristics, add the plurality of monochromatic candidate values and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of monochromatic candidate values to calculate pixel values of the monochromatic image candidate to produce the monochromatic image candidate.

The processing of the monochromatic image candidate production step may use a direction selective smoothing process to produce the monochromatic image candidate corresponding to the color and sensitivity mosaic image.

The program of the fourth recording medium of the present invention may further include an image pickup controlling step of controlling a process of picking up an image of a subject to produce the color and sensitivity mosaic image.

A fourth program of the present invention is characterized in that it causes a computer to execute a luminance image production step of producing a luminance image corresponding to the color and sensitivity mosaic image based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image and color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image, and a plurality of monochromatic image production steps each of producing a monochromatic image corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information, the color mosaic pattern information and the luminance image.

The luminance image production step may include a plurality of estimation steps each of calculating an estimated value of a color component corresponding to each of the pixels of the color and sensitivity mosaic image, and a luminance candidate value calculation step of calculating a luminance candidate value corresponding to each of the pixels of the color and sensitivity mosaic image using a plurality of the estimated values calculated individually by the processing of the plurality of estimation steps.

The processing of each of the estimation steps may calculate a plurality of estimated value candidates individually corresponding to the plurality of sensitivity characteristics, add the plurality of estimated value candidates and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of estimated value candidates.

The luminance image production step may further include a noise removal step of removing noise components of the luminance candidate value to produce a luminance value.

Each of the monochromatic image production steps may include a monochromatic image candidate production step of producing a monochromatic image candidate corresponding to the color and sensitivity mosaic image based on the sensitivity mosaic pattern information and the color mosaic pattern information, and a modification step of modifying the monochromatic image candidate based on the luminance image to produce the monochromatic image.

The processing of the monochromatic image candidate production step may calculate a plurality of monochromatic candidate values individually corresponding to the plurality of sensitivity characteristics, add the plurality of monochromatic candidate values and compensate for the non-linearity of the sensitivity characteristic appearing with the sum of the plurality of monochromatic candidate values to calculate pixel values of the monochromatic image candidate to produce the monochromatic image candidate.

The processing of the monochromatic image candidate production step may use a direction selective smoothing process to produce the monochromatic image candidate corresponding to the color and sensitivity mosaic image.

The fourth program of the present invention may further include an image pickup controlling step of controlling a process of picking up an image of a subject to produce the color and sensitivity mosaic image.

In the first image processing apparatus and method as well as program of the present invention, based on a color and sensitivity mosaic image wherein each of a plurality of pixels has one of a plurality of color components and one of a plurality of sensitivity characteristics with respect to the intensity of light and a plurality of ones of the pixels which have the same color component and the same sensitivity characteristic are arranged in a grating-like arrangement and besides a plurality of ones of the pixels which have the same color component irrespective of the sensitivity characteristic are arranged in a grating-like arrangement, a restoration image wherein the sensitivities of the pixels are uniformized and each of the pixels has all of the plurality of color components is restored.

In the second image processing apparatus and method as well as program of the present invention, based on a color and sensitivity mosaic image wherein each of a plurality of pixels has one of a plurality of color components and one of a plurality of sensitivity characteristics with respect to the intensity of light and a plurality of ones of the pixels which have the same color component and the same sensitivity

characteristic are arranged in a grating-like arrangement and besides a plurality of ones of the pixels which have the same sensitivity characteristic irrespective of the color component are arranged in a grating-like arrangement such that totaling 5 pixels including an arbitrary pixel and four pixels neighboring upwardly, downwardly, leftwardly and rightwardly of the arbitrary pixel include all of the color components, a restoration image wherein the sensitivities of the pixels are uniformized and each of the pixels has all of the plurality of color components is restored.

In the third image processing apparatus and method as well as program of the present invention, the sensitivity characteristics of the pixels are uniformized based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image, and color components of the pixels are interpolated based on color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image.

In the fourth image processing apparatus and method as well as program of the present invention, a luminance image corresponding to the color and sensitivity mosaic image is produced based on sensitivity mosaic pattern information representative of an arrangement of the sensitivity characteristics of the color and sensitivity mosaic image and color mosaic pattern information representative of an arrangement of the color components of the color and sensitivity mosaic image, and a monochromatic image corresponding to the color and sensitivity mosaic image is produced based on the sensitivity mosaic pattern information, the color mosaic pattern information and the luminance image.

Additional features and advantages are described herein, and will be apparent from the following Detailed Description and the figures.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** is a block diagram showing an example of a configuration of a digital still camera to which the present invention is applied;

FIG. **2** is a view illustrating general operation of the digital still camera;

FIG. **3** is a view showing an example of a subject;

FIG. **4** is a view showing an example of a color and sensitivity mosaic image corresponding to the example of FIG. **3**;

FIG. **5** is a view showing a color and sensitivity mosaic pattern P**1**;

FIG. **6** is a view showing a color and sensitivity mosaic pattern P**2**;

FIG. **7** is a view showing a color and sensitivity mosaic pattern P**3**;

FIG. **8** is a view showing a color and sensitivity mosaic pattern P**4**;

FIG. **9** is a view showing a color and sensitivity mosaic pattern P**5**;

FIG. **10** is a view showing a color and sensitivity mosaic pattern P**6**;

FIG. **11** is a view showing a color and sensitivity mosaic pattern P**7**;

FIG. **12** is a view showing a color and sensitivity mosaic pattern P**8**;

FIG. **13** is a view showing a color and sensitivity mosaic pattern P**9**;

FIG. **14** is a view showing a color and sensitivity mosaic pattern P**10**;

FIG. **15** is a view showing a color and sensitivity mosaic pattern P**11**;

FIG. **16** is a view showing a color and sensitivity mosaic pattern P**12**;

FIG. **17** is a view showing a color and sensitivity mosaic pattern P**13**;

FIG. **18** is a view showing a color and sensitivity mosaic pattern P**14**;

FIG. **19** is a view showing a cross section of a light receiving element of a CCD image sensor **4**;

FIG. **20** is a view illustrating a method for optically implementing a mosaic arrangement of sensitivity;

FIG. **21** is a view illustrating another method for optically implementing a mosaic arrangement of sensitivity;

FIG. **22** is a view illustrating a further method for optically implementing a mosaic pattern of sensitivity;

FIG. **23** is a view illustrating a first method for electronically implementing a mosaic pattern of sensitivity;

FIG. **24** is a view illustrating a second method for electronically implementing a mosaic pattern of sensitivity;

FIG. **25** is a schematic view showing an OR-type electrode structure;

FIG. **26** is a sectional view showing a cross section of the OR-type electrode structure;

FIG. **27** is a schematic view showing an AND-type electrode structure;

FIG. **28** is a view showing a combination of the OR-type electrode structure and the AND-type electrode structure for implementing the color and sensitivity mosaic pattern P**1**;

FIG. **29** is a view showing a combination of the OR-type electrode structure and the AND-type electrode structure for implementing the color and sensitivity mosaic pattern P**2**;

FIG. **30** is a view showing a combination of the OR-type electrode structure and the AND-type electrode structure for implementing the color and sensitivity mosaic pattern P**3**;

FIG. **31** is a view showing a combination of the OR-type electrode structure and the AND-type electrode structure for implementing the color and sensitivity mosaic pattern P**4**;

FIG. **32** is a view showing a combination of the OR-type electrode structure and the AND-type electrode structure for implementing the color and sensitivity mosaic pattern P**5**;

FIG. **33** is a view illustrating a definition of position coordinates of a pixel;

FIG. **34** is a view illustrating an outline of a first demosaic process;

FIG. **35** is a graph illustrating an outline of a first sensitivity uniformization process in the first demosaic process;

FIG. **36** is a graph illustrating an outline of the first sensitivity uniformization process in the first demosaic process;

FIG. **37** is a graph illustrating an outline of the first sensitivity uniformization process in the first demosaic process;

FIG. **38** is a graph illustrating an outline of a second sensitivity uniformization process in the first demosaic process;

FIG. **39** is a graph illustrating an outline of the second sensitivity uniformization process in the first demosaic process;

FIG. **40** is a view illustrating an outline of a second demosaic process;

FIG. **41** is a graph illustrating an outline of a first sensitivity uniformization process in the second demosaic process;

FIG. **42** is a graph illustrating an outline of the first sensitivity uniformization process in the second demosaic process;

FIG. **43** is a graph illustrating an outline of a second sensitivity uniformization process in the second demosaic process;

FIG. **44** is a graph illustrating an outline of the second sensitivity uniformization process in the second demosaic process;

FIG. **45** is a block diagram showing a first example of a configuration of an image processing section **7**;

FIG. **46** is a block diagram showing a first example of a configuration of a sensitivity uniformization section **51**;

FIG. **47** is a block diagram showing an example of a configuration of a color interpolation section **52**;

FIG. **48** is a block diagram showing an example of a configuration of a color difference image production section **72**;

FIG. **49** is a block diagram showing an example of a configuration of a luminance image production section **74**;

FIG. **50** is a flow chart illustrating the first demosaic process by the first example of the configuration of the image processing section **7**;

FIG. **51** is a flow chart illustrating the first sensitivity uniformization process by the first example of the configuration of the sensitivity uniformization section **51**;

FIG. **52** is a flow chart illustrating a sensitivity compensation process at step S**11**;

FIG. **53** is a flow chart illustrating a validity discrimination process at step S**12**;

FIG. **54** is a flow chart illustrating a missing interpolation process at step S**13**;

FIG. **55** is a flow chart illustrating a color interpolation process at step S**2**;

FIG. **56** is a flow chart illustrating a first color difference image production process at step S**52**;

FIG. **57** is flow chart illustrating a luminance image production process at step S**53**;

FIG. **58** is a flow chart illustrating a color space conversion process at step S**54**;

FIG. **59** is a block diagram showing a second example of a configuration of the sensitivity uniformization section **51**;

FIG. **60** is a flow chart illustrating a second sensitivity uniformization process by the second example of the configuration of the sensitivity uniformization section **51**;

FIG. **61** is a flow chart illustrating an interpolation process at step S**103**;

FIG. **62** is a flow chart illustrating a second color difference image production process;

FIG. **63** is a flow chart illustrating an image gradient vector arithmetic operation process at step S**123**;

FIG. **64** is a block diagram showing a second example of a configuration of the image processing section **7**;

FIG. **65** is a block diagram showing a first example of a configuration of a sensitivity uniformization section **111**;

FIG. **66** is a flow chart illustrating a missing interpolation process by a missing interpolation section **124**;

FIG. **67** is a block diagram showing a second example of a configuration of the sensitivity uniformization section **111**;

FIG. **68** is a flow chart illustrating the second sensitivity uniformization process in the second demosaic process by the second example of the configuration of the sensitivity uniformization section **111**;

FIG. **69** is a flow chart illustrating an interpolation color determination process at step S**163**;

FIG. **70** is a view illustrating an outline of a third demosaic process;

FIG. **71** is a view illustrating an outline of a by-sensitivity-basis color interpolation process in the third demosaic process;

FIG. **72** is a view illustrating an outline of the by-sensitivity-basis color interpolation process in the third demosaic process;

FIG. **73** is a block diagram showing a third example of a configuration of the image processing section **7**;

FIG. **74** is a block diagram showing an example of a configuration of a by-sensitivity-basis color interpolation section **151**;

FIG. **75** is a block diagram showing an example of a configuration of a sensitivity uniformization section **152**;

FIG. **76** is a flow chart illustrating the third demosaic process by the third example of the configuration of the image processing section **7**;

FIG. **77** is a flow chart illustrating the by-sensitivity-basis color interpolation process at step S**181**;

FIG. **78** is a view illustrating an extraction process at step S**193**;

FIG. **79** is a view illustrating the extraction process at step S**193**;

FIG. **80** is a flow chart illustrating a sensitivity uniformization process at step S**182**;

FIG. **81** is a view showing an example of a filter coefficient used in a local sum calculation process at step S**203**;

FIG. **82** is a block diagram showing a fourteen example of a configuration of the image processing section **7**;

FIG. **83** is a block diagram showing a first example of a configuration of a luminance image production section **181**;

FIG. **84** is a block diagram showing an example of a configuration of a monochromatic image production section **182**;

FIG. **85** is a flow chart illustrating a fourth demosaic process by the fourth example of the configuration of the image processing section **7**;

FIG. **86** is a flow chart illustrating a luminance image production process by the luminance image production section **181**;

FIG. **87** is a flow chart illustrating an R component estimation process by an estimation section **191**;

FIG. **88** is a view showing an example of interpolation filter coefficients for R/B components;

FIG. **89** is a view showing interpolation filter coefficients for a G component;

FIG. **90** is a view illustrating a synthetic sensitivity compensation LUT;

FIG. **91** is a view illustrating another synthetic sensitivity compensation LUT;

FIG. **92** is a view illustrating a further synthetic sensitivity compensation LUT;

FIG. **93** is a flow chart illustrating a noise removal process by a noise removal section **198**;

FIG. **94** is a flow chart illustrating a direction selective smoothing process by the noise removal section **198**;

FIG. **95** is a flow chart illustrating a monochromatic image production process by the monochromatic image production section **182**;

FIG. **96** is a flow chart illustrating a ratio value calculation process by a ratio value calculation section **202**;

FIG. **97** is a view illustrating an example of smoothing filter coefficients;

FIG. **98** is a block diagram showing a second example of a configuration of the luminance image production section **181**;

FIG. **99** is a flow chart illustrating an estimation process of RGB components by an estimation section **211**;

FIG. **100** is a view showing an arrangement of pixels used in an estimation pixel value C**0** interpolation process;

FIG. **101** is a flow chart illustrating the estimation pixel value C**0** interpolation process;

FIG. **102** is a view showing an arrangement of pixels used in an estimation pixel value C**1** interpolation process;

FIG. **103** is a flow chart illustrating the estimation pixel value C**1** interpolation process;

FIG. **104**A is a view showing an arrangement of pixels used in an estimation pixel value C**2** interpolation process;

FIG. **104**B is a view showing another arrangement of pixels used in the estimation pixel value C**2** interpolation process;

FIG. **105** is a flow chart illustrating the estimation pixel value C**2** interpolation process;

FIG. **106** is a view showing an arrangement of pixels used in an estimation pixel value C**3** interpolation process;

FIG. **107** is a flow chart illustrating the estimation pixel value C**3** interpolation process;

FIG. **108** is a flow chart illustrating an R candidate image production process by an interpolation section **201**-R;

FIG. **109** is a flow chart illustrating a B candidate image production process by an interpolation section **201**-B;

FIG. **110** is a flow chart illustrating a G candidate image production process by an interpolation section **201**-G; and

FIG. **111** is a block diagram showing a fifth example of a configuration of the image processing section **7**.

DETAILED DESCRIPTION

FIG. **1** shows an example of a configuration of a digital still camera which is an embodiment of the present invention. The digital still camera is roughly composed of an optical system, a signal processing system, a recording system, a display system and a control system.

The optical system includes a lens **1** for condensing an optical image of a subject, an iris **2** for adjusting the amount of light of the optical image, and a CCD image sensor **4** for photo-electrically converting the condensed optical image into an electric signal of a wide dynamic range.

The signal processing system includes a correlation double sampling circuit (CDS) **5** for sampling an electric signal from the CCD image sensor **4** to reduce noise of the electric signal, an A/D converter **6** for converting an analog signal outputted from the correlation double sampling circuit **5** into a digital signal, and an image processing section **7** for performing a predetermined image process for the digital signal inputted thereto from the A/D converter **6**. It is to be noted that details of the process executed by the image processing section **7** are hereinafter described.

The recording system includes a CODEC (Compression/Decompression) **8** for coding and recording an image signal processed by the image processing section **7** into a memory **9** and reading out, decoding and supplying the image signal to the image processing section **7**, and the memory **9** for storing an image signal.

The display system includes a D/A converter **10** for converting an image signal processed by the image processing section **7** into an analog signal, a video encoder **11** for encoding the analog image signal into a video signal of the format compatible with a display unit **12** in the following stage, and a display unit **12** formed from an LCD (Liquid Crystal Display) unit or the like for displaying an image corresponding to the video signal inputted thereto so that it functions as a viewfinder.

The control system includes a timing generator (TG) **3** for controlling operation timings of the components from the CCD image sensor **4** to the image processing section **7**, an operation inputting section **13** for allowing the user to input a shutter timing and other commands, and a control section **14** including a CPU (Central Processing Unit) and so forth for controlling a drive **15** to read out a controlling program stored on a magnetic disc **16**, an optical disc **17**, a magneto-optical disc **18** or a semiconductor memory **19** and controlling the entire digital still camera based on the controlling program read out, a command from the user inputted from the operation inputting section **13** and so forth.

In the digital still camera, an optical image (incoming light) of a subject is introduced into the CCD image sensor **4** through the lens **1** and the iris **2**, and it is photo-electrically converted by the CCD image sensor **4**. The resulting electric signal is subject to removal of noise by the correlation double sampling circuit **5** and is then converted into a digital signal by the A/D converter **6**, whereafter it is temporarily stored into an image memory built in the image processing section **7**.

It is to be noted that, in an ordinary state, an image signal is incessantly overwritten at a fixed frame rate into the image memory built in the image processing section **7** under the control of the timing generator **3** for the signal processing system. The image signal of the image memory built in the image processing section **7** is converted into an analog signal by the D/A converter **10** and further converted into a video signal by the video encoder **11**, and a corresponding image is displayed on the display unit **12**.

The display unit **12** further has a function as a viewfinder of the digital still camera. When the user depresses a shutter button included in the operation inputting section **13**, the control section **14** controls the timing generator **3** so that the signal processing system fetches an image signal immediately after the shutter button is depressed and thereafter inhibits an image signal from being overwritten into the image memory of the image processing section **7**. Thereafter, the image data written in the image memory of the image processing section **7** are coded by the CODEC **8** and recorded into the memory **9**. Fetching of image data of one frame is completed by such operation of the digital still camera as described above.

Subsequently, an outline of operation of the digital still camera is described with reference to FIG. **2**. The digital still camera picks up an image of a subject with a color and a sensitivity, which are different for each pixel, through an image pickup process of the optical system including the CCD image sensor **4** as a principal component to obtain an image wherein colors and sensitivities are distributed like a mosaic (such an image as just described is hereinafter referred to as color and sensitivity mosaic image, whose details are hereinafter described). Thereafter, the image obtained by the image pickup process is converted into an image wherein each pixel has all color components and the pixels have a uniform sensitivity by the signal processing system which includes the image processing section **7** as a principal component. In the following description, the process of the signal processing system including the image processing section **7** as a principal component for converting a color and sensitivity mosaic image into an image wherein each pixel has all color components and the pixels have a uniform sensitivity is referred to as demosaic process.

For example, if an image of such a subject as shown in FIG. **3** is picked up, then such a color and sensitivity mosaic image as shown in FIG. **4** is obtained through the image pickup process and is converted into an image wherein each pixel has all color components and the pixels have a uniform sensitivity through the image process. In particular, the

original colors of the subject shown in FIG. **3** are restored from the color and sensitivity mosaic image shown in FIG. **4**.

Arrangement patterns (hereinafter referred to as color and sensitivity mosaic patterns) P**1** to P**14** of color components and sensitivities of pixels which compose a color and sensitivity mosaic image are shown in FIGS. **5** to **18**, respectively. It is to be noted that, as a combination of colors which form a color and sensitivity mosaic pattern, a combination of three colors of R (red), G (green) and B (blue) and another combination of four colors of Y (yellow), M (magenta), C (cyan) and G (green) are available. As stages of the sensitivity, two stages of S**0** and S**1**, three stages which additionally include a sensitivity S**2** and four stages which additionally include a further sensitivity S**3** are available. It is to be noted that, in FIGS. **5** to **18**, each square corresponds to one pixel, and an alphabetical letter represents the color of the pixel and a numeral as a subscript to the alphabetical letter represents the sensitivity of the pixel. For example, a pixel denoted by G_0 represents that the color thereof is G (green) and the sensitivity thereof is S**0**. Further, it is assumed that, as regards the sensitivity, the higher the value, the higher the sensitivity.

The color and sensitivity mosaic patterns P**1** to P**14** can be classified based on the first to fourth characteristics described below.

The first characteristic is that, where attention is paid to those pixels which have the same color and the same sensitivity, they are arranged like a grating, and where attention is paid to those pixels which have the same color irrespective of the sensitivity, they are arranged like a grating. The first characteristic is described with reference to the color and sensitivity mosaic pattern P**1** shown in FIG. **5**.

In the color and sensitivity mosaic pattern P**1** of FIG. **5**, where attention is paid to those pixels which have the color R irrespective of the sensitivity, as can be seen apparently if the figure is viewed in a state rotated by 45 degrees in the clockwise direction, they are arranged like a grating wherein they are spaced from each other by $2^{1/2}$ in the horizontal direction and by $2^{3/2}$ in the vertical direction. Further, where attention is paid to those pixels which have the color B irrespective of the sensitivity, also they are arranged like a grating wherein they are spaced from each other by $2^{1/2}$ in the horizontal direction and by $2^{3/2}$ in the vertical direction. Further, where attention is paid to those pixels which have the color G irrespective of the sensitivity, also they are arranged like a grating wherein they are spaced from each other by $2^{1/2}$ both in the horizontal direction and in the vertical direction.

In addition to the color and sensitivity mosaic pattern P**1** shown in FIG. **5**, the color and sensitivity mosaic patterns P**2**, P**4**, P**6**, P**8**, P**9**, P**10**, P**11** and P**13** have the first characteristic.

The second characteristic is that, where attention is paid to those pixels which have the same color and the same sensitivity, they are arranged like a grating, and where attention is paid to those pixels which have the same sensitivity irrespective of the color, they are arranged like a grating, and besides, where attention is paid to an arbitrary pixel, all of colors included in the color and sensitivity mosaic pattern are included in colors which totaling five pixels including the pixel and four pixels positioned upwardly, downwardly, leftwardly and rightwardly of the pixel have.

In addition to the color and sensitivity mosaic pattern P**3** shown in FIG. **7**, the color and sensitivity mosaic patterns P**5**, P**7**, P**8**, P**9**, P**12** and P**14** have the second characteristic.

The third characteristic is that the color and sensitivity mosaic pattern has the first characteristic and uses three different colors and the pixels of the colors are arranged in a Bayer arrangement. The third characteristic is described with reference to the color and sensitivity mosaic pattern P**2** shown in FIG. **6**.

Where attention is paid to those pixels of the color and sensitivity mosaic pattern P**2** of FIG. **6** which have the color G irrespective of the sensitivity, they are arranged alternately in a checkered pattern. Where attention is paid to those pixels which have the color R irrespective of the sensitivity, they are arranged on every other line. Further, also where attention is paid to those pixels whose color is B irrespective of the sensitivity, they are arranged on every other line similarly. Accordingly, the pattern P**2** has a Bayer arrangement where attention is paid only to the colors of the pixels.

It is to be noted that, in addition to the color and sensitivity mosaic pattern P**2** of FIG. **6**, the color and sensitivity mosaic patterns P**10** and P**11** have the third characteristic.

The fourth characteristic is that the color and sensitivity mosaic pattern has the second characteristic and further, where attention is paid to those pixels which have the same sensitivity, the arrangement of them is a Bayer arrangement. The fourth characteristic is described with reference to the color and sensitivity mosaic pattern P**3** shown in FIG. **7**.

