US009270897B2

(12) **United States Patent**
Ito et al.

(10) **Patent No.: US 9,270,897 B2**
(45) **Date of Patent: Feb. 23, 2016**

(54) **APPARATUS, METHOD, AND PROGRAM FOR PROCESSING IMAGE**

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(73) Assignee: **Sony Corporation**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1729 days.

(21) Appl. No.: **12/487,922**

(22) Filed: **Jun. 19, 2009**

(65) **Prior Publication Data**

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(30) **Foreign Application Priority Data**

Jun. 20, 2008 (JP) P2008-161581

(51) **Int. Cl.**

H04N 5/228	(2006.01)
H04N 5/235	(2006.01)
H04N 5/243	(2006.01)
G06T 5/00	(2006.01)
H04N 5/14	(2006.01)

(52) **U.S. Cl.**

CPC ***H04N 5/243*** (2013.01); ***G06T 5/002*** (2013.01); ***G06T 5/003*** (2013.01); ***H04N 5/235*** (2013.01); *G06T 2207/20201* (2013.01); *H04N 5/145* (2013.01)

(58) **Field of Classification Search**

USPC 348/208.4, 208.13, 208.14, 208.99, 348/222.1; 382/103, 107, 216

See application file for complete search history.

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Primary Examiner — Trung Diep

(74) *Attorney, Agent, or Firm* — Finnegan, Henderson, Farabow, Garrett & Dunner, L.L.P.

(57) **ABSTRACT**

An image processing apparatus includes a correction parameter calculation unit for calculating a motion blur correction parameter for motion blur correction on the basis of motion information indicating a motion of an image between unit images, the unit images forming image data, and shutter speed information obtained at the image capturing of the image data, and a motion blur correction processing unit for correcting a motion blur quantity contained in the image data by performing at least a process of reducing a motion blur in accordance with the motion blur correction parameter.

11 Claims, 28 Drawing Sheets

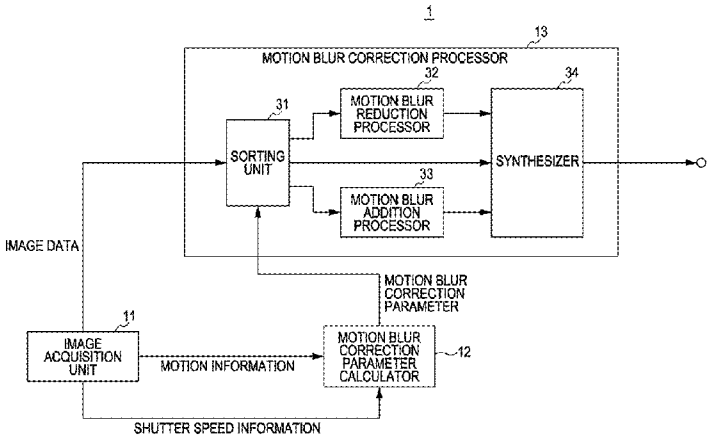

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FIG. 1

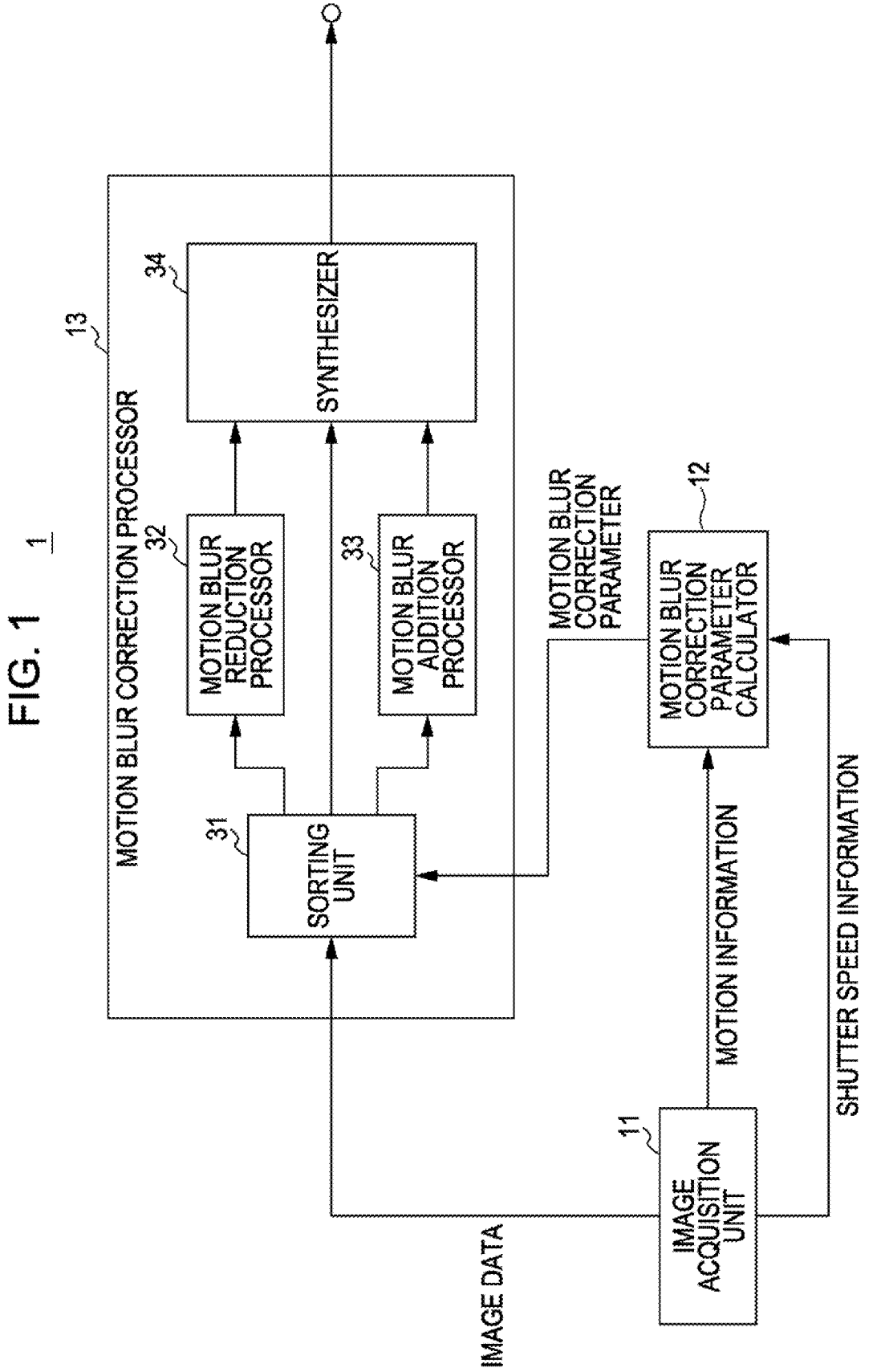

1
13
MOTION BLUR CORRECTION PROCESSOR
34
SYNTHESIZER
32
MOTION BLUR REDUCTION PROCESSOR
33
MOTION BLUR ADDITION PROCESSOR
31
SORTING UNIT
MOTION BLUR CORRECTION PARAMETER
12
MOTION BLUR CORRECTION PARAMETER CALCULATOR
MOTION INFORMATION
11
IMAGE ACQUISITION UNIT
SHUTTER SPEED INFORMATION
IMAGE DATA

FIG. 2

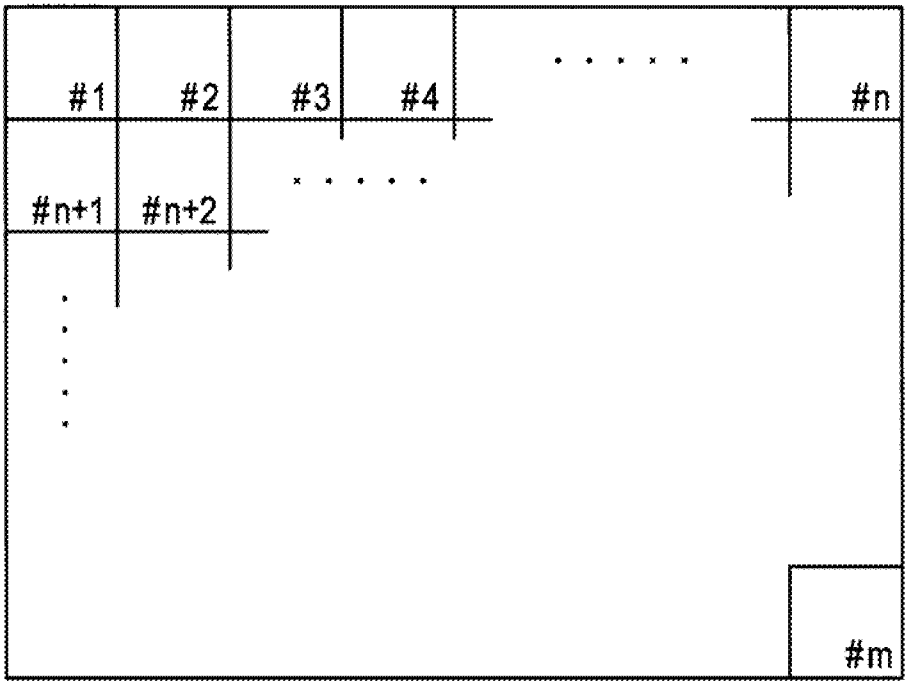


FIG. 3

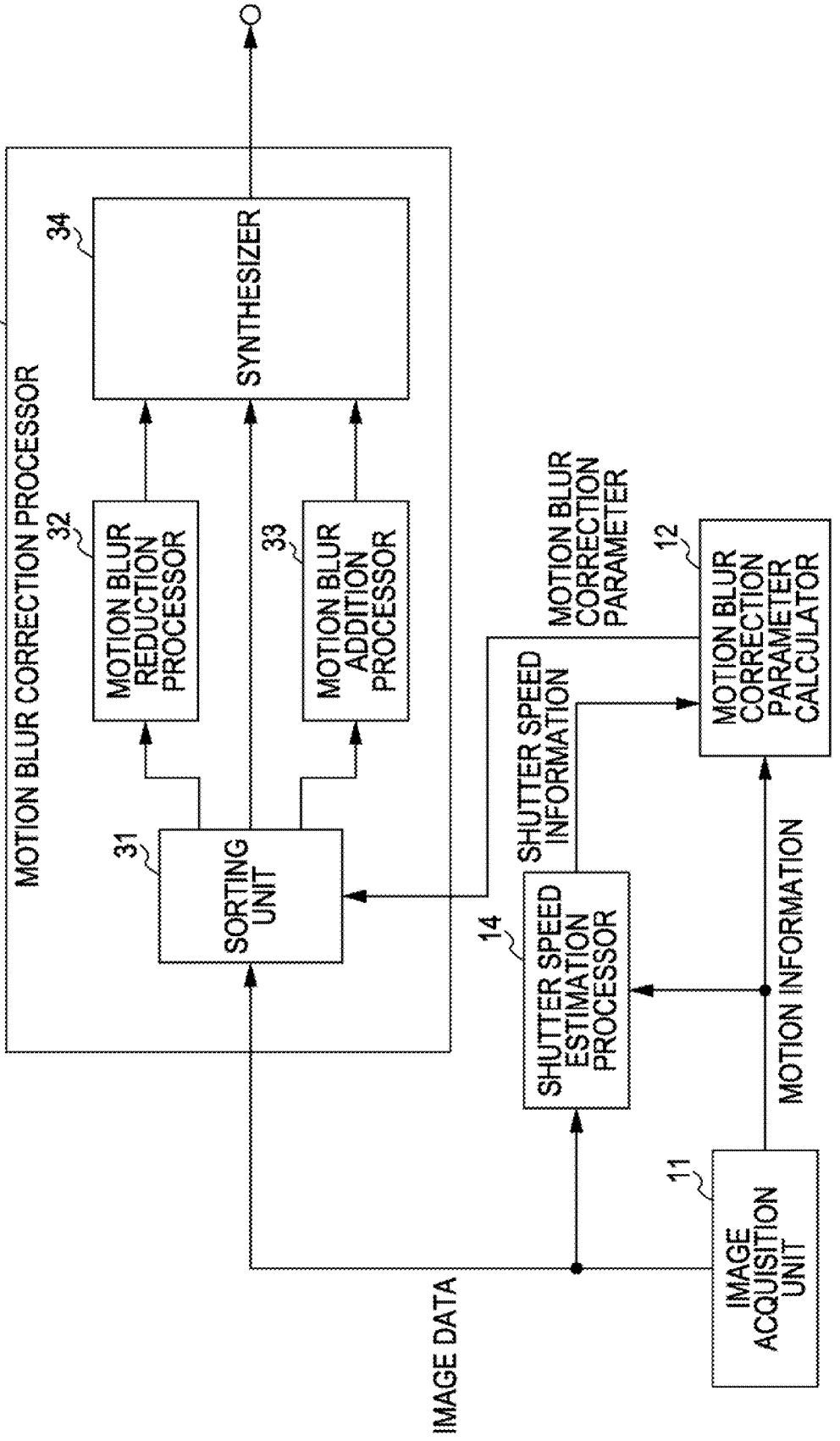

2
13
MOTION BLUR CORRECTION PROCESSOR
34
SYNTHESIZER
32
MOTION BLUR REDUCTION PROCESSOR
33
MOTION BLUR ADDITION PROCESSOR
31
SORTING UNIT
MOTION BLUR CORRECTION PARAMETER
12
MOTION BLUR CORRECTION PARAMETER CALCULATOR
SHUTTER SPEED INFORMATION
14
SHUTTER SPEED ESTIMATION PROCESSOR
MOTION INFORMATION
11
IMAGE ACQUISITION UNIT
IMAGE DATA

FIG. 4

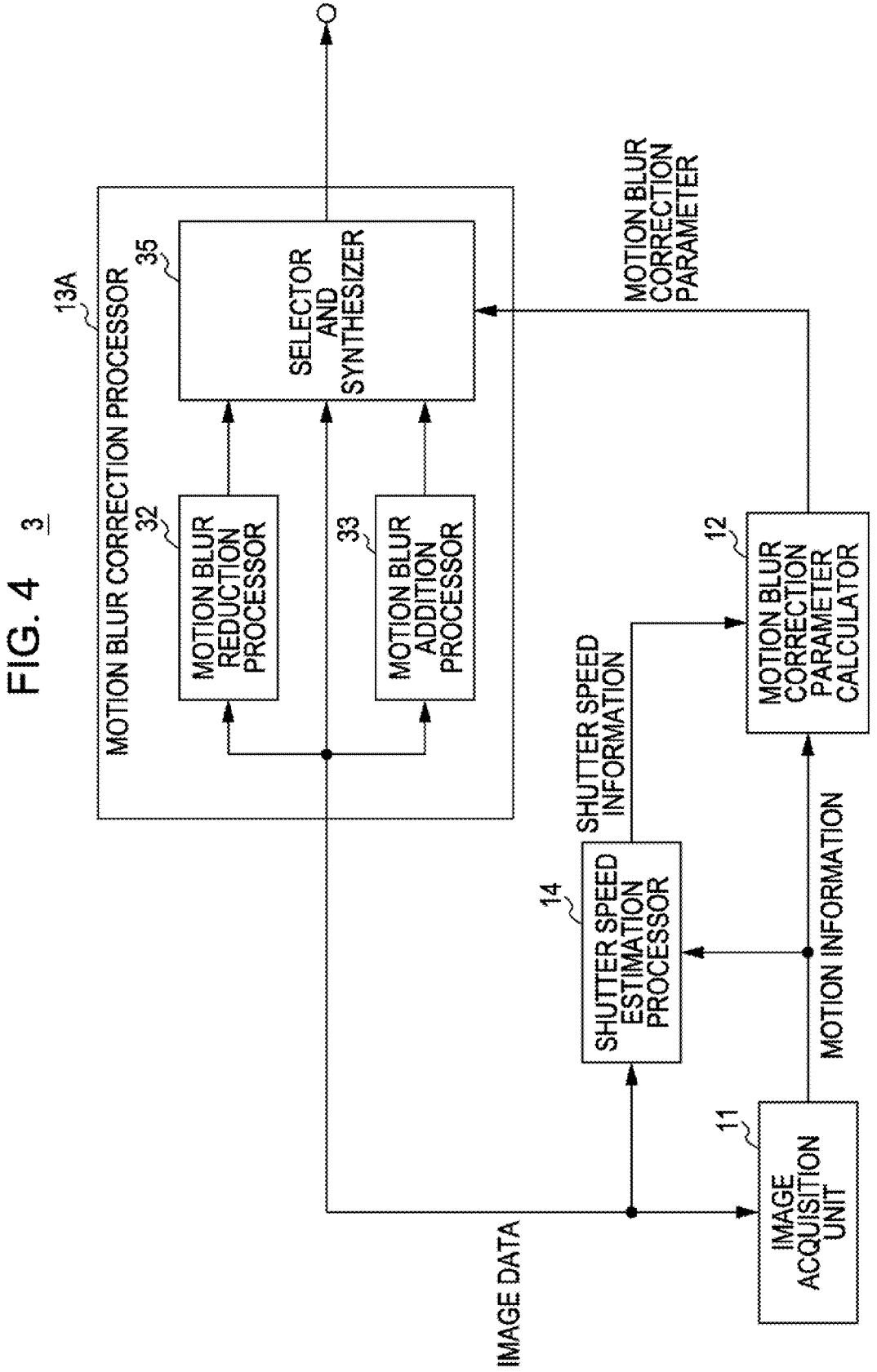

3
13A
MOTION BLUR CORRECTION PROCESSOR
35
SELECTOR AND SYNTHESIZER
32
MOTION BLUR REDUCTION PROCESSOR
33
MOTION BLUR ADDITION PROCESSOR
MOTION BLUR CORRECTION PARAMETER
12
MOTION BLUR CORRECTION PARAMETER CALCULATOR
SHUTTER SPEED INFORMATION
14
SHUTTER SPEED ESTIMATION PROCESSOR
MOTION INFORMATION
11
IMAGE ACQUISITION UNIT
IMAGE DATA

FIG. 5

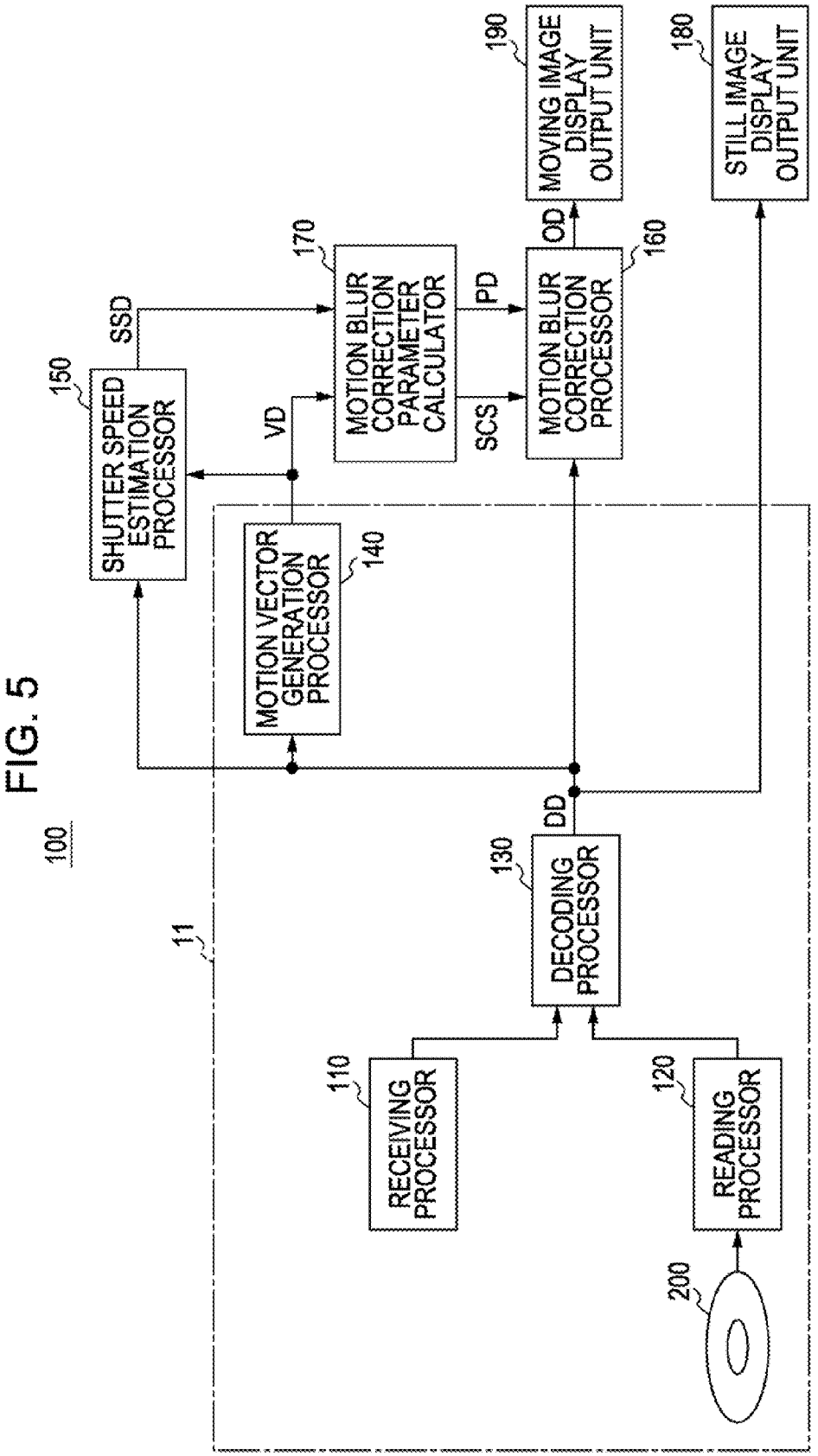

100
11
190
MOVING IMAGE DISPLAY OUTPUT UNIT
180
STILL IMAGE DISPLAY OUTPUT UNIT
170
MOTION BLUR CORRECTION PARAMETER CALCULATOR
160
MOTION BLUR CORRECTION PROCESSOR
OD
PD
SCS
SSD
150
SHUTTER SPEED ESTIMATION PROCESSOR
VD
MOTION VECTOR GENERATION PROCESSOR
140
DD
130
DECODING PROCESSOR
110
RECEIVING PROCESSOR
120
READING PROCESSOR
200

FIG. 6

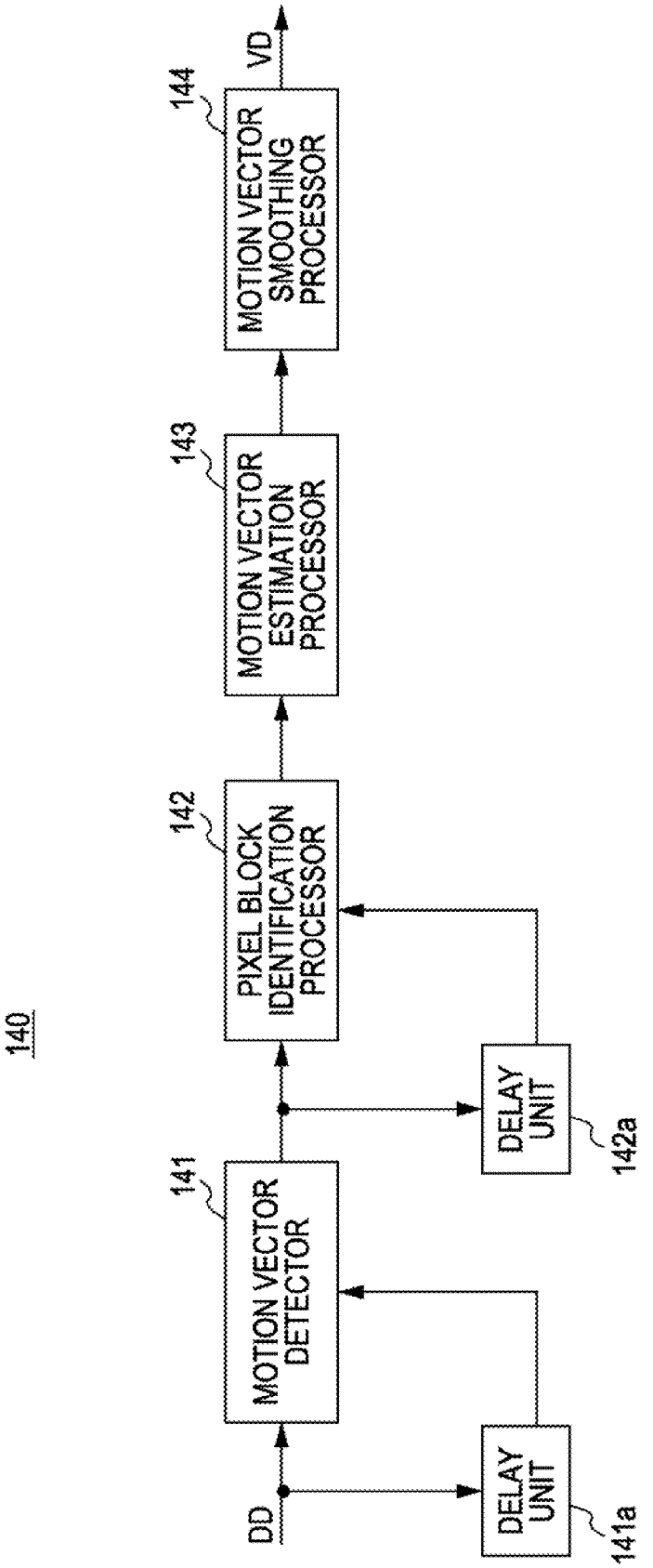

140
DD
MOTION VECTOR DETECTOR
141
DELAY UNIT
141a
PIXEL BLOCK IDENTIFICATION PROCESSOR
142
DELAY UNIT
142a
MOTION VECTOR ESTIMATION PROCESSOR
143
MOTION VECTOR SMOOTHING PROCESSOR
144
VD

FIG. 7

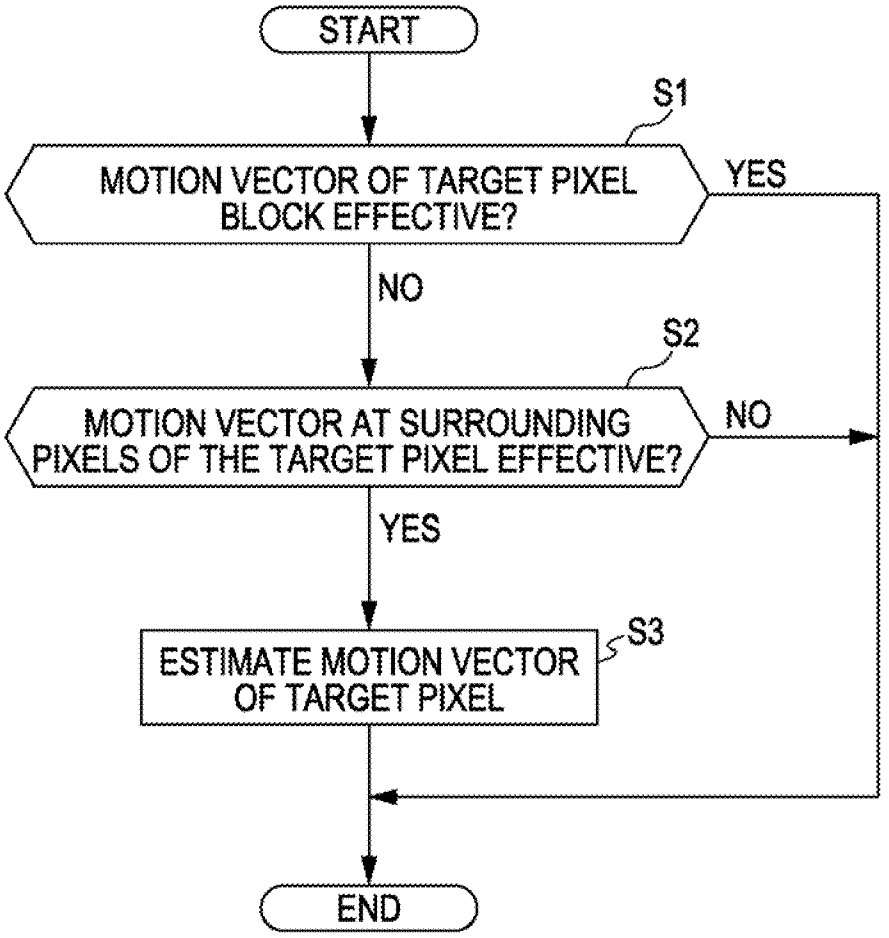

START
S1
MOTION VECTOR OF TARGET PIXEL BLOCK EFFECTIVE?
YES
NO
S2
MOTION VECTOR AT SURROUNDING PIXELS OF THE TARGET PIXEL EFFECTIVE?
NO
YES
S3
ESTIMATE MOTION VECTOR OF TARGET PIXEL
END

FIG. 8

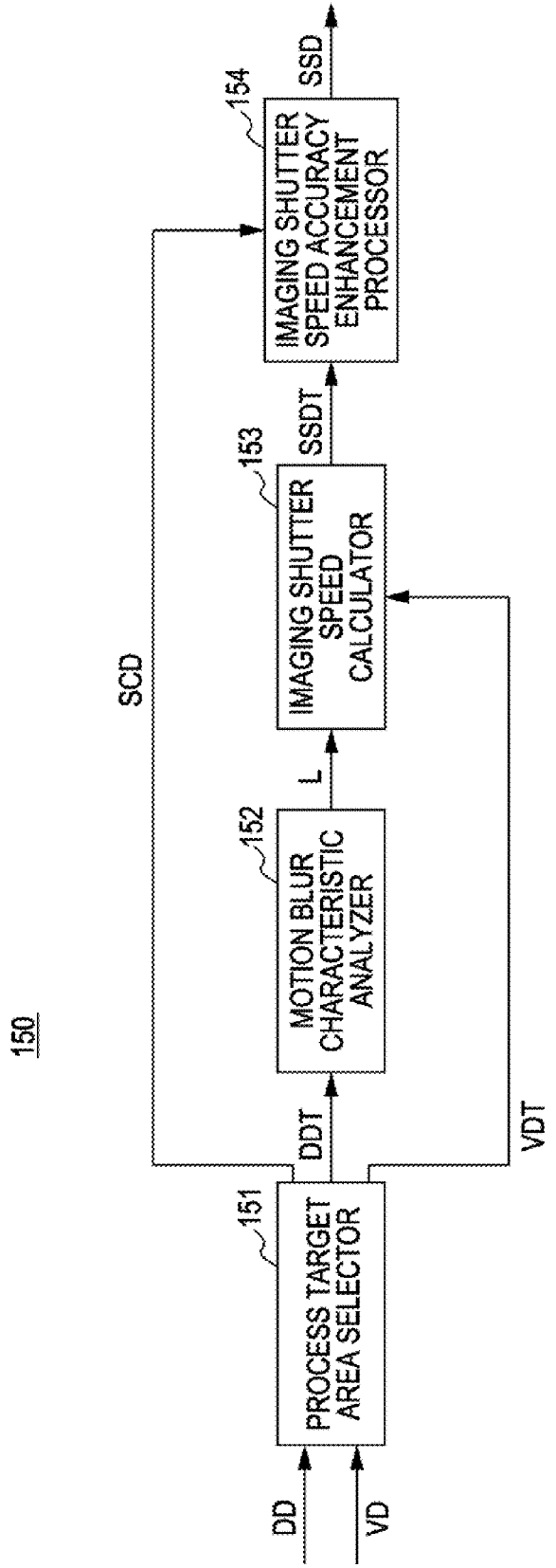
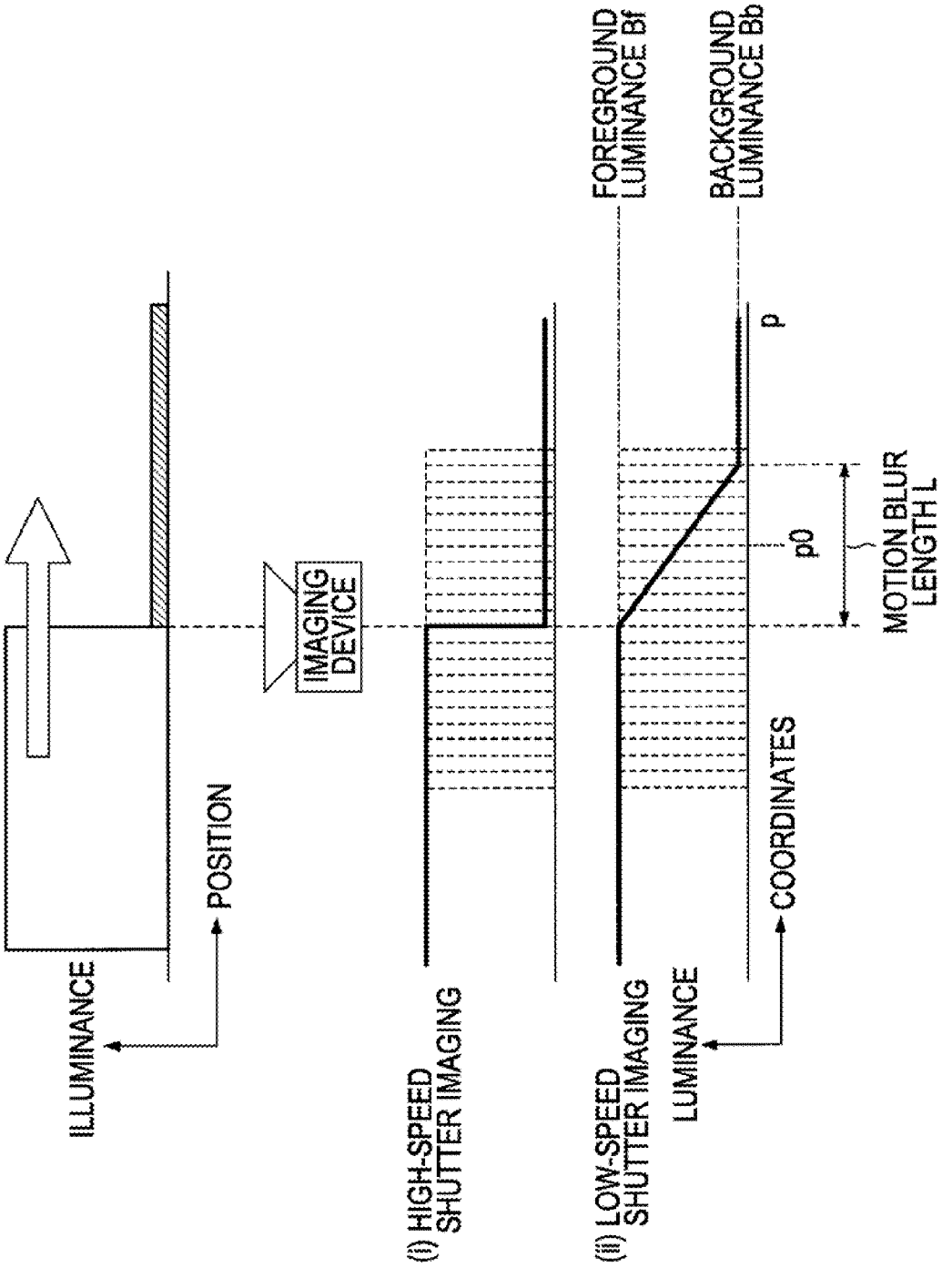

150
DD
VD
151
PROCESS TARGET AREA SELECTOR
DDT
152
MOTION BLUR CHARACTERISTIC ANALYZER
L
153
IMAGING SHUTTER SPEED CALCULATOR
SSDT
154
IMAGING SHUTTER SPEED ACCURACY ENHANCEMENT PROCESSOR
SSD
SCD
VDT

FIG. 9


ILLUMINANCE
POSITION
IMAGING DEVICE
(i) HIGH-SPEED SHUTTER IMAGING
(ii) LOW-SPEED SHUTTER IMAGING
LUMINANCE
COORDINATES
FOREGROUND LUMINANCE Bf
BACKGROUND LUMINANCE Bb
p
p0
MOTION BLUR LENGTH L

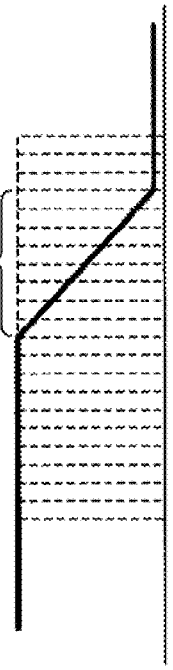


FIG. 10A2

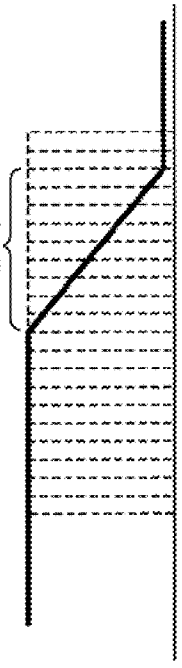


FIG. 10A1

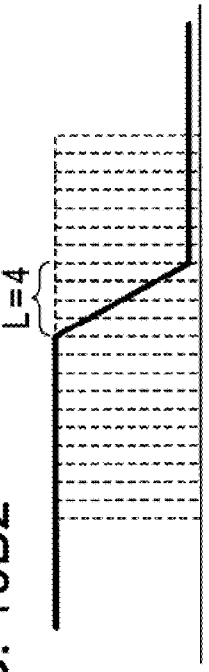


FIG. 10B2

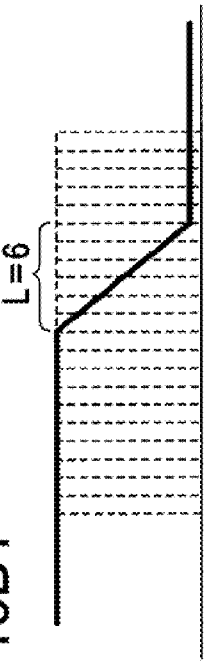


FIG. 10B1

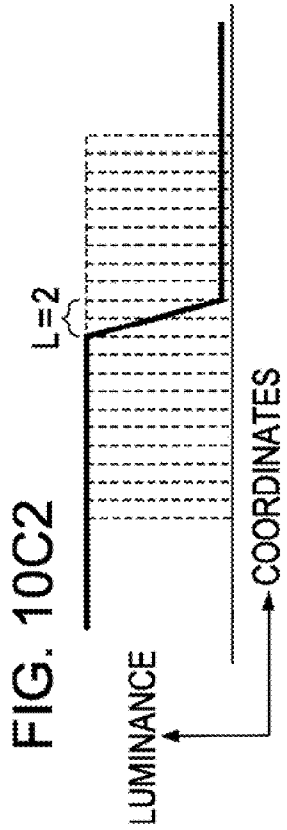


FIG. 10C2

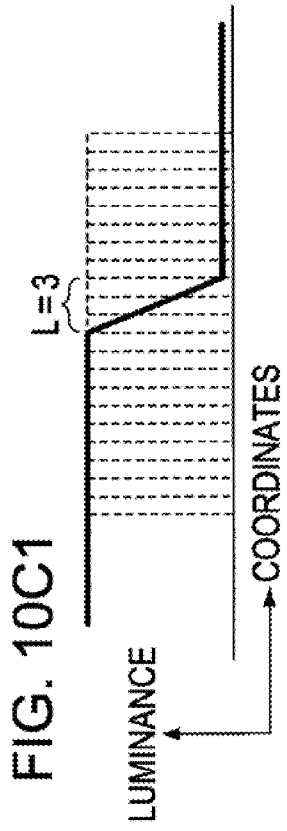


FIG. 10C1

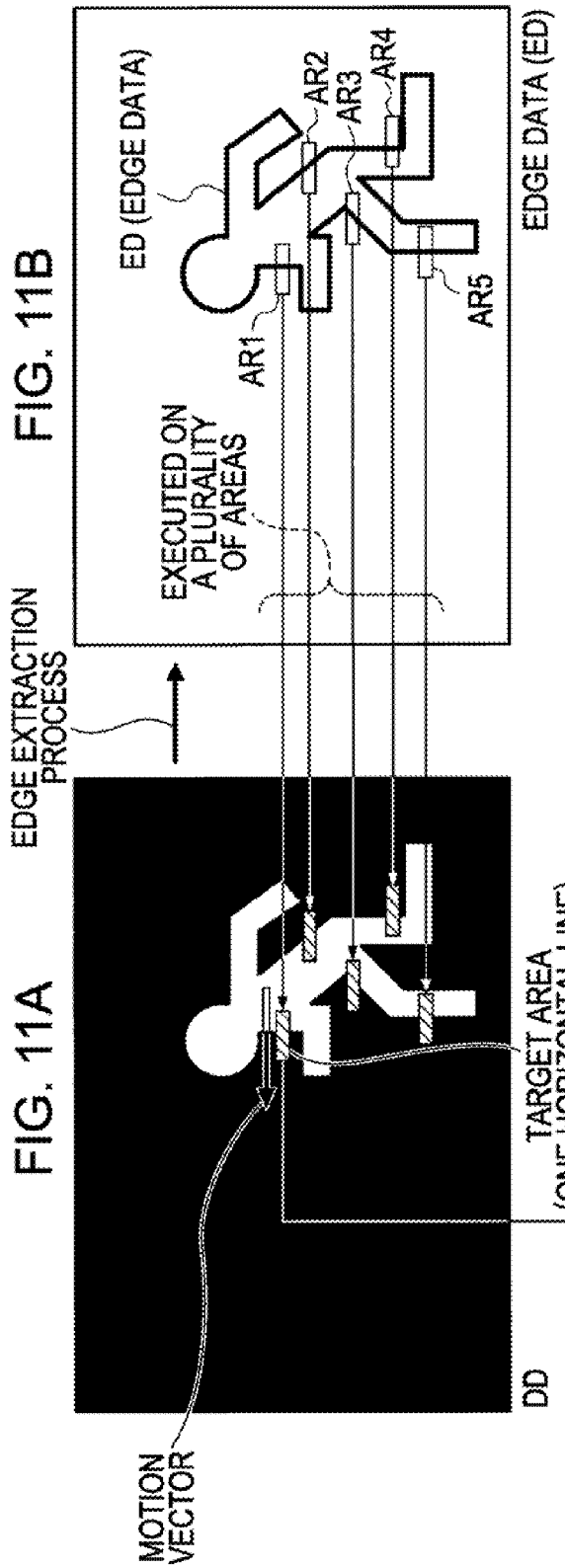


FIG. 11A
EDGE EXTRACTION PROCESS
ED (EDGE DATA)
AR1
AR2
AR3
AR4
AR5
EXECUTED ON A PLURALITY OF AREAS
EDGE DATA (ED)
TARGET AREA (ONE HORIZONTAL LINE)
DD
MOTION VECTOR

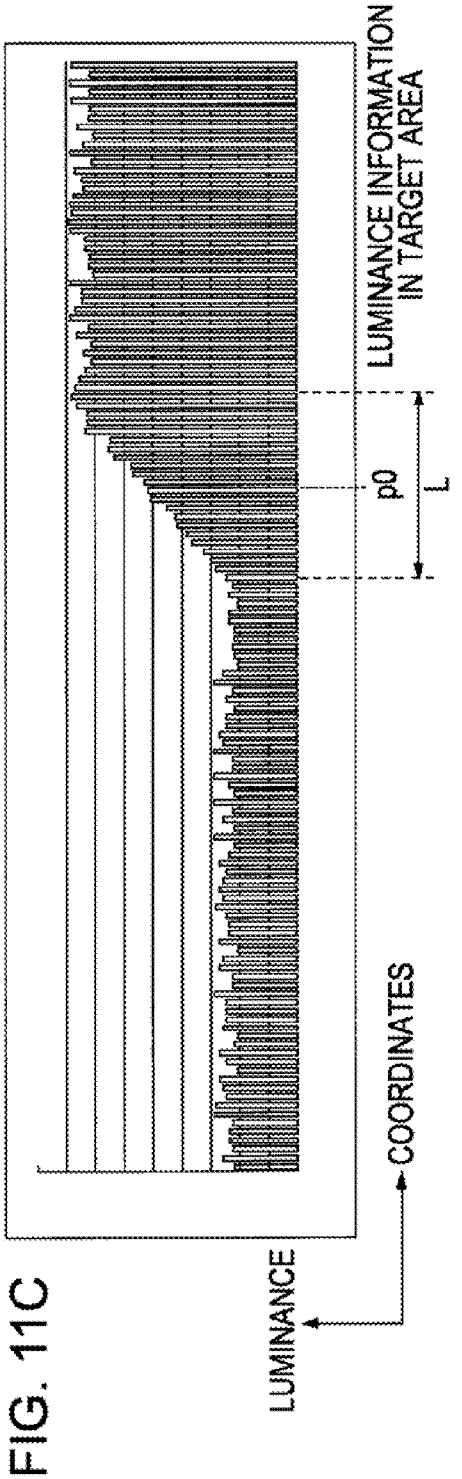


FIG. 11C
LUMINANCE INFORMATION IN TARGET AREA
p0
L
LUMINANCE
COORDINATES

FIG. 12

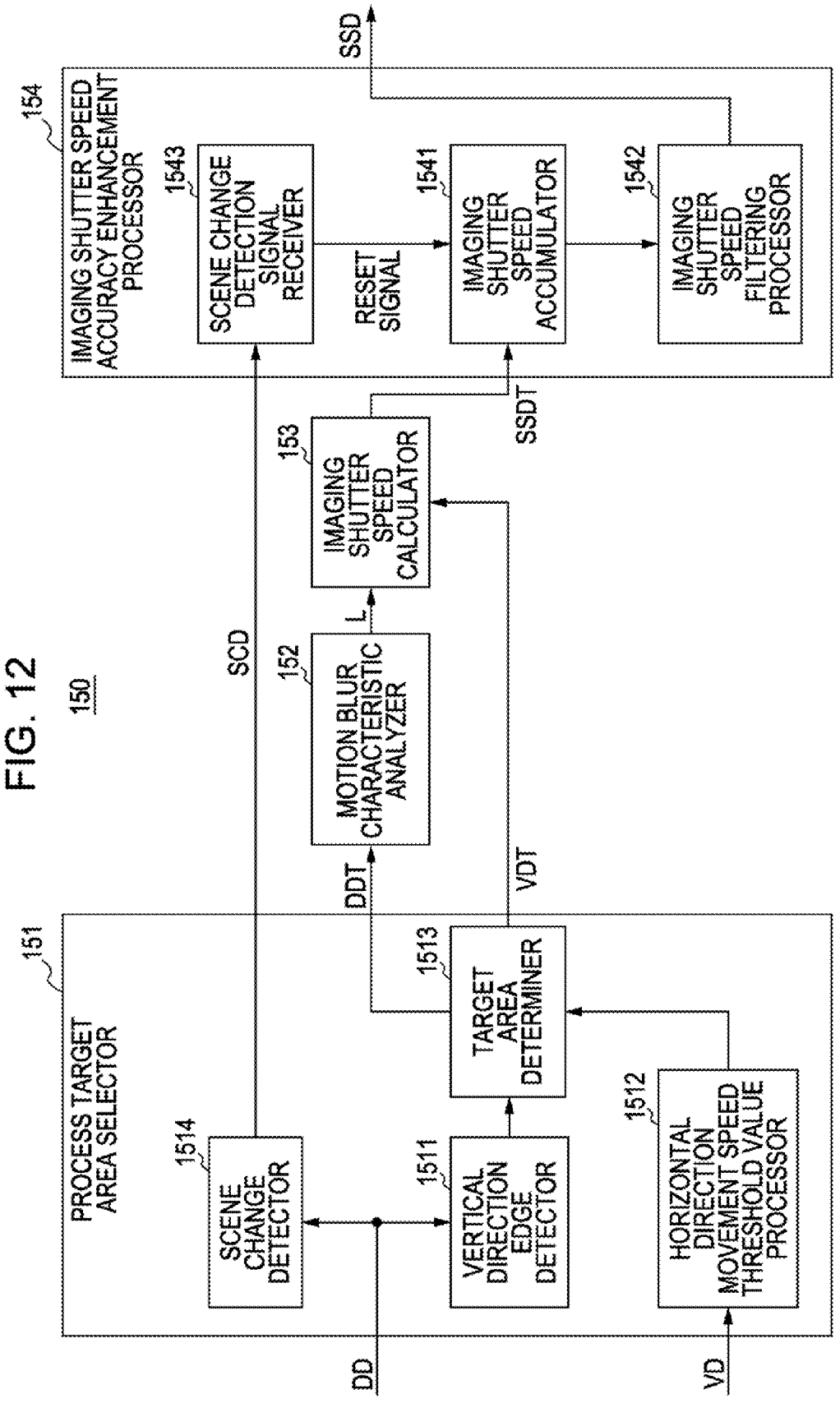

150
151
PROCESS TARGET AREA SELECTOR
SCENE CHANGE DETECTOR
1514
VERTICAL DIRECTION EDGE DETECTOR
1511
TARGET AREA DETERMINER
1513
HORIZONTAL DIRECTION MOVEMENT SPEED THRESHOLD VALUE PROCESSOR
1512
DD
VD
DDT
VDT
SCD
152
MOTION BLUR CHARACTERISTIC ANALYZER
L
153
IMAGING SHUTTER SPEED CALCULATOR
SSDT
154
IMAGING SHUTTER SPEED ACCURACY ENHANCEMENT PROCESSOR
SSD
1543
SCENE CHANGE DETECTION SIGNAL RECEIVER
RESET SIGNAL
1541
IMAGING SHUTTER SPEED ACCUMULATOR
1542
IMAGING SHUTTER SPEED FILTERING PROCESSOR