Where attention is paid only to those pixels in the color and sensitivity mosaic pattern P**3** shown in FIG. **7** which have the sensitivity S**0**, as can be seen apparently if the figure is viewed obliquely in a state inclined by 45 degrees, they are arranged in a spaced relationship by a distance of $2^{1/2}$ and in a Bayer arrangement. Also where attention is paid to those pixels which have the sensitivity S**1**, they are arranged in a Bayer arrangement similarly.

It is to be noted that, in addition to the color and sensitivity mosaic pattern P**3** of FIG. **7**, the color and sensitivity mosaic patterns P**5** and P**12** have the fourth characteristic.

Incidentally, an arrangement of any of the color and sensitivity mosaic patterns P**1** to P**14** shown in FIGS. **5** to **18** is hereinafter referred to as "color mosaic arrangement" where attention is paid only to the colors of the pixels irrespective of the sensitivity, but is hereinafter referred to as "sensitivity mosaic arrangement" where attention is paid only to the sensitivities irrespective of the color.

Subsequently, a method of implementing the color and sensitivity mosaic patterns described above on the CCD image sensor **4** is described.

Of the color and sensitivity mosaic patterns, the color mosaic arrangements are implemented by disposing an on-chip color filter, which passes only light of a different color for each pixel, on an upper face of a light receiving element of the CCD image sensor **4**.

Of the color and sensitivity mosaic patterns, the sensitivity mosaic arrangements are implemented by an optical method or an electronic method.

A method of optically implementing a sensitivity mosaic arrangement is described. FIG. **19** shows a cross section of a light receiving element of the CCD image sensor **4**. An on-chip lens **21** is formed on an upper surface of the light receiving element. The on-chip lens **21** is disposed so that it condenses incoming light from an upper portion of the figure on a photo-diode (PD) **23**. An on-chip color filter **22** limits a wavelength band of the incoming light (passes only a particular wavelength band therethrough). The photo-diode **23** is formed in a wafer at a lower portion of the light receiving element. The photo-diode **23** produces electric

charge in response to the amount of light inputted thereto. A vertical register **26** is formed on the opposite sides of the photo-diode **21**. A pair of vertical register driving electrodes **25** for driving the vertical register **21** are wired above the vertical register **26**.

Since the vertical register **26** is a region for transferring electric charge produced by the photo-diode **23**, the vertical register **26** and the vertical register driving electrodes **25** are shielded from light by a shield **24** so that no electric charge may be produced in the vertical register **26**. The shield **24** is open only above the photo-diode **23** such that the incoming light may pass the opening portion until it reaches the photodiode **23**.

The sensitivity of each light receiving element can be varied (the amount of incoming light to the photo-diode **23** can be varied) making use of the CCD image sensor **4** configured in such a manner as described above.

For example, the amount of condensed light can be varied depending upon whether or not the on-chip lens **21** is disposed as seen in FIG. **20**. Meanwhile, the light transmission factor can be varied, for example, by disposing a neutral density filter **31** above (or below) the on-chip color filter **22** as seen in FIG. **21**. Further, the incoming light amount to the photo-diode **23** can be varied, for example, by varying the area of the opening portion of the shield **24** as seen in FIG. **22**.

Now, two different methods for electronically implementing a mosaic arrangement of sensitivity are described.

For example, a first method of setting two adjacent light receiving elements (first and second light receiving elements) to different sensitivities by changing the timing of control is described with reference to FIG. **23**.

The first stage of FIG. **23** shows an exposure period of the CCD image sensor **4**. The second stage of FIG. **23** shows a timing of a pulse voltage for instruction of sweeping out of electric charge. The third stage of FIG. **23** shows a timing at which a control voltage for instruction of charge transfer is applied. The fourth stage of FIG. **23** shows a timing of a pulse voltage for instructing a first light receiving element to read out electric charge. The fifth stage of FIG. **23** shows a variation of the electric charge amount accumulated in the first light receiving element in response to application of the charge sweeping out pulse voltage and the charge reading out pulse voltage. The sixth stage of FIG. **23** shows a timing of a pulse voltage for instructing a second light receiving element to read out electric charge. The seventh stage of FIG. **23** shows a variation of the electric charge amount accumulated in the second light receiving element in response to application of the charge sweeping out pulse voltage and the charge reading out pulse voltage.

In the first method of electronically implementing a sensitivity mosaic arrangement, the charge sweeping out pulse voltage is supplied commonly to the first and second light receiving elements so that, except within an exposure period, electric charge is swept out (reset) from the photo-diode **23**, but within an exposure period, electric charge is reset only once at a predetermined timing.

The charge transfer voltage is supplied, except within an exposure period, as a waveform voltage for transferring electric charge to the vertical register **26** commonly to the first and second light receiving elements, but is not supplied, within an exposure period, so that transfer of electric charge from the vertical register **26** may be stopped.

The charge reading out pulse voltage is supplied at different timings to the light receiving elements. To the first light receiving element, the charge reading out pulse voltage for the first time is supplied immediately before the supplying timing of the charge sweeping out voltage within an exposure period (second stage of FIG. **23**), but the charge reading out pulse voltage for the second time is supplied immediately before the end of the exposure period.

As a result, from the first light receiving element, the accumulated charge amount of the first light receiving element is read out into the vertical register **26** at the supplying timings of the charge reading out pulse voltage for the first and second times. It is to be noted that, since transfer of electric charge of the vertical register **26** stops within an exposure period, the electric charge amounts read out twice are added in the vertical register **26** and transferred as data of the same frame from the vertical register **26** after the end of the exposure period.

Meanwhile, to the second light receiving element, the charge reading out pulse voltage is supplied only once immediately before the supplying timing of the charge sweeping out pulse voltage within an exposure period. As a result, from the second light receiving element, the accumulated electric charge amount of the second light receiving element at the only one supplying timing of the charge reading out pulse voltage is read out into the vertical register **26**. It is to be noted that, since transfer of electric charge of the vertical register **23** stops within an exposure period, the accumulated electric charge read out from the second light receiving element is transferred as data of the same frame as that of the accumulated electric charge read out from the first light receiving element from the vertical register **26** after the end of the exposure period.

By making the control timings for the first light receiving element and the second light receiving element different from each other in this manner, it is possible to set so that the accumulated electric charge amount read out from the first light receiving element and the accumulated electric charge amount read out from the second light receiving element within the same exposure period, or in other words, the sensitivities, may be different from each other.

Incidentally, the first method of electronically implementing a sensitivity mosaic arrangement has a problem in that, depending upon a light receiving element, information of a subject cannot be measured over an overall region within an exposure period.

Now, a second method of electronically implementing a sensitivity mosaic arrangement is described with reference to FIG. **24**. The first to sixth stages of FIG. **24** show, similarly to the first to sixth stages of FIG. **23**, an exposure period of the CCD image sensor **4**, a timing of a pulse voltage for instruction of sweeping out of electric charge, a timing at which a control voltage for instruction of charge transfer is applied, a timing of a pulse voltage for instructing the first light receiving element to read out electric charge, a variation of the electric charge amount accumulated in the first light receiving element in response to application of the charge sweeping out pulse voltage and the charge reading out pulse voltage, a timing of a pulse voltage for instructing the second light receiving element to read out electric charge, and a variation of the electric charge amount accumulated in the second light receiving element in response to application of the charge sweeping out pulse voltage and the charge reading out pulse voltage.

In the second method of electronically implementing a sensitivity mosaic arrangement, the charge sweeping out pulse voltage and the charge reading out pulse voltage are supplied repetitively by a plural number of times within an exposure period.

In particular, as regards the charge sweeping out pulse voltage, a set of the charge sweeping out pulse voltage for

the first time and the charge sweeping out pulse voltage for the second time are supplied by a plural number of times commonly to the first and second light receiving elements within an exposure period. As regards the charge reading out pulse voltage, to the first light receiving element, the charge reading out pulse voltage for the first time is supplied, for each set of the charge sweeping out pulse voltages for the first and second times, immediately before the charge sweeping out pulse voltage for the first time, and the charge reading out pulse voltage for the second time is supplied immediately before the charge sweeping out pulse voltage for the second time. Meanwhile, to the second light receiving element, for each set of the charge sweeping out pulse voltages, the charge reading out pulse voltage is supplied only once immediately before the charge sweeping out pulse voltage for the first time.

As a result, for each set of the charge sweeping out pulse voltages for the first and second times, the accumulated charge amount of the first light receiving element at the supplying timing of the charge reading out pulse voltage for the first time and the accumulated charge amount of the first light receiving element at the supplying timing of the charge reading out pulse voltage for the second time are read out from the first light receiving element. It is to be noted that, within an exposure period, since transfer of charge of the vertical register **26** stops, the charge amounts read out twice for each set are added by the vertical register **26**. From the second light receiving element, the accumulated charge amount of the second light receiving element at the supplying timing of the charge reading out pulse voltage which is supplied only once for each set of the charge sweeping out pulse voltage for the first and second times is read out. The charge amount read out once for each set is added by the vertical register **26**.

In such a second method for electronically implementing a sensitivity mosaic arrangement as described above, since reading out of charge is repeated by a plural number of times within an exposure period, information of the subject over an overall region of the exposure period can be measured.

It is to be noted that, in connection with the first and second methods for electronically implementing a sensitivity mosaic arrangement described above, reading out control of the CCD image sensor **4** is usually applied to the vertical register driving electrodes **25** wired for each horizontal line. For example, in order to implement a sensitivity mosaic arrangement wherein the sensitivity changes for each horizontal line as in the color and sensitivity mosaic pattern P**1** shown in FIG. **5**, the electrode structure may be utilized, and therefore, some improvements which allow application of different reading out pulse voltages to different lines should be made. Further, in a CCD image sensor of the progressive scanning type having a 3-phase driven vertical register, an arbitrary mosaic arrangement with two different sensitivity stages can be implemented electronically by devising the electrode structure.

FIG. **25** shows a first electrode structure of a poly-silicon electrode for vertical transfer by an electrode wiring line used to implement a sensitivity mosaic arrangement having two stages of sensitivity. FIG. **26** shows a cross sectional view of the CCD image sensor taken along line a-a' of FIG. **25**. Each of a first phase vertical register driving electrode **42** and a second phase vertical register driving electrode **43** is connected to electrodes of adjacent pixels on the same horizontal line, and therefore, the electrodes on the same horizontal line are driven in synchronism. Meanwhile, a third phase vertical register driving electrode **44** is connected to electrodes of adjacent pixels on the same vertical line, and therefore, the electrodes on the same vertical line are driven in synchronism. Further, the second phase vertical register driving electrode **43** and the third phase vertical register driving electrode **44** overly a reading out gate **41** adjacent the corresponding photo-diode **23**.

Accordingly, when a reading out pulse is applied to the second phase vertical register driving electrode **43** or the third phase vertical register driving electrode **44**, the barrier of the reading out gate **41** can be temporarily removed to allow charge accumulated in the corresponding photo-diode **23** to be transferred to the vertical register **26**. In the following description, the electrode structure shown in FIGS. **25** and **26** is referred to as OR type electrode structure.

FIG. **27** shows a second electrode structure of a polysilicon electrode for vertical transfer by electrode wiring lines used to implement a sensitivity mosaic arrangement having two stages of sensitivity. Also the cross section of the CCD image sensor taken along line a-a' of FIG. **27** is similar to that of the cross sectional view shown in FIG. **26**. In particular, also in the second electrode structure, similarly to the first electrode structure, each of the first phase vertical register driving electrode **42** and the second phase vertical register driving electrode **43** is connected to electrodes of adjacent pixels on the same horizontal line, and therefore, the electrodes on the same horizontal line are driven in synchronism. Since the third phase vertical register driving electrode **44** is connected to electrodes of adjacent pixels on the same vertical line similarly as in the first electrode structure, the electrodes on the same vertical line are driven in synchronism.

However, the second electrode structure is different from the first electrode structure in that the third phase vertical register driving electrode **44** is disposed along an edge portion of the corresponding photo-diode **23** on the reading out gate **41** adjacent the photo-diode **23** and a portion of the second phase vertical register driving electrode **43** which is worked in an elongated shape so as to be adjacent the edge portion of the photo-diode **23** overlies the reading out gate **41**.

Accordingly, when a reading out pulse is applied to only one of the second phase vertical register driving electrode **43** and the third phase vertical register driving electrode **44**, the barrier of the reading out gate **41** cannot be removed. In order to remove the barrier of the reading out gate **41** to allow charge accumulated in the photo-diode **23** to be transferred to the vertical register **26**, it is necessary to apply a reading out pulse to the second phase vertical register driving electrode **43** and the third phase vertical register driving electrode **44** simultaneously. In the following description, the electrode structure shown in FIG. **27** is referred to as AND type electrode structure.

An arbitrary mosaic arrangement with two stages of sensitivity can be produced by using the OR type electrode structure and the AND type electrode structure described above in combination in one CCD image sensor. For example, in order to implement a sensitivity mosaic arrangement of the color and sensitivity mosaic pattern P**1** shown in FIG. **5**, the OR type electrode structure and the AND type electrode structure should be used in such a combination as shown in FIG. **28**.

As can be seen apparently from comparison between FIGS. **5** and **28**, the AND type electrode structure is adopted for pixels having the low sensitivity S**0** from between the two sensitivity stages S**0** and S**1** while the OR type electrode structure is adopted for pixels of the high sensitivity S**1**. If the reading out pulse voltage is applied to the second phase

vertical register driving electrodes **43** of the CCD image sensor **4** formed from such a combination of the OR and AND type electrode structures as just described, then charge reading out is performed only with the OR type pixels, but if the reading out pulse voltage is applied to the second phase vertical register driving electrode **43** and the third phase vertical register driving electrode **44** simultaneously, then charge reading out is performed with both of the OR and AND type pixels, that is, all pixels.

It is to be noted that, if the supplying timings of the pulse voltage to the second phase vertical register driving electrode **43** and the third phase vertical register driving electrode **44** are such that both of the second phase and the third phase are driven at the supplying timing of the charge reading out pulse voltage for the first time in (D) of FIG. **23** (or FIG. **24**) from among the control timings shown in FIG. **23** (or FIG. **24**) and the supplying timing of the charge reading out pulse voltage of (F) of FIG. **23** (or FIG. **24**) whereas only the second phase is driven at the supplying timing of the charge reading out pulse voltage for the second time of (D) of FIG. **23** (or FIG. **24**), then the pixels of the OR type electrode structure have the high sensitivity S**1** while the pixels of the AND type electrode structure have the low sensitivity S**0**.

By a similar method, the other sensitivity mosaic arrangements having two stages of sensitivity can be produced. For example, in order to implement the sensitivity mosaic pattern of the color and sensitivity mosaic pattern P**2** shown in FIG. **6**, the OR type and the AND type are used in such a combination as shown in FIG. **29**. In order to implement the sensitivity mosaic pattern of the color and sensitivity mosaic pattern P**3** shown in FIG. **7**, the OR type and the AND type are used in such a combination as shown in FIG. **30**. In order to implement the sensitivity mosaic pattern of the color and sensitivity mosaic pattern P**4** shown in FIG. **8**, the OR type and the AND type are used in such a combination as shown in FIG. **31**. In order to implement the sensitivity mosaic pattern of the color and sensitivity mosaic pattern P**5** shown in FIG. **9**, the OR type and the AND type are used in such a combination as shown in FIG. **32**.

Now, a demosaic process of the image processing system including the image processing section **7** as a principal component is described. However, prior to the description of the demosaic process, a definition of position coordinates of a pixel which is used in the description hereinafter given is described with reference to FIG. **33**.

FIG. **33** shows a coordinate system (x, y) indicating a position of a pixel on an image. In particular, the left lower end of the image is represented by (0, 0) and the right upper end of the image is represented by (x_{max}, y_{max}). Pixels represented by in FIG. **33** have a horizontal dimension and a vertical dimension of a length l and are arranged on a grating. Accordingly, for example, the coordinates of the center of the pixel at the left lower end are (0.5, 0.5), and the coordinates of the center of the pixel at the right upper end are (x_{max}−0.5, y_{max}−0.5). Further, image data whose phase is displaced vertically and horizontally by a half pixel from the pixels represented by □ (pixel data at a position represented by ● in FIG. **33**) is sometimes used, and, for example, the coordinates of image data whose phase is displaced vertically and horizontally by a half pixel from the pixel at the left lower end are (1, 1).

FIG. **34** illustrates an outline of a first demosaic process of the image processing system including the image processing section **7** as a principal component.

The first demosaic process includes, as seen in FIG. **34**, a sensitivity uniformization process for uniformizing the sensitivities of pixels of a color and sensitivity mosaic image obtained by processing of the image pickup system without changing the colors of the pixels to produce a color mosaic image, and a color correction process for restoring RGB components of the pixels of a color and sensitivity mosaic image M.

An outline of the first sensitivity uniformization process in the first demosaic process is described with reference to FIGS. **35** to **37**. FIGS. **35** to **37** illustrate a pixel arrangement of a predetermined one line of an image to be processed. X**0** represents that the color component is X (for example, R (red)) and the sensitivity is S**0** from between the two stages of S**0** and S**1**; X**1** represents that the color component is X and the sensitivity is S**1** from between the two stages of S**0** and S**1**; Y**0** represents that the color component is Y (for example, G (green)) and the sensitivity is S**0** from between the two stages of S**0** and S**1**; and Y**1** represents that the color component is Y and the sensitivity is S**1** from between the two stages of S**0** and S**1**. Each pixel of the sensitivity S**0** measures the intensity of incoming light attenuated at a predetermined ratio while each pixel of the sensitivity S**1** measures the intensity of incoming light without any attenuation. Further, in FIGS. **35** to **37**, the axis of abscissa indicates the position of a pixel on a line, and the length of a vertical bar indicates the pixel value of a corresponding pixel.

The first sensitivity uniformization process in the first demosaic process can be divided into processes of two different stages. FIG. **35** shows pixel values of pixels in a predetermined one line of a color and sensitivity mosaic image before the first sensitivity uniformization process is performed. It is to be noted that a curve X indicates an intensity distribution of the color X of the incoming light, and another curve Y indicates an intensity distribution of the color Y.

A threshold value θ_H indicates a saturation level of the CCD image sensor **4**, and when the intensity of the incoming light exceeds the threshold value θ_H, the intensity cannot be measured accurately and the measurement value then is equal to the threshold value θ_H. Another threshold value θ_L indicates a noise level of the CCD image sensor **4**, and also when the intensity of the incoming light is lower than the threshold value θ_L, the intensity cannot be measured accurately and the measurement value then is equal to the threshold value θ_L.

A validity discrimination result is information representative of whether or not each pixel has successfully measured the intensity of the incoming light, that is, information representative of whether the pixel value of each pixel measured is valid (V) or invalid (I).

Through the first stage process of the first sensitivity uniformization process, the pixel values of the pixels of the sensitivity S**0** are scaled using the relative ratio of the sensitivity S**0** to the sensitivity S**1**. The pixel values of the pixels of the sensitivity S**1** are not scaled. FIG. **36** shows a result of application of the first stage process of the first sensitivity uniformization process. In the state after the first stage process is performed, as seen in FIG. **36**, the pixels whose validity discrimination result is valid have an original light intensity restored by the scaling, but the pixels whose validity discrimination result is invalid do not have an original restored light intensity.

Therefore, in the second stage process of the first sensitivity uniformization process, the pixel value of each of those pixels which are invalid is interpolated using the pixel values of those valid pixels of the same color which neighbor with the pixel. FIG. **37** illustrates a result of application

of the second stage process of the first sensitivity uniformization process. For example, the pixel of the color Y which is at the center of FIG. **37** and is invalid is interpolated in accordance with an interpolation curve Y' produced using the pixel values of those pixels of the color Y which neighbor with the pixel and are valid.

Subsequently, an outline of the second sensitivity uniformization process of the first demosaic process is described with reference to FIGS. **35**, **38** and **39**. Also the second sensitivity uniformization process can be divided into two stages of processes. The pixel values of pixels in a predetermined one line of a color and sensitivity mosaic image before the second sensitivity uniformization process is performed are similar to those in FIG. **35**.

By the first stage process of the second sensitivity uniformization process, pixel values with regard to the sensitivity S**0** and pixel values with regard to the sensitivity S**1** are estimated without changing the color of each pixel. For example, for a pixel of the sensitivity S**0** of the color X, the pixel value with regard to the sensitivity S**0** is used at it is, and an estimated value with regard to the sensitivity S**1** is interpolated using the pixel values of those pixels of the sensitivity S**1** and the color X which are present in the neighborhood of the pixel. FIG. **38** shows a result of application of the first stage process of the second sensitivity uniformization process. As shown in FIG. **38**, after the first stage process is performed, each pixel has a pixel value of sensitivity S**0** or a pixel value of the sensitivity S**1** of the original color.

By the second stage process of the second sensitivity uniformization process, for each pixel, the pixel values of the sensitivity S**0** and the pixel values of the sensitivity S**1** are synthesized to uniform the sensitivity. FIG. **39** shows a result of application of the second stage process of the second sensitivity uniformization process.

FIG. **40** shows an outline of the second demosaic process of the image processing system which includes the image processing section **7** as a principal component.

The second demosaic process includes, as shown in FIG. **40**, a sensitivity uniformization process wherein the colors of pixels of a color and sensitivity mosaic image obtained by the process of the image pickup system are changed to colors optimum for sensitivity uniformization and the sensitivities are uniformized to produce a color mosaic image, and a color correction process for restoring RGB components of pixels of the color and sensitivity mosaic image M.

An outline of the first sensitivity uniformization process of the second demosaic process is described with reference to FIGS. **35**, **41** and **42**.

Also the first sensitivity uniformization process of the second demosaic process can be divided into two stages of processes. It is assumed that the pixel values of pixels in a predetermined one line of a color and sensitivity mosaic image before the first sensitivity uniformization process is performed are similar to those in FIG. **35**.

Through the first stage process of the first sensitivity uniformization process of the second demosaic process, the pixel values of the pixels of the sensitivity S**0** are scaled using the relative ratio of the sensitivity S**0** to the sensitivity S**1**. The pixel values of the pixels of the sensitivity S**1** are not scaled. FIG. **41** shows a result of application of the first stage process of the first sensitivity uniformization process. In the state after the first stage process is performed, as seen in FIG. **41**, the pixels whose validity discrimination result is valid (V) have an original light intensity restored by the scaling, but the pixels whose validity discrimination result is invalid (I) do not have an original restored light intensity.

Therefore, in the second stage process of the first sensitivity uniformization process of the second demosaic process, the pixel value of each of those pixels which are invalid is interpolated using the pixel values of those valid pixels, regardless colors thereof, which neighbor with the pixel. FIG. **42** illustrates a result of application of the second stage process of the first sensitivity uniformization process. For example, the pixel value of the pixel of the color Y which is at the center of FIG. **41** and is invalid is interpolated in accordance with an interpolation curve X' produced using the pixel values of pixels of the color X which neighbor with the pixel and are valid.

Now, an outline of the second sensitivity uniformization process of the second demosaic process is described with reference to FIGS. **35**, **43** and **44**. Also the second sensitivity uniformization process of the second demosaic process can be divided into two stages of processes. It is assumed that the pixel values of pixels on a predetermined one line of a color and sensitivity mosaic image before the second sensitivity uniformization process is performed are similar to those in FIG. **35**.