FIG. 13

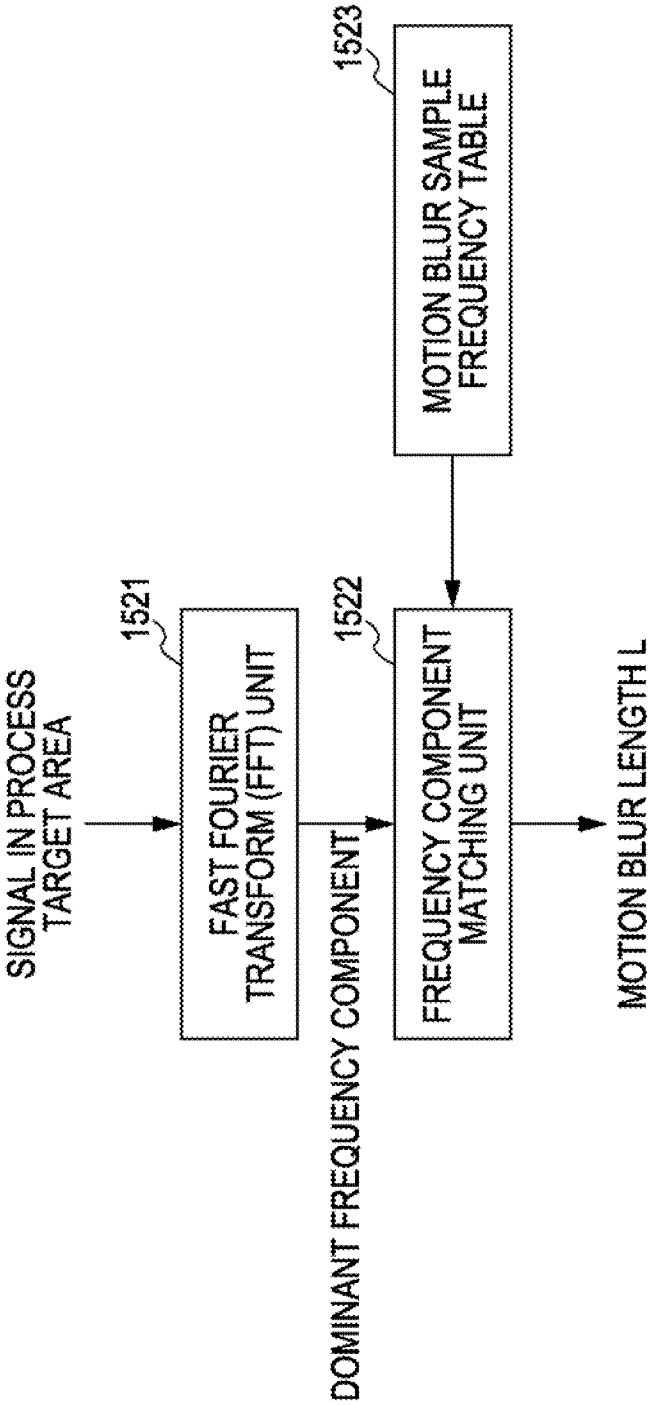

SIGNAL IN PROCESS TARGET AREA
1521
FAST FOURIER TRANSFORM (FFT) UNIT
DOMINANT FREQUENCY COMPONENT
1522
FREQUENCY COMPONENT MATCHING UNIT
MOTION BLUR LENGTH L
1523
MOTION BLUR SAMPLE FREQUENCY TABLE

FIG. 14

MOTION BLUR LENGTH (PIXELS)	TOP THREE VALUES OF FREQUENCY COMPONENTS (Hz)		
La	ak	bk	ck
Lb	al	bl	cl
Lc	am	bm	cm
Ld	an	bn	cn
Le	ao	bo	co
Lf	ap	bp	cp
. . .	. . .	. . .	. . .
Lmax	az	bz	cz

FIG. 15

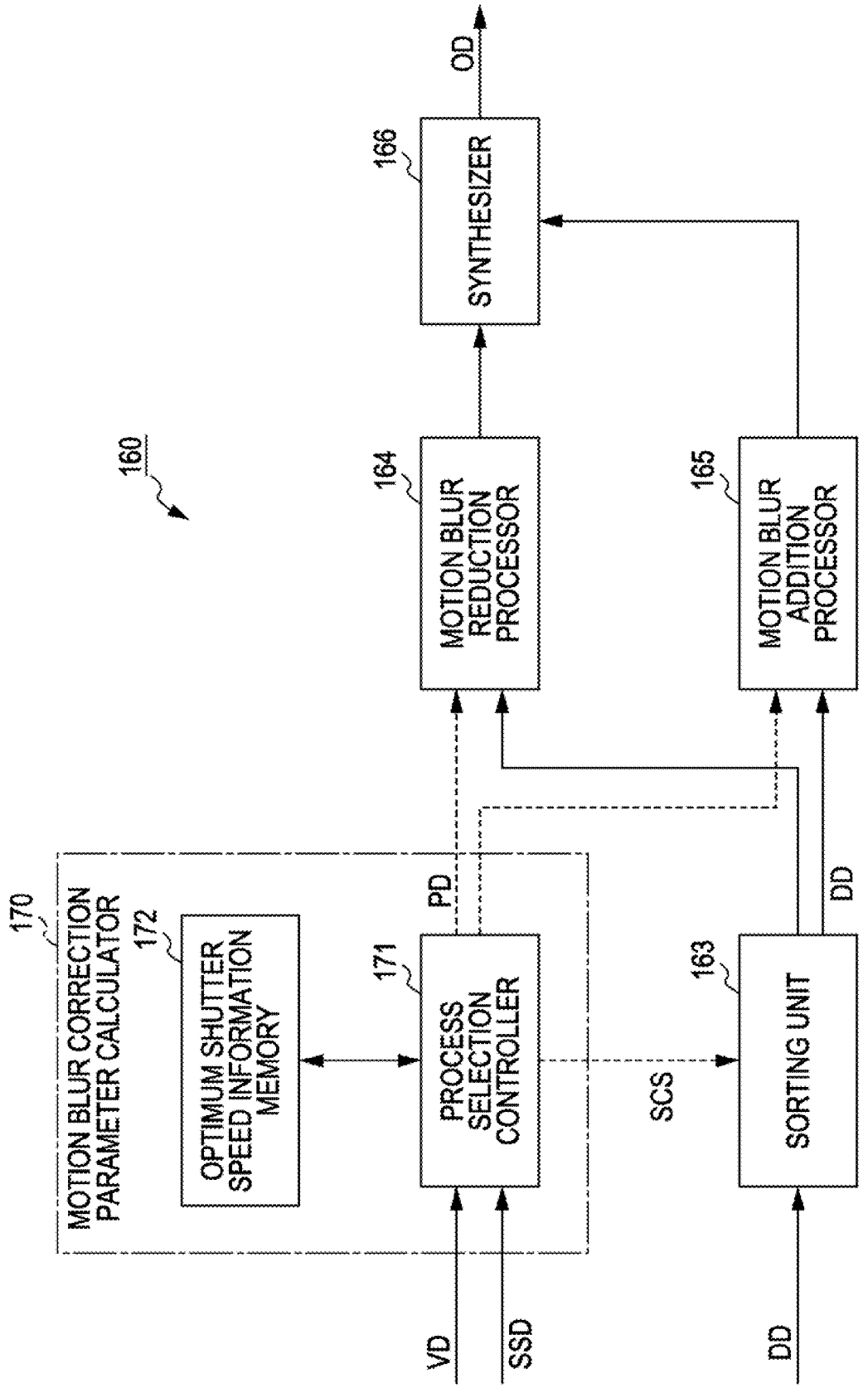

160
166
SYNTHESIZER
OD
164
MOTION BLUR REDUCTION PROCESSOR
165
MOTION BLUR ADDITION PROCESSOR
170
MOTION BLUR CORRECTION PARAMETER CALCULATOR
172
OPTIMUM SHUTTER SPEED INFORMATION MEMORY
171
PROCESS SELECTION CONTROLLER
PD
163
SORTING UNIT
DD
SCS
VD
SSD
DD

FIG. 16

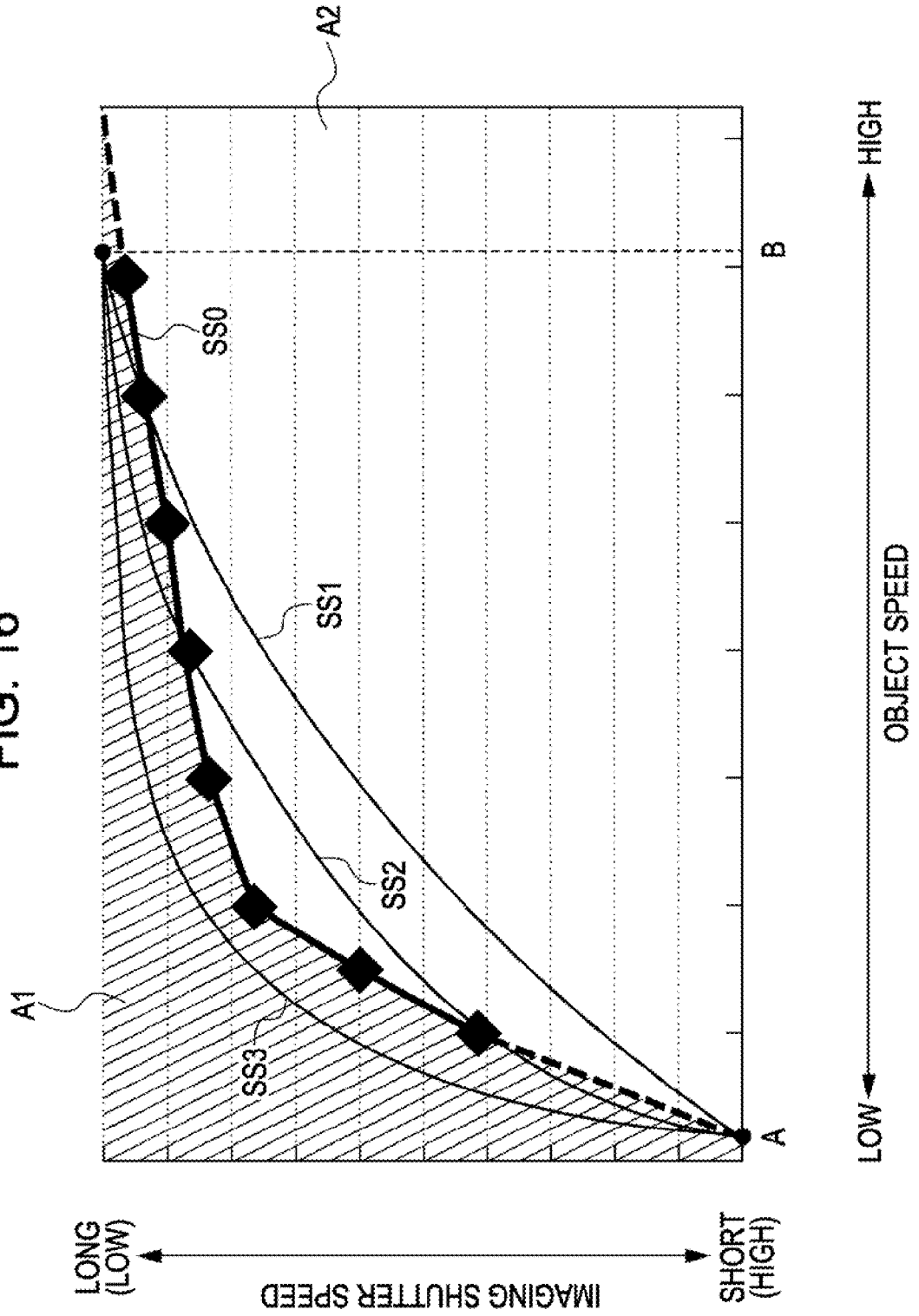

A2
B
SS0
SS1
SS2
SS3
A1
A
HIGH
OBJECT SPEED
LOW
LONG (LOW)
IMAGING SHUTTER SPEED
SHORT (HIGH)

FIG. 17

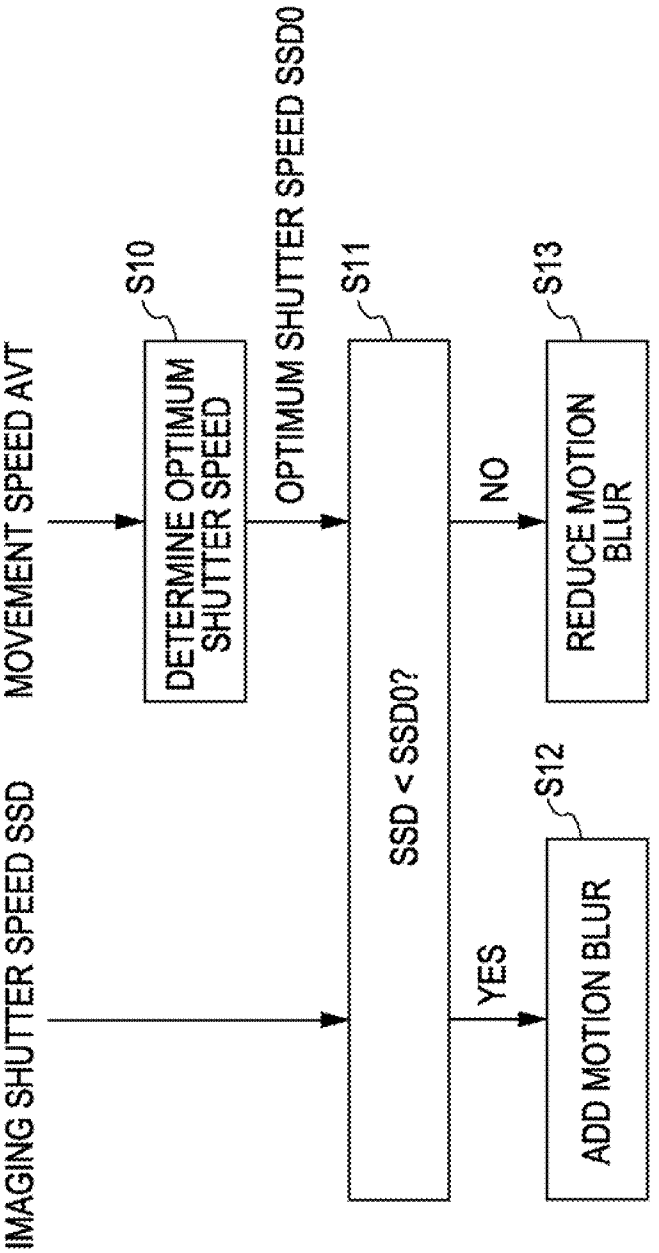

PARTITION AREA MOVEMENT SPEED AVT
IMAGING SHUTTER SPEED SSD
S10
DETERMINE OPTIMUM SHUTTER SPEED
OPTIMUM SHUTTER SPEED SSD0
S11
SSD < SSD0?
NO
YES
S12
ADD MOTION BLUR
S13
REDUCE MOTION BLUR

FIG. 18

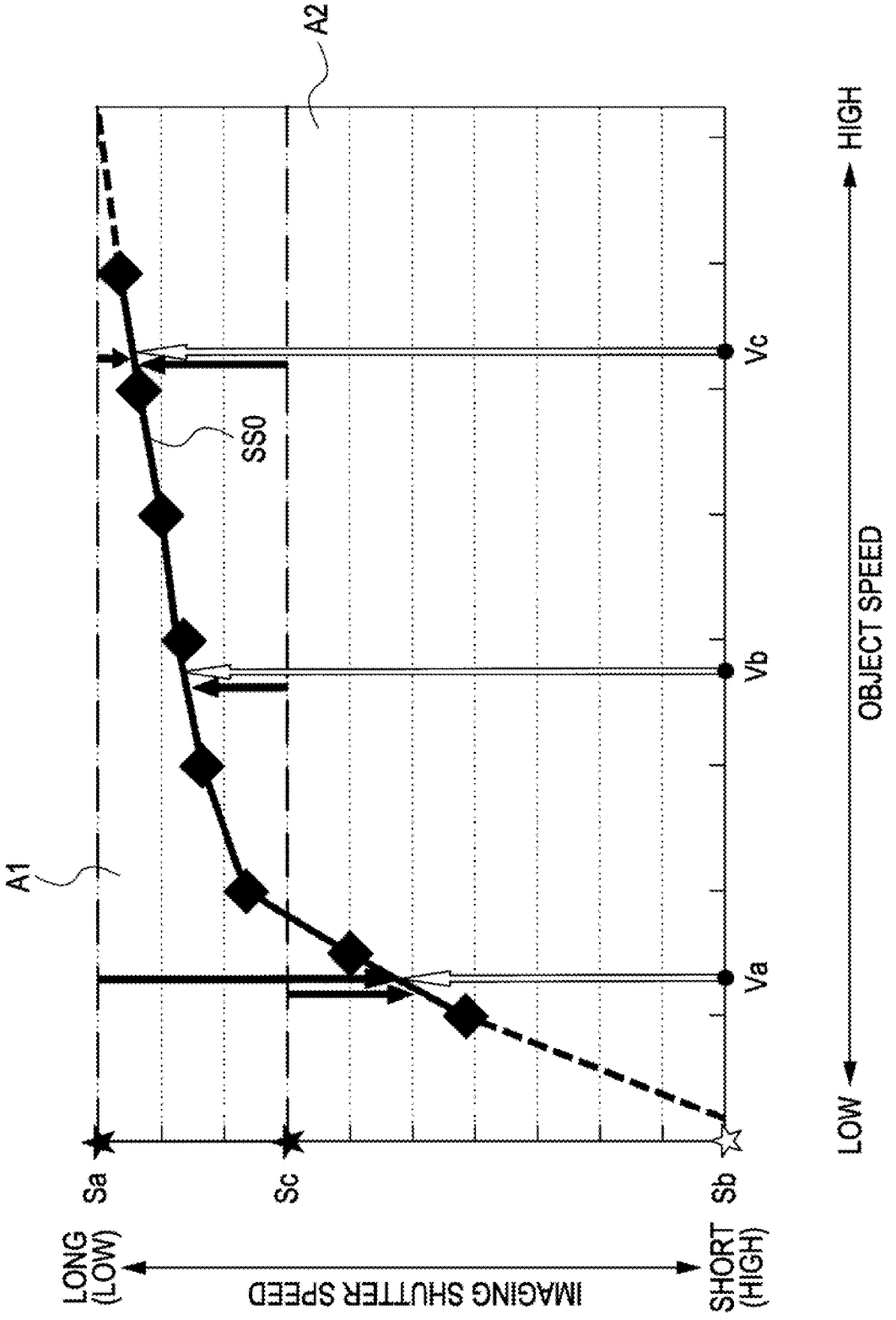

A2
SS0
Vc
Vb
Va
A1
HIGH
OBJECT SPEED
LOW
Sa
Sc
Sb
LONG (LOW)
IMAGING SHUTTER SPEED
SHORT (HIGH)

FIG. 19

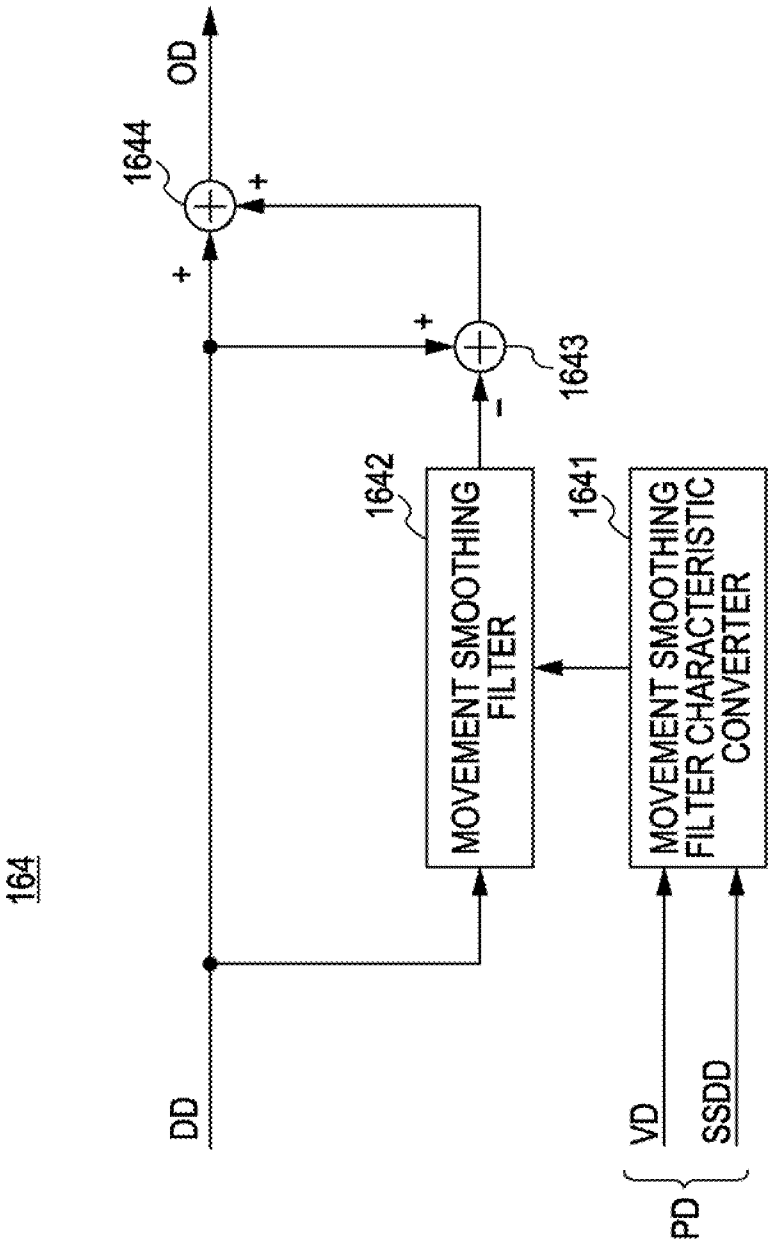

164
DD
OD
1644
1643
1642
1641
MOVEMENT SMOOTHING FILTER
MOVEMENT SMOOTHING FILTER CHARACTERISTIC CONVERTER
VD
SSDD
PD
+
+
+
-

FIG. 20A

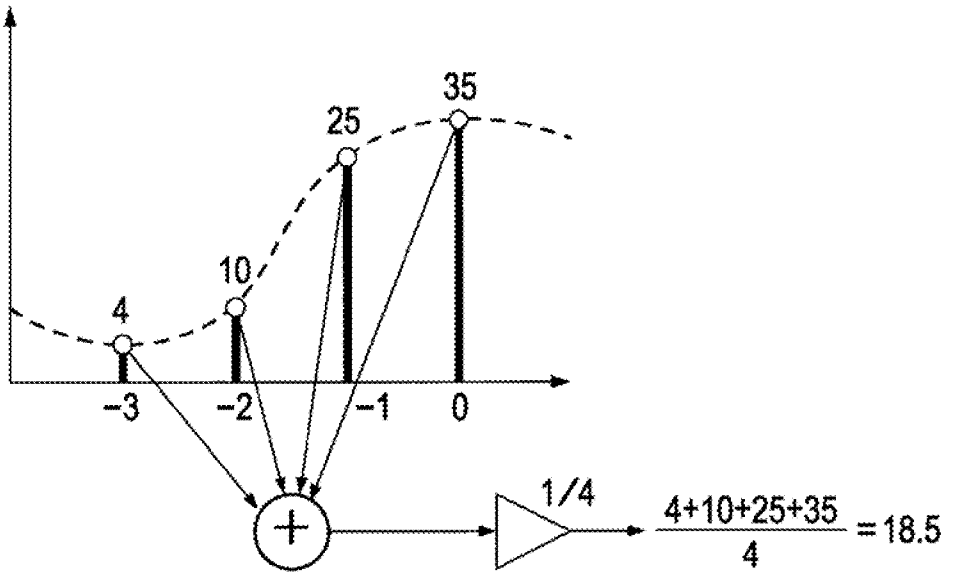


FIG. 20B

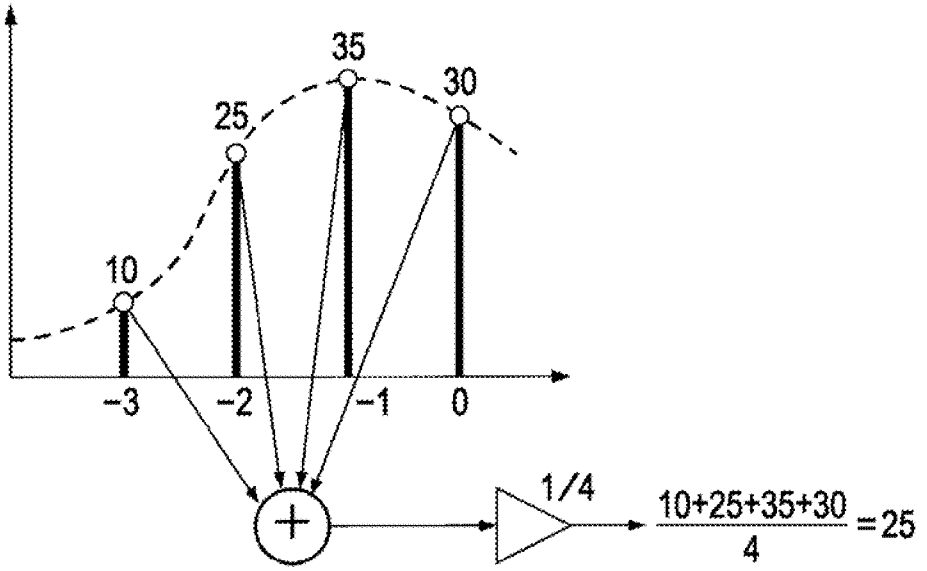


FIG. 21

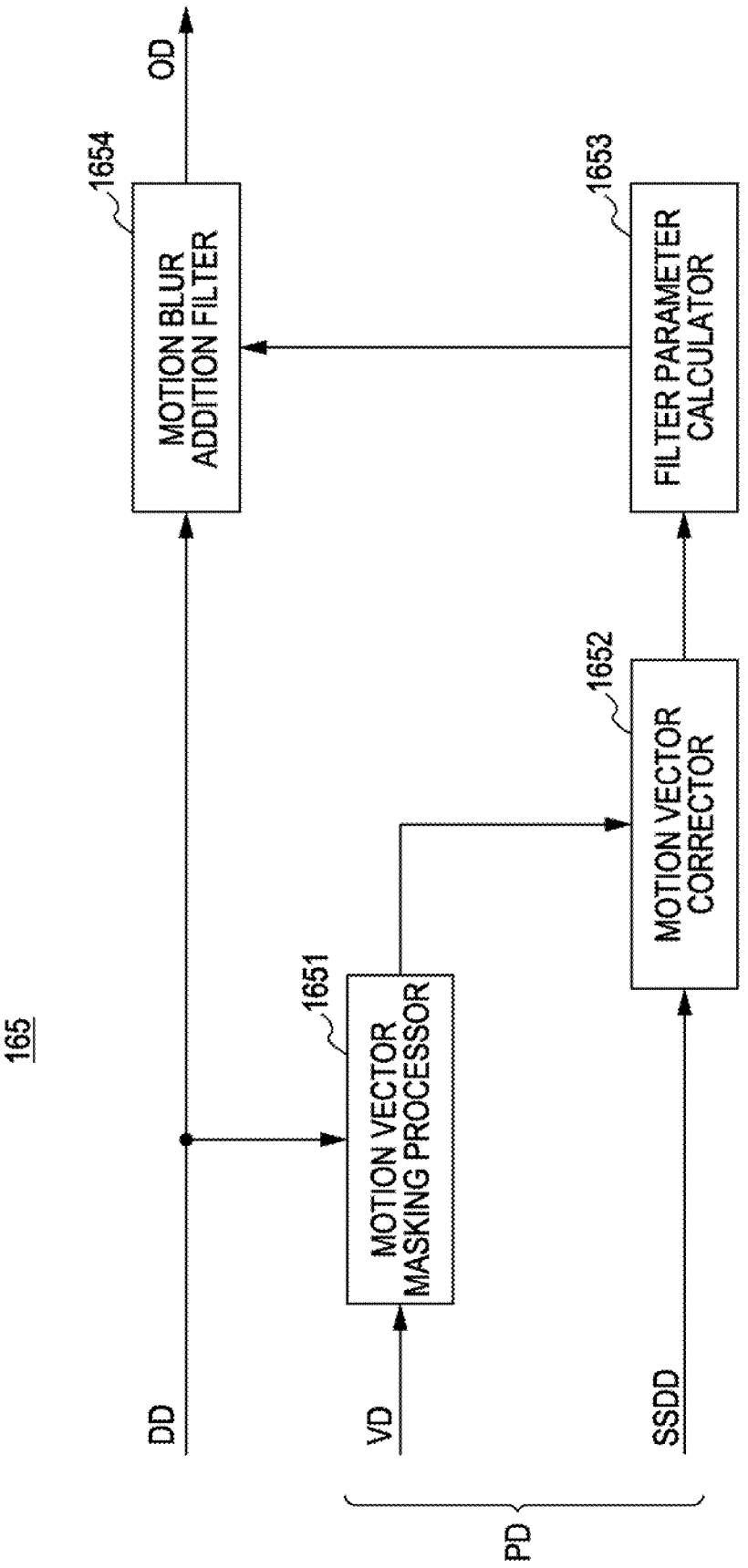

165
DD
VD
SSDD
PD
1651
MOTION VECTOR MASKING PROCESSOR
1652
MOTION VECTOR CORRECTOR
1653
FILTER PARAMETER CALCULATOR
1654
MOTION BLUR ADDITION FILTER
OD

FIG. 22

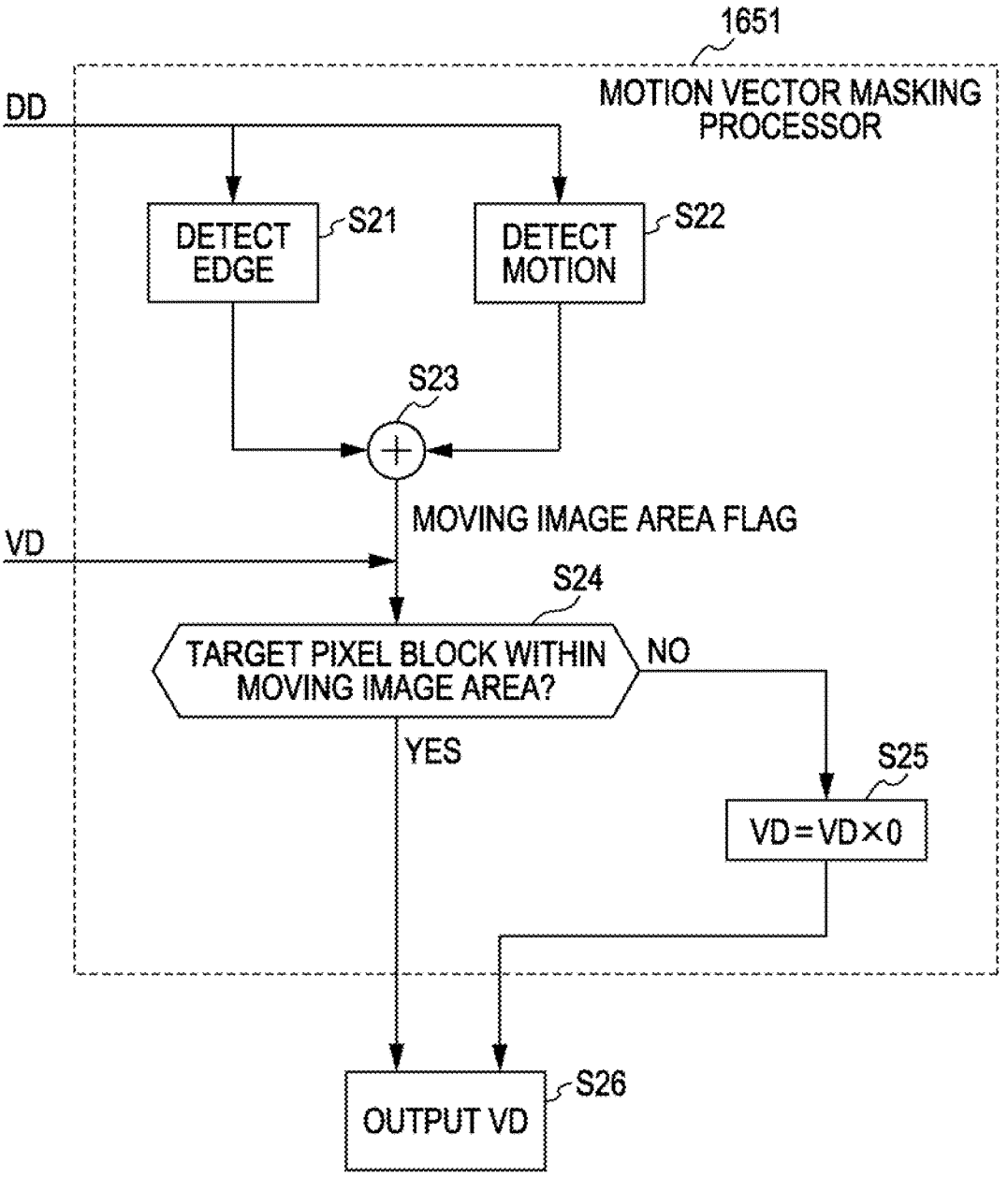

1651
MOTION VECTOR MASKING PROCESSOR
DD
DETECT EDGE
S21
DETECT MOTION
S22
S23
MOVING IMAGE AREA FLAG
VD
S24
TARGET PIXEL BLOCK WITHIN MOVING IMAGE AREA?
NO
YES
S25
VD=VD×0
OUTPUT VD
S26

FIG. 23

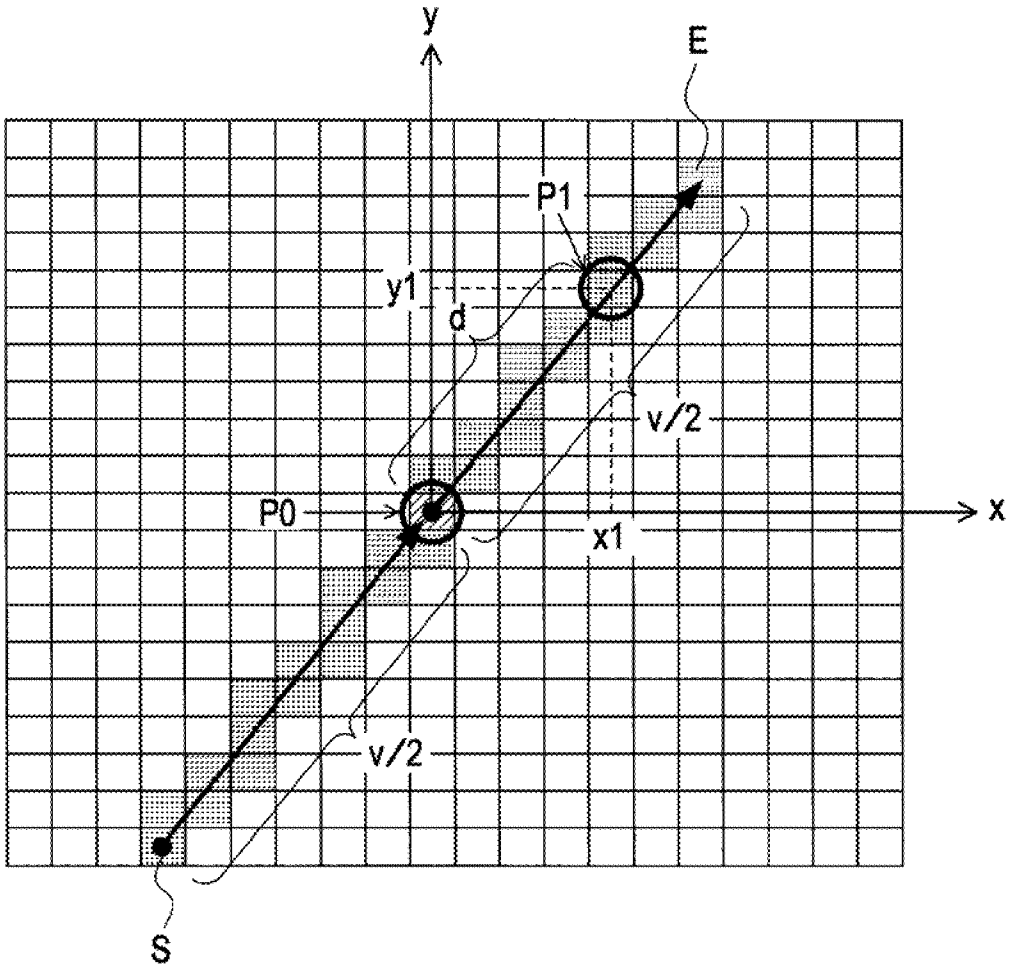


FIG. 24

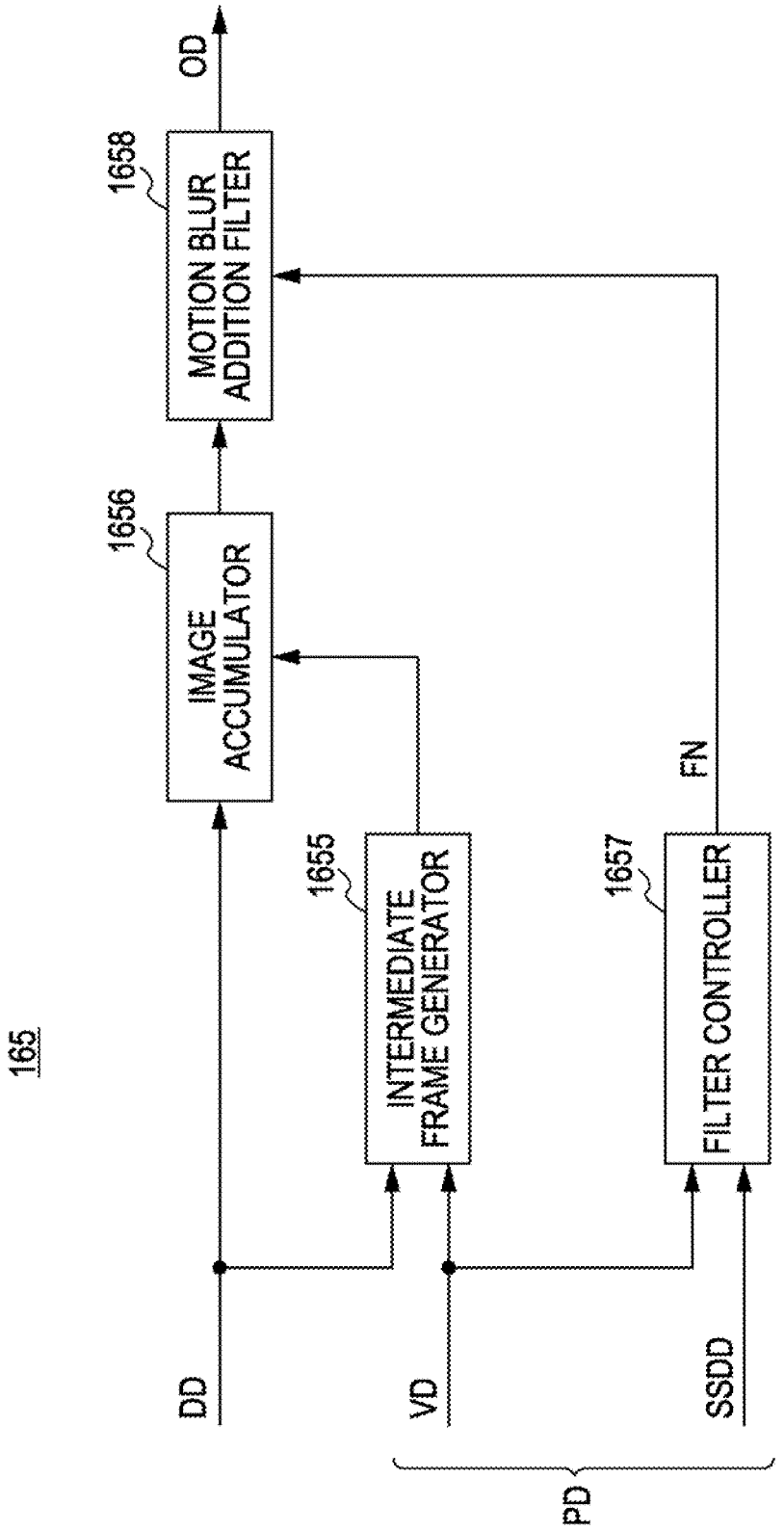
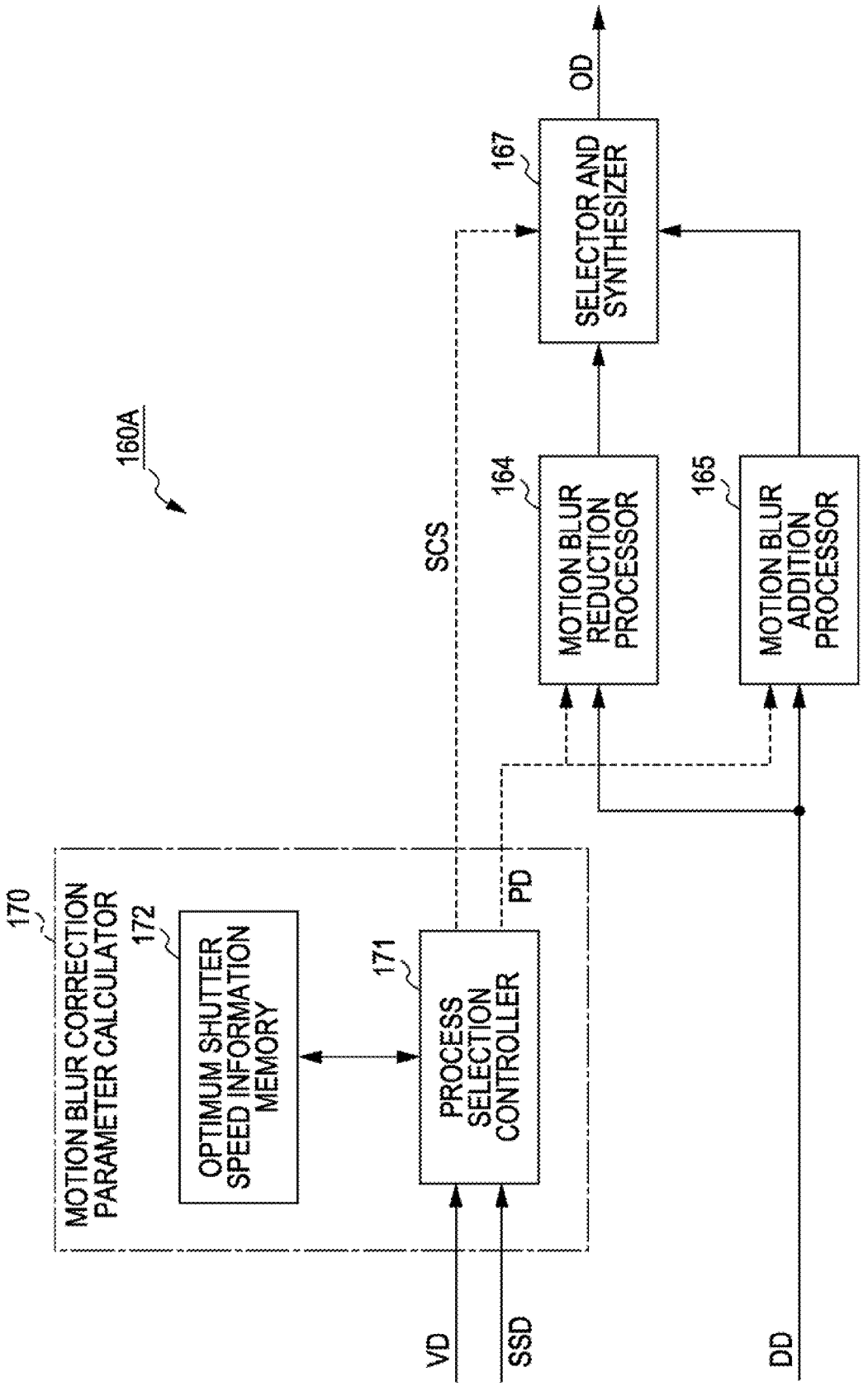

165
DD
VD
SSDD
PD
INTERMEDIATE FRAME GENERATOR
1655
FILTER CONTROLLER
1657
FN
IMAGE ACCUMULATOR
1656
MOTION BLUR ADDITION FILTER
1658
OD

FIG. 25


160A
170
MOTION BLUR CORRECTION PARAMETER CALCULATOR
172
OPTIMUM SHUTTER SPEED INFORMATION MEMORY
171
PROCESS SELECTION CONTROLLER
PD
SCS
164
MOTION BLUR REDUCTION PROCESSOR
165
MOTION BLUR ADDITION PROCESSOR
167
SELECTOR AND SYNTHESIZER
OD
VD
SSD
DD