In the first stage process of the second sensitivity uniformization process of the second demosaic process, for each pixel, the pixel values of neighboring pixels which are positioned comparatively near to the pixel irrespective of the color are used to estimate the pixel value with regard to the sensitivity S**0** and the pixel value with regard to the sensitivity S**1**. For example, as an estimated value of a pixel of the color X, where a pixel neighboring the pixel has the color Y, an estimated value with regard to the sensitivity S**1** of the color Y and the pixel value with regard to the sensitivity S**1** are interpolated. FIG. **43** illustrates a result of application of the first stage process of the second sensitivity uniformization process. As shown in FIG. **43**, after the first stage process is performed, each pixel has the pixel value with regard to the sensitivity S**0** and the pixel value with regard to the sensitivity S**1** of the original color because the color thereof has been changed to the color of the neighboring pixel irrespective of the original color.

In the second stage process of the second sensitivity uniformization process of the second demosaic process, for each pixel, the pixel value with regard to the sensitivity S**0** and the pixel value with regard to the sensitivity S**1** are synthesized to uniform the sensitivity. FIG. **44** shows a result of application of the second stage process of the second sensitivity uniformization process.

Now, a first example of a configuration of the image processing section **7** which principally executes the first demosaic process is described with reference to FIG. **45**. It is assumed that, in the following description, unless otherwise specified, the color and sensitivity mosaic image has the color and sensitivity mosaic pattern P**2** of FIG. **6**, or in other words, in the color and sensitivity mosaic image, the color of each pixel is one of the three primary colors of R, G and B and the sensitivity is one of S**0** and S**1**. However, the configuration and the operation described below can be applied to another color and sensitivity mosaic image which includes three colors other than R, G and B or a further color and sensitivity mosaic image which includes four colors.

In the first example of a configuration of the image processing section **7**, a color and sensitivity mosaic image from the image pickup system is supplied to a sensitivity uniformization section **51**. Color mosaic pattern information representative of a color mosaic arrangement of the color and sensitivity mosaic image is supplied to the sensitivity uniformization section **51** and a color interpolation section **52**. Sensitivity mosaic pattern information representative of

a sensitivity mosaic arrangement of the color and sensitivity mosaic image is supplied to the sensitivity uniformization section **51**.

The sensitivity uniformization section **51** performs a sensitivity uniformization process for the color and sensitivity mosaic image based on the color mosaic pattern information and the sensitivity mosaic pattern information to produce a color mosaic image M wherein the sensitivities of the pixels are uniformized while the colors of the pixels are not changed, and outputs the color mosaic image M to the color interpolation section **52**.

The color interpolation section **52** performs a color interpolation process, in which the color mosaic pattern information is used, for the color mosaic image M from the sensitivity uniformization section **51** to produce output images R, G and B.

It is to be noted that the color mosaic pattern information is information representative of the types of the colors (in the present case, the colors of R, G and B) of the pixels of the color and sensitivity mosaic image, and information of a color component of each of the pixels can be acquired using the position of the pixel as an index.

The sensitivity mosaic pattern information is information representative of the types of the sensitivities (in the present case, S**0** and S**1**) of the pixels of the color and sensitivity mosaic image, and information of the sensitivity of each of the pixels can be acquired using the position of the pixel as an index.

FIG. **46** shows a first example of the configuration of the sensitivity uniformization section **51**. The first example of a configuration is an example of a configuration of the sensitivity uniformization section **51** which executes the first sensitivity uniformization process described with reference to FIGS. **35** to **37**.

In the first example of the configuration of the sensitivity uniformization section **51**, a color and sensitivity mosaic image from the image pickup system is supplied to a sensitivity compensation section **61** and a validity discrimination section **63**. Color mosaic pattern information is supplied to a missing interpolation section **64**. Sensitivity mosaic pattern information is supplied to the sensitivity compensation section **61** and the validity discrimination section **63**.

The sensitivity compensation section **61** performs sensitivity compensation for the color and sensitivity mosaic image based a relative sensitivity value S obtained from a relative sensitivity value LUT **62** and outputs a resulting color and sensitivity mosaic image to the missing interpolation section **64**. The relative sensitivity value LUT **62** is a lookup table which outputs a relative sensitivity value S using the sensitivity of a pixel as an index.

The validity discrimination section **63** compares the pixel value of each of the pixels of the color and sensitivity mosaic image with the threshold value θ_H of the saturation level and the threshold value θ_L of the noise level to discriminate the validity of the pixel value and supplies a result of the discrimination as discrimination information to the missing interpolation section **64**. In the discrimination information, information representative of "valid" or "invalid" regarding the pixel value of each pixel is described.

The missing interpolation section **64** performs a missing interpolation process for the sensitivity-compensated color and sensitivity mosaic image based on the discrimination information from the validity discrimination section **63** to produce a color mosaic image M and outputs the color mosaic image M to the color interpolation section **52** in the next stage.

FIG. **47** shows an example of a configuration of the color interpolation section **52**. In the color interpolation section **52**, the color mosaic image M from the sensitivity uniformization section **51** is supplied to a gradation conversion section **71**. The color mosaic pattern information is supplied to color difference image production sections **72** and **73** and a luminance image production section **74**.

The gradation conversion section **71** performs a gradation conversion process for the color mosaic image M and supplies a resulting modulated color mosaic image Mg to the color difference image production sections **72** and **73** and the luminance image production section **74**. For the gradation conversion process, particularly conversion based on a power function of the power y or the like is used.

The color difference image production section **72** uses the modulated color mosaic image Mg to produce a color difference image C wherein all pixels have a color difference C (=R−G) component and supplies the color difference image C to the luminance image production section **74** and a color space conversion section **75**. The color difference image production section **73** produces a color difference image D wherein all pixels have a color difference D (=B−G) component and supplies the color difference image D to the luminance image production section **74** and the color space conversion section **75**. The luminance image production section **74** uses the modulated mosaic image Mg and the color difference images C and D to produce a luminance image L and supplies the luminance image L to the color space conversion section **75**.

The color space conversion section **75** performs a color space conversion process for the color difference images C and D and the luminance image L and supplies resulting modulated images (images in each of which the pixels have an R, G or B component) to gradation reverse conversion sections **76** to **78**.

The gradation reverse conversion section **76** raises the pixel values of the R components from the color space conversion section **75** to the (1/γ)th power to perform reverse conversion to the gradation conversion by the gradation conversion section **71** to obtain an output image R. The gradation reverse conversion section **77** raises the pixel values of the G components from the color space conversion section **75** to the (1/γ)th power to perform reverse conversion to the gradation conversion by the gradation conversion section **71** to obtain an output image G. The gradation reverse conversion section **78** raises the pixel values of the B components from the color space conversion section **75** to the (1/γ)th power to perform reverse conversion to the gradation conversion by the gradation conversion section **71** to obtain an output image B.

It is to be noted that, where the color mosaic image M supplied from the sensitivity uniformization section **51** has a Bayer arrangement, the color interpolation section **52** may execute a color interpolation process, for example, using the related-art method disclosed in the official gazette of Japanese Patent Laid-Open No. Sho 61-501424 and so forth.

FIG. **48** shows an example of a configuration of the color difference image production section **72**. In the color difference image production section **72**, the modulated color mosaic image Mg from the gradation conversion section **71** is supplied to smoothing sections **81** and **82**. Also the color mosaic pattern information is supplied to the smoothing sections **81** and **82**.

The smoothing section **81** uses, for each pixel, the pixel values of neighboring pixels having an R component to interpolate the R component of the pixel to produce a smoothed image R' of the R component and supplies the

image R' to a subtractor **83**. The smoothing section **82** uses, for each pixel, the pixel values of neighboring pixels having a G component to interpolate the G component of the pixel to produce a smoothed image G' of the G component and supplies the image G' to the subtractor **83**.

The subtractor **83** subtracts the pixel values of the pixels of the smoothed image G' of the G component from the smoothing section **82** from the pixel values of the corresponding pixels of the smoothed image R' of the R component from the smoothing section **81** to produce a color difference image C and supplies the color difference image C to the color space conversion section **75**.

It is to be noted that also the color difference image production section **73** has a similar configuration.

FIG. **49** shows an example of a configuration of the luminance image production section **74**. A luminance calculation section **91** which composes the luminance image production section **74** calculates a luminance candidate value of each pixel based on the modulated color mosaic image Mg from the gradation conversion section **71**, the color difference image C from the color difference image production section **72**, the color difference image D from the color difference image production section **73** and the color mosaic pattern information and outputs a luminance candidate value image Lc formed from luminance pixel values of the pixels to a noise removal section **92**.

The noise removal section **92** synthesizes a smoothing component (hereinafter described) with each of the pixel values (luminance candidate values) of the luminance candidate value image Lc to remove noise from the luminance candidate value image Lc and outputs a resulting luminance image L to the color space conversion section **75**.

Subsequently, the first demosaic process by the first example of the configuration of the image processing section **7** shown in FIG. **45** is described with reference to a flow chart of FIG. **50**.

At step S**1**, the sensitivity uniformization section **51** performs a sensitivity uniformization process for the color and sensitivity mosaic image based on the color mosaic pattern information and the sensitivity mosaic pattern information and outputs a resulting color mosaic image M to the color interpolation section **52**.

Details of the first sensitivity uniformization process by the first example of the configuration of the sensitivity uniformization section **51** shown in FIG. **46** are described with reference to a flow chart of FIG. **51**.

At step S**11**, the sensitivity compensation section **61** performs a sensitivity compensation process for the color and sensitivity mosaic image inputted thereto and supplies the sensitivity-compensated color and sensitivity mosaic image to the missing interpolation section **64**.

Details of the sensitivity compensation process are described with reference to a flow chart of FIG. **52**. At step S**21**, the sensitivity compensation section **61** discriminates whether or not all pixels of the color and sensitivity mosaic image have been used as a noticed pixel. If the sensitivity compensation section **61** discriminates that all pixels have not been used as a noticed pixel, then the processing advances to step S**22**. At step S**22**, the sensitivity compensation section **61** determines one by one pixel as a noticed pixel beginning with the left lowermost pixel and ending with the right uppermost pixel of the color and sensitivity mosaic image.

At step S**23**, the sensitivity compensation section **61** refers to the sensitivity mosaic pattern information to acquire the sensitivity (S**0** or S**1**) of the noticed pixel and further refers to the relative sensitivity value LUT **62** to acquire the relative sensitivity value S corresponding to the pixel of the noticed pixel.

At step S**24**, the sensitivity compensation section **61** divides the pixel value of the noticed pixel of the color and sensitivity mosaic image by the relative sensitivity value S to compensate for the sensitivity of the pixel value. The sensitivity-compensated pixel value is a pixel value of a sensitivity-compensated color and sensitivity mosaic image.

The processing returns to step S**21** so that the processing at steps S**21** to S**24** is repeated until it is discriminated at step S**21** that all pixels have been used as a noticed pixel. When it is discriminated at step S**21** that all pixels have been used as a noticed pixel, the processing returns to step S**12** of FIG. **51**.

At step S**12**, the validity discrimination section **63** performs a validity discrimination process for the color and sensitivity mosaic image to produce discrimination information representative of the validity of the pixel value of each pixel and supplies the discrimination information to the missing interpolation section **64**. It is to be noted that the validity discrimination process at step S**12** may be executed in parallel to the sensitivity compensation process at step S**61**.

Details of the validity discrimination process are described with reference to a flow chart of FIG. **53**. At step S**31**, the validity discrimination section **63** discriminates whether or not all pixels of the color and sensitivity mosaic image have been used as a noticed pixel. If it is discriminated that all pixels have not been used as a noticed pixel, then the processing advances to step S**32**. At step S**32**, the validity discrimination section **63** determines one by one pixel as a noticed pixel beginning with the left lowermost pixel and ending with the right uppermost pixel of the color and sensitivity mosaic image.

At step S**33**, the validity discrimination section **63** discriminates whether or not the pixel value of the noticed pixel of the color and sensitivity mosaic image is within the range between the threshold value θ_L of the noise level and the threshold value θ_H of the saturation level. If the validity discrimination section **63** discriminates that the pixel value is within the range between the threshold values, then the processing advances to step S**34**.

At step S**34**, the validity discrimination section **63** sets the discrimination information of the noticed pixel as valid. The processing returns to step S**31**.

If it is discriminated at step S**33** that the pixel value of the noticed pixel of the color and sensitivity mosaic image is not within the range between the threshold values, then the processing advances to step S**35**. At step S**35**, the validity discrimination section **63** discriminates whether or not the pixel value of the noticed pixel of the color and sensitivity mosaic image is equal to or higher than the threshold level θ_H of the saturation level. If the validity discrimination section **63** discriminates that the pixel value is higher than the threshold value θ_H of the saturation level, then the processing advances to step S**36**.

At step S**36**, the validity discrimination section **63** refers to the sensitivity mosaic pattern information to discriminate whether or not the noticed pixel has the sensitivity S**0**. If the validity discrimination section **63** discriminates that the noticed pixel has the sensitivity S**0**, then the processing advances to step S**34**. If the validity discrimination section **63** discriminates that the noticed pixel does not have the sensitivity S**0**, then the processing advances to step S**37**.

At step S37, the validity discrimination section **63** sets the discrimination information of the noticed pixel as invalid. The processing returns to step S31.

If it is discriminated at step S35 that the pixel value of the noticed pixel of the color and sensitivity mosaic image is not equal to or higher than the threshold value θ_H of the saturation level, then the processing advances to step S38. At step S38, the validity discrimination section **63** refers to the sensitivity mosaic pattern information to discriminate whether or not the noticed pixel has the sensitivity S1. If the validity discrimination section **63** discriminates that the noticed pixel has the sensitivity S1, then the processing advances to step S34. However, if the validity discrimination section **63** discriminates that the noticed pixel does not have the sensitivity S1, then the processing advances to step S37.

Thereafter, the processing at steps S31 to S38 is repeated until it is discriminated at step S31 that all pixels have been used as a noticed pixel. When it is discriminated at step S31 that all pixels have been used as a noticed pixel, the processing returns to step S13 of FIG. **51**.

At step S13, the missing interpolation section **64** performs a missing interpolation process for the sensitivity-compensated color and sensitivity mosaic image based on the discrimination information from the validity discrimination section **63** and supplies a resulting color mosaic image M to the color interpolation section **52**.

Details of the missing interpolation process are described with reference to a flow chart of FIG. **54**. At step S41, the missing interpolation section **64** discriminates whether or not all pixels of the sensitivity-compensated color and sensitivity mosaic image have been used as a noticed pixel. If the missing interpolation section **64** discriminates that all pixels have not been used as a noticed pixel, then the processing advances to step S42. At step S42, the missing interpolation section **64** determines one by one pixel as a noticed pixel beginning with the left lowermost pixel and ending with the right uppermost pixel of the sensitivity-compensated color and sensitivity mosaic image.

At step S43, the missing interpolation section **64** discriminates whether or not the discrimination information of the noticed pixel is invalid. If the missing interpolation section **64** discriminates that the discrimination information is invalid, then the processing advances to step S44.

At step S44, the missing interpolation section **64** refers to the color mosaic pattern information to discriminate the type of the color of the noticed pixel (in the present case, one of the colors of R, G and B), detect, from among neighboring pixels with the noticed pixel (for example, in the present case, 5×5 pixels centered at the noticed pixel), those pixels which have the same color and whose discrimination information is valid, and extracts the pixel values of the detected pixels (hereinafter referred to as reference pixels).

At step S45, the missing interpolation section **64** acquires a number of filter coefficients set in advance corresponding to relative positions of the reference pixels to the noticed pixel, the number being equal to the number of the reference pixels. At step S46, the missing interpolation section **64** multiplies the pixel values of the reference pixels by the corresponding filter coefficients and arithmetically operates the sum total of the products. Further, the missing interpolation section **64** divides the sum total of the products by the sum total of the used filter coefficients and determines the quotient as a pixel value of the noticed pixel of the color mosaic image M.

The processing returns to step S41 so that the processing at steps S41 to **46** is repeated until it is discriminated at step S41 that all pixels have been used as a noticed pixel. When it is discriminated at step S41 that all pixels have been used as a noticed pixel, the processing returns to step S2 of FIG. **50**.

At step S2, the color interpolation section **52** performs a color interpolation process for the color mosaic image M obtained by the sensitivity uniformization process at step S1 described above based on the color mosaic pattern information to produce output images R, G and B.

Details of the color interpolation process are described with reference to a flow chart of FIG. **55**. At step S51, the gradation conversion section **71** performs a gradation modulation process for the color mosaic image M (more particularly, raises the pixel values of the modulated color mosaic image Mg to the γth power) to produce a modulated color mosaic image Mg and supplies the modulated color mosaic image Mg to the color difference image production sections **72** and **73** and the luminance image production section **74**.

At step S52, the color difference image production section **72** uses the modulated color mosaic image Mg from the gradation conversion section **71** to produce a color difference image C and supplies the color difference image C to the luminance image production section **74** and the color space conversion section **75**. Meanwhile, the color difference image production section **73** uses the modulated color mosaic image Mg from the gradation conversion section **71** to produce a color difference image D and supplies the color difference image D to the luminance image production section **74** and the color space conversion section **75**.

The first process of the color difference image production section **72** producing a color difference image C is described with reference to a flow chart of FIG. **56**. At step S61, the smoothing sections **81** and **82** discriminate whether or not all pixels of the modulated color mosaic image Mg have been used as a noticed pixel. If the smoothing sections **81** and **82** discriminate that all pixels have not been used as a noticed pixel, then the processing advances to step S62. At step S62, the smoothing sections **81** and **82** determine one by one pixel as a noticed pixel beginning with the left lowermost pixel and ending with the right uppermost pixel of the modulated color mosaic image Mg.

At step S63, the smoothing section **81** refers to the color mosaic pattern information to detect, from among neighboring pixels with the noticed pixel (for example, 5×5 pixels centered at the noticed pixel), those pixels which have an R component, and extracts the pixel values of the detected pixels (hereinafter referred to as reference pixels). Meanwhile, also the smoothing section **82** similarly refers to the color mosaic pattern information to detect, from among neighboring pixels with the noticed pixel, those pixels which have a G component, and extracts the pixel values of the detected pixels.

At step S64, the smoothing section **81** acquires a number of filter coefficients set in advance corresponding to relative positions of the reference pixels having an R component to the noticed pixel, the number being equal to the number of the reference pixels. Meanwhile, also the smoothing section **82** similarly acquires a number of filter coefficients set in advance corresponding to relative positions of the reference pixels having a G component to the noticed pixel, the number being equal to the number of the reference pixels.

At step S65, the smoothing section **81** multiplies the pixel values of the reference pixels having an R component by the corresponding filter coefficients and arithmetically operates the sum total of the products. Further, the smoothing section **81** divides the sum total of the products by the sum total of the used filter coefficients and determines the quotient as a pixel value corresponding to the noticed pixel of an image

R' which includes only smoothed R components. Meanwhile, also the smoothing section **82** similarly multiplies the pixel values of the reference pixels having a G component by the corresponding filter coefficients and arithmetically operates the sum total of the products. Further, the smoothing section **82** divides the sum total of the products by the sum total of the used filter coefficients and determines the quotient as a pixel value corresponding to the noticed pixel of an image G' which includes only smoothed G components.

At step S**66**, the subtractor **83** subtracts the pixel value corresponding to the noticed pixel of the image R' which includes only smoothed R components from the smoothing section **81** from the pixel value corresponding to the noticed pixel of the image G' which includes only smoothed G components from the smoothing section **82** and determines the difference as a pixel value corresponding to the noticed pixel of a color difference image C.

The processing returns to step S**61** so that the processing at steps S**61** to S**66** is repeated until it is discriminated at step S**61** that all pixels have been used as a noticed pixel. When it is discriminated at step S**61** that all pixels have been used as a noticed pixel, the processing returns to step S**53** of FIG. **55**.

It is to be noted that, since the processing of the color difference image production section **73** when it produces a color difference image D is similar to the first process of the color difference image production section **72** when it produces the color difference image C described above, description of the processing is omitted.

At step S**53**, the luminance image production section **74** produces a luminance image L using the modulated mosaic image Mg and the color difference signals C and D and supplies the luminance image L to the color space conversion section **75**.

Details of the luminance image production process of the luminance image production section **74** are described with reference to a flow chart of FIG. **57**. At step S**71**, the luminance calculation section **91** discriminates whether or not all pixels of the modulated color mosaic image Mg have been used as a noticed pixel. If the luminance calculation section **91** discriminates that all pixels have not been used as a noticed pixel, then the processing advances to step S**72**. At step S**72**, the luminance calculation section **91** determines one by one pixel as a noticed pixel beginning with the left lowermost pixel and ending with the right uppermost pixel of the modulated color mosaic image Mg.

At step S**73**, the luminance calculation section **91** refers to the color mosaic pattern information to discriminate the type of the color of the noticed pixel (in the present case, one of the colors of R, G and B).

If it is discriminated at step S**73** that the type of the color of the noticed pixel is R, then the processing advances to step S**74**. At step S**74**, the luminance calculation section **91** applies the modulated color mosaic image Mg and the pixel values of the color difference signals C and D corresponding to the noticed pixel to the following expression (1) to calculate the pixel value of a luminance candidate image Lc corresponding to the noticed pixel:

$$Lc=3Mg-2C+D \tag{1}$$

If it is discriminated at step S**73** that the type of the color of the noticed pixel is G, then the processing advances to step S**75**. At step S**75**, the luminance calculation section **91** applies the modulated color mosaic image Mg and the pixel values of the color difference signals C and D corresponding to the noticed pixel to the following expression (2) to calculate the pixel value of the luminance candidate image Lc corresponding to the noticed pixel:

$$Lc=3Mg+C+D \tag{2}$$

If it is discriminated at step S**73** that the type of the color of the noticed pixel is B, then the processing advances to step S**76**. At step S**76**, the luminance calculation section **91** applies the modulated color mosaic image Mg and the pixel values Mg of the color difference signals C and D corresponding to the noticed pixel to the following expression (3) to calculate the pixel value of the luminance candidate image Lc corresponding to the noticed pixel:

$$Lc=3Mg+C-2D \tag{3}$$

It is to be noted that, in the expressions (1) to (3), Lc, Mg, C and D represent the pixel values of the luminance candidate image Lc, modulated color mosaic image Mg, color difference signal C and color difference image D corresponding to the noticed pixel, respectively.

The processing returns to step S**71** so that the processing at steps S**71** to S**76** is repeated until it is discriminated at step S**71** that all pixels have been used as a noticed pixel. When it is discriminated at step S**71** that all pixels have been used as a noticed pixel, the processing advances to step S**77**.

The luminance candidate image Lc produced by the processing at steps S**71** to S**76** described above is supplied to the noise removal section **92**.

At step S**77**, the noise removal section **92** discriminates whether or not all pixels of the modulated color mosaic image Mg have been used as a noticed pixel. If the noise removal section **92** discriminates that all pixels have not been used as a noticed pixel, then the processing advances to step S**78**. At step S**78**, the noise removal section **92** determines one by one pixel as a noticed pixel beginning with the left lowermost pixel and ending with the right uppermost pixel of the modulated color mosaic image Mg.