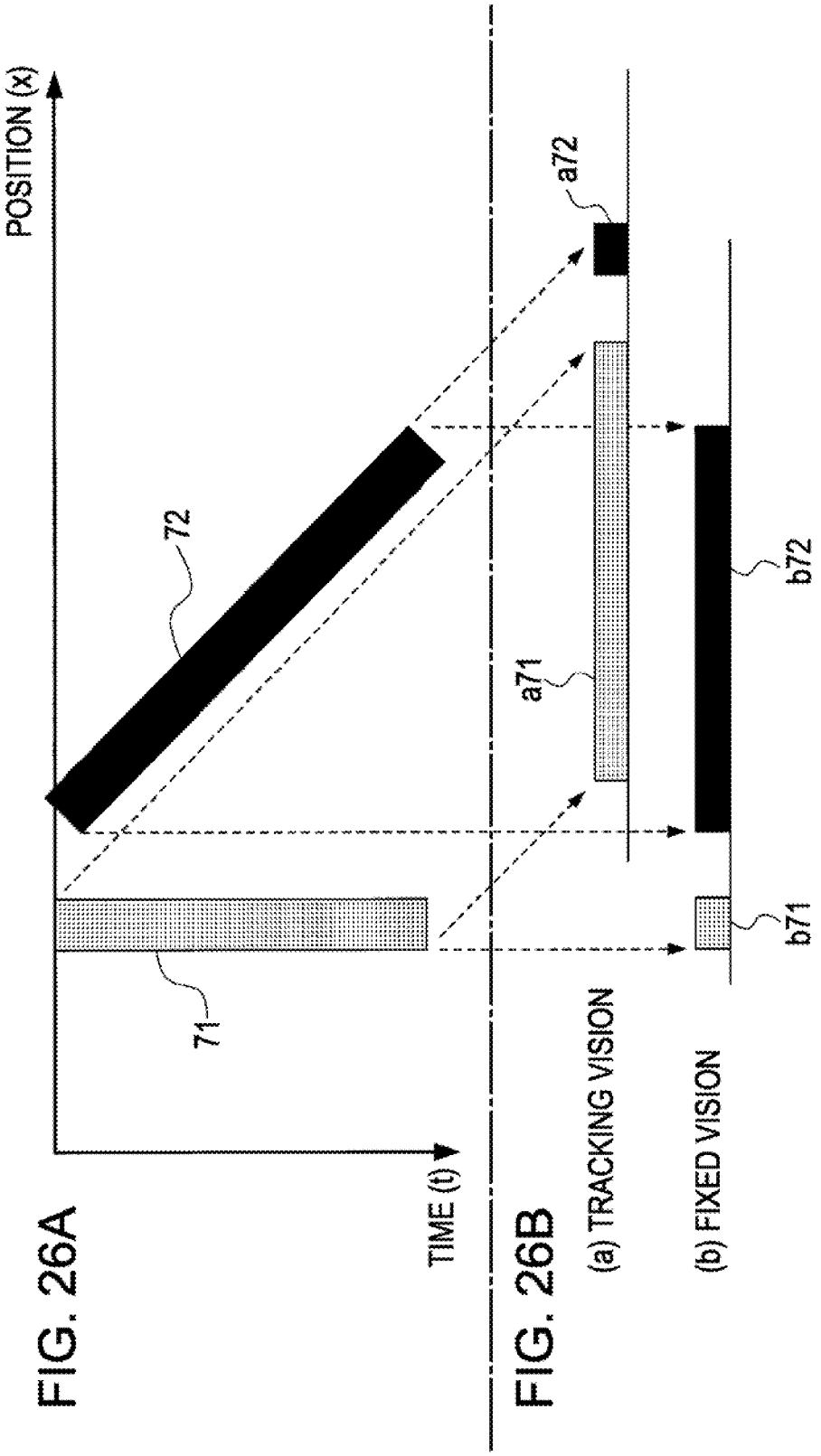


FIG. 26A

FIG. 26B

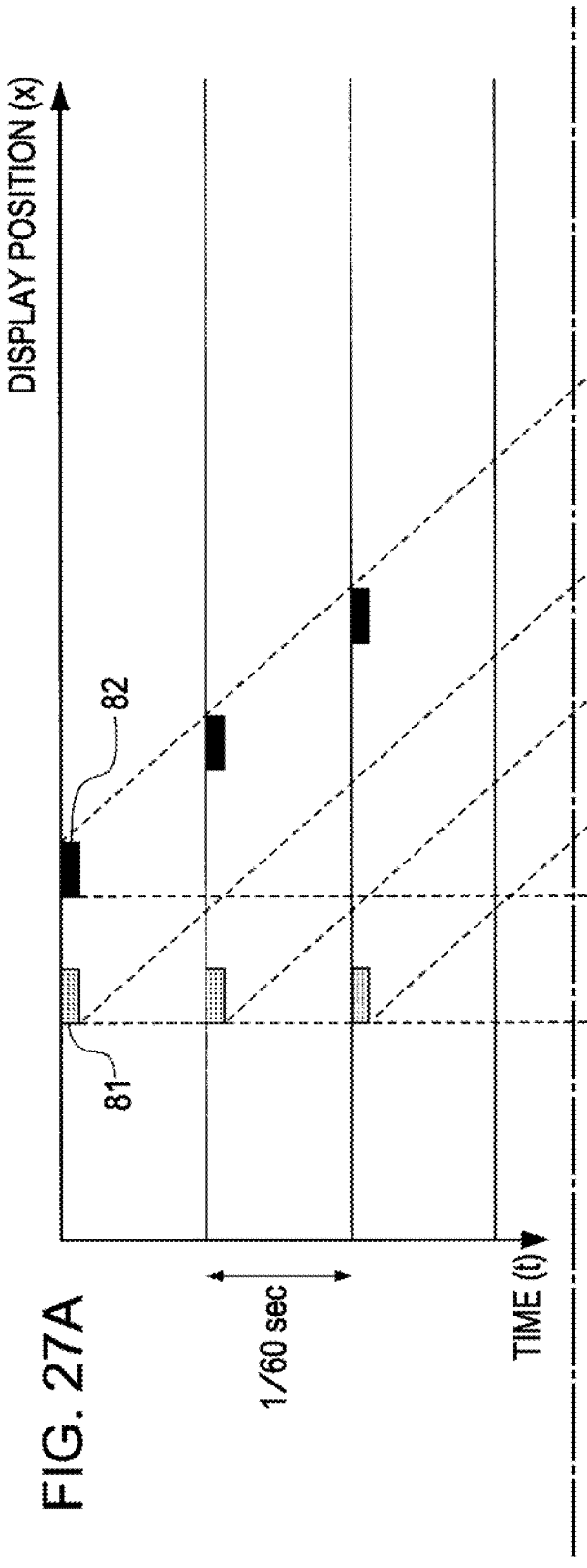


FIG. 27A

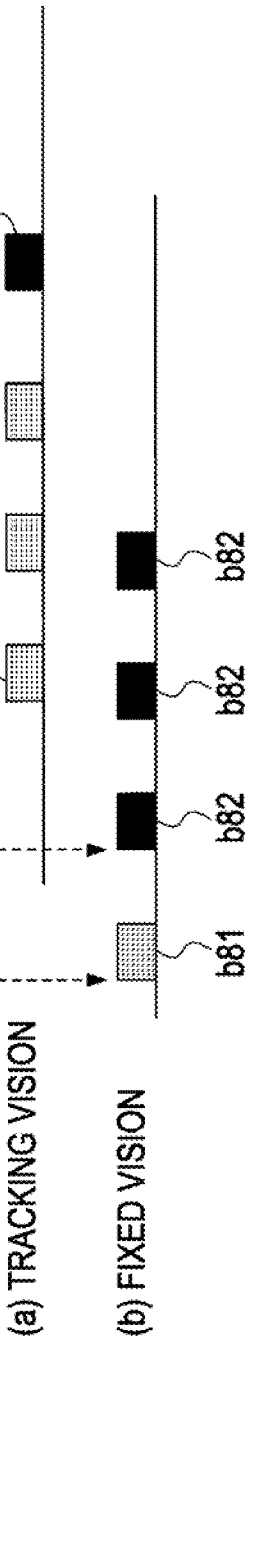


FIG. 27B

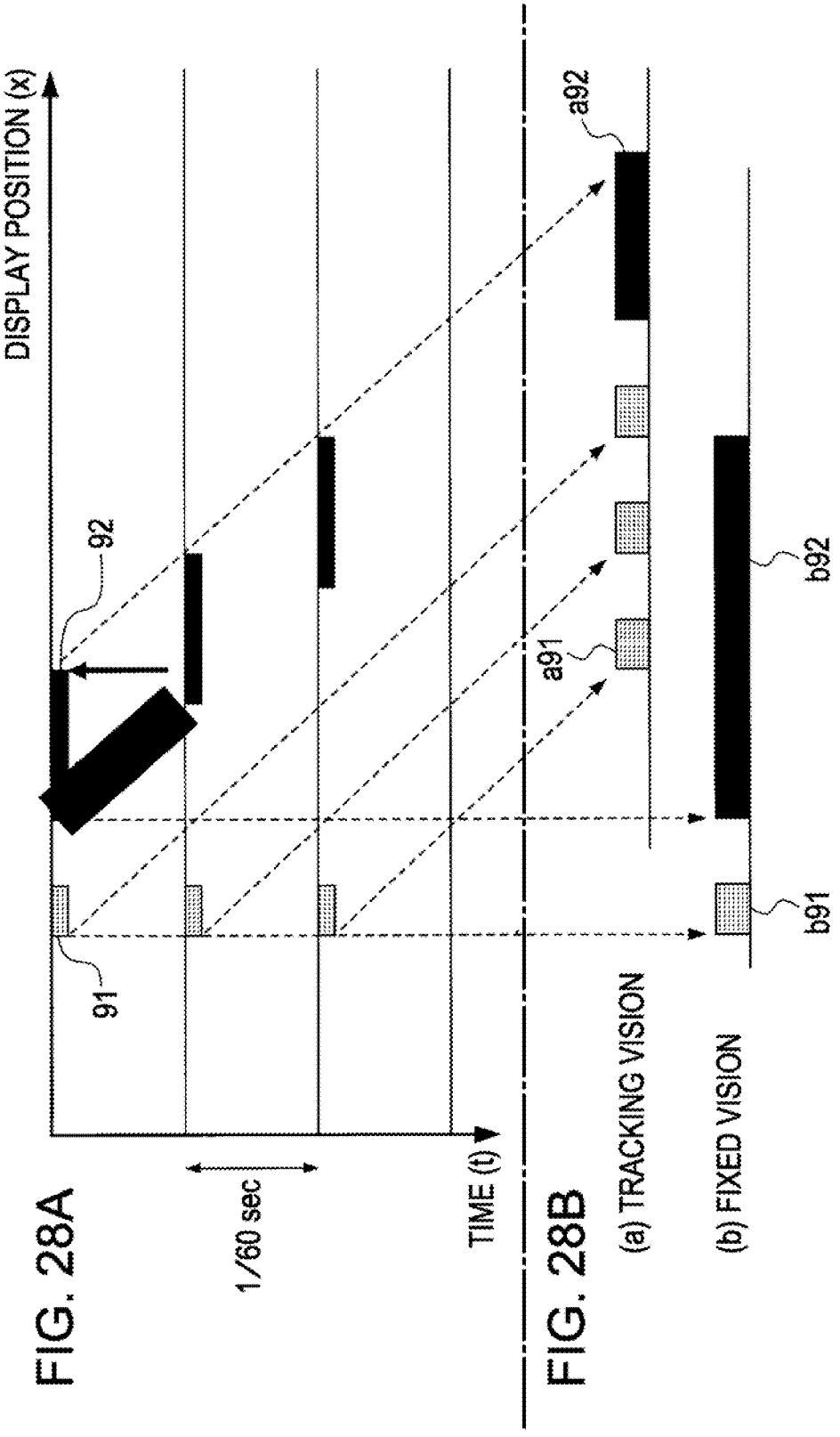


FIG. 28A

FIG. 28B

APPARATUS, METHOD, AND PROGRAM FOR PROCESSING IMAGE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an apparatus, method and program for processing an image and, in particular, to an image processing technique for obtaining a high-quality image taking into consideration a motion image blur on the image.

2. Description of the Related Art

When a moving image taken at a high-speed shutter or an animation is displayed on a display device such as a projector or a display, the motion of a moving object contained in an image can be displayed in a discontinued fashion. This leads to frequent image degradation in which a user sees multiple images of the moving object. The degradation of the moving image due to motion unnaturalness is generally referred to as motion jerkiness. On the other hand, when a moving image taken at a low-speed shutter such as with an open shutter is displayed, the image of an object may lack detail or an edge of the image becomes blurred because of the effect of motion blur. This phenomenon is referred to as motion blur, which is also one of the image degradations.

The principle of the generation of jerkiness and blur is described with reference to FIGS. **26**-**28**. In accordance with vision characteristics, humans are known to visually recognize a light ray incident on the eyes as a value that results from integrating the light ray for a predetermined period of time. FIGS. **26**-**28** diagrammatically illustrate the way an object is viewed by a viewer in accordance with the vision characteristics.

FIGS. **26**A and **26**B illustrate how a still object and a moving object look in the real world.

FIG. **26**A illustrate chronological movement of a still object **71** and a moving object **72** with the abscissa representing position (x) and the ordinate representing time (t). FIG. **26**B diagrammatically illustrates the vision of a viewer who views the still object **71** and the moving object **72**. The viewers views the objects in two vision conditions, i.e., a tracking vision tracking the moving object **72** and a fixed vision not tracking the moving object **72**, respectively illustrated as (a) tracking vision and (b) fixed vision.

If the moving object **72** is tracked by the viewer in (a) tracking vision as illustrated in FIG. **26**B, the moving object **72** looks like moving object vision information a**72**. This is identical to fixed object vision information b**71** in which the still object **71** looks in (b) fixed vision in FIG. **26**B. If the viewer views the moving object **72** in the tracking vision in this way, the moving object **72** looks in the same way as the still object **71** looks in the fixed vision. If the viewer views the moving object **72** in the fixed vision as in (b) fixed vision illustrated in FIG. **26**B, the moving object **72** looks like moving object vision information b**72** in FIG. **26**B. The viewer visually recognizes the moving object as a continuously moving object, and is free from any discomfort viewing.

FIGS. **27**A and **27**B illustrate the principle of the generation of jerkiness viewed by the viewer when a moving image taken at a high-speed shutter or an animation is displayed on a display device such as a projector or a display device. Jerkiness is a phenomenon in which the motion of a moving object contained in an image is displayed in a discontinuous manner, causing the viewer to visually recognize multiple images of the moving object.

A moving object in the real world in FIGS. **26**A and **26**B is imaged at a high-speed shutter, and then displayed on a display device at a refresh rate of 60 Hz. FIGS. **27**A and **27**B illustrate the way the viewer visually recognizes the moving object. FIG. **27**A illustrates a change in the display positions of a display still object **81** and a display moving object **82** on a display device. In FIG. **27**A, the ordinate represents time (t) and is graduated in refresh periods of the display device (each period being 1/60 second), and the abscissa represents display position (x). FIG. **27**B diagrammatically illustrates the vision status of the viewer who views the display still object **81** and the display moving object **82** displayed on the display device. The vision status of the viewer includes (a) tracking vision in which the viewer views the image with the display moving object **82** being tracked, and (b) fixed vision in which the viewer views the image with the display moving object **82** not tracked but with the vision of the viewer fixed.

When the display moving object **82** displayed on the display device is viewed by the viewer in (a) tracking vision as illustrated in FIG. **27**B, an image a**82** looks in the same way as the image a**72** looks in (a) tracking vision in FIG. **26**B. The viewer visually recognizes the image in the same way as the viewer views a still object in the fixed vision.

When the display moving object **82** displayed on the display device is viewed by the viewer in (b) fixed vision as illustrated in FIG. **27**B, the display moving object **82** looks like images b**82** not continuously moving but discontinuously moving in a manner different from the real world in the viewer's vision. As a result, the viewer visually recognizes as multiple images the moving object displayed on the display device based on the human vision characteristics. In human vision characteristics, humans visually recognize a light ray incident on the eyes as a value that results from integrating the light ray for a predetermined period of time.

The viewer thus views a single object as multiple objects. This phenomenon is called jerkiness. In principle, an object moving at a high speed suffers more from jerkiness. The lower the frame rate of the display device, the more jerkiness takes place, and the higher the frame rate, the less jerkiness takes place. Furthermore, jerkiness takes place more in a portion of an image where a change in spatial luminance is large, i.e., where a spatial contrast is high.

FIGS. **28**A and **28**B illustrate how a blur viewed by the viewer is generated when a moving image taken at a low-speed shutter such as with an open shutter or an animation is displayed on a display device such as a projector or a display. The blur is a phenomenon in which the image of an object may lack detail or an edge of the image becomes blurred because of the effect of motion blur.

FIGS. **28**A and **28**B diagrammatically illustrate how the moving object in the real world illustrated in FIGS. **26**A and **26**B looks to the viewer when the moving object is imaged at a low-speed shutter and then displayed on the display device at a refresh rate of 60 Hz. FIG. **28**A illustrates a change in the display positions of a display still object **91** and a display moving object **92** on the display device. In FIG. **28**A, the ordinate represents time (t) and is graduated in refresh periods of the display device (each period being 1/60 second), and the abscissa represents display position (x). FIG. **28**B diagrammatically illustrates the vision status of the viewer who views the display still object **91** and the display moving object **92** displayed on the display device. The vision status of the viewer includes (a) tracking vision in which the viewer views the image with the display moving object **92** being tracked, and (b) fixed vision in which the viewer views the image with the display moving object **92** not tracked but with the vision of the viewer fixed.

When the display moving object **92** displayed on the display device is viewed by the viewer in (b) fixed vision as

illustrated in FIG. **28**B, an image b**92** looks in the same way as the image b**72** looks in (b) fixed vision in FIG. **26**B. The viewer visually recognizes the moving object as a continuously moving object, and is free from any discomfort viewing.

When the display moving object **92** displayed on the display device is viewed by the viewer in tracking vision, an image a**92** looks to the viewer as a blurred image as illustrated in FIG. **28**B in a manner different from the case in which the still object is viewed in fixed vision. When the display moving object **92** in FIG. **28**A is imaged, the motion of the moving object during a long exposure of a low-speed shutter is recorded within one frame, and the moving object is thus displayed as a band in one frame. Such a phenomenon is referred to as blur.

In principle, there is a trade-off between jerkiness and blur with respect to the imaging shutter speed. Mere shutter control causes either the degradation of jerkiness or the degradation of blur to be pronounced. More specifically, if an image taken at a relatively high shutter speed with respect to the frame rate of the moving image is displayed as a still image, high sharpness is provided. If the image is displayed as a moving image, the motion of a moving area within the image, in particular, a moving area at a high speed is not smooth. Such an image looks unnatural to the vision of humans. If an image taken at a relatively low shutter speed with respect to the frame rate of the moving image is displayed as a moving image, high sharpness is provided. If the image is displayed as a moving image, the motion of a high-speed moving area within the image is smooth, but the entire image lacks sharpness.

Japanese Unexamined Patent Application Publication No. 2007-274299 (WO07/114220), assigned to the same assignee of the present invention, discloses a jerkiness reducing technique intended to be used on an image taken at a high shutter speed. In accordance with the disclosed technique, a motion blur is added through image processing. An added amount of motion blur is controlled through analysis of image processing so that the excessive addition of the motion blur does not cause blur degradation. A technical approach of reducing the motion blur through image processing performed mainly on an input image taken at a low shutter speed is widely studied. For example, image processing techniques for correcting blur of an image include mainly an inverse convolution technique based on a blur model, and a technique not using no blur model, such as a peaking technique or a shock filter technique. For example, the technique disclosed in the paper entitled "Extension of Coupled Nonlinear Diffusion to Motion De-blurring—Introduction of Anisotropic Peaking," Takahiro SAITO, Hiroyuki HARADA, and Takashi KOMATSU, The Institute of Image Information and Television Engineers Vol. 58, No. 12 pp. 1839-1844 (2004) is related to the blur-model-based inverse convolution technique as motion blur reduction means. The technique disclosed in the paper entitled "Motion De-blurring Using a Blur Model," Takahiro SAITO, Hiroyuki HARADA, Taishi SANO, and Takashi KOMATSU, The Institute of Image Information and Television Engineers Vol. 59, No. 11, pp. 1714-1721 (2005) is related to the technique not using no blur model as motion blur reduction means.

SUMMARY OF THE INVENTION

As described above, there is a trade-off between jerkiness and blur with respect to the imaging shutter speed. Mere shutter control causes either jerkiness or blur to be pronounced.

It is thus desirable to provide an image processing technique appropriately responding to the causes of the above-described image degradations and adaptively applied to jerkiness and blur to control jerkiness and blur degradations.

In accordance with one embodiment of the present invention, an image processing apparatus includes correction parameter calculation means for calculating a motion blur correction parameter for motion blur correction on the basis of motion information indicating a motion of an image between unit images, the unit images forming image data, and shutter speed information obtained at the image capturing of the image data, and motion blur correction processing means for correcting a motion blur quantity contained in the image data by performing at least a process of reducing a motion blur in accordance with the motion blur correction parameter.

The motion blur correction processing means may perform a process of adding a motion blur on the image data and the process of reducing a motion blur in accordance with the motion blur correction parameter.

The image processing apparatus may further include shutter speed estimation processing means for estimating shutter speed information by analyzing the image data, wherein the correction parameter calculation means uses the shutter speed information estimated by the shutter speed estimation processing means in order to calculate the motion blur correction parameter.

The motion blur correction processing means may adaptively select in response to each partition area of the image data one of the process of adding the motion blur and the process of reducing the motion blur on the image data, in accordance with the motion blur correction parameter.

The motion blur correction processing means may perform on the image separately the process of adding the motion blur and the process of reducing the motion blur, and select between data resulting from the process of adding the motion blur and data resulting from the process of reducing the motion blur in accordance with the motion blur correction parameter as data to be adaptively output for each partition area of the image data.

The image processing apparatus may further include motion vector generating means for generating from the image data a motion vector as the motion information.

The shutter speed estimation processing means may include a motion blur characteristic analyzer for extracting a shutter speed calculation parameter by analyzing motion blur characteristics contained in a target area of the image data, and an imaging shutter speed calculator for calculating the shutter speed at the image capturing of the image data.

The shutter speed estimation processing means may further include a process target area selector for extracting and identifying from the unit image forming the image data the target area of the analysis process of the motion blur characteristic analyzer.

The image processing apparatus may further include motion vector generating means for generating from the image data a motion vector as the motion information. The process target area selector in the shutter speed estimation processing means identifies the target area using edge information of the image data, and the motion vector generated by the motion vector generating means.

The shutter speed estimation processing means may further include an imaging shutter speed accuracy enhancement processor. The motion blur characteristic analyzer extracts the shutter speed calculation parameters of a plurality of target areas. The imaging shutter speed calculator calculates a plurality of shutter speeds using the shutter speed calculation parameters of the plurality of target areas and the motion

information of the respective target areas. The imaging shutter speed accuracy enhancement processor estimates an imaging shutter speed using calculation results of the plurality of shutter speeds.

The shutter speed estimation processing means may estimate the shutter speed once within a period from the detection of a scene change to the detection of a next scene change in the input image data, and hold the estimated shutter speed within the period.

The shutter speed estimation processing means may include an imaging shutter speed accuracy enhancement processor. The imaging shutter speed accuracy enhancement processor estimates the shutter speed by a plurality of times within a period from the detection of a scene change to the detection of a next scene change in the input image data, and estimates an imaging shutter speed on the basis of the calculation results of the plurality shutter speeds estimated.

The correction parameter calculation means may acquire an optimum shutter speed corresponding to a speed of an object from each partition area of the image data by referencing mapping information mapping the object speed to an imaging shutter speed at which image quality degradation of an output image is reduced, and calculate the motion blur correction parameter as selection control information for selecting between a process of adding a motion blur and a process of reducing a motion blur on the image data by comparing information regarding an input imaging shutter speed with the optimum shutter speed. The motion blur correction processing means may selectively perform on the image data the process of adding the motion blur and the process of reducing the motion blur in accordance with the motion blur correction parameter.

The correction parameter calculation means may acquire an optimum shutter speed corresponding to a speed of an object from each partition area of the image data by referencing mapping information mapping the object speed to an imaging shutter speed at which image quality degradation of an output image is reduced, and calculate the motion blur correction parameter as selection control information for selecting between a process of adding a motion blur and a process of reducing a motion blur on the image data by comparing information regarding an input imaging shutter speed with the optimum shutter speed. The motion blur correction processing means may perform on the image separately the process of adding the motion blur and the process of reducing the motion blur, and select between data resulting from the process of adding the motion blur and data resulting from the process of reducing the motion blur in accordance with the motion blur correction parameter as data to be adaptively output for each partition area of the image data.

The correction parameter calculation means may calculate the motion blur correction parameter indicating one of the degree of addition of the motion blur and the degree of reduction of the motion blur, respectively used by the motion blur correction processing means in the process of adding the motion blur and the process of reducing the motion blur on the image data.

The motion blur correction parameter indicating one of the degree of addition of the motion blur and the degree of reduction of the motion blur may include one of an imaging shutter speed and a difference between the imaging shutter speed and an optimum shutter speed.

The motion blur correction parameter indicating one of the degree of addition of the motion blur and the degree of reduction of the motion blur may include movement speed information of a partition area.

In accordance with another embodiment of the present invention, an image processing method includes the steps of calculating a motion blur correction parameter for motion blur correction on the basis of motion information indicating a motion of an image between unit images, the unit images forming image data, and shutter speed information obtained at the image capturing of the image data, and correcting a motion blur quantity contained in the image data by performing at least a process of reducing a motion blur in accordance with the motion blur correction parameter.

In accordance with yet another embodiment of the present invention, a program causes a computer to perform an image processing method. The image processing method includes the steps of calculating a motion blur correction parameter for motion blur correction on the basis of motion information indicating a motion of an image between unit images, the unit images forming image data, and shutter speed information obtained at the image capturing of the image data, and correcting a motion blur quantity contained in the image data by performing at least a process of reducing a motion blur in accordance with the motion blur correction parameter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a first basic structure of an image processing apparatus in accordance with one embodiment of the present invention;

FIG. **2** illustrates a partition area in accordance with one embodiment of the present invention;

FIG. **3** is a block diagram of a second basic structure of the image processing apparatus in accordance with one embodiment of the present invention;

FIG. **4** is a block diagram of a third basic structure of the image processing apparatus in accordance with one embodiment of the present invention;

FIG. **5** is a block diagram of an image reproducing apparatus in accordance with one embodiment of the present invention;

FIG. **6** is a block diagram of a motion vector generation processor in accordance with one embodiment of the present invention;

FIG. **7** is a flowchart illustrating operation of the motion vector generation processor of one embodiment of the present invention;

FIG. **8** is a block diagram illustrating a shutter speed estimation processor in accordance with one embodiment of the present invention;

FIG. **9** illustrates a motion blur length in accordance with one embodiment of the present invention;

FIGS. **10**A**1** through **10**C**2** illustrate the motion blur length in accordance with one embodiment of the present invention;

FIGS. **11**A-**11**C illustrate a calculation process of the motion blur length in accordance with one embodiment of the present invention;

FIG. **12** is a detailed block diagram illustrating a shutter speed estimation processor in accordance with one embodiment of the present invention;

FIG. **13** illustrates a process of a motion blur characteristic analyzer in accordance with one embodiment of the present invention;

FIG. **14** is a motion blur sample frequency table in accordance with one embodiment of the present invention;

FIG. **15** is a block diagram of a motion blur correction parameter calculator and a motion blur correction processor in accordance with one embodiment of the present invention;

FIG. **16** illustrates an optimum shutter speed in accordance with one embodiment of the present invention;

FIG. **17** is a flowchart of a process of a process selection controller in accordance with one embodiment of the present invention;

FIG. **18** illustrates a process performed in response to a speed of an object and an imaging shutter speed in accordance with one embodiment of the present invention;

FIG. **19** is a block diagram of a motion blur reduction processor in accordance with one embodiment of the present invention;

FIGS. **20**A and **20**B illustrate a smoothing filter in accordance with one embodiment of the present invention;

FIG. **21** is a block diagram of a motion blur addition processor in accordance with one embodiment of the present invention;

FIG. **22** is a flowchart illustrating of a motion vector masking process in accordance with one embodiment of the present invention;

FIG. **23** illustrates a filter parameter calculation process in accordance with one embodiment of the present invention;

FIG. **24** is a block diagram of another motion blur addition processor in accordance with one embodiment of the present invention;

FIG. **25** is a block diagram illustrating another motion blur correction processor in accordance with one embodiment of the present invention;

FIGS. **26**A and **26**B illustrate the generation principle of jerkiness and blur relating to how a still object and a moving object look;

FIGS. **27**A and **27**B illustrate the generation principle of jerkiness; and

FIGS. **28**A and **28**B illustrate the generation principle of blur.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The embodiments of the present invention are described below with reference to the drawings.

First through third basic structures of image processing apparatuses of embodiments of the present invention are described below. The present invention is not limited to the three basic structures described below.

An image processing apparatus of one embodiment of the present invention is intended to generate an image with jerkiness and blur thereof reduced through image processing. If a moving image taken at simple shutter control is displayed on a display device, that moving image may look unnatural due to human vision characteristics with either jerkiness or blur pronounced. In accordance with one embodiment of the present invention, the generation of jerkiness is reduced by adding a motion blur to a high-speed shutter captured image in accordance with information regarding a shutter speed used at the capturing of an input image. If a low-speed shutter captured image is input, a process of reducing a motion blur is performed in order to reduce a blur degradation. More specifically, two processes (of adding and reducing a motion blur) are adaptively performed in response to conditions of an input image signal, and the relationship between a shutter speed used at the image capturing and a movement speed of an object. Both the jerkiness degradation and blur degradation are thus controlled. A high-quality image process is performed by generating an image signal with less image degradation and outputting the high-quality image.

FIG. **1** illustrates an image processing apparatus **1** having the first basic structure.

The image processing apparatus **1** includes an image acquisition unit **11**, a motion blur correction parameter calculator **12**, and a motion blur correction processor **13**. The image acquisition unit **11** acquires image data into the image processing apparatus **1**. The motion blur correction parameter calculator **12** sets a parameter for correcting a motion blur on the image acquired by the image acquisition unit **11**. The motion blur correction processor **13** performs a motion blur correction process on the image data acquired by the image acquisition unit **11**.

The motion blur correction parameter calculator **12** receives motion information of the image data acquired by the image acquisition unit **11**, and shutter speed information indicating an exposure time of each frame when the image data is captured. The motion blur correction parameter calculator **12** calculates from these pieces of input information an optimum parameter for correcting the motion blur of the acquired image data on a per partition area basis in each frame of the image data, and then supplies the calculated optimum parameter to the motion blur correction processor **13**. As illustrated in FIG. **2**, for example, the motion blur correction parameter calculator **12** sets a plurality of partition areas (pixel blocks) #**1**-#m within one frame, calculates a motion blur correction parameter for each of the partition areas #**1**-#m, and then supplies the motion blur correction parameter to the motion blur correction processor **13**. The motion information is not limited to information indicating a motion of an image between frames. The motion information may be information representing a motion of an image between unit images forming a moving image, such as information representing a motion of an image between fields.

The motion blur correction processor **13** corrects a quantity of motion blur of the image data, using the motion blur correction parameter calculated by the motion blur correction parameter calculator **12** and then externally outputs the motion blur corrected image data from within the image processing apparatus **1**. The motion blur correction processor **13** includes a sorting unit **31**, a motion blur reduction processor **32**, a motion blur addition processor **33**, and a synthesizer **34**.

The sorting unit **31** outputs the image data of each of the partition areas #**1**-#m of the input image data to one of the motion blur reduction processor **32** and the motion blur addition processor **33**, depending on whether the motion blur quantity of the partition area is to be reduced or increased. The motion blur reduction processor **32** performs a process of reducing the motion blur quantity of the corresponding area of the input image data. The motion blur addition processor **33** performs a process of increasing the motion blur quantity of the corresponding area of the input image data. If motion blur correction is not using in a given partition area, the sorting unit **31** outputs the image data of that partition area to the synthesizer **34**. Optionally, if motion blur correction is not using, the motion blur reduction processor **32** and the motion blur addition processor **33** may perform the processes thereof in a setting with a correction motion blur quantity set to zero.

The synthesizer **34** performs a synthesis process, synthesizing, as a frame image, the image data of each partition area, corrected by one of the motion blur reduction processor **32** and the motion blur addition processor **33**, and the image data of a partition area having undergone no correction.

The sorting unit **31** in the motion blur correction processor **13** receives the motion blur correction parameter calculated by the motion blur correction parameter calculator **12**. The motion blur correction parameter is calculated for each of the partition areas in each frame of the image data, and contains information regarding the motion blur correction process to be performed on a partition area being currently set as a process target of the image data. The motion blur correction

process of the motion blur correction processor **13** includes performing one of a process of reducing the motion blur (de-blur process) in the area where the blur degradation is likely, and a process of adding the motion blur (ad-blur process) in the area where an insufficient motion blur, i.e., a jerkiness degradation is likely. The sorting unit **31** sorts the image data of each partition area in response to the motion blur correction parameter. More specifically, the sorting unit **31** outputs the image data of the partition area that is to be de-blurred to the motion blur reduction processor **32** and the image data of the partition area that is to be ad-blurred to the motion blur addition processor **33**.

The image data output to one of the motion blur reduction processor **32** and the motion blur addition processor **33** thus undergoes the optimum motion blur correction process in order to reduce both the jerkiness degradation and the blur degradation. The image data having undergone the optimum motion blur correction process is supplied to the synthesizer **34**. The areas of the image data having undergone the motion blur correction process are synthesized by the synthesizer **34** and the resulting image data is thus output. The motion blur correction processor **13** outputs a moving image signal with the jerkiness degradation and blur degradation thereof reduced.

In one embodiment of the present invention, the image processing apparatus may perform only the correction process of the motion blur reduction processor **32** with the motion blur addition processor **33** eliminated from the motion blur correction processor **13**. Alternatively, only the motion blur addition processor **33** performs the correction process with the motion blur reduction processor **32** eliminated from the motion blur correction processor **13**. In such a case, however, one of the jerkiness degradation and the blur degradation might persist. For example, if only the de-blur process is performed, the jerkiness degradation may not be reduced in response to the image data that has been captured at a high shutter speed. Conversely, if only the ad-blur process is performed, the blur degradation occurring in the area where an object is moving may not be reduced in response to the image data that has been captured at a low shutter speed.

A combination of the de-blur process and the ad-blur process in the structure of FIG. **1** reduces both the jerkiness degradation and the blur degradation regardless of conditions such as an imaging shutter speed of the image data. The same is true of the structures illustrated in FIGS. **3** and **4**. When the image data is displayed, the jerkiness degradation and the blur degradation take place, causing the image of the image data to look unnatural to the eyes of humans. The image processing apparatus **1** thus constructed reduces the jerkiness degradation and the blur degradation by correcting adaptively the motion blur of the image data in response to the motion information of the image data and the information of the shutter speed at the image capturing.

FIG. **3** illustrates as the second structure an image processing apparatus **2** in accordance with one embodiment of the present invention. The image processing apparatus **1** having the first structure is based on the premise that the image acquisition unit **11** obtains the shutter speed information of the image data. The shutter speed information at the image capturing is referred to in the selection of the motion blur correction processes (ad-blur process and de-blur process). For example, the image processing apparatus **1** including the image acquisition unit **11** having an image capturing function executes an image capturing operation, thereby obtaining the image data. With the image capturing function, the image processing apparatus **1** can easily extract a shutter speed value used in the actual image capturing operation. If the shutter speed information is contained as metadata or the like of the image data, the value of the shutter speed is acquired from the metadata. If the image processing apparatus is part of an apparatus that displays an image signal by receiving the image signal or by reproducing the image signal from a recording medium, the shutter speed at the image capturing of the image data typically remains unknown.

The image processing apparatus **2** having the second structure analyzes an input image signal through image processing, thereby estimating a shutter speed at the image capturing of the image signal. FIG. **3** illustrates the image processing apparatus **2** having the second structure, in which the image acquisition unit **11** does not acquire the shutter speed information indicating an exposure time of each frame of the image data. The image processing apparatus **2** is different from the image processing apparatus **1** of FIG. **1** in that a shutter speed estimation processor **14** is included.

The shutter speed estimation processor **14** receives the image data, which is also acquired by the image acquisition unit **11**, and the motion information of the image data. The shutter speed estimation processor **14** performs image processing in order to analyze the input image data, and thus estimates the shutter speed information indicating the exposure time of each frame at the image capturing of the image data. The estimated shutter speed information is output to the motion blur correction parameter calculator **12**. The process performed by the motion blur correction parameter calculator **12** and the motion blur correction processor **13** is identical to the process of the counterparts in the image processing apparatus **1** illustrated in FIG. **1**.

The jerkiness degradation and the blur degradation typically take place in the displayed image, causing the image of the image data to look unnatural to the eyes of humans. The image processing apparatus **2** thus constructed analyzes the image data using the motion information of the image data affecting the jerkiness degradation and the blur degradation. The image processing apparatus **2** estimates the information of the shutter speed at the image capturing of the image data, and corrects the motion blur of the image data adaptively in response to the estimated shutter speed information. The image processing apparatus **2** thus reduces both the jerkiness degradation and the blur degradation.

FIG. **4** illustrates an image processing apparatus **3** having the third structure. The image processing apparatus **3** includes a motion blur correction processor **13**A instead of the motion blur correction processor **13** included in the image processing apparatus **2** illustrated in FIG. **3**. The rest of the image processing apparatus **3** is identical in structure to the image processing apparatus **2**. The motion blur correction processor **13**A includes the motion blur reduction processor **32**, the motion blur addition processor **33**, and a selector and synthesizer **35**. The motion blur reduction processor **32** performs the motion de-blur process on all the partition areas of the input image data. The motion blur addition processor **33** performs the motion ad-blur process on all the partition areas of the input image data.

The selector and synthesizer **35** receives from the motion blur reduction processor **32** the image data at all the partition areas that have undergone the motion de-blur process. The selector and synthesizer **35** receives from the motion blur addition processor **33** the image data at all the partition areas that have undergone the motion ad-blur process. The selector and synthesizer **35** also receives the input image data (image data not motion blur corrected). In response to the motion blur correction parameter, the selector and synthesizer **35** selects the motion blur reduced data, the motion blur added data, or the uncorrected data. The selector and synthesizer **35** synthe-

sizes the selected data at each partition area, thereby generating and outputting the image data of one frame. Prior to the correction process, the sorting unit **31** in each of the first and second basic structures selects the correction process to be performed. In contrast in the third basic structure illustrated in FIG. **4**, the motion de-blur process and the motion ad-blur process are performed on all the partition areas, and then the image data at an appropriate correction state is selected and output as output image data.

In one option, the image processing apparatus **3** illustrated in FIG. **4** may have the same structure as the image processing apparatus **2** illustrated in FIG. **3** except the motion blur correction processor **13**A. In another option, the image processing apparatus **3** may have the same structure as the image processing apparatus **1** illustrated in FIG. **1** except the motion blur correction processor **13**A.

The image processing apparatus **2** having the second basic structure in accordance with one embodiment of the present invention is described further in detail. The image processing apparatus **1** having the first basic structure can be considered to be a particular version of the image processing apparatus **2** in which the imaging shutter speed information is available. The discussion that follows focuses on the image processing apparatus **2**. The image processing apparatus **1** is also considered to be a particular version of the image processing apparatus, discussed with reference to FIG. **5** and subsequent drawings, without element for the shutter speed estimation process. The third basic structure will be further described later.

FIG. **5** illustrates an image reproducing apparatus **100** to which the image processing apparatus **2** having the second basic structure is applied. The image reproducing apparatus **100** receives and reproduces image data transmitted via a transmission line, or reproduces image data recorded on a recording medium **200**, such as digital versatile disc (DVD) or Blu-ray Disc (Registered Trademark of Sony Corporation).

Referring to FIG. **5**, the image reproducing apparatus **100** includes a receiving processor **110** receiving encoded image data transmitted via a transmission line, and a reading processor **120** reading encoded image data from the recording medium **200**. The image reproducing apparatus **100** also includes a decoding processor **130** decoding the encoded data into image data DD, and a motion vector generation processor **140** generating a motion vector VD from the decoded image data DD. The image reproducing apparatus **100** also includes a shutter speed estimation processor **150** estimating a shutter speed SSD of the image data at the image capturing, using the decoded image data DD and the motion vector VD, and a motion blur correction parameter calculator **170**. The image reproducing apparatus **100** further includes a motion blur correction processor **160** correcting a motion blur quantity of the decoded image data DD in accordance with the motion vector VD and the shutter speed SSD. The image reproducing apparatus **100** also includes a moving image display output unit **190** that causes a display device to display a moving image that has the jerkiness degradation thereof reduced with a motion blur added. The image reproducing apparatus **100** further includes a still image display output unit **180** that causes the display device to display a decoded image as a still image.

The receiving processor **110**, the reading processor **120**, the decoding processor **130**, and the motion vector generation processor **140**, enclosed in an dot-and-dash chain lined box, correspond to the image acquisition unit **11** in the third basic structure illustrated in FIG. **3**. The shutter speed estimation processor **150** corresponds to the shutter speed estimation processor **14** illustrated in FIG. **3**. The motion blur correction parameter calculator **170** corresponds to the motion blur correction parameter calculator **12** illustrated in FIG. **3**. The motion blur correction processor **160** corresponds to the motion blur correction processor **13** illustrated in FIG. **3**.

Referring to FIG. **5**, the receiving processor **110** and the reading processor **120** retrieve image data predictive coded in accordance with image motion information such as moving picture experts group (MPEG), and supplies the image data to the decoding processor **130**. The image data retrieved as a moving image by the receiving processor **110** and the reading processor **120** has a unit time of 1 second, and contains 60 frames of images per unit time. More specifically, the image data is a progressive unit image of a frame rate of 60 frames per second (fps). The image data is not limited to the progressive image. The image data may be an interlace image that is processed on a field image unit basis. The frame rate is not limited to 60 fps.

The image reproducing apparatus **100** may have at least one of the receiving processor **110** and the reading processor **120** to perform an image data retrieval function for retrieving an image from the outside. In addition to the image data retrieval function, the image reproducing apparatus **100** may acquire the shutter speed information contained as metadata of the image data. In such a case, the image reproducing apparatus **100** becomes similar to the image processing apparatus **1** having the first basic structure, and does not use the shutter speed estimation processor **150** for estimating the shutter speed SSD at the image capturing.

The decoding processor **130** decodes the image data retrieved from one of the receiving processor **110** and the reading processor **120**. The decoding processor **130** then supplies the decoded image data DD to each of the motion vector generation processor **140**, the shutter speed estimation processor **150**, and the motion blur correction processor **160**. When the decoded image data DD is processed as a still image, the decoding processor **130** supplies the decoded image data DD to the still image display output unit **180** only, and is free from handling the image data as a moving image.

The motion vector generation processor **140** generates the motion vector VD as the motion information of the decoded image data DD from the decoded image data DD supplied from the decoding processor **130**. The motion vector herein is information representing a position of a moving image between frames and a movement direction of the moving image. The motion vector can be generated by pixel to acquire the motion information of a moving object at a high accuracy level. The motion vector generation processor **140** of one embodiment of the present invention generates the motion vector by pixel block to reduce the calculation load on the process. The frame image is here divided into a plurality of pixel blocks.

The image data encoded in accordance with the MPEG standard or the like contains a motion vector as encoding information. In accordance with one embodiment of the present invention, the use of the motion vector as the encoding information is possible and useful from the standpoint of the reduction of workload. The motion vector for encoding serves as information to encode primarily a moving image. The encoding process is performed in combination with residual information or the like in addition to the motion vector, and the motion vector does not necessarily faithfully represent a value responsive to a motion of an actual moving object over the entire image. In accordance with one embodiment of the present invention, the motion vector generation processor **140** detects accurately a motion vector responsive to a motion of an actual moving object in a decoded image through a process step to be discussed later. The motion

vector generation processor **140** thus adds a motion blur faithful to the motion of the actual moving object.

The shutter speed estimation processor **150** estimates the shutter speed SSD at the image capturing of the image data from the decoded image data DD supplied from the decoding processor **130**. The shutter speed estimation process is performed as a process in which the motion vector VD supplied from the motion vector generation processor **140** is used as will be described later. The shutter speed information here is information related to a shutter speed that affects a motion blur to be added to the captured image of the image data. More specifically, the shutter speed information represents an exposure time of unit image taken when an imaging apparatus having a shutter function captures the image data. The shutter function may be performed by one of an electronic shutter controlling a drive time of an imaging element, a mechanical shutter that allows light to pass through a lens to the imaging element by opening a closing mechanism for an exposure time, and a liquid-crystal shutter that allows light to pass through a lens to an imaging element by controlling the transmittance ratio of a liquid-crystal element for an exposure time in the imaging apparatus.

In a process to be specifically discussed later, the motion blur correction parameter calculator **170** calculates the motion blur correction parameter in accordance with the shutter speed SSD supplied from the shutter speed estimation processor **150**, and the motion vector VD supplied from the motion vector generation processor **140**, and then supplies the calculated motion blur correction parameter to the motion blur correction processor **160**.

In a process to be specifically discussed later, the motion blur correction processor **160** performs the motion blur correction process based on the decoded image data DD supplied from the decoding processor **130** and the motion blur correction parameter supplied from the motion blur correction parameter calculator **170**. The motion blur correction process may be interpreted as a process to convert the partition areas of the decoded image data DD into a pseudo image that is captured at an optimum shutter speed. The optimum shutter speed is intended to reduce the generation of jerkiness and blur in response to a movement speed of each partition area contained in the motion vector VD. In this case, the motion blur correction processor **160** references the shutter speed SSD of an input image signal prior to the conversion operation. If the optimum shutter speed in each partition area is lower than the shutter speed SSD, the motion blur correction processor **160** performs the motion ad-blur process. Conversely, if the optimum shutter speed in each partition area is higher than the shutter speed SSD, the motion blur correction processor **160** performs the motion de-blur process. The motion blur correction processor **160** synthesizes images having respectively converted partition areas into one frame, thereby generating an output image signal OD. The output image signal OD is output to the moving image display output unit **190**.

The moving image display output unit **190** outputs to a display device such as a liquid-crystal display (LCD) a moving image that has been motion blur corrected with the jerkiness degradation and the blur degradation reduced by the motion blur correction processor **160**. The still image display output unit **180** outputs to the display device such as the LCD the decoded image data DD received from the decoding processor **130** as a still image.

The elements illustrated in FIG. **5** are described in detail. A structure and operation of the motion vector generation processor **140** are described first. The motion vector generation processor **140** generates accurately the motion vector on a per pixel block basis. With reference to FIG. **6**, the motion vector generation processor **140** includes a motion vector detector **141**, a pixel block identification processor **142**, a motion vector estimation processor **143**, a motion vector smoothing processor **144**, and delay units **141***a* and **142***a*.

The motion vector detector **141** detects a motion vector from a process target frame and an immediately preceding frame. The pixel block identification processor **142** identifies a pixel block having a high correlation by comparing the motion vector of the process target frame with the motion vector of the immediately preceding fame on a per pixel block basis. The motion vector estimation processor **143** estimates the motion vector of a pixel block other than the pixel block identified by the pixel block identification processor **142**, based on the motion vector of the pixel block identified by the pixel block identification processor **142**. The motion vector smoothing processor **144** performs a smoothing process on the motion vector.

The decoded image data DD supplied from the decoding processor **130** is supplied to the motion vector detector **141**, and the delay unit **141***a* delaying the decoded image data DD by one frame. The motion vector detector **141** sets the decoded image data DD supplied from the decoding processor **130** as a process target frame. The motion vector detector **141** then detects the motion vector of each process target frame on a per pixel block basis based on the process target frame and the immediately preceding frame that is delayed by one frame by the delay unit **141***a*. If the process of the motion vector detector **141** is implemented in software, the motion vector may be detected on a pixel block basis using a typically available block matching method.

The motion vector detected by the motion vector detector **141** is supplied to the pixel block identification processor **142** and the delay unit **142***a*. The delay unit **142***a* delays the input motion vector by one frame. On a per pixel block basis, the pixel block identification processor **142** compares the motion vector of the process target frame supplied from the motion vector detector **141** with the motion vector of the immediately preceding frame delayed by the delay unit **142***a* as described below. From the comparison results, the pixel block identification processor **142** identifies a pixel block having a high correlation.

More specifically, the pixel block identification processor **142** calculates a vector correlation coefficient σ of that pixel block in accordance with the following equation (1).

$$\sigma = \begin{cases} 1: \begin{cases} \alpha \times x < x' < (2-\alpha) \times x \\ \& \\ \alpha \times y < y' < (2-\alpha) \times y \\ \because \\ (\text{case}) x = 0 \\ -(1-\alpha) \times y < x' < (1-\alpha) \times y \\ (\text{case}) y = 0 \\ -(1-\alpha) \times x < y' < (1-\alpha) \times x \end{cases} \\ 0: \text{Others} \end{cases} \tag{1}$$

where let (x,y) represent the motion vector of one pixel block of the process target frame, (x',y') represent the motion vector of a pixel block of the immediately preceding frame corresponding to the first block, and α represent any correlation determination coefficient.

The correlation determination coefficient α has a range of $0<\alpha<1$. The larger the correlation determination coefficient α, the more the calculated vector correlation coefficient σ is likely to be 1.

The pixel block identification processor **142** calculates the vector correlation coefficient σ of each pixel block in accordance with equation (1), and identifies a pixel block having 1 for the vector correlation coefficient σ as a motion vector having a high correlation.

The motion vector estimation processor **143** estimates, from the motion vector of the pixel block determined as having a vector correlation coefficient σ of 1 by the pixel block identification processor **142**, a motion vector of a pixel block having a vector correlation coefficient σ of 0. On the premise that the pixel block determined as having a vector correlation coefficient σ of 1 by the pixel block identification processor **142** has an effective motion vector, the motion vector estimation processor **143** updates the motion vector of another pixel block, i.e., a pixel block having the vector correlation coefficient σ thereof being zero and thus determined as having an ineffective motion vector.

The process of the motion vector estimation processor **143** is specifically described with reference to FIG. **7**. In step S**1**, the motion vector estimation processor **143** determines whether the vector correlation coefficient σ of a pixel block serving currently as a target pixel block in the process target frame is 1 or 0. More specifically, the motion vector estimation processor **143** determines whether the motion vector of the pixel block is effective or not. If it is determined in step S**1** that the motion vector of the pixel block is effective, the motion vector estimation processor **143** ends the process without updating the value of the motion vector. If it is determined in step S**1** that the motion vector of the pixel block is not effective, the motion vector estimation processor **143** proceeds to step S**2**.

In step S**2**, the motion vector estimation processor **143** determines on the target pixel block whether a surrounding pixel block having an effective motion vector is present around the target pixel block. More specifically, the motion vector estimation processor **143** determines eight pixel blocks next to the target pixel block as surrounding pixel blocks contain an effective motion vector. If an effective motion vector is present, the motion vector estimation processor **143** proceeds to step S**3**. If there is not any effective motion vector, the motion vector estimation processor **143** does not update the motion vector of the target pixel block, and ends the process thereof.

Because of the following reasons, the estimation process is not performed on the surrounding blocks present within a larger area with respect to the target pixel block having no effective motion vector. Firstly, the estimation process can be performed on the surrounding blocks present within a larger area at any rate. However, if the estimation process is performed on the surrounding blocks present within a larger area, a storage area storing temporarily the image data handled as the surrounding blocks is increased in capacity to complete the process within a fixed time. Secondly, in the later portion of the process of FIG. **6**, ineffective motion vectors may be corrected by performing a smoothing process on the motion vector of the target pixel block using the surrounding pixel blocks larger in area than the eight adjacent pixel blocks.

In step **33**, the motion vector estimation processor **143** estimates and updates the motion vector of the target pixel block based on the motion vectors of the surrounding pixel blocks having the effective motion vectors. The motion vector estimation processor **143** thus ends the process. In one example of the estimation process, the motion vector estimation processor **143** includes a median filter. The median filter receives the motion vectors of the surrounding pixel blocks having the effective motion vectors, and outputs a smoothed motion vector of the surrounding pixel blocks.

The motion vector estimation processor **143** thus estimates the motion vector of the process target frame on a pixel block basis. The motion vector estimation processor **143** thus supplies the motion vectors including the motion vector identified by the pixel block identification processor **142** to the motion vector smoothing processor **144**.

The motion vector smoothing processor **144** performs a smoothing process on the motion vectors of the pixel blocks forming a process target image. More specifically, the motion vector smoothing processor **144** receives as an input I(x+i,y+j) the motion vector of the target pixel block prior to the smoothing process, and the motion vector of a surrounding pixel blocks larger than in area than the above-described adjacent pixel blocks, and outputs a motion vector J(x,y) of the target pixel block that has smoothed through a Gaussian function described in the following equation (2):

$$J(x,y)=\left(\frac{\sum I(x+i,y+j)*e^{-\frac{r^2}{2\sigma^2}-\frac{(I(x+i,y+j)-I(x,y))^2}{t^2}}}{\sum e^{-\frac{r^2}{2\sigma^2}-\frac{(I(x+i,y+j)-I(x,y))^2}{t^2}}}\right) \quad (2)$$

where r represents a distance in a two-dimensional space between the target pixel block and each surrounding pixel block, σ2 represents a variance of the distance r, and t**2** represents a variance of the motion vector. More specifically, σ2 and t**2** are parameters to any values representing the degree of smoothing.

The motion vector smoothing processor **144** performs the above-described smoothing process on each pixel block forming the process target frame, and outputs the resulting motion vector VD to the motion blur correction parameter calculator **170**.

The motion vector smoothing processor **144** identifies a pixel block having an effective motion vector from pixel blocks forming the process target frame, and estimates another motion vector from the effective motion vector. The motion vector smoothing processor **144** can generate the motion vector responsive to the motion of an actual moving object. In the motion vector generation processor **140**, the motion vector detected by the motion vector detector **141** may be supplied to the motion vector smoothing processor **144** in the smoothing process with the pixel block identification processor **142** and the motion vector estimation processor **143** skipped. Even in such a process, the motion vector generation processor **140** can provide a more accurate motion vector responsive to the motion of the moving object than when the above-described encoding information is used as the motion vector.

The specific structure of the shutter speed estimation processor **150** is described below with reference to FIG. **8**. FIG. **8** is a block diagram illustrating the shutter speed estimation processor **150**. The shutter speed estimation processor **150** includes a process target area selector **151**, a motion blur characteristic analyzer **152**, an imaging shutter speed calculator **153**, and an imaging shutter speed accuracy enhancement processor **154**. The shutter speed estimation processor **150** receives the decoded image data DD and the motion vector VD. The shutter speed estimation processor **150** image analyzes these pieces of input information, thereby estimating and outputting the shutter speed SSD at which the image data has been captured.

The decoded image data DD and the motion vector VD, input to the shutter speed estimation processor **150**, are first received by the process target area selector **151**. The process target area selector **151** selects a process target frame on which image analysis is to be performed in order to calculate the shutter speed. The process target area selector **151** also selects a target area within the selected frame. The process target area selector **151** then outputs the image data as a selected target area DDT and a motion vector VDT responsive to the target area DDT to subsequent stages. As will be described later, the target area DDT refers to the image data at an area that is extracted as a target of the shutter speed estimation process within one frame. The process target area selector **151** detects a scene change from the decoded image data DD input as a moving image, and then outputs the scene change detection signal SCD to the imaging shutter speed accuracy enhancement processor **154**.

The process target area DDT is input to the motion blur characteristic analyzer **152**. The motion blur characteristic analyzer **152** performs an image analysis process on the image data as the process target area DDT (i.e., image data that is within a pixel area serving as a process target area within one frame). The motion blur characteristic analyzer **152** calculates a "motion blur length L" generated in the process target area. The motion blur length L will be described later. The calculated motion blur length L is output to the imaging shutter speed calculator **153**.

The imaging shutter speed calculator **153** calculates an estimation imaging shutter speed SSDT based on the value of the motion blur length L generated in the process target area DDT and the motion vector VDT responsive to the process target area. The estimation imaging shutter speed SSDT is an estimated value of the shutter speed at the image capturing. The calculated estimation imaging shutter speed SSDT is output to the imaging shutter speed accuracy enhancement processor **154**. The imaging shutter speed accuracy enhancement processor **154** receives the estimation imaging shutter speeds SSDT estimated from a plurality of process target areas. In response to the values of these pieces of information, the imaging shutter speed accuracy enhancement processor **154** calculates a highly accurate, estimation imaging shutter speed SSD, and outputs the calculated estimation imaging shutter to the motion blur correction parameter calculator **170**.

Motion blur characteristics serving as a basis of the process to be performed by the shutter speed estimation processor **150** are described before describing a process to be performed in each process block by the shutter speed estimation processor **150** of FIG. **8**. The process of the shutter speed estimation processor **150** is a process to estimate a shutter speed from an image having an unknown shutter speed at the image capturing. The relationship of the generation of motion blur, a movement speed, and an imaging shutter speed is described first in order to describe the basic motion blur characteristic. The estimation method of the shutter speed taking into consideration the characteristics of a generated motion blur is then described.