At step S**79**, the noise removal section **92** applies the pixel values (luminance candidate values) of the pixels positioned upwardly, downwardly, leftwardly and rightwardly of the noticed pixel to the following expression (4) to calculate a gradient ∇ corresponding to the noticed pixel. It is to be noted that the gradient ∇ is a vector whose factors are linear differential coefficients in the horizontal direction and the vertical direction of the image. Further, the pixel values (luminance candidate values) of the pixels positioned upwardly, downwardly, leftwardly and rightwardly of the noticed pixel are represented by Lc(U), Lc(D), Lc(L) and Lc(R), respectively.

$$\text{gradient } \nabla=(Lc(R)-Lc(L),Lc(U)-Lc(D)) \tag{4}$$

At step S**80**, the noise removal section **92** applies the pixel values (luminance candidate values) of the pixels positioned leftwardly, rightwardly, upwardly and downwardly of the noticed pixel to the following expressions (5) and (6) to calculate a smoothed component Hh in the horizontal direction and a smoothed component Hv in the vertical direction corresponding to the noticed pixel:

$$Hh=(Lc(L)+Lc(R))/2 \tag{5}$$

$$Hv=(Lc(U)+Lc(D))/2 \tag{6}$$

At step S**81**, the noise removal section **92** calculates a smoothing contribution wh in the horizontal direction and a smoothing contribution wv in the vertical direction corresponding to the absolute value

$\|\nabla\|$ of the gradient ∇ corresponding to the noticed pixel calculated at step S**79**.

More particularly, where the absolute value of the gradient ∇ is higher than 0, the absolute value of the inner product of the normalized gradient ∇/‖∇‖ and the vector (1, 0) is subtracted from 1 as given by the following expression (7) to obtain the smoothing contribution wh in the horizontal direction. Further, as given by the following expression (8), the absolute value of the inner product of the normalized gradient ∇/‖∇‖ and the vector (0, 1) is subtracted from 1 to obtain the smoothing contribution wv in the vertical direction:

$$wh=1-|\nabla/\|\nabla\|,(1,0)| \quad (7)$$

$$wv=1-|\nabla/\nabla\|\nabla\|,(0,1)| \quad (8)$$

Where the absolute value of the gradient ∇ is 0, the smoothing contribution wh in the horizontal direction and the smoothing contribution wv in the vertical direction are both set to 0.5.

At step S**82**, the noise removal section **92** uses the following expression (9) to calculate the pixel value (luminance value) of the luminance image L corresponding to the noticed pixel:

$$L=Lc+(wh\cdot Hh+wv\cdot Hv)/(wh+wv) \quad (9)$$

It is to be noted that Lc and L in the expression (9) represent the pixel values of the luminance candidate image Lc and the luminance image L corresponding to the noticed pixel.

The processing returns to step S**77** so that the processing at steps S**77** to S**82** is repeated until it is discriminated at step S**77** that all pixels have been used as a noticed pixel. When it is discriminated at step S**77** that all pixels have been used as a noticed pixel, the processing returns to step S**54** of FIG. **55**.

At step S**54**, the color space conversion section **75** performs a color space conversion process for the color difference images C and D and the luminance image L to produce modulated images in each of which each pixel has an R, G or B component and supplies the modulated images to the gradation reverse conversion sections **76** to **78**, respectively.

Details of the color space conversion process are described with reference to a flow chart of FIG. **58**. At step S**91**, the color space conversion section **75** discriminates whether or not all pixels of the luminance image L (which may alternatively be the color difference image C or the color difference image D) have been used as a noticed pixel. If the color space conversion section **75** discriminates that all pixels have not been used as a noticed pixel, then the processing advances to step S**92**. At step S**92**, the color space conversion section **75** determines one by one pixel as a noticed pixel beginning with the left lowermost pixel and ending with the right uppermost pixel of the color and sensitivity mosaic image.

At step S**93**, the color space conversion section **75** applies the pixel values of the luminance image L, color difference image C and color difference image D corresponding to the noticed pixel to the following expressions (10), (11) and (12) to calculate the value Rg of the R component, the value Gg of the G component and the value Bg of the B component of the modulated images corresponding to the noticed pixel:

$$Rg=(L+2C-D)/3 \quad (10)$$

$$Gg=(L-C-D)/3 \quad (11)$$

$$Bg=(L-C+2D)/3 \quad (12)$$

It is to be noted that, in the expressions (10) to (12), L, C and D are the pixel values of the luminance image L, color difference signal C and color difference image D corresponding to the noticed pixel, respectively.

The processing returns to step S**91** so that the processing at steps S**91** to S**93** is repeated until it is discriminated at step S**91** that all pixels have been used as a noticed pixel. When it is discriminated at step S**91** that all pixels have been used as a noticed pixel, the processing returns to step S**55** of FIG. **55**.

At step S**55**, the gradation reverse conversion section **76** performs a gradation reverse conversion process corresponding to the gradation conversion process at step S**51** (more particularly, to raise pixel values to the 1/γth power) for the R component of each pixel of the modulated image supplied from the color space conversion section **75** to produce an output image R. Similarly, the gradation reverse conversion section **77** performs a gradation reverse conversion process corresponding to the gradation conversion process at step S**51** for the G component of each pixel of the modulated image supplied from the color space conversion section **75** to produce an output image G. The gradation reverse conversion section **78** performs a gradation reverse conversion process corresponding to the gradation conversion process at step S**51** for the B component of each pixel of the modulated image supplied from the color space conversion section **75** to produce an output image B. Through such a color interpolation process as described above, the output images R, G and BG are produced.

Description of the first demosaic process by the first example of the configuration of the sensitivity uniformization section **51** shown in FIG. **45** is ended thereby.

Now, a second example of the configuration of the sensitivity uniformization section **51** which can be used in place of the second example of the configuration of the sensitivity uniformization section **51** shown in FIG. **46** is described with reference to FIG. **59**.

The second example of the configuration is an example of the configuration wherein the second sensitivity uniformization process in the first demosaic process described with reference to FIGS. **35**, **38** and **39** is executed by the sensitivity uniformization section **51**.

It is assumed that, in the color and sensitivity mosaic image described below, the color of each pixel is one of the three primary colors of R, G and B and the sensitivity is one of four stages S**0**, S**1**, S**2** and S**3** as in the color and sensitivity mosaic pattern P**10** of FIG. **14** or the color and sensitivity mosaic pattern P**1** of FIG. **15**. However, the configuration and the operation described below can be applied also to another color and sensitivity mosaic image which includes three colors other than R, G and B or a further color and sensitivity mosaic image which includes four colors. Further, they can be applied also to a color and sensitivity mosaic pattern wherein the sensitivity has two stages or three stages.

In the second example of the configuration of the sensitivity uniformization section **51**, a color and sensitivity mosaic image from the image pickup system, color mosaic pattern information and sensitivity mosaic pattern information are supplied to interpolation sections **101-1** to **101-4**.

The interpolation section **101-1** performs an interpolation process of the sensitivity S**0** without changing the color of each pixel of the color and sensitivity mosaic image and outputs an interpolation value corresponding to the resulting sensitivity S**0** to an adder **102**. The interpolation section **101-2** performs an interpolation process of the sensitivity S**1** without changing the color of each pixel of the color and sensitivity mosaic image and outputs an interpolation value corresponding to the resulting sensitivity S**1** to the adder

102. The interpolation section **101-3** performs an interpolation process of the sensitivity S2 without changing the color of each pixel of the color and sensitivity mosaic image and outputs an interpolation value corresponding to the resulting sensitivity S2 to the adder **102**. The interpolation section **101-4** performs an interpolation process of the sensitivity S3 without changing the color of each pixel of the color and sensitivity mosaic image and outputs an interpolation value corresponding to the resulting sensitivity S3 to the adder **102**.

The adder **102** adds, for each pixel, the sensitivities S0 to S3 inputted thereto from the interpolation sections **101-1** to **101-4** and supplies the sum as a pixel value of a color mosaic candidate image to a synthetic sensitivity compensation section **103**.

The synthetic sensitivity compensation section **103** collates the pixel value of the color mosaic candidate image supplied thereto from the adder **102** with a synthetic sensitivity compensation LUT **104** to produce a color mosaic image M wherein the resulting value is used as a pixel value and supplies the color mosaic image M to the color interpolation section **52**. The synthetic sensitivity compensation LUT **104** is configured so as to acquire a pixel value of the color mosaic image M using a pixel value of the color mosaic candidate image as an index.

The second sensitivity uniformization process in the first demosaic process by the second example of the configuration of the sensitivity uniformization section **51** shown in FIG. **59** is described with reference to a flow chart of FIG. **60**.

At step S**101**, the interpolation sections **101-1** to **101-4** discriminate whether or not all pixels of the color and sensitivity mosaic image have been used as a noticed pixel. If the interpolation sections **101-1** to **101-4** discriminate that all pixels have not been used as a noticed pixel, then the processing advances to step S**102**. At step S**102**, the interpolation sections **101-1** to **101-4** determine one by one pixel as a noticed pixel beginning with the left lowermost pixel and ending with the right uppermost pixel of the color and sensitivity mosaic image.

At step S**103**, the interpolation sections **101-1** to **101-4** perform an interpolation process without changing the color of each pixel of the color and sensitivity mosaic image to produce interpolation values corresponding to the sensitivities S0, S1, S2 and the sensitivity S3, respectively, and output the interpolation values to the adder **102**.

The interpolation process for the sensitivity S0 by the interpolation section **101-1** is described with reference to a flow chart of FIG. **61**. At step **111**, the interpolation section **101-1** detects those of pixels positioned in the neighborhood of the noticed pixel of the color and sensitivity mosaic image (for example, 5×5 pixels centered at the noticed pixel) which have a color same as that of the noticed pixel and have the sensitivity S0, and extracts the pixel values of the detected pixels (hereinafter referred to as reference pixels). At step S**112**, the interpolation section **101-1** acquires a number of filter coefficients set in advance corresponding to relative positions of the detected reference pixels to the noticed pixel, the number being equal to the number of the reference pixels. At step S**113**, the interpolation section **101-1** multiplies the pixel values of the reference pixels and the corresponding filter coefficients and arithmetically operates the sum total of the products. Further, the interpolation section **101-1** divides the sum total of the products by the sum total of the used filter coefficients and determines the quotient as an interpolation value corresponding to the sensitivity S0 of the noticed pixel. The processing returns to step S**60** of FIG. **60**.

It is to be noted that, since the interpolation processes for the sensitivities S1 to S3 by the interpolation sections **101-2** and **101-3** are similar to the interpolation process for the sensitivity S0 by the interpolation section **101-1** described above, description of the interpolation processes is omitted.

At step S**104**, the adder **102** adds the interpolation values for the sensitivities S0 to S3 corresponding to the noticed pixel inputted from the interpolation sections **101-1** to **101-4** and supplies the sum as a pixel value of a color mosaic candidate image corresponding to the noticed pixel to the synthetic sensitivity compensation section **103**.

At step S**105**, the synthetic sensitivity compensation section **103** collates the pixel value of the color mosaic candidate image supplied thereto from the adder **102** with the synthetic sensitivity compensation LUT **104** and determines a detected value as a pixel value of a color mosaic image M corresponding to the noticed pixel.

The processing returns to step S**101** so that the processing at steps S**101** to S**105** is repeated until it is discriminated at step S**101** that all pixels have been used as a noticed pixel. When it is discriminated at step S**101** that all pixels have been used as a noticed pixel, the second sensitivity uniformization process of the first demosaic process is ended.

It is to be noted that, after the second sensitivity uniformization process, the color interpolation process described hereinabove with reference to the flow chart of FIG. **55** is executed.

Now, a second process for producing a color difference image C which can be executed by the color difference image production section **72** in place of the first process (FIG. **56**) for producing a color difference image C described hereinabove is described with reference to a flow chart of FIG. **62**.

At step S**121**, the smoothing sections **81** and **82** discriminate whether or not all pixels of the modulated color mosaic image Mg have been used as a noticed pixel. If the smoothing sections **81** and **82** discriminate that all pixels have not been used as a noticed pixel, then the processing advances to step S**122**. At step S**122**, the smoothing sections **81** and **82** determine one by one pixel as a noticed pixel beginning with the left lowermost pixel and ending with the right uppermost pixel of the modulated color mosaic image Mg.

At step S**123**, the smoothing section **81** arithmetically operates an image gradient vector g corresponding to the noticed pixel.

Details of the image gradient vector arithmetic operation process are described with reference to a flow chart of FIG. **63**. In the image gradient vector arithmetic operation process, only those of all pixels of the color mosaic image Mg which have a single type of a color are used to arithmetically operate the image gradient vector g.

It is to be noted that, although a predetermined single type of a color may be selected arbitrarily, for example, where the color mosaic pattern of the color mosaic image Mg has a Bayer arrangement, since the number of pixels having a G component is equal to twice that of pixels having an R component or pixels having a B component, the single type of a color is reasonably set to G. Accordingly, the following description proceeds assuming that the color mosaic pattern of the color mosaic image Mg has a Bayer arrangement and that G is selected as the predetermined single type of a color.

At step S**141**, the smoothing section **81** discriminates whether or not the color of the noticed pixel is G. If the smoothing section **81** discriminates that the color of the

noticed pixel is G, then the processing advances to step S142. In this instance, the colors of the four pixels positioned upwardly, downwardly, leftwardly and rightwardly of the noticed pixel are not G, and the colors of the four pixels positioned in the oblique directions from the noticed pixel are G.

At step S142, the smoothing section **81** interpolates the values G(U), G(D), G(L) and G(R) of G components corresponding to the four pixels positioned upwardly, downwardly, leftwardly and rightwardly of the noticed pixel, respectively, by applying the pixel value G(LU) of the pixel neighboring leftwardly upwards of the noticed pixel and having a G component, the pixel value G(LD) of the pixel neighboring leftwardly downwards of the noticed pixel and having a G component, the pixel value G(RU) of the pixel neighboring rightwardly upwards of the noticed pixel and having a G component and the pixel value G(RD) of the pixel neighboring rightwardly downwards of the noticed pixel and having a G component to the following expressions (13) to (16):

$$G(U)=(G(LU)+G(RU))/2 \tag{13}$$

$$G(D)=(G(LD)+G(RD))/2 \tag{14}$$

$$G(L)=(G(LU)+G(LD))/2 \tag{15}$$

$$G(R)=(G(RU)+G(RD))/2 \tag{16}$$

At step S143, the smoothing section **81** applies the values G(U), G(D), G(L) and G(R) of the G components corresponding to the four pixels positioned upwardly, downwardly, leftwardly and rightwardly of the noticed pixel to the following expressions (17) to (19) to calculate a vector g' and normalize the vector g' in accordance with the following expression (20) to calculate a gradient vector g:

$$gh-G(R)-G(L) \tag{17}$$

$$gv=G(U)-G(D) \tag{18}$$

$$g'=(gh,gv) \tag{19}$$

$$g=G'/\|g'\| \tag{20}$$

It is to be noted that, if it is discriminated at step S141 that the color of the noticed pixel is not G, then the processing advances to step S144. In this instance, the colors of the four pixels positioned upwardly, downwardly, leftwardly and rightwardly of the noticed pixel are G.

At step S144, the smoothing section **81** acquires the pixel values of the four pixels positioned upwardly, downwardly, leftwardly and rightwardly of the noticed pixel and substitutes them into the values G(U), G(D), G(L) and G(R), respectively.

The image gradient vector g corresponding to the noticed pixel is arithmetically operated in such a manner as described above. It is to be noted that, also where the color mosaic pattern of the color mosaic image Mg does not have a Bayer arrangement, a similar process can be applied to arithmetically operate the image gradient vector g.

The processing returns to step S124 of FIG. **62**.

At step S124, the smoothing section **81** refers to the color mosaic pattern information to detect those of pixels neighboring with the noticed pixel (for example, 5×5 pixels centered at the noticed pixel) which have an R component, and extracts the pixel values of the detected pixels (hereinafter referred to as reference pixels). Meanwhile, also the smoothing section **82** similarly refers to the color mosaic pattern information to detect those of pixels neighboring with the noticed pixel which have a G component, and extracts the pixel values of the detected pixels.

At step S125, the smoothing section **81** calculates the position vectors n from the noticed pixel to the reference pixels which have an R component and normalizes them. Meanwhile, also the smoothing section **82** similarly calculates the position vectors n from the noticed pixel to the reference pixels which have a G component and normalizes them.

At step S126, as shown in the following expression (21), the smoothing section **81** divides, for each of the reference pixels having an R component, the absolute value of an inner product of the gradient vector g of the noticed pixel and the position vector n from 1 and arithmetically operates the difference to the ρth power to calculate a significance ω of the reference pixel. Meanwhile, also the smoothing section **82** similarly calculates a significance ω for each of the reference pixels having a G component. Here, ρ is a constant for adjusting the sharpness of direction selection and is set in advance.

$$\omega=(1-|(n,g)|)^{\rho} \tag{21}$$

At step S127, the smoothing section **81** acquires a number of filter coefficients set in advance corresponding to relative positions of the reference pixels having an R component to the noticed pixel, the number being equal to the number of the reference pixels. Meanwhile, also the smoothing section **82** similarly acquires a number of filter coefficients set in advance corresponding to relative positions of the reference pixels having a G component to the noticed pixel, the number being equal to the number of the reference pixels.

At step S128, the smoothing section **81** multiplies the pixel values of the reference pixels having an R component by the corresponding filter coefficients and significances ω and arithmetically operates the sum total of the products. Further, the smoothing section **81** multiplies the filter coefficients and the significances ω corresponding to the reference pixels and arithmetically operates the sum total of the products. Meanwhile, also the smoothing section **82** similarly multiplies the pixel values of the reference pixels having a G component by the corresponding filter coefficients and significances ω and arithmetically operates the sum total of the products. Further, the smoothing section **82** multiplies the filter coefficients and the significances ω corresponding to the reference pixels and arithmetically operates the sum total of the products.

At step S129, the smoothing section **81** divides the sum total of the products of the pixel values of the reference pixels having an R component and the corresponding filter coefficients and significances ω by the sum total of the products of the filter coefficients and the significances ω corresponding to the reference pixels calculated at step S128 and determines the quotient as a pixel value corresponding to the noticed pixel of the image R' which includes only smoothed R components. Meanwhile, also the smoothing section **82** divides the sum total of the products of the pixel values of the reference pixels having a G component and the corresponding filter coefficients and significances ω by the sum total of the products of the filter coefficients and the significances ω corresponding to the reference pixels calculated at step S128 and determines the quotient as a pixel value corresponding to the noticed pixel of the image G' which includes only smoothed G components.

At step S130, the subtractor **83** subtracts the pixel value corresponding to the noticed pixel of the image G', which only includes smoothed G components, from the smoothing section **82** from the pixel value corresponding to the noticed

pixel of the image R', which only includes smoothed R components, from the smoothing section **81**, and determines the difference as a pixel value of the noticed pixel of the color difference image C.

The processing returns to step S**121** so that the processing at steps S**121** to **130** is repeated until it is discriminated at step S**121** that all pixels have been used as a noticed pixel. When it is discriminated at step S**121** that all pixels have been used as a noticed pixel, the color difference image production process is ended and the processing returns to step S**53** of FIG. **55**.

It is to be noted that, since the process of the color difference image production section **73** when it produces a color difference image D is similar to the second process of the color difference image production section **72** when it produces the color difference image C described above, description of it is omitted.

In the second process for producing a color difference image C, since a contour of an object in an image is detected and smoothing is executed in parallel to the contour, occurrence of a color moire effect can be suppressed when compared with that in the first process for producing the color difference image C.

Subsequently, a second example of a configuration of the image processing section **7** which principally executes the second demosaic process is described with reference to FIG. **64**. In the second example of the configuration of the image processing section **7**, a color and sensitivity mosaic image from the image pickup system, color mosaic pattern information representative of a color mosaic arrangement of the color and sensitivity mosaic image and sensitivity mosaic pattern information representative of a sensitivity mosaic arrangement of the color and sensitivity mosaic image are supplied to a sensitivity uniformization section **111**.

The sensitivity uniformization section **111** performs a sensitivity uniformization process for the color and sensitivity mosaic image based on the color mosaic pattern information and the sensitivity mosaic information and outputs a resulting color mosaic image M having a uniformized sensitivity to the color interpolation section **52**. It is to be noted, however, that, since the color mosaic arrangement of the resulting color mosaic image M is not necessarily same as the color mosaic arrangement of the original color and sensitivity mosaic image, the sensitivity uniformization section **111** updates the color mosaic pattern information and supplies it to a color interpolation section **112**.

The color interpolation section **112** performs, similarly to the color interpolation section **52** of FIG. **45**, a color interpolation process, in which the color mosaic pattern information is used, for the color mosaic image M from the sensitivity uniformization section **111** to produce output images R, G and B.

FIG. **65** shows a first example of a configuration of the sensitivity uniformization section **111**. The first example of the configuration is an example of a configuration of the sensitivity uniformization section **111** which executes the first sensitivity uniformization process in the second demosaic process described hereinabove with reference to FIGS. **35**, **41** and **42**.

In the first example of the configuration of the sensitivity uniformization section **111**, a color and sensitivity mosaic image from the image pickup system is supplied to a sensitivity compensation section **121** and a validity discrimination section **123**. Color mosaic pattern information is supplied to a missing interpolation section **124**. Sensitivity mosaic pattern information is supplied to the sensitivity compensation section **121** and the validity discrimination section **123**.

The sensitivity compensation section **121** performs sensitivity compensation for the color and sensitivity mosaic image based on a relative sensitivity value S obtained from a relative sensitivity value LUT **122** and outputs the resulting color and sensitivity mosaic image to the missing interpolation section **124**. The relative sensitivity value LUT **122** is a lookup table which outputs a relative sensitivity value S using a sensitivity of a pixel as an index.

The validity discrimination section **123** compares the pixel value of each of the pixels of the color and sensitivity mosaic image with the threshold value θ_H of the saturation level and the threshold value θ_L of the noise level to discriminate the validity of the pixel value and supplies a result of the discrimination as discrimination information to the missing interpolation section **124**. In the discrimination information, information representative of "valid" or "invalid" regarding the pixel value of each pixel is described.

The missing interpolation section **124** uses, based on the discrimination information from the validity discrimination section **123**, the pixel values of those pixels from among all pixels of the sensitivity-compensated color and sensitivity mosaic image whose discrimination information is valid as they are, but uses, for each of those pixels whose discrimination information is invalid, the pixel values of those pixels having a color which is included most in the sensitivity-compensated color and sensitivity mosaic image to interpolate the pixel value of the color component. Use of the pixel values of those pixels having a color which is included most in this manner facilitates restoration of a high frequency component. Further, the missing interpolation section **124** updates the color mosaic pattern information corresponding to the color mosaic arrangement of the produced color mosaic image M and outputs the updated color mosaic pattern information to the color interpolation section **112**.

Now, a second demosaic process executed principally by the second example of the configuration of the image processing section **7** shown in FIG. **64** is described. However, most part of the second demosaic process is similar to that of the first demosaic process described hereinabove. Therefore, a process different from that of the first demosaic process described hereinabove, that is, a missing interpolation process of the missing interpolation section **124** which composes the sensitivity uniformization section **111** is described with reference to a flow chart of FIG. **66**. In the following description, it is assumed that the number of pixels having a G component is greatest in the color and sensitivity mosaic image. However, a similar process can be applied similarly also where the number of pixels having any other color component is greatest.

At step S**151**, the missing interpolation section **124** discriminates whether or not all pixels of the sensitivity-compensated color and sensitivity mosaic image have been used as a noticed pixel. If the missing interpolation section **124** discriminates that all pixels have not been used as a noticed pixel, then the processing advances to step S**152**. At step S**152**, the missing interpolation section **124** determines one by one pixel as a noticed pixel beginning with the left lowermost pixel and ending with the right uppermost pixel of the sensitivity-compensated color and sensitivity mosaic image.

At step S**153**, the missing interpolation section **124** discriminates whether or not the discrimination information of the noticed pixel is invalid. If the missing interpolation

section **124** discriminates that the discrimination information is invalid, then the processing advances to step S**154**.

At step S**154**, the missing interpolation section **124** refers to the color mosaic pattern information to detect those pixels neighboring with the noticed pixel (for example, 5×5 pixels centered at the noticed pixel) which have a G component and whose discrimination information is valid, and extracts the pixel values of the detected pixels (hereinafter referred to as reference pixels). Further, the missing interpolation section **124** acquires a number of filter coefficients set in advance corresponding to relative positions of the reference pixels to the noticed pixel, the number being equal to the number of the reference pixels. Furthermore, the missing interpolation section **124** multiplies the pixel values of the reference pixels and the corresponding filter coefficients and arithmetically operates the sum total of the products. Further, the missing interpolation section **124** divides the sum total of the products by the sum total of the used filter coefficients and determines the quotient as a pixel value of the noticed pixel of the color mosaic image M.

At step S**155**, the missing interpolation section **124** updates the color of the noticed pixel in the color mosaic pattern information to G.

It is to be noted that, if it is discriminated at step S**153** that the discrimination information of the noticed pixel is not invalid, then the processes at steps S**154** and S**155** are skipped.

The processing returns to step S**151** so that the processing at steps S**151** to **155** is repeated until it is discriminated at step S**151** that all pixels have been used as a noticed pixel. When it is discriminated at step S**151** that all pixels have been used as a noticed pixel, the missing interpolation process is ended and the color mosaic image M obtained and the updated color mosaic pattern information are supplied to the color interpolation section **112** in the following stage.

Now, a second example of a configuration of the sensitivity uniformization section **111** which can be used in place of the first example of the configuration of the sensitivity uniformization section **111** shown in FIG. **65** is described with reference to FIG. **67**.

The second example of the configuration is an example of a configuration for allowing the sensitivity uniformization section **111** to execute the second sensitivity uniformization process of the second demosaic process described hereinabove with reference to FIGS. **35**, **43** and **44**.

The following description proceeds assuming that, in the color and sensitivity mosaic image, the color of each pixel is one of the three primary colors of R, G and B as in the color and sensitivity mosaic pattern P**10** of FIG. **14** or the color and sensitivity mosaic pattern P**1** of FIG. **15** and the sensitivity is one of sensitivities of four stages of S**0**, S**1**, S**2** and S**3**. However, the configuration and the operation described below can be applied also to another color and sensitivity mosaic image which includes three colors other than R, G and B or a further color and sensitivity mosaic image which includes four colors. Furthermore, they can be applied also to a color and sensitivity mosaic pattern wherein the number of stages of sensitivity is two or three.

In the second example of the configuration of the sensitivity uniformization section **111**, a color and sensitivity mosaic image from the image pickup system, color mosaic pattern information and sensitivity mosaic pattern information are supplied to interpolation sections **132-1** to **132-4**. The color mosaic pattern information is supplied also to an interpolation color determination section **131**.

The interpolation color determination section **131** designates the color (interpolation color) of interpolation values to be interpolated by the interpolation sections **132-1** to **132-3** based on the color mosaic pattern information. Further, the interpolation color determination section **131** updates the color mosaic pattern information in accordance with determination of the interpolation colors.

The interpolation section **131-1** performs an interpolation process of the sensitivity S**0** for the color and sensitivity mosaic image in accordance with the designation of an interpolation color from the interpolation color determination section **131** and outputs a resulting interpolation value corresponding to the sensitivity S**0** to an adder **133**. The interpolation section **131-2** performs an interpolation process of the sensitivity S**1** for the color and sensitivity mosaic image in accordance with the designation of the interpolation color from the interpolation color determination section **131** and outputs a resulting interpolation value corresponding to the sensitivity S**1** to the adder **133**. The interpolation section **131-3** performs an interpolation process of the sensitivity S**2** for the color and sensitivity mosaic image in accordance with the designation of the interpolation color from the interpolation color determination section **131** and outputs a resulting interpolation value corresponding to the sensitivity S**2** to the adder **133**. The interpolation section **131-4** performs an interpolation process of the sensitivity S**3** for the color and sensitivity mosaic image in accordance with the **131** designation of the interpolation color from the interpolation color determination section and outputs a resulting interpolation value corresponding to the sensitivity S**3** to the adder **133**.

The adder **133** adds the interpolation values of the sensitivities S**0** to S**3** inputted thereto from the interpolation sections **132-1** to **132-4** for each pixel and supplies the sum as a pixel value of a color mosaic candidate image to a synthetic sensitivity compensation section **134**.

The synthetic sensitivity compensation section **134** collates the pixel value of the color mosaic candidate image supplied thereto from the adder **133** with a synthetic sensitivity compensation LUT **135** and produces and supplies a color mosaic image wherein the resulting value is used as a pixel value to the color interpolation section **112**. The synthetic sensitivity compensation LUT **135** allows a pixel value of the color and sensitivity mosaic image M using a pixel value of the color mosaic candidate image as an index.

A second sensitivity uniformization process in the second demosaic process by the second example of the configuration of the sensitivity uniformization section **111** shown in FIG. **67** is described with reference to a flow chart of FIG. **68**.

At step S**161**, the interpolation sections **132-1** to **132-4** discriminate whether or not all pixels of the color and sensitivity mosaic image have been used as a noticed pixel. If the interpolation sections **132-1** to **132-4** discriminate that all pixels have not been used as a noticed pixel, then the processing advances to step S**162**. At step S**162**, the interpolation sections **132-1** to **132-4** determine one by one pixel as a noticed pixel beginning with the left lowermost pixel and ending with the right uppermost pixel of the color and sensitivity mosaic image.

At step S**163**, the interpolation color determination section **131** executes an interpolation color determination process based on the color mosaic pattern information and issues a notification of a resulting interpolation color of the noticed pixel to the interpolation sections **132-1** to **132-4**.

Details of the interpolation color determination process of the interpolation color determination section **131** are described with reference to a flow chart of FIG. **69**. It is to be noted that the object of the interpolation color determi-

nation process is to interpolate the pixel value of the noticed pixel using pixels comparatively neighboring with the noticed pixel and it is assumed that the color mosaic arrangement of the color and sensitivity mosaic image has a Bayer arrangement.

At step **S171**, the interpolation color determination section **131** refers to the color mosaic pattern information to discriminate the color of the noticed pixel.

If it is discriminated at step **S171** that the color of the noticed pixel is G, then the processing advances to step **S172**. In this instance, also the colors of the four pixels neighboring in the oblique directions with the noticed pixel are G. At step **S172**, the interpolation color determination section **131** determines the interpolation color of the noticed pixel as G and issues a notification of this to the interpolation sections **132-1** to **132-4**. Further, the interpolation color determination section **131** updates the color mosaic pattern information corresponding to the noticed pixel to G.

If it is discriminated at step **S171** that the color of the noticed pixel is R, then the processing advances to step **S173**. In this instance, the colors of the four pixels neighboring in the oblique directions with the noticed pixel are B. At step **S173**, the interpolation color determination section **131** determines the interpolation color of the noticed pixel as B and issues a notification of this to the interpolation sections **132-1** to **132-4**. Further, the interpolation color determination section **131** updates the color mosaic pattern information corresponding to the noticed pixel to G.

If it is discriminated at step **S171** that the color of the noticed pixel is B, then the processing advances to step **S174**. In this instance, also the colors of the four pixels neighboring in the oblique directions with the noticed pixel are R. At step **S174**, the interpolation color determination section **131** determines the interpolation color of the noticed pixel as R and issues a notification of this to the interpolation sections **132-1** to **132-4**. Further, the interpolation color determination section **131** updates the color mosaic pattern information corresponding to the noticed pixel to R.

With the interpolation color determination process described above, the interpolation color of the noticed pixel is designated so that R and B of the color and sensitivity mosaic image whose color mosaic arrangement is a Bayer arrangement are exchanged for each other. Therefore, also the updated color mosaic pattern information maintains the Bayer arrangement.

The processing returns to step **S164** of FIG. **68**. At step **S164**, the interpolation sections **132-1** to **132-4** individually perform an interpolation process for the color and sensitivity mosaic image in accordance with the designation of the interpolation color from the interpolation color determination section **131** to produce an interpolation value corresponding to the sensitivity **S0**, **S1**, **S2** or **S3** and outputs the interpolation value to the adder **133**.

More particularly, for example, the interpolation section **132-1** detects, from among pixels positioned in the neighborhood of the noticed pixel of the color and sensitivity mosaic image (for example, from among 5×5 pixels centered at the noticed pixel), those pixels which have the color designated from the interpolation color determination section **131** and whose sensitivity is **S0**, and extracts the pixel values of the detected pixels (hereinafter referred to as reference pixels). Further, the interpolation section **132-1** acquires a number of filter coefficients set in advance corresponding to relative positions of the detected reference pixels to the noticed pixel, the number being equal to the number of the reference pixels. Furthermore, the interpolation section **132-1** multiplies the pixel values of the reference pixels and the corresponding filter coefficients and arithmetically operates the sum total of the products. Further, the interpolation section **132-1** divides the sum total of the products by the sum total of the used filter coefficients and determines the quotient as an interpolation value corresponding to the sensitivity **S0** of the noticed pixel.

It is to be noted that the interpolation processes for the sensitivities **S1** to **S3** by the interpolation sections **132-2** to **132-3** are similar to the interpolation process for the sensitivity **S0** by the interpolation section **132-1**, and therefore, description of it is omitted.

At step **S165**, the adder **133** adds the interpolation values for the sensitivities **S0** to **S3** corresponding to the noticed pixel inputted therefrom from the interpolation sections **132-1** to **132-4** and supplies the sum as a pixel value of the color mosaic candidate image corresponding to the noticed pixel to the synthetic sensitivity compensation section **133**.

At step **S166**, the synthetic sensitivity compensation section **134** collates the pixel value of the color mosaic candidate image supplied thereto from the adder **133** with the synthetic sensitivity compensation LUT **135** and determines a resulting value as a pixel value of the color mosaic image M corresponding to the noticed pixel.

The processing returns to step **S161** so that the processing at steps **S161** to **166** is repeated until it is discriminated at step **S161** that all pixels have been used as a noticed pixel. When it is discriminated at step **S161** that all pixels have been used as a noticed pixel, the second sensitivity uniformization process in the second demosaic process is ended.

It is to be noted that, although a color interpolation process is performed by the color interpolation section **112** for the color mosaic image M obtained by the second sensitivity uniformization process of the second demosaic process, since the process is similar to the color interpolation process described hereinabove with reference to the flow chart of FIG. **55**, description of it is omitted.

FIG. **70** illustrates an outline of a third demosaic process of the image processing system which includes the image processing section **7** as a principal component.

The third demosaic process includes, as seen in FIG. **70**, a by-sensitivity-basis color interpolation process wherein RGB components of pixels of a color and sensitivity mosaic image obtained by processing of the image pickup section are interpolated without changing the sensitivities of the pixels to produce a sensitivity mosaic image MsR for an R component, a sensitivity mosaic image MsG for a G component and a sensitivity mosaic image MsB for a B component, and a sensitivity uniformization process for uniformizing the sensitivities of the sensitivity mosaic image for an R component, the sensitivity mosaic image for a G component and the sensitivity mosaic image for a B component to produce output images R, G and B, respectively.

The by-sensitivity-basis color interpolation process of the third demosaic process includes an extraction process for extracting only those pixels which have the same sensitivity from the color and sensitivity mosaic image, a color interpolation process for interpolating the pixel values of the RGB components of the pixels extracted by the extraction process, and an insertion process for synthesizing the pixel values interpolated by the color interpolation process for each of the RGB components to produce sensitivity mosaic images.

For example, in the extraction process, only the pixels which have the sensitivity **S1** are extracted from the color and sensitivity mosaic image to produce a color mosaic image McS1 wherein the pixels are disposed in a checkered

manner. In the color interpolation process, an image Rs1 wherein the pixels which have the sensitivity S1 and have an R component are disposed in a checkered manner, another image Gs1 wherein the pixels which have the sensitivity S1 and have a G component are disposed in a checkered manner and a further image Bs1 wherein the pixels which have the sensitivity S1 and have a B component are disposed in a checkered manner are produced from the color mosaic image McS1.

For example, in the insertion process, an image RS0 and another image RS1 produced by the color interpolation process are combined to produce a sensitivity mosaic image MsR.

Subsequently, a third example of a configuration of the image processing section **7** which principally executes the third demosaic process is described with reference to FIG. **73**.

In the third example of the configuration of the image processing section **7**, a color and sensitivity mosaic image from the image pickup system is supplied to a by-sensitivity-basis color interpolation section **151**. Color mosaic pattern information representative of a color mosaic arrangement of the color and sensitivity mosaic image is supplied to the by-sensitivity-basis color interpolation section **151**. Sensitivity mosaic pattern information representative of a sensitivity mosaic arrangement of the color and sensitivity mosaic image is supplied to the by-sensitivity-basis color interpolation section **151** and sensitivity uniformization sections **152** to **154**.

It is to be noted that, in the following description, unless otherwise specified, the color and sensitivity mosaic image has the color and sensitivity mosaic pattern P3 of FIG. **7**. In particular, each pixel has a color which is one of the three primary colors of R, G and B and has a sensitivity of one of S0 and S1. Further, where attention is paid to only the pixels of the sensitivity S0 irrespective of the color, they are arranged in a checkered manner. Similarly, the pixels of the sensitivity S1 are arranged in a checkered manner.

However, the configuration and the operation described below can be applied also to another color and sensitivity mosaic image having three colors other than R, G and B or a further color and sensitivity mosaic image which has four colors.

The by-sensitivity-basis color interpolation section **151** performs a by-sensitivity-basis color interpolation process for the color and sensitivity mosaic image and supplies resulting sensitivity mosaic image MsR for an R component, sensitivity mosaic image MsG for a G component and sensitivity mosaic image MsB for a B component to corresponding ones of the sensitivity uniformization sections **152** to **154**, respectively.

The sensitivity uniformization section **152** performs a sensitivity uniformization process for the sensitivity mosaic image MsR for an R component to produce an output image R. The sensitivity uniformization section **153** performs a sensitivity uniformization process for the sensitivity mosaic image MsG for a G component to produce an output image G. The sensitivity uniformization section **154** performs a sensitivity uniformization process for the sensitivity mosaic image MsB for a B component to produce an output image B.

FIG. **74** shows an example of a configuration of the by-sensitivity-basis color interpolation section **151**. In the by-sensitivity-basis color interpolation section **151**, the color and sensitivity mosaic image, color mosaic pattern information and sensitivity mosaic pattern information are supplied to an extraction section **161**.

The extraction section **161** performs an extraction process of the sensitivity S1 (in the present case, i=0 or 1) for the color and sensitivity mosaic image and supplies a resulting color mosaic image McSi which includes pixels of the sensitivity Si to a color interpolation section **162**. It is to be noted that the color mosaic image McSi is an image represented using an st coordinate system different from the xy coordinate system of the original color and sensitivity mosaic image (details are hereinafter described with reference to FIGS. **78** and **79**). Further, the extraction section **161** produces color mosaic pattern information of the sensitivity Si representative of a color mosaic arrangement of the color mosaic image McSi and supplies the color mosaic pattern information to the color interpolation section **162**. Furthermore, the extraction section **161** produces original position information of the sensitivity Si which has a positional relationship between the color mosaic image McSi and the original color and sensitivity mosaic image and supplies the original position information of the sensitivity Si to insertion sections **163** to **165**.

The color interpolation section **162** interpolates RGB components of all pixels of the color mosaic image McSi from the extraction section **161** and supplies resulting images Rsi, Gsi and Bsi to the corresponding insertion sections **163** to **165**, respectively. The image Rsi is an image composed of pixel values of R components corresponding to the pixels of the color mosaic image McSi. The image Gsi is an image composed of pixel values of G components corresponding to the pixels of the color mosaic image McSi. The image Bsi is an image composed of pixel values of B components corresponding to the pixels of the color mosaic image McSi. Further, the images Rsi, Gsi and Bsi are represented using a coordinate system same as that of the color mosaic image McSi. It is to be noted that the color interpolation section **162** is configured in a similar manner as in the example of the configuration of the color interpolation section **52** shown in FIG. **47**.

The insertion section **163** combines a number of images Rsi of an R component equal to the number of kinds of sensitivities supplied from the color interpolation section **162** based on the original position information of the sensitivity Si supplied from the extraction section **161** to produce a sensitivity mosaic image MsR, and supplies the sensitivity mosaic image MsR to the sensitivity uniformization section **152**. The insertion section **164** combines a number of images Gsi of a G component equal to the number of kinds of sensitivities supplied from the color interpolation section **162** based on the original position information of the sensitivity Si supplied from the extraction section **161** to produce a sensitivity mosaic image MsG, and supplies the sensitivity mosaic image MsG to the sensitivity uniformization section **153**. The insertion section **165** combines a number of images Bsi of a B component equal to the number of kinds of sensitivities supplied from the color interpolation section **162** based on the original position information of the sensitivity Si supplied from the extraction section **161** to produce a sensitivity mosaic image MsB, and supplies the sensitivity mosaic image MsB to the sensitivity uniformization section **154**.

FIG. **75** shows an example of a configuration of the sensitivity uniformization section **152**. In the sensitivity uniformization section **152**, the sensitivity mosaic image MsR supplied from the insertion section **163** of the by-sensitivity-basis color interpolation section **151** is supplied to a local sum calculation section **171**. The local sum calculation section **171** performs, for each pixel of the sensitivity mosaic image MsR, a local sum calculation

process using pixels neighboring with the pixel and supplies resulting the local sum corresponding to each of the pixels to a synthetic sensitivity compensation section **172**. The synthetic sensitivity compensation section **172** collates the local sums with a synthetic sensitivity compensation LUT **173** to acquire corresponding compensation values and produces an output image R using the compensation values as pixel values. The synthetic sensitivity compensation LUT **173** can supply a corresponding compensation value when a local sum is inputted as an index thereto.

It is to be noted that examples of configurations of the sensitivity uniformization sections **153** and **154** are similar to the example of the configuration of the sensitivity uniformization section **152** shown in FIG. **75**, and therefore, description of them is omitted.

Subsequently, a third demosaic process by the third example of the configuration of the image processing section **7** shown in FIG. **73** is described with reference to a flow chart of FIG. **76**.

At step **181**, the by-sensitivity-basis color interpolation section **151** performs a by-sensitivity-basis color interpolation process for the color and sensitivity mosaic image to produce an R component sensitivity mosaic image MsR, a G component sensitivity mosaic image MsG and a B component sensitivity mosaic image MsB and supplies them to the sensitivity uniformization sections **152** to **154**, respectively.

Details of the by-sensitivity-basis color interpolation process of the by-sensitivity-basis color interpolation section **151** are described with reference to a flow chart of FIG. **77**. At step S**191**, the extraction section **161** discriminates whether or not all sensitivities (in the present case, S**0** and S**1**) included in the sensitivity mosaic pattern information have been designated. If the extraction section **161** discriminates that all sensitivities have not been designated, then the processing advances to step S**192**.

At step S**192**, the extraction section **161** determines one of all kinds of sensitivities included in the sensitivity mosaic pattern information. The designated sensitivity is represented by Si.

At step S**193**, the extraction section **161** extracts only pixels of the sensitivity Si from among all pixels of the color and sensitivity mosaic image to produce a color mosaic image McSi of the sensitivity Si and supplies the color mosaic image McSi to the color interpolation section **162**. Further, the extraction section **161** produces original position information of the sensitivity Si which keeps a positional relationship between the color mosaic image McSi and the original color and sensitivity mosaic image and supplies the original position information to the insertion sections **163** to **165**. Further, the extraction section **161** produces color mosaic pattern information of the sensitivity Si representative of a color mosaic arrangement of the color mosaic image McSi and supplies the color mosaic pattern information to the color interpolation section **162**.

Details of the process at step S**193** are described with reference to FIGS. **78** and **79**.

Since pixels of the sensitivity Si extracted do not have a pixel distance of the original color and sensitivity mosaic image, the color mosaic image McSi of the sensitivity Si produced is formed in a grating wherein the pixel distance, the original and the direction are different from those of the original color and sensitivity mosaic image. Therefore, the extraction section **61** produces, simultaneously with production of the color mosaic image McSi, original position information which allows, for each pixel, information of the original position to be referred to based on a corresponding relationship between the coordinate system of the original color and sensitivity mosaic image and the coordinate system of the color mosaic image McSi.

The corresponding relationship between the coordinate systems of the original color and sensitivity mosaic image and the color mosaic image McSi to be produced is such as illustrated in FIG. **78** or **79**. Referring to FIGS. **78** and **79**, the original color and sensitivity mosaic image is indicated on the xy coordinate system while the color mosaic image McSi is indicated on the st coordinate system. Further, ■ of the color and sensitivity mosaic image represents a pixel of the sensitivity S**0**, and □ of the color and sensitivity mosaic image represents a pixel of the sensitivity S**0**. By using the st coordinate system set obliquely with respect to the xy coordinate system in this manner, pixels of the sensitivity Si disposed in a checkered manner on the original color and sensitivity mosaic image can be extracted as a pixel arrangement of an equal distance grating.

Extraction of pixels of the sensitivity S**0** represented by ■ of the color and sensitivity mosaic image is described with reference to FIG. **78**. For example, a pixel A in FIG. **78** is represented as (x_A, y_A) on the xy coordinate system which represents the original color and sensitivity mosaic image but is represented as (s_A, t_A) on the st coordinate system which represents the color mosaic image McSi to be produced. (s_A, t_A) and (x_A, y_A) have such relationships as represented by the following expression (22):

$$s_A=\{(x_A-1)+y_A\}/2$$

$$t_A=\{(x_{max}-1-x_A)+y_A\}/2 \tag{22}$$

The extraction section **161** applies the coordinates (x_A, y_A) of the pixel of the sensitivity S**0** of the original color and sensitivity mosaic image to the expression (22) to calculate the coordinates (s_A, t_A) on the color mosaic image McSi and uses the value of the pixel for the coordinates to produce a color mosaic image McSi. Simultaneously, the extraction section **161** places the coordinates (x_A, y_A) in a corresponding relationship to the coordinates (s_A, t_A) into the original position information of the sensitivity S**0**.

Extraction of a pixel of the sensitivity S**1** represented by □ of the color and sensitivity mosaic image is described with reference to FIG. **79**. For example, a pixel B in FIG. **79** is represented as (x_B, y_B) on the xy coordinate system which represents the original color and sensitivity mosaic image but is represented as (s_B, t_B) on the st coordinate system which represents the color mosaic image McSi to be produced. (s_B, t_B) and (x_B, y_B) have such a relationship as represented by the following expression (23):

$$s_B=(x_B+y_B)/2$$

$$t_B=\{(x_{max}-1-x_B)+y_B\}/2 \tag{23}$$

The extraction section **161** applies the coordinates (x_B, y_B) of the pixel of the sensitivity S**1** of the original color and sensitivity mosaic image to the expression (22) to calculate the coordinates (s_B, t_B) on the color mosaic image McSi and uses the value of the pixel for the coordinates to produce a color mosaic image McSi. Simultaneously, the extraction section **161** places the coordinates (x_B, y_B) in a corresponding relationship to the coordinates (s_B, t_B) into the original position information of the sensitivity S**1**.