The relationship of the generation of motion blur, the movement speed, and the imaging shutter speed are briefly described with reference to FIGS. **9** and **10**. FIG. **9** illustrates the motion blur characteristics generated when an image is captured. The upper portion of FIG. **9** focuses on the relationship between a spatial position and brightness at a target area within the real space. As shown, the spatial position is plotted in the horizontal direction and illuminance is represented in the vertical direction. The foreground is moving in position from right to left at a constant speed. The bright foreground is overriding the dark background. The lower portion of FIG. **9** simulates an image signal, which has been obtained by image capturing the target area in the real space illustrated in the upper portion using an imaging apparatus illustrated in FIG. **9**, in terms of the relationship between the coordinates of one line extending in the horizontal direction and brightness of the target area. As shown in the lower portion of FIG. **9**, the coordinates of the image signal are plotted in the horizontal direction and luminance is plotted in the vertical direction. Broken lines represent pixels. The imaging apparatus here having a shutter function controls a shutter speed that is an exposure time throughout which an image is acquired.

An image signal labeled (i) in FIG. **9** is captured when an ideal high-speed shutter of the shutter function (with the exposure time being infinitesimal) is performed. An image signal labeled (ii) in FIG. **9** is captured when a low-speed shutter of the shutter function (with a predetermined exposure time) is performed. In comparison of the image signals (i) and (ii), the image signal (i) is a step function signal while the image signal (ii) is captured with light being integrated for a longer exposure time. The motion blur takes place in addition to the image signal (i). FIG. **9** illustrates that the motion blur in the vicinity of the outline of the moving object has low-pass filter characteristics. In the discussion that follows, an area having a luminance slope is defined as a motion blur area between luminance Bf of the illustrated foreground and an area where luminance Bb is recorded in a stable fashion. The motion blur length L is defined as a distance of the area in the horizontal direction.

FIGS. **10A1**, **10B1** and **10C1** illustrate the relationship between the movement speed of the object and the motion blur length L. FIGS. **10A1**, **10B1**, and **10C1** illustrate the motion blur characteristics that are generated when the movement speed of the foreground in the upper portion of FIG. **9**. The shutter speed at the image capturing remains constant in FIGS. **10A1**, **10B1**, and **10C1**.

Let A, B, and C represent the movement speeds of the foreground shown in FIGS. **10A1**, **10B1**, and **10C1**, and the movement speeds are now related in magnitude as A:B:C=3:2:1. Referring to FIGS. **10A1**, **10B1**, and **10C1**, the motion blur lengths L are also related as 3:2:1 because L=nine pixels in FIG. **10A**, L=six pixels in FIG. **10B**, and L=three pixels in FIG. **10C**. Since the image signal is recorded with light integrated for the same exposure time, the distance of travel of the object during the exposure time becomes a motion blur area. The motion blur length L generated in the vicinity of a pixel having a movement speed is thus proportional to the magnitude of the movement speed of the object.

FIGS. **10A2**, **10B2**, and **10C2** illustrate the relationship of the imaging shutter speed and the motion blur length L. FIGS. **10A2**, **10B2**, and **10C2** show the motion blur characteristics taking place when the shutter speed of the imaging apparatus is changed in the upper portion of FIG. **9**. The movement speed of the foreground remains unchanged in FIGS. **10A2**, **10B2**, and **10C2**. If the imaging shutter speeds FIGS. **10A2**, **10B2**, and **10C2** are now respectively "a," "b," and "c," the ratio of the imaging shutter speeds is a:b:c=4:2:1. The motion blur lengths L are related as 4:2:1 because L=eight pixels in FIG. **10A2**, L=four pixels in FIG. **10B2**, and L=two pixels in FIG. **10C2**. Light is integrated during the exposure time of the image capturing. If the movement speed of the object to be picked up remains constant, the longer the exposure time, the more the motion blur area extends. The motion blur length L generated in the vicinity of a pixel having the movement speed is proportional to the magnitude of the shutter speed.

As described above, the motion blur length L is proportional to the movement speed of the object, and is also proportional to the imaging shutter speed.

Let L represent the motion blur length (pixels), V represent the movement speed of the object within the image signal (pixels/frame), S represent the imaging shutter speed (seconds), and F represent the frame rate of the moving image (frames/second), and the following equation (3) holds:

$$L=V\times S\times F \tag{3}$$

In equation (3), VS is by the frame rate F because the movement speed V is an amount of distance within one frame period.

If the movement speed is 8 (pixels/frame), the imaging shutter speed is S=T in FIG. **10**A**2**, the imaging shutter speed is S=T/2 in FIG. **10**B**2** and the imaging shutter speed is S=T/4 in FIG. **10**A**2**, and the frame rate is F=1/T (T being a frame period (seconds)), the following relationship holds:

$L=8\times T\times(1/T)=8$ (pixels) in FIG. 10*A*2,

$L=8\times(T/2)\times(1/T)=4$ (pixels) in FIG. 10*B*2, and

$L=8\times T(T/4)\times(1/T)=2$ (pixels) in FIG. 10*C*2.

The determined motion blur lengths are thus equal to the motion blur lengths L in FIGS. **10**A**2**, **10**B**2**, and **10**C**2**.

The relationship of the generation of motion blur, the movement speed and the imaging shutter speed has been discussed based on a simple example. Since the shutter speed estimation processor **150** is intended to estimate an unknown imaging shutter speed of an image, the above-described equation (3) is rearranged into equation (4):

$$S=L/(V\times F) \tag{4}$$

In accordance with equation (4), the movement speed V of a target area in the image, and the frame rate F are known. An unknown shutter speed S at the image capturing is obtained if the motion blur length L is obtained.

In the following discussion, the process of each element in one example of the shutter speed estimation processor **150** illustrated in FIG. **8** is clarified, and the procedure of the shutter speed estimation is described. The estimation method of an imaging shutter speed from an image is not limited to this method. For example, in a method discussed below, the shutter speed at the image capturing is calculated by identifying the motion blur length L as defined above.

The decoded image data DD and the motion vector VD serving as the inputs to the shutter speed estimation processor **150** are first supplied to the process target area selector **151**. The process target area selector **151** extracts an area (hereinafter referred to as a "target area") as a target of the image analysis in the shutter speed estimation, and outputs the process target area DDT and the motion vector VDT responsive to the process target area DDT to the subsequent stage. The process target area selector **151** performs the extraction process on the premise that the extraction process is not necessarily performed on all the areas of the frame in the input moving image signal having an area where the motion blur takes place. Any method may be used to select the target area serving the target of the analysis process.

The reasons why no problem arises with the estimation of the imaging shutter speed performed in only the limited area are described below. The shutter speed at the image capturing is typically uniform within one frame image. Furthermore, a smaller number of target areas to be processed is advantageous in terms of process costs.

If the shutter speed estimation process is performed on one target area within the frame, no shutter speed estimation is necessary on the other areas. As long as process costs permit, performing the shutter speed estimation process within a plurality of extracted target areas is greatly useful from the standpoint of accuracy enhancement of the shutter speed estimation. In accordance with one embodiment, a process to be described later is performed in a plurality of target areas from within one frame, and the imaging shutter speed SSD is estimated from a plurality of obtained results. If a plurality of shutter speeds are obtained, a process of increasing reliability is carried out by the subsequent stage, i.e., the imaging shutter speed accuracy enhancement processor **154**. Such a process will be described later.

A method of selecting a target area of the analysis process from a given frame of the decoded image data DD is not limited to any one method. The target area is preferably in the vicinity of a border outline edge of an object illustrated in FIGS. **9** and **10**A**1** through **10**C**2** in order to perform effectively the analysis process of the motion blur characteristics to be discussed in detail later. If the movement speed of a given area is zero, no motion blur takes place in that area. In the selection of the target area, movement speed information may be used so that an area having a predetermined movement speed is selected as a target area. If the direction of an edge is approximately perpendicular to the direction of the movement speed, the analysis process of the generated motion blur is easily performed. In summary, the area to be selected has a certain degree of movement speed, and is a target area close to the edge as perpendicular as possible to the direction of the movement speed.

When an analysis process is performed in the image processing, pixels are preferably picked up in a scan line direction in view of the process costs. The target area is thus conveniently extracted from a region close to a vertical edge having a horizontal movement speed. When the target area is selected, a motion blur characteristic analysis process to be discussed in detail later is performed along one line rather than across a plurality of lines. Focusing on the region close to the vertical edge having a horizontal movement speed, the use of only a sufficient number of pixels in a horizontal direction with respect to the movement speed serves the purpose of the motion blur characteristic analysis process to be discussed later.

FIGS. **11**A-**11**C illustrate how the target area is selected. FIG. **11**A illustrates one frame of the decoded image data DD. As discussed heretofore, an edge extraction process is performed on the decoded image data DD, for example, using the Sobel filter, and edge data ED illustrated in FIG. **11**B is obtained. As previously discussed, one horizontal line in the vicinity of a vertical edge having a horizontal movement speed is selected. For example, areas AR**1**-AR**5** are set to be target areas. The target areas AR**1**-AR**5** may be a portion of each horizontal line. Luminance information of each target area is obtained as illustrated in FIG. **11**C. In FIG. **11**C, the abscissa represents coordinates of each pixel in the target area and the ordinate represents luminance.

The discussion heretofore is related to the selection process in one frame. No problem arises even if the selection process is not performed on the entire region of one frame. Likewise, it is not necessary to select all the target areas in the frame. This is because the moving image forming a plurality of frames typically has an imaging shutter speed remaining unchanged at least until a frame in which a scene change takes place. The imaging shutter speed estimated through analysis of one frame can be held at the value thereof until a next scene change is detected.

It suffices if the shutter speed estimation process is performed at least in one given frame within a period from the

detection of a scene change to the detection of a next scene change. However, it is acceptable that a plurality of target areas are detected from within one frame, and that the shutter speed estimation process is performed in each of the target areas. Likewise, performing the shutter speed estimation process in a plurality of frames is particularly useful as long as process costs permit. This enhances the accuracy level of shutter speed estimation. The imaging shutter speed accuracy enhancement processor **154** performs a reliability enhancing process if a plurality of different shutter speed values are estimated.

A target area selection process of the process target area selector **151** is specifically described with reference to FIG. **12**. FIG. **12** illustrates, for operation description purposes, an internal functional structure of the process target area selector **151** and the imaging shutter speed accuracy enhancement processor **154** illustrated in FIG. **8**.

Referring to FIG. **12**, the process target area selector **151** includes a vertical direction edge detector **1511**, a horizontal direction movement speed threshold value processor **1512**, a target area determiner **1513**, and a scene change detector **1514**. In this arrangement, an area having a horizontal speed equal to or higher than a constant value in the vicinity of a vertical edge is extracted as a target area from within one frame, and the shutter speed estimation process is performed on only the extracted target area.

The vertical direction edge detector **1511** performs an edge detection process on each area within the frame of input decoded image data DD. In this case, only a vertical edge may be extracted using a direction selective mask process of the Sobel filter or the like. The input image data at an area determined as a vertical edge is output, as is, to the target area determiner **1513**. An area not determined as a vertical edge is output to the target area determiner **1513** with all the pixel signals within that area set to "0." A motion vector VD is input to the horizontal direction movement speed threshold value processor **1512**. To select an area having a horizontal speed equal to or higher than the constant value, a horizontal component of the motion vector of each area, represented by a horizontal component VDx, is objected to a threshold value process. If the horizontal component VDx is larger than a predetermined threshold value TH (VDx>TH), the motion vector signal of the input area is output as is to the target area determiner **1513**. If the horizontal component VDx is equal to or lower than the threshold value TH (VDx≦TH), all the motion vectors of the areas are set to "0," and then output to the target area determiner **1513**.

The target area determiner **1513** determines that the area is a target of the shutter speed estimation process only if both the image data and the motion vector of the input area are not zero. Only in this case, the area is determined as the process target area DDT. As previously described, the process target area DDT is the image data of the area that is determined as a target. The target area determiner **1513** outputs the process target area DDT to the motion blur characteristic analyzer **152**, and the motion vector VDT of the area to the imaging shutter speed calculator **153**.

Each frame of the decoded image data DD input to the process target area selector **151** is supplied to the scene change detector **1514**. The scene change detector **1514** performs a scene change detection process. Any scene change detection technique may be used. For example, the scene change detection technique disclosed in Japanese Unexamined Patent Application Publication No. 2004-282318 may be used. When a scene change is detected, the scene change detector **1514** outputs a scene change detection signal SCD to the imaging shutter speed accuracy enhancement processor **154**.

As described above, the process target area selector **151** identifies the process target area DDT, and then outputs the process target area DDT to the motion blur characteristic analyzer **152**. The process target area selector **151** also extracts the motion vector VDT responsive to the position of the process target area DDT and outputs the motion vector VDT to the imaging shutter speed calculator **153**. The process of the motion blur characteristic analyzer **152** is described below. The analysis of the motion blur characteristics is a process of estimating the motion blur length L of the motion blur (see (ii) low speed shutter image in FIG. **9** and FIG. **11**C).

Several methods are contemplated to determine the motion blur length L. Two main types of the method of determining the motion blur length L are described here. In a first method, the motion blur length L is estimated by defining a mathematical model of motion blur and finding a parameter in the mathematical model minimizing an error function to a motion blur occurring in an actual image signal. In a second method, the motion blur length L is estimated by matching a motion blur sample pattern prepared beforehand to a motion blur actually taking place in an image signal.

One example of the first method is described first. The motion blur length L is estimated by expressing in a mathematical model a luminance value close to an edge affected by a motion blur as disclosed in the paper entitled "Photometric Registration Based on Defocus and Motion Blur Estimation for Augmented Reality," Bunyo OKUMURA, Masayuki KANBARA, and Naokazu YOKOYA, The Institute of Electronics, Information and Communication Engineers, D Vol. J90-D No. 8 pp. 2126-2136. In accordance with the disclosed technique, let coordinates p represent each pixel in the vicinity of an edge and **p0** represent coordinates (unknown) of a center position of a blur occurring in the vicinity of the edge, and variable t is expressed in the following equation (5):

$$t=2*(p-p0)/L \tag{5}$$

where the center position coordinates P**0** is illustrated in (ii) low-speed shutter image in FIG. **9**.

Using equation (5), function g(t) simulating the motion blur characteristics in the vicinity of the edge is defined as equation (6):

$$g(t)=\frac{1}{2}+\frac{1}{\pi}\left(t\sqrt{1-t^2}+\arcsin t\right) \tag{6}$$

To compare with the actual motion blur, the following equation (7) is used:

$$f(p;L;p0;Bf;Bb)=\begin{cases} Bf & (t<-1) \\ g(t)*(Bf-Bb)+Bb & (-1\leqq t\leqq 1) \\ Bb & (t>1) \end{cases} \tag{7}$$

The luminance Bf of the foreground and the luminance Bb of the background in (ii) low-speed shutter image in FIG. **9** are used in equation (7).

Pixel coordinates p in the vicinity of the edge are substituted in equation (5), and parameters L, **p0**, Bf, and Bb minimizing a distance function to the value of the actual motion blur are found from equations (5), (6) and (7). The motion blur length L is thus estimated. To search for the four unknowns minimizing the distance function, a numerical

analysis method such as quasi-Newton method may be used. The distance function is typically a comparison of squared values of differences, each between pixel values of an actual image and a function f, or a comparison of the linear sum of the absolute values of the differences, each between pixel values of an actual image and a function f. Taking into consideration imaging conditions, such as an optical low-pass filter and focus, as in equation (6), a function simulating a dominant motion blur characteristic is defined. The function may be a simple discontinuous function such as the one of (ii) low-speed shutter image signal in FIG. **9**.

In a second method, the motion blur length L is estimated from a spatial frequency component in a target area in the vicinity of an edge selected as a target in the image signal as described above. As described with reference to FIG. **9**, the motion blur generated in the vicinity of a pixel having a movement speed can be expressed as a low-pass filter. Taking advantage of the low-pass filter, the motion blur length L is estimated through matching of frequency analysis results.

As illustrated in FIG. **9**, the characteristics of the motion blur are determined by the exposure time. If the movement speed is constant, the motion blurs having the same motion blur length should have the same frequency characteristics. For example, motion blur sample patterns having a variety of given motion blur lengths L are prepared as in (ii) image signal in FIG. **9** suffering from the motion blur during image capturing, a predetermined frequency analysis is performed on the image signals, and a frequency component of each sample pattern is stored. The frequency analysis method may be one of typical methods including Fourier transform and wavelet analysis. When the target area is input as a target of analysis, the same frequency analysis as the one performed on the sample pattern is performed on the target area, and the sample pattern having the frequency component closest to the frequency component of the target area is determined using an error function or the like. The motion blur length L of the sample pattern having the frequency component closest to the target area becomes the motion blur length L of an edge in the analysis target area.

FIG. **13** illustrates a specific process flow of the estimation of the motion blur length L through matching frequency analysis results. The target area in the vicinity of the edge determined to be an analysis target is input to a fast Fourier transform (FFT) unit **1521**. A fast Fourier transform (FFT) process is performed on the target area, and a dominant frequency component of the target area is output to a frequency component matching unit **1522**. The frequency power spectrum is calculated as a result of the fast Fourier transform, and frequencies having top three power values are sent to the frequency component matching unit **1522**. The frequency component matching unit **1522** searches a motion blur sample frequency table **1523** for a motion blur sample having a frequency pattern most similar to the dominant frequency component of the input target area, and outputs the motion blur length L of the hit sample.

FIG. **14** illustrates an example of the motion blur sample frequency table **1523**. As illustrated, the motion blur sample frequency table **1523** lists frequency components for each of the motion blur lengths L (La, . . . , Lmax). The frequency component matching unit **1522** searches the lookup table of FIG. **14** for a sample having the frequency component most similar to the top three frequency components of the target area. To this end, a function evaluating an error is prepared. For example, evaluation of the error may be performed using a typical distance function that linearly sums squared differences. The motion blur length of the sample motion blur pattern determined is the sought motion blur length L.

The above-described estimation method of the motion blur length L of matching the motion blur sample pattern to the motion blur actually taking place in the image signal focuses on the spatial frequency component. It is also contemplated that the sample pattern and the area in the vicinity of the edge determined to be the analysis target are compared to each other in the real space. In other words, the sample motion blur pattern is stored as an image signal, and a sample motion blur pattern having a error function resulting in a minimum value to an actual image signal is searched for.

The motion blur characteristic analyzer **152** in the shutter speed estimation processor **150** estimates the motion blur length L using one of the above-described techniques, and outputs the resulting motion blur length L. The output motion blur length L is input to the imaging shutter speed calculator **153**.

The imaging shutter speed calculator **153** determines the estimation imaging shutter speed SSDT based on the motion blur length L of the motion blur in the process target area DDT, and the motion vector VDT responsive to the process target area DDT. In other words, the process performed by the imaging shutter speed calculator **153** is merely solving equation (4). As previously described, the frame rate F in equation (4) is known. The movement speed V is a horizontal component of the motion vector VDT responsive to the process target area DDT, and is also known. The motion blur length L is estimated by the motion blur characteristic analyzer **152**. The shutter speed S is easily determined by solving equation (4). The shutter speed S becomes the estimation imaging shutter speed SSDT to be output by the imaging shutter speed calculator **153**.

Finally, the imaging shutter speed accuracy enhancement processor **154** generates and outputs the imaging shutter speed SSD. The imaging shutter speed accuracy enhancement processor **154** receives the estimation imaging shutter speed SSDT estimated by the imaging shutter speed calculator **153**. In this case, estimation imaging shutter speeds estimated from a plurality of target areas are input. As previously discussed, the estimation process may be theoretically performed in one area selected from one frame within a period from the detection of one scene change to the detection of a next scene change. Performing the estimation process in a plurality of target areas within one frame as well as within a plurality of frames is useful to enhance estimation accuracy. For this reason, a plurality of estimation imaging shutter speeds SSDT may be used to generate the shutter speed SSD. If a plurality of different estimation imaging shutter speeds SSDT are estimated, a weight average or a median value of the speeds may be determined as the shutter speed SSD to be finally output. Process reliability is thus enhanced.

Operation of the imaging shutter speed accuracy enhancement processor **154** is described with reference to FIG. **12**. The imaging shutter speed accuracy enhancement processor **154** illustrated in FIG. **12** includes an imaging shutter speed accumulator **1541**, an imaging shutter speed filtering processor **1542**, and a scene change detection signal receiver **1543**.

The estimation imaging shutter speed SSDT calculated on the target area by the imaging shutter speed calculator **153**, input to the imaging shutter speed accuracy enhancement processor **154**, is received by the imaging shutter speed accumulator **1541**. The imaging shutter speed accumulator **1541** accumulates the value of the estimation imaging shutter speeds SSDT. The imaging shutter speed filtering processor **1542** performs a predetermined filtering process using at least one of the values of the estimation imaging shutter speeds SSDT accumulated on the imaging shutter speed accumulator **1541**. As previously discussed, the filtering process is

intended to enhance process reliability when a plurality of different estimation imaging shutter speeds SSDT are input. The filtering process may include an averaging operation, a weighted averaging operation, and a medium value detection operation. To reduce the data size of the estimation imaging shutter speed SSDT to be accumulated on the imaging shutter speed accumulator **1541**, the use of an infinite impulse response (IIR) filter is advisable. With the IIR filter, it suffices if immediately preceding process results only are stored, and operation becomes efficient.

The scene change detection signal receiver **1543** receives the scene change detection signal SCD input from the scene change detector **1514** in the process target area selector **151**. Upon receiving the scene change detection signal SCD, the scene change detection signal receiver **1543** determines that a scene change has taken place in the target frame, and thus determines that the imaging shutter speed has changed. The scene change detection signal receiver **1543** outputs a reset signal to the imaging shutter speed accumulator **1541**, and deletes the estimation values of the imaging shutter speeds heretofore stored. The imaging shutter speed filtering processor **1542** calculates a highly reliable imaging shutter speed using the estimation value of the imaging shutter speed newly input to the imaging shutter speed accumulator **1541**.

The process results of the imaging shutter speed filtering processor **1542** are output as the shutter speed SSD of the current frame or of the current scene (lasting from the detection of an immediately preceding scene change to the detection of a next scene change).

The serial operations of the shutter speed estimation method of the shutter speed estimation processor **150** have been discussed. The shutter speed SSD estimated through the above-described process is output to the motion blur correction parameter calculator **170**.

The process of the motion blur correction parameter calculator **170** and the motion blur correction processor **160** illustrated in FIG. **5** is described below. The motion blur correction parameter calculator **170** and the motion blur correction processor **160** perform a filtering process on each partition area (see FIG. **2**) of the decoded image data DD in response to the value of the motion vector VD input from the motion vector generation processor **140** while referencing the shutter speed SSD input from the shutter speed estimation processor **150**. The motion blur correction parameter calculator **170** and the motion blur correction processor **160** output to the moving image display output unit **190** an output image with both jerkiness and blur reduced. The motion blur correction process performed by the motion blur correction parameter calculator **170** and the motion blur correction processor **160** includes the filtering process of reducing or adding the motion blur on a per partition area basis. The selection of the filtering process is adaptively performed in accordance with a technique to be discussed later.

FIG. **15** illustrates a specific structure of the motion blur correction parameter calculator **170** and the motion blur correction processor **160**. The motion blur correction parameter calculator **170** includes a process selection controller **171** and an optimum shutter speed information memory **172**. The motion blur correction processor **160** includes a sorting unit **163**, a motion blur reduction processor **164**, a motion blur addition processor **165**, and a synthesizer **166**.

The motion vector VD output from the motion vector generation processor **140** and the shutter speed SSD output from the shutter speed estimation processor **150** are first received by the process selection controller **171**. Using a motion vector value responsive to the partition area of the input motion vector VD, the process selection controller **171** references optimum shutter information stored on the optimum shutter speed information memory **172**, and determines the shutter speed SSD**0** of the partition area. The process selection controller **171** also compares the shutter speed SSD supplied from the shutter speed estimation processor **150** with the shutter speed SSD**0** for evaluation. The process selection controller **171** thus determines whether the filtering process to be executed on the partition area is the motion de-blur process, the motion ad-blur process, or no motion blur correction at all. The process selection controller **171** then transfers the determination to the sorting unit **163**.

The process selection controller **171** also outputs a filter parameter PD to the selected motion blur correction filtering blocks, i.e., the motion blur reduction processor **164** and the motion blur addition processor **165**. The motion blur correction may be performed in either the motion de-blur process and the motion ad-blur process. The filter parameter PD is used to adjust the degree of such a process (in terms of amount and intensity).

The sorting unit **163** has already received the decoded image data DD, and outputs the decoded image data DD to one of the motion blur reduction processor **164** and the motion blur addition processor **165** on a per partition area basis in response to process selection control information SCS. Optionally, the sorting unit **163** may output the partition area where performance of a motion blur correction process is not necessary to the synthesizer **166** instead of supplying the partition area to one of the motion blur reduction processor **164** and the motion blur addition processor **165**. The partition area where performance of a motion blur correction process is not necessary is processed by one of the motion blur reduction processor **164** and the motion blur addition processor **165** with the correction amount set to zero therewithin.

The motion blur reduction processor **164** performs on the image data of the partition area supplied from the sorting unit **163** the filtering process to reduce the motion blur quantity in a method to be discussed later, and outputs the resulting image data to the synthesizer **166**. The motion blur addition processor **165** performs on the image data of the partition area supplied from the sorting unit **163** the filtering process to add the motion blur quantity in a method to be discussed later, and outputs the resulting image data to the synthesizer **166**. The image data at the partition area having undergone the filtering process is output to the synthesizer **166**. The synthesizer **166** then reconstructs the received image data into a frame image, and then outputs the frame image as the output image signal OD.