Referring back to FIG. **77**, the color interpolation section **162** interpolates RGB components of all pixels of the color mosaic image McSi from the extraction section **161** to produce images Rsi, Gsi and Bsi and supplies the images Rsi, Gsi and Bsi to the corresponding insertion sections **163** to **165**, respectively. It is to be noted that details of process-

ing of the color interpolation section **162** are similar to those of the color interpolation process of the color interpolation section **52** described with reference to FIG. **55**, and therefore, description of them is omitted.

The processing returns to step S**191** so that the processing at steps S**191** to S**194** is repeated until it is discriminated at step S**191** that all sensitivities included in the sensitivity mosaic pattern information have been designated. When it is discriminated at step S**191** that all sensitivities included in the sensitivity mosaic pattern information have been designated, the processing advances to step S**195**.

At step S**195**, the insertion section **163** combines a number of images Rsi of an R component (in the present case, the images Rs**0** and images Rs**1**) equal to the number of kinds of sensitivities supplied from the color interpolation section **162** based on all of the original position information supplied from the extraction section **161** to produce a sensitivity mosaic image MsR, and supplies the sensitivity mosaic image MsR to the sensitivity uniformization section **152**. Similarly, the insertion section **164** produces and supplies a sensitivity mosaic image MsG to the sensitivity uniformization section **153**, and the insertion section **165** produces and supplies a sensitivity mosaic image MsB to the sensitivity uniformization section **154**.

The processing returns to step S**182** of FIG. **76**. At step S**182**, the sensitivity uniformization section **152** performs a sensitivity uniformization process for the R component sensitivity mosaic image MsR to produce an output image R. The sensitivity uniformization section **153** performs a sensitivity uniformization process for the G component sensitivity mosaic image MsG to produce an output image G. The sensitivity uniformization section **154** performs a sensitivity uniformization for the B component sensitivity mosaic image MsB to produce an output image B.

The sensitivity uniformization process of the sensitivity uniformization section **152** is described with reference to a flow chart of FIG. **80**. At step S**201**, the local sum calculation section **171** discriminates whether or not all pixels of the R component sensitivity mosaic image MsR have been used as a noticed pixel. If the local sum calculation section **171** discriminates that all pixels have not been used as a noticed pixel, then the processing advances to step S**202**. At step S**202**, the local sum calculation section **171** determines one by one pixel as a noticed pixel beginning with the left lowermost pixel and ending with the right uppermost pixel of the sensitivity mosaic image MsR.

At step S**203**, the local sum calculation section **171** calculates a local sum corresponding to the noticed pixel and supplies it to the synthetic sensitivity compensation section **172**. More particularly, the pixel values of 5×5 pixels (hereinafter referred to as reference pixels) centered at the noticed pixel are extracted, and the pixel values are multiplied by such filter coefficients set in advance corresponding to relative positions of the reference pixels to the noticed pixel as seen in FIG. **81**, whereafter the sum total of the products is arithmetically operated. Further, the sum total of the products is divided by the sum total of the 25 filter coefficients, and the quotient is determined as a local sum corresponding to the noticed pixel.

At step S**204**, the synthetic sensitivity compensation section **172** collates the local sum with the synthetic sensitivity compensation LUT **173** to acquire a corresponding compensation value and determines the compensation value as a pixel value of the output image R corresponding to the noticed pixels.

The processing returns to step S**201** so that the processing at steps S**201** to S**204** is repeated until it is discriminated at step S**201** that all pixels have been used as a noticed pixel. When it is discriminated at step S**201** that all pixels have been used as a noticed pixel, the sensitivity uniformization process is ended, and the processing returns to FIG. **76**.

It is to be noted that, although also the sensitivity uniformization sections **153** and **154** execute a similar sensitivity uniformization process in parallel to the sensitivity uniformization process of the sensitivity uniformization section **152**, detailed description of it is omitted.

Description of the third demosaic process by the third example of the configuration of the image processing section **7** is ended therewith.

Subsequently, an outline of a fourth demosaic process of the image processing system including the image processing section **7** as a principal component is described.

The fourth demosaic process includes a luminance image production process for producing a luminance image from a color and sensitivity mosaic image obtained by processing of the image pickup system, and a monochromatic image process for producing output images R, G and B using the color and sensitivity mosaic image and the luminance image.

FIG. **82** shows a fourth example of a configuration of the image processing section **7** which principally executes the fourth demosaic process.

In the fourth example of the configuration of the image processing section **7**, a color and sensitivity mosaic image from the image pickup system, color mosaic pattern information which indicates a color mosaic arrangement of the color and sensitivity mosaic image and sensitivity mosaic pattern information which indicates a sensitivity mosaic arrangement of the color and sensitivity mosaic image are supplied to a luminance image production section **181** and monochromatic image production sections **182** to **184**.

It is to be noted that, in the following description, unless otherwise specified, the color and sensitivity mosaic image has the color and sensitivity mosaic pattern P**2** of FIG. **6**. In particular, each pixel has a color which is one of the three primary colors of R, G and B and has a sensitivity of one of S**0** and S**1**, and further, where attention is paid only to the color irrespective of the sensitivity, the pixels of the color are arranged in a Bayer arrangement.

However, the configuration and the operation described below can be applied also to another color and sensitivity mosaic image which includes three colors other than R, G and B or a further color and sensitivity mosaic image which includes four colors.

The luminance image production section **181** performs a luminance image production process for the color and sensitivity mosaic image supplied thereto and supplies a resulting luminance image to the monochromatic image production sections **182** to **184**.

The monochromatic image production section **182** produces an output image R using the color and sensitivity mosaic image and the luminance image supplied thereto. The monochromatic image production section **183** produces an output image G using the color and sensitivity mosaic image and the luminance image supplied thereto. The monochromatic image production section **184** produces an output image B using the color and sensitivity mosaic image and luminance image supplied thereto.

FIG. **83** shows a first example of a configuration of the luminance image production section **181**. In the first example of the configuration of the luminance image production section **181**, a color and sensitivity mosaic image,

color mosaic pattern information and sensitivity mosaic pattern information are supplied to estimation sections **191** to **193**.

The estimation section **191** performs an R component estimation process for the color and sensitivity mosaic image and supplies an estimation value R' of an R component for each pixel obtained by the process to a multiplier **194**. The estimation section **192** performs a G component estimation process for the color and sensitivity mosaic image and supplies an estimation value G' of a G component for each pixel obtained by the process to another multiplier **195**. The estimation section **193** performs a B component estimation process for the color and sensitivity mosaic image and supplies an estimation value B' of a B component for each pixel obtained by the process to a further multiplier **196**.

The multiplier **194** multiplies the estimation value R' supplied from the estimation section **191** by a color balance coefficient K_R and outputs the product to an adder **197**. The multiplier **195** multiplies the estimation value G' supplied from the estimation section **192** by a color balance coefficient K_G and outputs the product to the adder **197**. The multiplier **196** multiplies the estimation value B' supplied from the estimation section **193** by a color balance coefficient K_B and outputs the product to the adder **197**.

The adder **197** adds the product R'□k_R inputted from the multiplier **194**, the product G'□k_G inputted from the multiplier **195** and the product B'□k_B inputted from the multiplier **196**, and produces a luminance candidate image wherein the resulting sum is used as a pixel value and supplies the luminance candidate image to a noise removal section **198**.

Here, the color balance coefficients k_R, k_G and k_B are values set in advance and, for example, k_R=0.3, k_G=0.6 and k_B=0.1. It is to be noted that, basically, the color balance coefficients k_R, k_G and k_B may have any values only if they can be used to calculate, as a luminance candidate value, a value having a correlation to a luminance variation. Accordingly, for example, the color balance coefficients may be k_R=k_G=k_B.

The noise removal section **198** performs a noise removal process for the luminance candidate image supplied from the adder **197** and supplies the resulting luminance image to monochromatic image production sections **182** to **184**.

FIG. **84** shows an example of a configuration of the monochromatic image production section **182**. In the monochromatic image production section **182**, the color and sensitivity mosaic image, the color mosaic pattern information and the sensitivity mosaic pattern information are supplied to an interpolation section **201**. The luminance image is supplied to a ratio value calculation section **202** and a multiplier **203**.

The interpolation section **201** performs an interpolation process for the color and sensitivity mosaic image and outputs an R candidate image wherein all resulting pixels have pixel values of an R component to the ratio value calculation section **202**. The ratio value calculation section **202** calculates a low-frequency component of an intensity ratio (the low-frequency component is hereinafter referred to merely as an intensity ratio) between corresponding pixels of the R candidate image and the luminance image and produces ratio value information which represents an intensity ratio corresponding to each pixel, and supplies the ratio value information to the multiplier **203**.

The multiplier **203** multiplies the pixel value of each pixel of the luminance image by the corresponding intensity ratio and produces an output image R having the product as a pixel value.

It is to be noted that, since also examples of a configuration of the monochromatic image production sections **183** and **184** are similar to the example of the configuration of the monochromatic image production section **182**, description of them is omitted.

Now, the fourth demosaic process by the fourth example of the configuration of the image processing section **7** is described with reference to a flow chart of FIG. **85**.

At step S**211**, the luminance image production section **181** performs a luminance image production process for the color and sensitivity mosaic image to produce a luminance image and supplies the luminance image to the monochromatic image production sections **182** to **184**.

The luminance image production process of the luminance image production section **181** is described with reference to a flow chart of FIG. **86**.

At step S**221**, the estimation sections **191** to **193** discriminate whether or not all pixels of the color and sensitivity mosaic image have been used as a noticed pixel. If the estimation sections **191** to **193** discriminate that all pixels have not been used as a noticed pixel, then the processing advances to step S**222**. At step S**222**, the estimation sections **191** to **193** determine one by one pixel as a noticed pixel beginning with the left lowermost pixel and ending with the right uppermost pixel of the color and sensitivity mosaic image.

At step S**223**, the estimation section **191** performs an R component estimation process for the color and sensitivity mosaic image to estimate an estimation value R' corresponding to the noticed pixel and supplies the estimation value R' to the multiplier **194**. The estimation section **192** performs a G component estimation process for the color and sensitivity mosaic image to estimate an estimation value G' corresponding to the noticed pixel and supplies the estimation value G' to the multiplier **194**. The estimation section **193** performs a B component estimation process for the color and sensitivity mosaic image to estimate an estimation value B' corresponding to the noticed pixel and supplies the estimation value B' to the multiplier **194**.

The R component estimation process of the estimation section **191** is described with reference to a flow chart of FIG. **87**. At step S**231**, the estimation section **191** refers to the color mosaic pattern information and the sensitivity mosaic pattern information to detect those of pixels neighboring with the noticed pixel (for example, 15×15 pixels centered at the noticed pixel) which have an R component and have the sensitivity S**0**, and extracts the pixel values of the detected pixels (hereinafter referred to as reference pixels).

At step S**232**, the estimation section **191** acquires a number of such R component interpolation filter coefficients set in advance corresponding to relative positions of the reference pixels to the noticed pixel as shown in FIG. **88**, the number being equal to the number of the reference pixels. Further, the estimation section **191** multiplies the pixel values of the reference pixels and the corresponding filter coefficients and arithmetically operates the sum total of the products. Furthermore, the estimation section **191** divides the sum total of the products by the sum total of the used R component interpolation filter coefficients to acquire a first quotient.

At step S**233**, the estimation section **191** refers to the color mosaic pattern information and the sensitivity mosaic pattern information to detect those of pixels neighboring with the noticed pixel (for example, 15×15 pixels centered at the noticed pixel) which have an R component and have the

sensitivity S1, and extracts the pixel values of the detected pixels (hereinafter referred to as reference pixels).

At step S234, the estimation section **191** acquires a number of R component interpolation filter coefficients corresponding to relative positions of the reference pixels to the noticed pixel, the number being equal to the number of the reference pixels. Further, the estimation section **191** multiplies the pixel values of the reference pixels and the corresponding filter coefficients and arithmetically operates the sum total of the products. Furthermore, the estimation section **191** divides the sum total of the products by the sum total of the used interpolation filter coefficients to acquire a second quotient.

At step S235, the estimation section **191** adds the first quotient acquired at step S232 and the second quotient acquired at step S234. At step S235, the estimation section **191** collates the sum of the first quotient and the second quotient arithmetically operated at step S235 with a synthetic sensitivity compensation LUT (hereinafter described) built therein to acquire a compensation value of a compensated sensitivity characteristic. The acquired compensation value is determined as an estimation value R' corresponding to the noticed pixel. The processing returns to step S224 of FIG. **86**.

It is to be noted that, since the G component interpolation processes of the estimation section **192** and the B component interpolation processes of the estimation section **193** are similar to the R component interpolation process of the estimation section **191**, description of them is omitted. It is to be noted, however, in the G component estimation process of the estimation section **192**, reference pixels are detected from among 7×7 pixels centered at the noticed pixel, and further, the G component interpolation filter coefficients illustrated in FIG. **89** are used.

Here, the synthetic sensitivity compensation LUT used by the estimation section **191** is described with reference to FIGS. **90** to **92**. FIG. **90** shows a characteristic curve b of pixels of the sensitivity S0 and another characteristic curve a of pixels of the sensitivity S1, and the axis of abscissa indicates the intensity of incoming light and the axis of ordinate indicate the pixel value. In FIG. **90**, the sensitivity S1 of the high sensitivity has a sensitivity as high as four times that of the sensitivity S0 of the low sensitivity.

In the estimation process, a first quotient calculated from a pixel of the sensitivity S0 measured with such a characteristic as indicated by the characteristic curve b of FIG. **90** and a second quotient calculated using a pixel of the sensitivity S1 measured with such a characteristic as indicated by the characteristic curve a of FIG. **90** are added. Accordingly, the sum of the first quotient and the second quotient has such a characteristic synthesized from the characteristics of the sensitivity S0 and the sensitivity S1 as indicated by a characteristic curve c of FIG. **91**.

While the synthesized characteristic curve c exhibits a characteristic of a wide dynamic range from a low luminance to a high luminance, since it has a shape of a polygonal line, an original linear characteristic is restored using a characteristic curve reverse to the sensitivity characteristic curve c. More particularly, the sum of the first product and the second product is applied to a reverse characteristic curve d to the sensitivity characteristic curve c of FIG. **91** as shown in FIG. **92** to compensate for the non-linearity.

In particular, the synthetic sensitivity compensation LUT is obtained by converting the reverse characteristic curve d of FIG. **92** into a lookup table.

Description is given with reference back to FIG. **86**. At step S224, the multiplier **194** multiplies the estimation value R' supplied from the estimation section **191** by a color balance coefficient k_R and outputs the product to the adder **197**. The multiplier **195** multiplies the estimation value G' supplied from the estimation section **192** by a color balance coefficient k_G and outputs the product to the adder **197**. The multiplier **196** multiplies the estimation value B' supplied from the estimation section **193** by a color balance coefficient k_B and outputs the product to the adder **197**. The adder **197** adds the product $R' \cdot k_R$ inputted from the multiplier **194**, the product $G' \cdot k_G$ inputted from the multiplier **195** and the product $B' \cdot k_B$ inputted from the multiplier **196**, and determines the sum as a pixel value (luminance candidate value) of a luminance candidate image corresponding to the noticed pixel.

The processing returns to step S221 so that the processing at steps S221 to S224 is repeated until it is discriminated at step S221 that all pixels have been used as a noticed pixel. When it is discriminated at step S221 that all pixels have been used as a noticed pixel, the processing advances to step S225. It is to be noted that the luminance candidate image produced by the processes at steps S221 to 224 is supplied to the noise removal section **198**.

At step S225, the noise removal section **198** performs a noise removal process for the luminance candidate image supplied thereto from the adder **197** to produce a luminance image and supplies the luminance image to the monochromatic image production sections **182** to **184**.

The noise removal process of the noise removal section **198** is described with reference to a flow chart of FIG. **93**. At step S241, the noise removal section **198** discriminates whether or not all pixels of the luminance candidate image have been used as a noticed pixel. If the noise removal section **198** discriminates that all pixels have not been used as a noticed pixel, then the processing advances to step S242. At step S242, the noise removal section **198** determines one by one pixel as a noticed pixel beginning with the left lowermost pixel and ending with the right uppermost pixel of the luminance candidate image.

At step S243, the noise removal section **198** acquires the pixel values (luminance candidate values) of the pixels positioned upwardly, downwardly, leftwardly and rightwardly of the noticed pixel and substitutes the acquired luminance candidate values of the pixels positioned upwardly, downwardly, leftwardly and rightwardly of the noticed pixel into variables a3, a0, a1 and a2, respectively.

At step S244, the noise removal section **198** executes a direction selective smoothing process to acquire a smoothed value corresponding to the noticed pixel.

The direction selective smoothing process of the noise removal section **198** is described with reference to a flow chart of FIG. **94**. At step S251, the noise removal section **198** applies the variables a3, a0, a1, a2 to the following expression (24) to calculate a luminance gradient vector g corresponding to the noticed pixel:

luminance gradient vector g

$$=(a2-a1,a3-a0) \tag{24}$$

At step S252, the noise removal section **198** arithmetically operates the magnitude (absolute value)

$\|\nabla\|$ of the luminance gradient vector g.

At step S253, the noise removal section **198** applies the variables a0 to a3 to the following expressions (25) and (26) to calculate a smoothed component Hh in the horizontal direction and a smoothed component Hv in the vertical direction corresponding to the noticed pixel:

$$Hh=(a1+a2)/2 \quad (25)$$

$$Hv=(a3+a0)/2 \quad (26)$$

At step **S254**, the noise removal section **198** arithmetically operates a significance wh in the horizontal direction and a significance wv in the vertical direction corresponding to the absolute value

$\|g\|$ of the luminance gradient vector g.

More particularly, where the absolute value $\|g\|$ of the luminance gradient vector g is higher than 0, the absolute value of the inner product of the normalized luminance gradient vector $g/\|g\|$ and the vector (1, 0) is subtracted from 1 to obtain the significance wh in the horizontal direction as given by the following expression (27). Further, the absolute value of the inner product of the normalized luminance gradient vector $g/\|g\|$ and the vector (0, 1) is subtracted from 1 to obtain the significance wv in the vertical direction as given by the following expression (28).

$$wh=1-|(g/\|g\|,(1,0))| \quad (27)$$

$$wv=1-|(g/\|g\|,(0,1))| \quad (28)$$

Where the absolute value $\|g\|$ of the luminance gradient vector g is 0, the smoothing contribution rate wh in the horizontal direction and the smoothing contribution rate wv in the vertical direction are both set to 0.5.

At step **S255**, the noise removal section **198** arithmetically operates a smoothed value a corresponding to the noticed pixel using the following expression (29):

$$\alpha=(wh\cdot Hh+wv\cdot Hv)/(wh+wv) \quad (29)$$

The processing returns to step **S245** of FIG. **93**. At step **S245**, the noise removal section **198** arithmetically operates an average value between the pixel value (luminance candidate value) of the noticed pixel and the smoothed value a corresponding to the noticed pixel calculated at step **S244** and determines the average value as a pixel value (luminance value) of the luminance image corresponding to the noticed pixel.

The processing returns to step **S241** so that the processing at steps **S241** to **S245** is repeated until it is discriminated at step **S241** that all pixels have been used as a noticed pixel. When it is discriminated at step **S241** that all pixels have been used as a noticed pixel, the noise removal process is ended and also the luminance image production process is ended, and the processing returns to step **S212** of FIG. **85**.

At step **S212**, the monochromatic image production sections **182** to **184** produce the output images R, G, and B, respectively by using the supplied color and sensitivity mosaic image and the luminance image.

A first monochromatic image production process of the monochromatic image production section **182** is described with reference to a flow chart of FIG. **95**.

At step **S261**, the interpolation section **201** performs an interpolation process for the color and sensitivity mosaic image to produce an R candidate image wherein all pixels have pixel values of an R component and outputs the R candidate image to the ratio value calculation section **202**.

It is to be noted that the interpolation process of the interpolation section **201** is similar to the R component estimation process of the estimation section **191** which composes the luminance image production section **181** described hereinabove with reference to the flow chart of FIG. **87**, and therefore, description of it is omitted.

At step **S262**, the ratio value calculation section **202** performs a ratio value calculation process to calculate an intensity ratio and further produces ratio value information representative of the intensity ratio corresponding to each pixel, and supplies the intensity ratio and the ratio value information to the multiplier **203**.

The ratio value calculation process of the ratio value calculation section **202** is described with reference to a flow chart of FIG. **96**. At step **S271**, the ratio value calculation section **202** discriminates whether or not all pixels of the R candidate image have been used as a noticed pixel. If the ratio value calculation section **202** discriminates that all pixels have not been used as a noticed pixel, then the processing advances to step **S272**. At step **S272**, the ratio value calculation section **202** determines one by one pixel as a noticed pixel beginning with the left lowermost pixel and ending with the right uppermost pixel of the R candidate image.

At step **S273**, the ratio value calculation section **202** refers to those pixels which are positioned in the neighborhood of the noticed pixel (for example, 7×7 pixels centered at the noticed pixel) to acquire the pixel values (monochromatic candidate values of R components) of the pixels. Further, the ratio value calculation section **202** extracts the pixel values (luminance values) of the pixels of the luminance image which are positioned at the same coordinates as those of the reference pixels.

At step **S274**, the ratio value calculation section **202** acquires a number of smoothing filter coefficients set in advance as shown in FIG. **97** corresponding to relative positions of the reference pixels to the noticed pixel, the number being equal to the number of the reference pixels.

At step **S275**, the ratio value calculation section **202** multiplies the monochromatic candidate values for an R component of the reference pixels and the corresponding filter coefficients, divides the products by the corresponding luminance values and arithmetically operates the sum total of the quotients. Further, the ratio value calculation section **202** divides the sum total of the quotients by the sum total of the used smoothing filter coefficients and determines the quotient as an intensity ratio corresponding to the noticed pixel to produce ratio value information.

The processing returns to step **S271** so that the processing at steps **S271** to **S275** is repeated until it is discriminated at step **S271** that all pixels of the R candidate image have been used as a noticed pixel. When it is discriminated at step **S271** that all pixels of the R candidate image have been used as a noticed pixel, the ratio value information produced is supplied to the multiplier **203**, and the processing returns to step **S263** of FIG. **95**.

At step **S263**, the multiplier **203** multiplies the pixel values of the pixels of the luminance image by the corresponding intensity ratios to produce an output image R wherein the products are used as pixel values.

It is to be noted that, simultaneously with the first monochromatic image production process of the monochromatic image production section **182**, also the monochromatic image production sections **183** and **184** execute similar processes.

Description of the fourth demosaic process by the fourth example of the configuration of the image processing section **7** is ended therewith.

FIG. **98** shows a second example of a configuration of the luminance image production section **181**. The second example of the configuration of the luminance image production section **181** replaces the estimation sections **191** to **193** of the first example of the configuration of the luminance image production section **181** shown in FIG. **83** with an estimation section **211**.

In the second example of the configuration of the luminance image production section **181**, a color and sensitivity mosaic image, color mosaic pattern information and sensitivity mosaic pattern information are supplied to the estimation section **211**.

The estimation section **121** performs a component estimation process for the color and sensitivity mosaic image and supplies an estimation value R' of an R component, a estimation value G' of a G component and an estimation value B' of a B component for each pixel obtained by the component estimation process to the corresponding multipliers **194** to **196**, respectively.

It is to be noted that the elements from the multiplier **194** to the noise removal section **198** included in the second example of the configuration of the luminance image production section **181** are similar to the elements from the multiplier **194** to the noise removal section **198** included in the first example of the configuration of the luminance image production section **181** shown in FIG. **83** in which like reference numerals are applied, and therefore, description of them is omitted.

Now, the estimation process for RGB components by the estimation section **211** is described with reference to a flow chart of FIG. **99**. It is to be noted that the estimation process for RGB components is a process which can be executed in place of the R component estimation process described hereinabove with reference to FIG. **87** as a process at step S**223** of FIG. **86**. Accordingly, the processing at steps S**281** et seq. is described assuming that a noticed pixel of a color and sensitivity mosaic image has already been determined by the estimation section **211**.

At step S**281**, the estimation section **211** calculates an estimated pixel value C**0** corresponding to the noticed pixel through an estimated pixel value C**0** interpolation process wherein the pixel values of such four pixels centered at the noticed pixel as shown in FIG. **100** are used. The estimated pixel value C**0** interpolation process is described with reference to a flow chart of FIG. **101**.

At step S**291**, the estimation section **211** substitutes the pixel values of the four pixels positioned upwardly, downwardly, leftwardly and rightwardly of the noticed pixel indicated by ○ each with a space of one pixel left therebetween into variables a**3**, a**0**, a**1** and a**2** and applies a direction selective smoothing process described hereinabove with reference to FIG. **94** to arithmetically operate a smoothed value α.

The process of substituting the pixel values of four pixels positioned upwardly, downwardly, leftwardly and rightwardly of a designated pixel into the variables a**3**, a**0**, a**1** and a**2** and applying the direction selective smoothing process described hereinabove with reference to FIG. **94** to arithmetically operate a smoothed value α in this manner is hereinafter defined as a vertical direction selective smoothing process corresponding to the designated pixel.

At step S**292**, the estimation section **211** adds the smoothed value α obtained at step S**291** to the pixel value of the noticed pixel and determines the sum as the estimated pixel value C**0** of the noticed pixel. The processing returns to step S**282** of FIG. **99**.

At step S**282**, the estimation section **211** calculates an estimated pixel value C**1** corresponding to the noticed pixel through an estimated pixel value C**1** interpolation process wherein such 12 pixels centered at the noticed pixel as shown in FIG. **102** are used. The estimated pixel value C**1** interpolation process is described with reference to a flow chart of FIG. **103**.

At step S**301**, the estimation section **211** discriminates whether or not the color of the noticed pixel is G. If the estimation section **211** discriminates that the color of the noticed pixel is G, then the processing advances to step S**302**. At step S**302**, the estimation section **211** substitutes the pixel values of four pixels positioned leftwardly downwards, leftwardly upwards, rightwardly downwards and rightwardly upwards in the neighborhood of the noticed pixel represented by ○ as shown in FIG. **102** into the variables a**0**, a**1**, a**2** and a**3**, respectively, and applies the direction selective smoothing process described hereinabove with reference to FIG. **94** to arithmetically operate a smoothed value α.

The process of substituting the pixel values of four pixels positioned leftwardly downwards, leftwardly upwards, rightwardly downwards and rightwardly upwards in the neighborhood of a designated pixel into the variables a**0**, a**1**, a**2** and a**3**, respectively, and applying the direction selective smoothing process described hereinabove with reference to FIG. **94** to arithmetically operate a smoothed value α is hereinafter defined as an oblique direction selective smoothing process corresponding to the designated pixel.

At step S**303**, the estimation section **211** multiplies the smoothed value α obtained at step S**302** by 2 and determines the product as an estimated pixel value C**1** of the noticed pixel. The processing returns to step S**283** of FIG. **99**.

It is to be noted that, if it is discriminated at step S**301** that the color of the noticed pixel is not G, then the processing advances to step S**304**.

At step S**304**, the estimation section **211** executes the vertical direction selective smoothing process using four pixels positioned with a space of one pixel left from the pixel neighboring leftwardly upwards of the noticed pixel to calculate a smoothed value α and substitutes the smoothed value α into the variable a**1**. At step S**305**, the estimation section **211** executes the vertical direction selective smoothing process using four pixels positioned with a space of one pixel left from the pixel neighboring rightwardly downwards of the noticed pixel to calculate a smoothed value α and substitutes the smoothed value α into the variable a**2**. At step S**306**, the estimation section **211** substitutes the pixel value of the pixel neighboring leftwardly downwards of the noticed pixel into the variable a**0** and substitutes the pixel value of the pixel neighboring rightwardly upwards of the noticed pixel into the variable a**3**.

At step S**307**, the estimation section **211** applies the variables a**0**, a**1**, a**2** and a**3** whose values have been set at steps S**304** to S**306** to the direction selective smoothing process described hereinabove with reference to FIG. **94** to arithmetically operate a smoothed value α and determines the value of the smoothed value α as a smoothed value α'.

At step S**308**, the estimation section **211** executes the vertical direction selective smoothing process using four pixels positioned with a space of one pixel left from the pixel neighboring leftwardly downwards of the noticed pixel to calculate a smoothed value α and substitutes the smoothed value α into the variable a**0**. At step S**309**, the estimation section **211** executes the vertical direction selective smoothing process using four pixels positioned with a space of one pixel left from the pixel neighboring rightwardly upwards of the noticed pixel to calculate a smoothed value α and substitutes the smoothed value α into the variable a**3**. At step S**310**, the estimation section **211** substitutes the pixel value of the pixel neighboring leftwardly upwards of the noticed pixel into the variable a**1** and substitutes the pixel value of the pixel neighboring rightwardly downwards of the noticed pixel into the variable a**2**.

At step S311, the estimation section 211 applies the variables a0, a1, a2 and a3 whose values have been set at steps S308 to S310 to the direction selective smoothing process described hereinabove with reference to FIG. 94 to arithmetically operate a smoothed value α and determines the value of the smoothed value α as a smoothed value α".

At step S312, the estimation section 211 adds the smoothed value α' obtained at step S307 and the smoothed value α" obtained at step S311 and determines the sum as an estimated pixel value C1 corresponding to the noticed pixel. The processing returns to step S283 of FIG. 99.

At step S283, the estimation section 211 calculates a estimated pixel value C2 corresponding to the noticed pixel through a estimated pixel value C2 interpolation process wherein such four pixels centered at the noticed pixel as shown in FIG. 104A or such eight pixels centered at the noticed pixel as shown in FIG. 104B are used. The estimated pixel value C2 interpolation process is described with reference to a flow chart of FIG. 105.

At step S321, the estimation section 211 discriminates whether or not the color of the noticed pixel is G. If the estimation section 211 discriminates that the color of the noticed pixel is G, then the processing advances to step S322.

At step S322, the estimation section 211 executes the vertical direction selective smoothing process using four pixels positioned with a space of one pixel left from the pixel neighboring upwardly of the noticed pixel to calculate a smoothed value α and determines it as a smoothed value α'.

At step S323, the estimation section 211 executes the vertical direction selective smoothing process using four pixels positioned with a space of one pixel left from the pixel neighboring downwardly of the noticed pixel to calculate a smoothed value α and determines it as a smoothed value α".

At step S324, the estimation section 211 adds an average value of the pixel value of the pixel neighboring downwardly of the noticed pixel and the smoothed value α' obtained at step S322 and an average value of the pixel value of the pixel neighboring upwardly of the noticed pixel and the smoothed value α" obtained at step S323 and determines the sum as an estimated pixel value C2 corresponding to the noticed pixel. The processing returns to step S284 of FIG. 99.

It is to be noted that, if it is discriminated at step S321 that the color of the noticed pixel is not G, then the processing advances to step S325.

At step S325, the estimation section 211 executes the oblique direction selective smoothing process using four pixels positioned obliquely in the neighborhood of the pixel neighboring leftwardly of the noticed pixel to calculate a smoothed value α and substitutes it into the variable a1. At step S326, the estimation section 211 executes the oblique direction selective smoothing process using four pixels positioned obliquely in the neighborhood of the pixel neighboring rightwardly of the noticed pixel to calculate a smoothed value α and substitutes it into the variable a2. At step S327, the estimation section 211 substitutes the pixel value of the pixel neighboring downwardly of the noticed pixel into the variable a0 and substitutes the pixel value of the pixel neighboring upwardly of the noticed pixel into the variable a3.

At step S328, the estimation section 211 applies the variables a0, a1, a2 and a3 whose values have been set at steps S325 to S327 to the direction selective smoothing process described hereinabove with reference to FIG. 94 to arithmetically operate a smoothed value α and determines the value of the smoothed value α as a smoothed value α'.

At step S329, the estimation section 211 executes the oblique direction selective smoothing process using four pixels positioned obliquely in the neighborhood of the pixel neighboring downwardly of the noticed pixel to calculate a smoothed value α and substitutes it into the variable a0. At step S330, the estimation section 211 executes the oblique direction selective smoothing process using four pixels positioned obliquely in the neighborhood of the pixel neighboring upwardly of the noticed pixel to calculate a smoothed value α and substitutes it into the variable a3. At step S331, the estimation section 211 substitutes the pixel value of the pixel neighboring leftwardly of the noticed pixel into the variable a1 and substitutes the pixel value of the pixel neighboring rightwardly of the noticed pixel into the variable a2.

At step S332, the estimation section 211 applies the variables a0, a1, a2 and a3 whose values have been set at steps S329 to S331 to the direction selective smoothing process described hereinabove with reference to FIG. 94 to arithmetically operate a smoothed value α and determines the value of the smoothed value α as a smoothed value α".

At step S333, the estimation section 211 adds the smoothed value α' obtained at step S328 and the smoothed value α" obtained at step S322 and determines the sum as an estimated pixel value C2 corresponding to the noticed pixel. The processing returns to step S284 of FIG. 99.

At step S284, the estimation section 211 calculates a estimated pixel value C3 corresponding to the noticed pixel through an estimated pixel value C3 interpolation process wherein such eight pixels centered at the noticed pixel as shown in FIG. 106 are used. The estimated pixel value C3 interpolation process is described with reference to a flow chart of FIG. 107.

At step S341, the estimation section 211 discriminates whether or not the color of the noticed pixel is G. If the estimation section 211 discriminates that the color of the noticed pixel is G, then the processing advances to step S342.

At step S342, the estimation section 211 executes the vertical direction selective smoothing process using four pixels positioned with a space of one pixel left from the pixel neighboring rightwardly of the noticed pixel to calculate a smoothed value α and determines it as a smoothed value α'.

At step S343, the estimation section 211 executes the vertical direction selective smoothing process using four pixels positioned with a space of one pixel left from the pixel neighboring leftwardly of the noticed pixel to calculate a smoothed value α and determines it as a smoothed value α".

At step S344, the estimation section 211 adds an average value of the pixel value of the pixel neighboring leftwardly of the noticed pixel and the smoothed value α' obtained at step S342 and an average value of the pixel value of the pixel neighboring rightwardly of the noticed pixel and the smoothed value α" obtained at step S343 and determines the sum as an estimated pixel value C3 corresponding to the noticed pixel. The processing returns to step S285 of FIG. 99.

It is to be noted that, if it is discriminated at step S341 that the color of the noticed pixel is G, then the processing advances to step S345. At step S345, the estimation section 211 sets the estimated pixel value C3 corresponding to the noticed pixel to 0. The processing returns to step S285 of FIG. 99.

At step S285, the estimation section 211 refers to the color mosaic pattern information and the sensitivity mosaic pattern information to discriminate the color and the sensitivity of the noticed pixel, and applies, based on a result of the

discrimination, the estimated pixel values C0 to C3 corresponding to the noticed pixel obtained at steps S281 to S284 to a synthetic sensitivity compensation LUT (similar to the synthetic sensitivity compensation LUT described hereinabove with reference to FIGS. 90 to 92) built therein to calculate estimated values R', G' and B'.

In particular, where the color of the noticed pixel is G and the sensitivity is S0, a value LUT(C2) when the estimated pixel value C2 is applied to the synthetic sensitivity compensation LUT is determined as the estimated value R', and a value LUT((C0+C1/)2)) when an average value of the estimated pixel values C0+C1 is applied to the synthetic sensitivity compensation LUT is determined as the estimated value G' while a value LUT(C3) when the estimated pixel value C3 is applied to the synthetic sensitivity compensation LUT is determined as the estimated value B'.

Where the color of the noticed pixel is G and the sensitivity is S1, a value LUT(C3) when the estimated pixel value C3 is applied to the synthetic sensitivity compensation LUT is determined as the estimated value R', and a value LUT ((C0+C1/)2)) when an average value of the estimated pixel values C0+C1 is applied to the synthetic sensitivity compensation LUT is determined as the estimated value G' while a value LUT(C2) when the estimated pixel value C2 is applied to the synthetic sensitivity compensation LUT is determined as the estimated value B'.

Where the color of the noticed pixel is R, a value LUT(C0) when the estimated pixel value C0 is applied to the synthetic sensitivity compensation LUT is determined as the estimated value R', and a value LUT(C2) when an average value of the estimated pixel value C2 is applied to the synthetic sensitivity compensation LUT is determined as the estimated value G' while a value LUT(C1) when the estimated pixel value C1 is applied to the synthetic sensitivity compensation LUT is determined as the estimated value B'.

Where the color of the noticed pixel is B, a value LUT(C1) when the estimated pixel value C1 is applied to the synthetic sensitivity compensation LUT is determined as the estimated value R', and a value LUT(C2) when an average value of the estimated pixel value C2 is applied to the synthetic sensitivity compensation LUT is determined as the estimated value G' while a value LUT(C0) when the estimated pixel value C0 is applied to the synthetic sensitivity compensation LUT is determined as the estimated value B'.

Since, in the estimation process of RGB components by the estimation section 211, the estimated pixel values C0 to C3 produced making use of the direction selective smoothing process are used in such a manner as described above, deterioration of the resolution of an image signal is suppressed.

Description of the estimation process for RGB components by the estimation section 211 is ended therewith.

Incidentally, it is described in the foregoing description that the monochromatic image production sections 183 and 184 of the fourth example of the configuration of the image processing section 7 are configured similarly to the example of the configuration of the monochromatic image production section 182 shown in FIG. 84 and execute a process similar to the monochromatic image production process (FIG. 95) of the monochromatic image production section 182 described with reference to FIG. 95. However, the monochromatic image production sections 182 to 184 may otherwise execute unique processes individually optimized therefor in place of the monochromatic candidate image process (step S261 of FIG. 95) included in the monochromatic image production process.

The R candidate image production process executed by the monochromatic image production section 182 in place of the monochromatic candidate image production process at step S261 is described with reference to a flow chart of FIG. 108. It is to be noted that, for the convenience of description, the interpolation section 201 which composes the monochromatic image production section 182 is hereinafter referred to as interpolation section 201-R.

At step S351, the interpolation section 201-R discriminates whether or not all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the first time. If the interpolation section 201-R discriminates that all pixels have not been used as a noticed pixel for the first time, then the processing advances to step S352. At step S352, the interpolation section 201-R determines one by one pixel as a noticed pixel for the first time beginning with the left lowermost pixel and ending with the right uppermost pixel of the color and sensitivity mosaic image.

At step S353, the interpolation section 201-R discriminates whether or not the color of the noticed pixel for the first time is R. If the interpolation section 201-R discriminates that the color of the noticed pixel for the first time is R, then the processing advances to step S354. At step S354, the interpolation section 201-R executes the vertical direction selective smoothing process using four pixels positioned upwardly, downwardly, leftwardly and rightwardly of the noticed pixel for the first time with a space of one pixel left therebetween to calculate a smoothed value α. At step S355, the interpolation section 201-R applies the sum of the pixel value of the noticed pixel for the first time and the smoothed value α calculated at step S354 to a synthetic sensitivity compensation LUT (a synthetic sensitivity compensation LUT similar to that described with reference to FIGS. 90 to 92) built therein and determines the resulting value as a pixel value corresponding to the noticed pixel for the first time of an R candidate image. The processing returns to step S351.

It is to be noted that, if it is discriminated at step S353 that the color of the noticed pixel for the first time is not R, then the processing returns to step S351 skipping the steps S354 and S355.

Thereafter, the processing at steps S351 to S355 is repeated until it is discriminated at step S351 that all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the first time. When it is discriminated at step S351 that all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the first time, the processing advances to step S356.

At step S356, the interpolation section 201-R discriminates whether or not all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the second time. If the interpolation section 201-R discriminates that all pixels have not been used as a noticed pixel for the second time, then the processing advances to step S357. At step S357, the interpolation section 201-R determines one by one pixel as a noticed pixel for the second time beginning with the left lowermost pixel and ending with the right uppermost pixel of the color and sensitivity mosaic image.

At step S358, the interpolation section 201-R discriminates whether or not the color of the noticed pixel for the second time is B. If the interpolation section 201-R discriminates that the color of the noticed pixel for the second time is B, then the processing advances to step S359. At step S359, the interpolation section 201-R executes the oblique direction selective smoothing process using four pixels positioned obliquely in the neighborhood of the noticed pixel for the second time to calculate a smoothed value α. At step S360, the interpolation section 201-R determines the

smoothed value α calculated at step S359 as a pixel value corresponding to the noticed pixel for the second time of the R candidate image. The processing returns to step S356.

It is to be noted that, if it is discriminated at step S358 that the color of the noticed pixel for the second time is not B, then the processing returns to step S356 skipping the steps S359 and S360.

Thereafter, the processing at steps S356 to S360 is repeated until it is discriminated at step S356 that all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the second time. When it is discriminated at step S356 that all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the second time, the processing advances to step S351.

At step S361, the interpolation section 201-R discriminates whether or not all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the third time. If the interpolation section 201-R discriminates that all pixels have not been used as a noticed pixel for the third time, then the processing advances to step S362. At step S362, the interpolation section 201-R determines one by one pixel as a noticed pixel for the third time beginning with the left lowermost pixel and ending with the right uppermost pixel of the color and sensitivity mosaic image.

At step S363, the interpolation section 201-R discriminates whether or not the color of the noticed pixel for the third time is G. If the interpolation section 201-R discriminates that the color of the noticed pixel for the third time is G, then the processing advances to step S364. At step S364, the interpolation section 201-R executes the vertical direction selective smoothing process using four pixels positioned upwardly, downwardly, leftwardly and rightwardly of the noticed pixel for the third time to calculate a smoothed value α. At step S365, the interpolation section 201-R determines the smoothed value α calculated at step S364 as a pixel value corresponding to the noticed pixel for the third time of an R candidate image.

It is to be noted that, if it is discriminated at step S363 that the color of the noticed pixel for the third time is not G, then the processing returns to step S351 skipping the steps S364 and S365.

Thereafter, the processing at steps S361 to S365 is repeated until it is discriminated at step S361 that all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the third time. When it is discriminated at step S361 that all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the third time, the R candidate image production process is ended.

The B candidate image production process executed by the monochromatic image production section 184 is described with reference to a flow chart of FIG. 109. It is to be noted that, for the convenience of description, the component of the monochromatic image production section 184 which corresponds to the interpolation section 201 of the monochromatic image production section 182 is hereinafter referred to as interpolation section 201-B.

At step S371, the interpolation section 201-B discriminates whether or not all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the first time. If the interpolation section 201-B discriminates that all pixels have not been used as a noticed pixel for the first time, then the processing advances to step S372. At step S372, the interpolation section 201-B determines one by one pixel as a noticed pixel for the first time beginning with the left lowermost pixel and ending with the right uppermost pixel of the color and sensitivity mosaic image.

At step S373, the interpolation section 201-B discriminates whether or not the color of the noticed pixel for the first time is B. If the interpolation section 201-B discriminates that the color of the noticed pixel for the first time is B, then the processing advances to step S374. At step S374, the interpolation section 201-B executes the vertical direction selective smoothing process using four pixels positioned upwardly, downwardly, leftwardly and rightwardly of the noticed pixel for the first time with a space of one pixel left therebetween to calculate a smoothed value α. At step S375, the interpolation section 201-B applies the sum of the pixel value of the noticed pixel for the first time and the smoothed value α calculated at step S374 to a synthetic sensitivity compensation LUT (a synthetic sensitivity compensation LUT similar to that described with reference to FIGS. 90 to 92) built therein and determines the resulting value as a pixel value corresponding to the noticed pixel for the first time of a B candidate image. The processing returns to step S371.

It is to be noted that, if it is discriminated at step S373 that the color of the noticed pixel for the first time is not B, then the processing returns to step S371 skipping the steps S374 and S375.

Thereafter, the processing at steps S371 to S375 is repeated until it is discriminated at step S371 that all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the first time. When it is discriminated at step S371 that all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the first time, the processing advances to step S376.

At step S376, the interpolation section 201-B discriminates whether or not all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the second time. If the interpolation section 201-B discriminates that all pixels have not been used as a noticed pixel for the second time, then the processing advances to step S377. At step S377, the interpolation section 201-B determines one by one pixel as a noticed pixel for the second time beginning with the left lowermost pixel and ending with the right uppermost pixel of the color and sensitivity mosaic image.

At step S378, the interpolation section 201-B discriminates whether or not the color of the noticed pixel for the second time is R. If the interpolation section 201-B discriminates that the color of the noticed pixel for the second time is R, then the processing advances to step S379. At step S379, the interpolation section 201-B executes the oblique direction selective smoothing process using four pixels positioned obliquely in the neighborhood of the noticed pixel for the second time to calculate a smoothed value α. At step S380, the interpolation section 201-B determines the smoothed value α calculated at step S379 as a pixel value corresponding to the noticed pixel for the second time of the B candidate image. The processing returns to step S376.

It is to be noted that, if it is discriminated at step S378 that the color of the noticed pixel for the second time is not R, then the processing returns to step S376 skipping the steps S379 and S380.

Thereafter, the processing at steps S376 to S380 is repeated until it is discriminated at step S376 that all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the second time. When it is discriminated at step S376 that all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the second time, the processing advances to step S381.

At step S381, the interpolation section 201-B discriminates whether or not all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the third time. If the interpolation section 201-B discriminates that all

pixels have not been used as a noticed pixel for the third time, then the processing advances to step S382. At step S382, the interpolation section 201-B determines one by one pixel as a noticed pixel for the third time beginning with the left lowermost pixel and ending with the right uppermost pixel of the color and sensitivity mosaic image.

At step S383, the interpolation section 201-B discriminates whether or not the color of the noticed pixel for the third time is G. If the interpolation section 201-B discriminates that the color of the noticed pixel for the third time is G, then the processing advances to step S384. At step S384, the interpolation section 201-B executes the vertical direction selective smoothing process using four pixels positioned upwardly, downwardly, leftwardly and rightwardly in the neighborhood of the noticed pixel for the third time to calculate a smoothed value α. At step S385, the interpolation section 201-B determines the smoothed value α calculated at step S384 as a pixel value corresponding to the noticed pixel for the third time of a B candidate image. The processing returns to step S381.

It is to be noted that, if it is discriminated at step S383 that the color of the noticed pixel for the third time is not G, then the processing returns to step S381 skipping the steps S384 and S385.

Thereafter, the processing at steps S381 to S385 is repeated until it is discriminated at step S381 that all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the third time. When it is discriminated at step S381 that all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the third time, the B candidate image production process is ended.

The G candidate image production process executed by the monochromatic image production section 183 is described with reference to a flow chart of FIG. 110. It is to be noted that, for the convenience of description, the component of the monochromatic image production section 183 which corresponds to the interpolation section 201 of the monochromatic image production section 182 is hereinafter referred to as interpolation section 201-G.

At step S391, the interpolation section 201-G discriminates whether or not all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the first time. If the interpolation section 201-G discriminates that all pixels have not been used as a noticed pixel for the first time, then the processing advances to step S392. At step S392, the interpolation section 201-G determines one by one pixel as a noticed pixel for the first time beginning with the left lowermost pixel and ending with the right uppermost pixel of the color and sensitivity mosaic image.

At step S393, the interpolation section 201-G discriminates whether or not the color of the noticed pixel for the first time is G. If the interpolation section 201-G discriminates that the color of the noticed pixel for the first time is G, then the processing advances to step S394. At step S394, the interpolation section 201-G executes the oblique direction selective smoothing process using four pixels positioned obliquely in the neighborhood of the noticed pixel for the first time to calculate a smoothed value α. At step S395, the interpolation section 201-G applies the sum of the pixel value of the noticed pixel for the first time and the smoothed value α calculated at step S394 to a synthetic sensitivity compensation LUT (a synthetic sensitivity compensation LUT similar to that described with reference to FIGS. 90 to 92) built therein and determines the resulting value as a pixel value corresponding to the noticed pixel for the first time of a G candidate image. The processing returns to step S391.

It is to be noted that, if it is discriminated at step S393 that the color of the noticed pixel for the first time is not G, then the processing returns to step S391 skipping the steps S394 and S395.

Thereafter, the processing at steps S391 to S395 is repeated until it is discriminated at step S391 that all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the first time. When it is discriminated at step S391 that all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the first time, the processing advances to step S396.

At step S396, the interpolation section 201-G discriminates whether or not all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the second time. If the interpolation section 201-G discriminates that all pixels have not been used as a noticed pixel for the second time, then the processing advances to step S397. At step S397, the interpolation section 201-G determines one by one pixel as a noticed pixel for the second time beginning with the left lowermost pixel and ending with the right uppermost pixel of the color and sensitivity mosaic image.

At step S398, the interpolation section 201-G discriminates whether or not the color of the noticed pixel for the second time is G. If the interpolation section 201-G discriminates that the color of the noticed pixel for the second time is not G, then the processing advances to step S399. At step S399, the interpolation section 201-G executes the vertical direction selective smoothing process using four pixels positioned upwardly, downwardly, leftwardly and rightwardly in the neighborhood of the noticed pixel for the second time to calculate a smoothed value α. At step S400, the interpolation section 201-G determines the smoothed value α calculated at step S399 as a pixel value corresponding to the noticed pixel for the second time of the G candidate image. The processing returns to step S396.

It is to be noted that, if it is discriminated at step S398 that the color of the noticed pixel for the second time is R, then the processing returns to step S396 skipping the steps S399 and S400.

Thereafter, the processing at steps S396 to S400 is repeated until it is discriminated at step S396 that all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the second time. When it is discriminated at step S396 that all pixels of the color and sensitivity mosaic image have been used as a noticed pixel for the second time, the R candidate image production process is ended.

Incidentally, as described hereinabove, in the fourth demosaic process, a luminance image and monochromatic images are produced from a color and sensitivity mosaic image, and all colors are restored making use of the correlation between the luminance and the color components to restore all pixels having a uniform sensitivity and all color components. However, the luminance image to be produced first may have a biased spectral characteristic only if color information to be restored has the correlation and the signal can be restored with a high resolution. For example, the characteristic of a color mosaic arrangement of a color and sensitivity mosaic image that it includes a number of pixels of G equal to twice that of pixels of R or pixels of B like a Bayer arrangement may be utilized to produce an image of a G component in place of a luminance image, and the correlation between G and R or between G and B may be utilized to produce an image of an R component and an image of a B component.

To execute such processing as just described, the image processing section 7 may be configured in such a manner as shown in FIG. 110. A luminance image production section

221 executes processing similar to that of the interpolation section 201 (FIG. 84) of the monochromatic image production section 182 in the fourth example of the configuration of the image processing section 7 to produce an output image G. Monochromatic image production sections 222 and 223 execute processing similar to that of the monochromatic image production sections 182 and 184 in the fourth example of the configuration of the image processing section 7 to produce an output image R and an output image B, respectively.

Description of the examples of the configuration of the image processing section 7 for executing the first to fourth demosaic processes is ended therewith.

It is to be noted that, while the series of processes described above can be executed by hardware, it may otherwise be executed by software. Where the series of processes is executed by software, a program which constructs the software is installed from a recording medium into a computer incorporated in hardware for exclusive use or, for example, a personal computer for universal use which can execute various functions by installing various programs.

The recording medium is formed as a package medium such as, as shown in FIG. 1, a magnetic disc 16 (including a floppy disc), an optical disc 17 (including a CD-ROM (Compact Disc-Read Only Memory) and a DVD (Digital Versatile Disc)), or a magneto-optical disc 18 (including an MD (Mini Disc)), or a semiconductor memory 19 which has the program recorded thereon or therein and is distributed to provide the program to a user separately from a computer. Else, the recording medium is formed as a ROM, a hard disc or the like in which the program is recorded and which is provided to a user in a state wherein the program is incorporated in a computer.

It is to be noted that, in the present specification, the steps which describe the program recorded in a recording medium may be but need not necessarily be processed in a time series in the order as described, and include processes which are executed in parallel or individually without being processed in a time series.

INDUSTRIAL APPLICABILITY

As described above, according to the present invention, a restored image wherein the sensitivities of pixels are uniformized and each pixel has all of a plurality of color components.

It should be understood that various changes and modifications to the presently preferred embodiments described herein will be apparent to those skilled in the art. Such changes and modifications can be made without departing from the spirit and scope of the present subject matter and without diminishing its intended advantages. It is therefore intended that such changes and modifications be covered by the appended claims.

The invention claimed is as follows:

[1. An image processing apparatus comprising:

restoration means for generating a restoration image based on a color-and-sensitivity mosaic image wherein

each of a plurality of pixels has one of first to third color components and one of a plurality of sensitivity characteristics with respect to intensity of light,

in terms of the sensitivity characteristics of the pixels, the pixels disposed in a same line have a same sensitivity characteristic, and the pixels disposed in different lines, which are adjacent to each other, have different sensitivity characteristics,

in terms of the color components of the pixels, the pixels having the first color component are arranged in a checker pattern irrespective of the pixels' sensitivity characteristics, the pixels having the second color component are arranged so as to be disposed in adjacent different lines and adjacent in a diagonal direction, and the pixels having the third color component are arranged so as to be disposed in adjacent different lines and adjacent in a diagonal direction,

in the restoration image, for each color component, the sensitivities of the pixels are uniformized, using as inputs (i) color mosaic pattern information, (ii) a color and sensitivity mosaic image, and (iii) sensitivity mosaic pattern information, so that each of the pixels having different sensitivity characteristics are (i) scaled to the same light intensity as the pixels having the same sensitivity characteristics to create sensitivity compensated pixel information for each of the pixels having different sensitivity characteristics and (ii) compared with a threshold value to discriminate the validity of the pixel value to create discrimination information for each of the pixels having different sensitivity characteristics, and each of the uniformized pixels has all of the plurality of color components.]

[2. An image processing method comprising:

a restoration step of generating a restoration image based on a color-and-sensitivity mosaic image wherein,

each of a plurality of pixels has one of first to third color components and one of a plurality of sensitivity characteristics with respect to intensity of light,

in terms of sensitivity characteristics of the pixels, the pixels disposed in a same line have a same sensitivity characteristic, and the pixels disposed in different lines, which are adjacent to each other, have different sensitivity characteristics,

in terms of color components of the pixels, the pixels having the first color component are arranged in a checker pattern irrespective of the pixels' sensitivity characteristics, the pixels having the second color component are arranged so as to be disposed in adjacent different lines and adjacent in a diagonal direction, and the pixels having the third color component are arranged so as to be disposed in adjacent different lines and adjacent in a diagonal direction,

in the restoration image, for each color component, the sensitivities of the pixels are uniformized, using as inputs (i) color mosaic pattern information, (ii) a color and sensitivity mosaic image, and (iii) sensitivity mosaic pattern information, so that each of the pixels having different sensitivity characteristics are (i) scaled to the same light intensity as the pixels having the same sensitivity characteristics to create sensitivity compensated pixel information for each of the pixels having different sensitivity characteristics and (ii) compared with a threshold value to discriminate the validity of the pixel value to create discrimination information for each of the pixels having different sensitivity characteristics, and each of the uniformized pixels has all of the plurality of color components.]

[3. An image processing apparatus comprising:

restoration means for generating a restoration image based on a color-and-sensitivity mosaic image wherein

each of a plurality of pixels has one of first to third color components and one of a plurality of sensitivity characteristics with respect to intensity of light,

the pixels having the first to third color components are arranged in a Bayer pattern with their color components,

the pixels having the first color component have different sensitivity characteristics from each other in different lines,

the pixels having the second color component are arranged so as to form a checker pattern with their sensitivity characteristics,

the pixels having the third color component are arranged so as to form a checker pattern with their sensitivity characteristics, and

in the restoration image, for each color component, the sensitivities of the pixels are uniformized, using as inputs (i) color mosaic pattern information, (ii) a color and sensitivity mosaic image, and (iii) sensitivity mosaic pattern information, so that each of the pixels having different sensitivity characteristics are (i) scaled to the same light intensity as the pixels having the same sensitivity characteristics to create sensitivity compensated pixel information for each of the pixels having different sensitivity characteristics and (ii) compared with a threshold value to discriminate the validity of the pixel value to create discrimination information for each of the pixels having different sensitivity characteristics, and each of the uniformized pixels has all of the plurality of color components.]

[4. An image processing method comprising:

a restoration step of generating a restoration image based on a color-and-sensitivity mosaic image wherein

each of a plurality of pixels has one of first to third color components and one of a plurality of sensitivity characteristics with respect to intensity of light,

the pixels having the first to third color components are arranged in a Bayer pattern with their color components,

the pixels having the first color component have different sensitivity characteristics from each other in different lines,

the pixels having the second color component are arranged so as to form a checker pattern with their sensitivity characteristics,

the pixels having, the third color component are arranged so as to form a checker pattern with their sensitivity characteristics, and

in the restoration image, for each color component, the sensitivities of the pixels are uniformized, using as inputs (i) color mosaic pattern information, (ii) a color and sensitivity mosaic image, and (iii) sensitivity mosaic pattern information, so that each of the pixels having different sensitivity characteristics are (i) scaled to the same light intensity as the pixels having the same sensitivity characteristics to create sensitivity compensated pixel information for each of the pixels having different sensitivity characteristics and (ii) compared with a threshold value to discriminate the validity of the pixel value to create discrimination information for each of the pixels having different sensitivity characteristics, and each of the uniformized pixels has all of the plurality of color components.]

5. An image pickup device comprising:

a plurality of pixels configured to sense light, each of the plurality of pixels having one of a plurality of color components and one of a plurality of sensitivity characteristics to light intensity, wherein pixels having a same color component and a same sensitivity characteristic are arranged in a lattice arrangement, and pixels having the same color component irrespective of the sensitivity characteristic are arranged in a lattice arrangement;

a photo-electric conversion unit configured to produce a color and sensitivity mosaic image based on the light sensed by the plurality of pixels; and

a restoration unit configured to (i) use the color and sensitivity mosaic image as an input for scaling each of the pixels having different sensitivity characteristics to a same light intensity as the pixels having a same sensitivity characteristic to create sensitivity compensated pixel information for each of the pixels having different sensitivity characteristics, (ii) use the color and sensitivity mosaic image as an input for comparing each of the pixels having different sensitivity characteristics with a threshold value to discriminate the validity of a pixel value to create discrimination information for each of the pixels having different sensitivity characteristics, and (iii) interpolate the sensitivity compensated pixel information based on the discrimination information.

6. The image pickup device according to claim 5, wherein the plurality of color components include three color components.

7. The image pickup device according to claim 5, wherein the plurality of color components include red, green, and blue color components.

8. The image pickup device according to claim 5, wherein the plurality of color components include green and blue color components.

9. The image pickup device according to claim 5, wherein the plurality of color components include red and blue color components.

10. The image pickup device according to claim 5, wherein the plurality of color components include red and green color components.

11. The image pickup device according to claim 5, wherein the plurality of color components include at least a color component besides red, green and blue.

12. The image pickup device according to claim 5, wherein the plurality of color components include red, green, and blue color components and a fourth color component.

13. The image pickup device according to claim 5, wherein the plurality of sensitivity characteristics include two patterns.

14. The image pickup device according to claim 5, wherein the image pickup device changes between a normal mode and a high dynamic range mode.

15. An image pickup method comprising:

a step for sensing light by a plurality of pixels, each of the plurality of pixels having one of a plurality of color components and one of a plurality of sensitivity characteristics to light intensity, wherein pixels having a same color component and a same sensitivity characteristic are arranged in a lattice arrangement, and pixels having the same color component irrespective of the sensitivity characteristic are arranged in a lattice arrangement;

a step for producing a color and sensitivity mosaic image based on the light sensed by the plurality of pixels;

using the color and sensitivity mosaic image as an input, a step for scaling each of the pixels having different sensitivity characteristics to a same light intensity as the pixels having a same sensitivity characteristic to

create sensitivity compensated pixel information for each of the pixels having different sensitivity characteristics;

using the color and sensitivity mosaic image as an input, a step for comparing each of the pixels having different sensitivity characteristics with a threshold value to discriminate the validity of a pixel value to create discrimination information for each of the pixels having different sensitivity characteristics; and

a step for interpolating the sensitivity compensated pixel information based on the discrimination information.

16. A program stored on a non-transitory computer readable storage medium, which when executed, causes a computer to:

sense light by a plurality of pixels, each of the plurality of pixels having one of a plurality of color components and one of a plurality of sensitivity characteristics to light intensity, wherein pixels having a same color component and a same sensitivity characteristic are arranged in a lattice arrangement, and pixels having the same color component irrespective of the sensitivity characteristic are arranged in a lattice arrangement;

produce a color and sensitivity mosaic image based on the light sensed by the plurality of pixels;

use the color and sensitivity mosaic image as an input for scaling each of the pixels having different sensitivity characteristics to a same light intensity as the pixels having a same sensitivity characteristic to create sensitivity compensated pixel information for each of the pixels having different sensitivity characteristics;

use the color and sensitivity mosaic image as an input for comparing each of the pixels having different sensitivity characteristics with a threshold value to discriminate the validity of a pixel value to create discrimination information for each of the pixels having different sensitivity characteristics; and

interpolate the sensitivity compensated pixel information based on the discrimination information.

17. An image pickup apparatus comprising:

a plurality of pixels configured to sense light, each of the plurality of pixels having one of a plurality of color components and one of a plurality of sensitivity characteristics to light intensity, wherein pixels having a same color component and a same sensitivity characteristic are arranged in a lattice arrangement, and pixels having the same color component irrespective of the sensitivity characteristic are arranged in a lattice arrangement;

a photo-electric conversion unit configured to produce a color and sensitivity mosaic image based on the light sensed by the plurality of pixels; and

a restoration unit configured to produce a restoration image based on the color and sensitivity mosaic image by (i) using the color and sensitivity mosaic image as an input for scaling each of the pixels having different sensitivity characteristics to a same light intensity as the pixels having a same sensitivity characteristic to create sensitivity compensated pixel information for each of the pixels having different sensitivity characteristics, (ii) using the color and sensitivity mosaic image as an input for comparing each of the pixels having different sensitivity characteristics with a threshold value to discriminate the validity of a pixel value to create discrimination information for each of the pixels having different sensitivity characteristics, and (iii) interpolating the sensitivity compensated pixel information based on the discrimination information,

wherein the restoration image has uniform sensitivities of the pixels.

18. The image pickup apparatus according to claim 17, wherein the plurality of color components include three color components.

19. The image pickup apparatus according to claim 17, wherein the plurality of color components include red, green, and blue color components.

20. The image pickup apparatus according to claim 17, wherein the plurality of color components include green and blue color components.

21. The image pickup apparatus according to claim 17, wherein the plurality of color components include red and blue color components.

22. The image pickup apparatus according to claim 17, wherein the plurality of color components include red and green color components.

23. The image pickup apparatus according to claim 17, wherein the plurality of color components include at least a color component besides red, green and blue.

24. The image pickup apparatus according to claim 17, wherein the plurality of color components include red, green, and blue color components and a fourth color component.

25. The image pickup apparatus according to claim 17, wherein the plurality of sensitivity characteristics include two patterns.

26. The image pickup apparatus according to claim 17, wherein the image pickup apparatus changes between a normal mode and a high dynamic range mode.

27. An image pickup method comprising:

a step for sensing light by a plurality of pixels, each of the plurality of pixels having one of a plurality of color components and one of a plurality of sensitivity characteristics to light intensity, wherein pixels having a same color component and a same sensitivity characteristic are arranged in a lattice arrangement, and pixels having the same color component irrespective of the sensitivity characteristic are arranged in a lattice arrangement;

a step for producing a color and sensitivity mosaic image based on the light sensed by the plurality of pixels; and

producing a restoration image based on the color and sensitivity mosaic image by (i) using the color and sensitivity mosaic image as an input, a step for scaling each of the pixels having different sensitivity characteristics to a same light intensity as the pixels having a same sensitivity characteristic to create sensitivity compensated pixel information for each of the pixels having different sensitivity characteristics, (ii) using the color and sensitivity mosaic image as an input, a step for comparing each of the pixels having different sensitivity characteristics with a threshold value to discriminate the validity of a pixel value to create discrimination information for each of the pixels having different sensitivity characteristics, and (iii) a step for interpolating the sensitivity compensated pixel information based on the discrimination information,

wherein the restoration image has uniform sensitivities of the pixels.

28. A program stored on a non-transitory computer readable storage medium, which when executed, causes a computer to:

sense light by a plurality of pixels, each of the plurality of pixels having one of a plurality of color components and one of a plurality of sensitivity characteristics to light intensity, wherein pixels having a same color

component and a same sensitivity characteristic are arranged in a lattice arrangement, and pixels having the same color component irrespective of the sensitivity characteristic are arranged in a lattice arrangement;

produce a color and sensitivity mosaic image based on the light sensed by the plurality of pixels; and

produce a restoration image based on the color and sensitivity mosaic image by (i) using the color and sensitivity mosaic image as an input for scaling each of the pixels having different sensitivity characteristics to a same light intensity as the pixels having a same sensitivity characteristic to create sensitivity compensated pixel information for each of the pixels having different sensitivity characteristics, (ii) using the color and sensitivity mosaic image as an input for comparing each of the pixels having different sensitivity characteristics with a threshold value to discriminate the validity of a pixel value to create discrimination information for each of the pixels having different sensitivity characteristics, and (iii) interpolating the sensitivity compensated pixel information based on the discrimination information,

wherein the restoration image has uniform sensitivities of the pixels.

29. An image pickup apparatus comprising:

a plurality of pixels configured to sense light, each of the plurality of pixels having one of a plurality of color components and one of a plurality of sensitivity characteristics to light intensity, wherein pixels having a same color component and a same sensitivity characteristic are arranged in a lattice arrangement, and pixels having the same color component irrespective of the sensitivity characteristic are arranged in a lattice arrangement;

a photo-electric conversion unit configured to produce a color and sensitivity mosaic image based on the light sensed by the plurality of pixels; and

an image processing unit configured to produce a mosaic image based on the color and sensitivity mosaic image by (i) using the color and sensitivity mosaic image as an input for scaling each of the pixels having different sensitivity characteristics to a same light intensity as the pixels having a same sensitivity characteristic to create sensitivity compensated pixel information for each of the pixels having different sensitivity characteristics, (ii) using the color and sensitivity mosaic image as an input for comparing each of the pixels having different sensitivity characteristics with a threshold value to discriminate the validity of a pixel value to create discrimination information for each of the pixels having different sensitivity characteristics, and (iii) interpolating the sensitivity compensated pixel information based on the discrimination information,

wherein the mosaic image has uniform sensitivities of the pixels and each of the pixels has one of the plurality of color components.

30. The image pickup apparatus according to claim 29, wherein the plurality of color components include three color components.

31. The image pickup apparatus according to claim 29, wherein the plurality of color components include red, green, and blue color components.

32. The image pickup apparatus according to claim 29, wherein the plurality of color components include green and blue color components.

33. The image pickup apparatus according to claim 29, wherein the plurality of color components include red and blue color components.

34. The image pickup apparatus according to claim 29, wherein the plurality of color components include red and green color components.

35. The image pickup apparatus according to claim 29, wherein the plurality of color components include at least a color component besides red, green and blue.

36. The image pickup apparatus according to claim 29, wherein the plurality of color components include red, green, and blue color components and a fourth color component.

37. The image pickup apparatus according to claim 29, wherein the plurality of sensitivity characteristics include two patterns.

38. The image pickup apparatus according to claim 29, wherein the image pickup apparatus changes between a normal mode and a high dynamic range mode.

39. An image pickup method comprising:

a step for sensing light by a plurality of pixels, each of the plurality of pixels having one of a plurality of color components and one of a plurality of sensitivity characteristics to light intensity, wherein pixels having a same color component and a same sensitivity characteristic are arranged in a lattice arrangement, and pixels having the same color component irrespective of the sensitivity characteristic are arranged in a lattice arrangement;

a step for producing a color and sensitivity mosaic image based on the light sensed by the plurality of pixels; and

producing a mosaic image based on the color and sensitivity mosaic image by (i) using the color and sensitivity mosaic image as an input, a step for scaling each of the pixels having different sensitivity characteristics to a same light intensity as the pixels having a same sensitivity characteristic to create sensitivity compensated pixel information for each of the pixels having different sensitivity characteristics, (ii) using the color and sensitivity mosaic image as an input, a step for comparing each of the pixels having different sensitivity characteristics with a threshold value to discriminate the validity of a pixel value to create discrimination information for each of the pixels having different sensitivity characteristics, and (iii) a step for interpolating the sensitivity compensated pixel information based on the discrimination information,

wherein the mosaic image has uniform sensitivities of the pixels and each of the pixels has one of the plurality of color components.

40. A program stored on a non-transitory computer readable storage medium, which when executed, causes a computer to:

sense light by a plurality of pixels, each of the plurality of pixels having one of a plurality of color components and one of a plurality of sensitivity characteristics to light intensity, wherein pixels having a same color component and a same sensitivity characteristic are arranged in a lattice arrangement, and pixels having the same color component irrespective of the sensitivity characteristic are arranged in a lattice arrangement;

produce a color and sensitivity mosaic image based on the light sensed by the plurality of pixels; and

produce a mosaic image based on the color and sensitivity mosaic image by (i) using the color and sensitivity mosaic image as an input for scaling each of the pixels having different sensitivity characteristics to a same

light intensity as the pixels having a same sensitivity characteristic to create sensitivity compensated pixel information for each of the pixels having different sensitivity characteristics, (ii) using the color and sensitivity mosaic image as an input for comparing each of the pixels having different sensitivity characteristics with a threshold value to discriminate the validity of a pixel value to create discrimination information for each of the pixels having different sensitivity characteristics, and (iii) interpolating the sensitivity compensated pixel information based on the discrimination information,

wherein the mosaic image has uniform sensitivities of the pixels and each of the pixels has one of the plurality of color components.

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