Processes of the elements illustrated in FIG. **15** are described below. In the course of discussion of the processes of the elements, the optimum shutter speed, the selection method of the motion blur reduction process (motion de-blur process) and the motion blur addition process (motion blur addition process), and the filtering process for the motion blur reduction and addition processes are specifically described. Such a discussion is helpful in the understanding of the process performed by the motion blur correction processor **160**.

The process selection controller **171** first references the optimum shutter speed information stored beforehand on the optimum shutter speed information memory **172** using the value of the vector responsive to the partition area of the input motion vector VD, and determines the shutter speed SSD**0** for the partition area. Before describing the process selection controller **171**, the optimum shutter speed is described.

FIG. **16** illustrates an object speed indicating a movement speed of an object detected as a motion vector, and an optimum shutter speed curve responsive to the object speed. The optimum shutter speed responsive to a given movement speed

is a value at which both the jerkiness degradation and the blur degradation are reduced if image capturing is performed at that shutter speed. More specifically, the optimum shutter speed is a shutter speed at which the jerkiness degradation is less visible in accordance with the vision characteristics in response to the movement speed of the object, and at which the blur degradation is also less visible. In the blur degradation, the object lacks a detail or sharpness with an excessive motion blur added. The higher the shutter speed value as the exposure time at the image capturing, the larger the motion blur quantity becomes. If the object is photographed at a shutter speed higher than the optimum shutter speed, the captured image may suffer from jerkiness. If the object is photographed at a shutter speed lower than the optimum shutter speed, the captured image may suffer from motion blur.

The optimum shutter speed information memory **172** pre-stores the optimum shutter speed information represented in FIG. **16**. The optimum shutter speed information memory **172** uses the optimum shutter speed as a motion blur adjustment reference, thereby determining the content of the filtering process to adjust the motion blur quantity at subsequent stages. In other words, the filtering process performed by the subsequent stages, i.e., the motion blur reduction processor **164** and the motion blur addition processor **165**, is interpreted as a process converting each area of the image into an image having a motion blur responsive to a "motion blur quantity captured at the optimum shutter speed."

The optimum shutter speed curve SS**0** in FIG. **16** illustrates a relationship between any object speed and the optimum shutter speed, more specifically, is a curve connecting results of a psychological experiment. A motion blur region A**1** illustrated in FIG. **16** is determined as having an excess degree of motion blur caused by a motion of the object in accordance with the optimum shutter speed curve SS**0**. Similarly, a jerkiness region A**2** is determined as having no motion blur caused by the motion of the object in accordance with the optimum shutter speed curve SS**0** and having a jerkiness degradation in vision characteristics. In order to determine an optimum shutter speed responsive to the motion vector using the optimum shutter speed curve SS**0**, the optimum shutter speed information responsive to the motion vector in steps of any value is pre-stored on the optimum shutter speed information memory **172** as a table and then referenced.

In accordance with one embodiment of the present invention, the optimum shutter speed responsive to the motion vector may be calculated using a function similar to the optimum shutter speed curve denoted by the solid line in FIG. **16**. The process selection controller **171** calculates a shutter speed SSD' in accordance with an approximate function of the optimum shutter speed curve of the following equation (8):

$$SSD' = \left(\frac{v - A}{B - A}\right)^{\gamma} \times (v - A) + A \tag{8}$$

where v represents the motion vector of a given partition area, and parameters A, B, and γ are set to appropriate values in accordance with the optimum shutter curve illustrated in FIG. **16**. FIG. **16** illustrates, as specific examples, curves SS**1**-SS**3** with the parameters A and B of the parameters of equation (8) set to fixed values, and γ changed at three steps.

SS**0** represents the optimum shutter speed curve produced on the basis of the value obtained from an objective evaluation experiment, SS**1**-SS**3** are optimum shutter speed curves approximating the optimum shutter speed curve **330** in accordance with equation (8). SS**1**-SS**3** may be used to adjust the optimum shutter speed curve in accordance with a preference of a user of the apparatus.

A format of the data stored on the optimum shutter speed information memory **172** is not only a graph in FIG. **16** and a mathematical expression such as equation (8) but also a table listing quantized values of the optimum shutter speed curve. The optimum shutter speed minimizing the jerkiness degradation and the blur degradation has been described.

Described below is the determination method of the optimum shutter speed SSD**0** in the partition area performed by the process selection controller **171**. The process selection controller **171** performs the determination method on the premise that the optimum shutter speed information memory **172** stores the optimum shutter speed information in the form of graph illustrated in FIG. **16**.

A movement speed AVT of the partition area represents the absolute value of the vector value responsive to the partition area of the motion vector VD. The value of the movement speed AVT is plotted as a point in the abscissa of the graph in FIG. **16**. A point corresponding to that point in the abscissa is then found on the curve of interest. Then, a value in the ordinate corresponding to the point in the curve is read. The read value is the optimum shutter speed SSD**0** in the partition area.

FIG. **17** illustrates a process flow of the process selection controller **171**. In step S**10**, the process selection controller **171** determines the optimum shutter speed SSD**0** of the partition area in the manner described above. In step S**11**, the process selection controller **171** compares the determined optimum shutter speed SSD**0** with the optimum shutter speed SSD input to the process selection controller **171**. The comparison results determine whether the filtering process to be performed on the partition area is the motion de-blur process or the motion ad-blur process. The criterion of the selection process is that if the optimum shutter speed in the partition area is lower than the imaging shutter speed SSD, the motion ad-blur process is to be performed (step S**12**), and that if the optimum shutter speed is higher than the imaging shutter speed SSD, the motion de-blur process is to be performed (step S**13**).

With reference to FIG. **15**, the process selection controller **171** outputs the filter parameter PD to the selected motion blur correction filtering blocks, namely, the motion blur reduction processor **164** and the motion blur addition processor **165**. The filter parameter PD is used to adjust the degree of selected one of the motion de-blur process and the motion ad-blur process (in terms of amount and intensity). In accordance with the present embodiment, in particular, a shutter speed difference SSDD between the imaging shutter speed of each partition area and the optimum shutter speed, and the motion vector VD are supplied as the filter parameter PD to each of the motion blur reduction processor **164** and the motion blur addition processor **165**. The shutter speed difference SSDD is calculated by the process selection controller **171** at the comparison and evaluation phase that is performed when it is determined whether the motion blur correction process is the motion de-blur process or the motion ad-blur process. If the shutter speed difference SSDD is calculated from an equation of SSDD=SSD−SSD**0**, the motion de-blur process is performed in response to a positive shutter speed difference SSDD or the motion ad-blur process is performed in response to a negative shutter speed difference SSDD.

FIG. **18** illustrates the imaging shutter speed and the object speed (the speed of the object) illustrated in FIG. **16** with a specific example added thereto. With reference to the

example, the selection as to whether the motion de-blur process or the motion ad-blur process is to be performed as the filter process is specifically described. Also, the operation of each of the two filtering processes is described below. FIG. **18** illustrates imaging shutter speeds Sa-Sc as examples of the shutter speed at the image capturing and the object speeds Va-Vc as the movement speed of the object. For convenience of explanation in the discussion that follows, only SS**0** is selected as the optimum shutter speed curve from the curves illustrated in FIG. **16**. It is acceptable that any of the curves SS**0**-SS**3** is selected.

A motion blur quantity adjustment process is described in each of three values Sa, Sb, and Sc of imaging shutter speed with reference to FIG. **18**.

The imaging shutter speed Sa means an open shutter speed. The optimum shutter speed is higher than the actual shutter speed Sa in each of all the object speeds Va, Vb, and Vc. For this reason, the de-blur process as the motion blur reduction process is performed in order to generate an image having the degree of motion blur that is otherwise caused at the optimum shutter speed. The process selection controller **171** thus outputs to the sorting unit **163** the process selection control information SCS indicating that the motion de-blur process has been selected. The sorting unit **163** outputs the signal of each partition area in the input decoded image data DD to the motion blur reduction processor **164**.

The motion de-blur process performed by the motion blur reduction processor **164** is specifically described below. FIG. **19** illustrates a structure of the motion blur reduction processor **164**. The motion blur reduction processor **164** includes a smoothing filter characteristic converter **1641**, a smoothing filter **1642**, a subtractor **1643**, and an adder **1644**. The motion blur reduction processor **164** reduces the motion blur quantity of each partition area of the input decoded image data DD.

The smoothing filter **1642** is one of the simplest types of low-pass filters, and calculates and outputs an average value of the a process target pixel and the surrounding pixels thereof each time the process target pixel moves by one pixel. For example, as illustrated in FIG. **20**A, n sample values including a current sample value (four sample values in FIG. **20**A) are averaged at a given time point. As illustrated in FIG. **20**B, n sample values including a current sample value (four sample values in FIG. **20**B) are averaged at the next time point. The sample value refers to a pixel value. Each time the process target pixel moves by one pixel, n sample values including the values of the process target pixel and the surrounding pixels are averaged.

The smoothing filter characteristic converter **1641** receives the filter parameter PD. The smoothing filter characteristic converter **1641** extracts from the input filter parameters PD a filter parameter positionally corresponding to the partition area in the decoded image data DD, and determines, based on the extracted filter parameter, filter characteristics of the process to be performed by the smoothing filter **1642**. For example, smoothing filters are respectively prepared for a plurality of filter parameters PD so that a filter to be used for a target pixel is determined. This process is specifically described below.

The smoothing filter characteristics are interpreted as how many pixels of the pixels surrounding the target pixel are averaged, and the shutter speed difference SSDD and the motion vector VD are used as examples of the filter parameters. In this case, one table is prepared which determines the number of pixels to be used for the smoothing filter with respect to a combination of a shutter speed difference SSDD and a motion vector VD. Each time the shutter speed difference SSDD and the motion vector VD are input, the number of pixels to be used for the smoothing filter is output. The determined number of pixels to be used for the smoothing filter is output to the smoothing filter **1642**.

The smoothing filter **1642** (low-pass filter) performs a filtering process on a predetermined block containing the target pixel within the process target frame in accordance with the filter characteristics determined by the smoothing filter characteristic converter **1641**, thereby converting the pixel value of the target pixel. The pixel value of the target pixel converted by the smoothing filter **1642** is output to the subtractor **1643**. More specifically, the subtractor **1643** receives the pixel value of the target pixel converted by the smoothing filter **1642** although in a polarity inverted form of the pixel value. The subtractor **1643** also receives the target pixel of the process target frame of the input decoded image data DD. The subtractor **1643** calculates a difference value between the pixel value of the pixel in the input image data DD and the pixel value of the target pixel converted by the smoothing filter **1642**, and then outputs the difference value to the adder **1644**. The adder **1644** receives the difference value between the values before and after the operation of the smoothing filter. The adder **1644** also receives the target pixel of the process target frame in the decoded image data DD. The adder **1644** adds to the uncorrected pixel value of the target pixel the difference value between the values before and after the operation of the smoothing filter, and outputs the addition results as a portion of an output image.

The process of the motion blur reduction processor **164** illustrated in FIG. **19** has been described. The process of the motion blur reduction processor **164** is easy to understand if it is considered in terms of frequency domain. The difference value between the values before and after the operation of the smoothing filter, as the output signal of the subtractor **1643**, is now considered in terms of frequency domain. On a given frequency, a difference between a gain of an input image signal and a gain of the image signal that has been filtered by the smoothing filter becomes a gain of the output signal of the adder **1644**. The gain of the output image signal of the adder **1644** is the sum of the gain of the input image signal and the gain difference between before and after the operation of the smoothing filter. More specifically, on each frequency, the gain of the output image signal is the gain of the input image signal raised by the gain difference between before and after the operation of the smoothing filter. Since the smoothing filter **1642** is a low-pass filter, the entire process of the motion blur reduction processor **164** illustrated in FIG. **19** is basically equivalent to a high-pass filtering operation.

Japanese Unexamined Patent Application Publication No. 2006-81150 (US Patent Application No. 2007-0070221A1) discloses a technique of performing a motion blur reduction process by directly high-pass filtering a partition area. The high-pass filter is based on the premise that an inverse function of a transfer function of a smoothing filter is used. The frequency characteristics of the smoothing filter contains a frequency that results in zero gain. A complete inverse smoothing filter may not be realized. Also from the standpoint of facilitating the process, the use of a low-pass filter such as the smoothing filter **1642** in the motion blur reduction processor **164** illustrated in FIG. **19** is more appropriate.

The motion blur reduction process is performed in the manner discussed above. The method of reducing the motion blur is not limited to the method described above.

The imaging shutter speed Sb as illustrated in FIG. **18** is considered. The imaging shutter speed Sb is high enough, and the optimum shutter speed is lower than the imaging shutter speed Sb at all the object speeds Va, Vb, and Vc. To generate

an image containing a motion blur corresponding to the optimum shutter speed, the motion ad-blur process is performed.

The process selection controller **171** outputs to the sorting unit **163** the process selection control information SCS indicating that the motion ad-blur process has been selected. The sorting unit **163** outputs the signal of each partition area in the decoded image data DD to the motion blur addition processor **165**. The motion ad-blur process to be performed by the motion blur addition processor **165** is specifically described. An output image is here generated through spatial filtering.

With reference to FIG. **21**, the motion blur addition processor **165** includes a motion vector masking processor **1651** generating motion vector mask information identifying an image area to which a motion blur is added, and a motion vector corrector **1652** correcting a motion vector. The motion blur addition processor **165** further includes a filter parameter calculator **1653** calculating a filter parameter for adding the motion blur responsive to a pixel in the process target frame, and a motion blur addition filter **1654** performing a motion blur filtering process on the pixel value of each pixel in the process target frame.

All the processes can be performed on a per pixel basis. However, to reduce the workload in each process, the motion blur addition processor **165** performs the process of the motion vector masking processor **1651** and the motion vector corrector **1652** on a per partition area basis with the partition area being a pixel block. The filtering process of the filter parameter calculator **1653** and the motion blur addition filter **1654** to add the motion blur to the decoded image data DD is performed on a pixel basis rather on a pixel block basis.

In order to identify in the process target frame an image area to which the motion blur is to be added, the motion vector masking processor **1651** performs a mask process illustrated in FIG. **22** on the motion vector VD of the supplied partition area. The motion vector masking processor **1651** then supplies to the motion vector corrector **1652** the mask processed motion vector of the partition area. The image area which is susceptible to jerkiness degradation and for which motion blur addition is necessary is concentrated in the vicinity of an edge of a moving image on the screen. In the process of FIG. **22**, the motion vector masking processor **1651** outputs, as an effective value, the motion vector of only a pixel block, having a high spatial contrast and susceptible to jerkiness, in the vicinity of the edge. In step S**21**, the motion vector masking processor **1651** detects an edge of an image in the decoded image data DD supplied from the sorting unit **163**. The edge is detected on a per pixel block basis in order to identify an area having a high spatial contrast within the process target frame. In parallel with step S**21**, the motion vector masking processor **1651** detects a moving image area by calculating a difference between frames on a pixel block basis in order to identify the moving image area in the process target frame.

In step S**23**, the motion vector masking processor **1651** determines on a per pixel block basis whether an area subject to jerkiness has been detected in step S**21** and/or step S**22**. The motion vector masking processor **1651** sets a mask processing flag "**1**" to the pixel block that has been determined as being subject to jerkiness. The motion vector masking processor **1651** sets a masking process flag "**0**" to the pixel block that has not been determined as being subject to jerkiness.

In step S**24**, the motion vector masking processor **1651** determines whether the motion vector VD supplied from the process selection controller **171** is the motion vector VD of the pixel block having the above-described flag "**1**." The motion vector masking processor **1651** outputs the motion vector of the pixel block having the flag "**1**" to the motion vector corrector **1652** without no change added to the value of the motion vector (processing proceeds from step S**25** to step S**26**). In step S**25**, the motion vector masking processor **1651** performs the mask process on the motion vector of the pixel block having the above-described flag "**0**," thereby setting the value of the motion vector to "0" or invalidating the value of the motion vector. The motion vector masking processor **1651** then outputs the mask processed motion vector to the motion vector corrector **1652** (processing thus proceeds from step S**24** to step S**25** to step S**26**).

The process of the motion vector corrector **1652** corrects the motion vector VD using the shutter speed difference SSDD of the input partition area. The motion vector is corrected by the motion vector corrector **1652** if the shutter speed difference SSDD is negative. Let F (frames/second) represents a frame rate of the decoded image data DD as a moving image, and the shutter speed difference SSDD is not smaller than −1/F (seconds). The shutter speed difference SSDD is a difference value between the imaging shutter speed SSD that is not smaller than zero and the optimum shutter speed SSD**0** that is not greater than 1/F (seconds).

In the process of adding motion blur, the smaller the shutter speed difference SSDD (the larger the absolute value of the shutter speed difference SSDD), the greater the motion blur quantity to be added becomes. The closer the shutter speed difference SSDD is to zero, the smaller the motion blur quantity to be added becomes. In other words, the smaller the value of the shutter speed difference SSDD, the larger the value of the motion vector VD serving as an indicator of a motion blur quantity to be added. The closer the shutter speed difference SSDD is to zero, the smaller the value of the motion vector VD. The motion vector corrector **1652** thus multiplies the vector value by a function fs (SSDD). In the target pixel block, the function fs (SSDD) converges to 1 as the shutter speed difference SSDD becomes closer to "−1/F" and converges to "0" as the shutter speed difference SSDD becomes closer to "0".

A value A closer to −1/F, and a value B closer to 0 are set wherein the magnitude relationship $-1/F<A<<B<0$ holds. The output value of the function fs is set to 1 for a value equal to or smaller than the value A and the output value of the function fs is set to be 0 for a value equal to or larger than the value B. This method is referred to as a clipping method.

Instead of the function fs (SSDD), the motion vector corrector **1652** may perform a multiplication process with fs (VD) having the motion vector VD as a variable or fs (SSDD, VD) as two variables as the shutter speed difference SSDD and the motion vector VD. The process of adding the motion blur quantity is performed in this way using to the motion vector VD the value of the filter parameter PD such as the shutter speed difference SSDD or the motion vector VD itself. When the data with the motion blur added thereto at the later stage is displayed as a moving image, a more naturally looking image quality in vision characteristics results.

The filter parameter calculator **1653** calculates the filter parameter described below on a per pixel basis in order to add the motion blur to each pixel forming the process target frame. The filter parameter calculator **1653** identifies a pixel positioned on a motion vector of each target pixel (hereinafter referred to as a parameter calculation target pixel). The target pixel is a pixel having effective motion vector information. The filter parameter calculator **1653** calculates a filter parameter responsive to a relative position of the parameter calculation target pixel identified with respect to the target pixel in the manner described below.

Referring to FIG. **23**, the filter parameter calculator **1653** identifies as the parameter calculation target pixels all the pixels present on a motion vector having a target pixel P**0** at

the midpoint between a start point S and an end point E. As illustrated in FIG. **23**, the absolute value v is the absolute value of the motion vector of the target pixel. The filter parameter calculator **1653** then calculates a strength σ of motion blur addition in accordance with the following equation (9) based on the absolute value v of the motion vector, and a distance d between a pixel position of the target pixel P**0** and a pixel position of a parameter calculation target pixel P**1** identified in the process described above:

$$\sigma = -0.5 \times (d - 0.5)^2 + 0.5 \times \left(\frac{v}{2}\right)^2 \tag{9}$$

where equation (9) is derived so that the square of the strength σ becomes a variance in the Gaussian function of the subsequent-stage motion blur addition filter **1654**.

The filter parameter calculator **1653** calculates an angular direction θ of the motion blur addition in accordance with the following equation (10):

$$\theta = \tan^{-1}\left(\frac{y_1}{x_1}\right) \tag{10}$$

where (x**1**,y**1**) represents coordinates of the parameter calculation target pixel P**1** in the x-y orthogonal coordinates plane system with the target pixel P**0** at the origin of the system.

The filter parameter calculator **1653** identifies the parameter calculation target pixel from the motion vector of the target pixel, sets parameter information (σ,θ) for each identified parameter calculation target pixel, and then supplies the parameter information (σ,θ) to the motion blur addition filter **1654** on a per process target frame basis.

In the process of the filter parameter calculator **1653**, a plurality of parameter calculation target pixels can be identified with respect to a given pixel. To facilitate the process in such a case, one of a plurality of pieces of parameter information having the largest σ is set as the parameter information of that pixel. The filter parameter calculator **1653** may perform a smoothing process such as a Gaussian function filtering process or a median filtering process on the parameter information (σ,θ) of each parameter calculation target pixel so that the image quality of the moving image output from the subsequent motion blur addition filter **1654** is increased.

In response to the parameter information supplied from the filter parameter calculator **1653**, the motion blur addition filter **1654** performs a spatial filtering process within the process target frame described below on the pixel value of each pixel within the process target frame of the decoded image data DD. The motion blur addition filter **1654** outputs an image with a motion blur added thereto by a first filtering process and/or a second filtering process.

The first filtering process is described first. In the first filtering process, the motion blur addition filter **1654** receives, in the form of an input I(x+i,y+j), a pixel value of a motion blur addition target pixel prior to the addition of the motion blur and a pixel value of a pixel surrounding the target pixel. The motion blur addition filter **1654** then performs a Gaussian function filtering process on the input I(x+i,y+j) in accordance with a Gaussian function expressed as equation (11), thereby outputting a filter processed pixel value J(x,y):

$$J(x, y) = \left(\frac{\sum I(x+i, y+j) \times e^{-\frac{r^2}{2\sigma^2}}}{\sum e^{-\frac{r^2}{2\sigma^2}}} \right) \tag{11}$$

where the surrounding pixel having the input I(x+i,y+j) is set in accordance with an angle direction in which the motion vector is added, and r represents a distance between the motion blur addition target pixel and the surrounding pixel.

The motion blur addition filter **1654** performs the above-described filtering process on each pixel having the parameter information (σ,θ) set therefor from among all the pixels forming the process target frame, thereby updating the pixel value of the pixel. The motion blur addition filter **1654** thus supplies a moving image with jerkiness reduced therefrom to the moving image display output unit **190**.

Some of the pixels surrounding the target pixel may be positioned within a stationary area, i.e., a background area. The surrounding pixels positioned within the background area are not taken into consideration in the motion blur addition to the target pixel. The second filtering process focuses on this point. In the second filtering process, the motion blur addition filter **1654** calculates the pixel value J(x,y) of the target pixel in accordance with equation (11) with the pixel value I(x,y) of the target pixel replaced with a pixel value I(x+i**0**,y+j**0**) of a surrounding pixel if the surrounding pixel has a motion vector with zero value or an invalid motion vector. The motion blur addition filter **1654** outputs an image with jerkiness reduced in a more natural look than with the first filtering process.

The motion blur addition processor **165** performs the spatial filtering process in the above discussion. Alternatively, the motion blur addition processor **165** may generate an output image by performing a time filtering process. In such a case, a method of adding a motion blur with an appropriate number of intermediate frames generated is useful. The structure of such a method is illustrated in FIG. **24**. The motion blur addition processor **165** illustrated in FIG. **24** includes an intermediate frame generator **1655**, an image accumulator **1656**, a filter controller **1657**, and a motion blur addition filter **1658**.

The input decoded image data DD is supplied to the intermediate frame generator **1655** and the image accumulator **1656**. The intermediate frame generator **1655** generates a predetermined number of new frames interpolating between existing prior and subsequent frames in time direction in accordance with a predetermined intermediate frame generation technique. The intermediate frame generator **1655** then supplies the new frames to the image accumulator **1656**. A variety of available methods may be applied as the intermediate frame generation technique. For example, in one method, existing prior and subsequent frames may be blended with weight incorporated. In another method, the motion vector is weighted using information regarding the motion vector at each area input to the intermediate frame generator **1655** and image blending is performed. More accurate intermediate frames can thus be generated.

The filter controller **1657** receives the imaging shutter speed SSD and the motion vector VD, and calculates a filter parameter FN of each partition area for use by the motion blur addition filter **1658** in accordance with the received imaging shutter speed SSD and motion vector VD. The process performed by the motion blur addition filter **1658** is described before the discussion of the filter parameter FN.

The process of the motion blur addition filter **1658** is a frame averaging operation, and the number of frames used in the frame averaging operation is adaptively determined on a per partition area basis. In other words, the frame averaging operation is performed on the number of frames different from partition area to partition area using one frame in the input decoded image data DD and a plurality of frames generated by the intermediate frame generator **1655**. In simple terms, the larger the number of frames to be used in the averaging operation, the larger the motion blur quantity to be added becomes, and the smaller the number of frames to be used in the averaging operation, the smaller the motion blur quantity to be added becomes.

Returning to the discussion of the filter controller **1657**, the number of frames to be used in the averaging operation is determined in response to each partition area. The filter controller **1657** then outputs the number of frames to the motion blur addition filter **1658**. The number of frames to be used in the averaging operation is the filter parameter FN. The minimum number of frames to be used in the averaging operation (the filter parameter FN) is one at minimum, and when the number of frames is one, one frame in the decoded image data DD is output as is without being processed. Let K represent the number of frames generated by the intermediate frame generator **1655** between the existing prior and subsequent frames, and the maximum number of frames is K+1 with the input frame added to the K frames. The filter parameter FN is determined from within a range of from 1 to K+1. As described above, the larger the number of frames, the larger the motion blur quantity to be added becomes.

The determination method of the filter parameter FN is not limited to any one method. In accordance with one embodiment of the present invention, the filter parameter FN is determined using the shutter speed difference SSDD input to the filter controller **1657** as described below. The shutter speed difference SSDD, if negative, is used by the motion blur addition processor **165**. Let F (frames/second) represent a frame rate of the decoded image data DD as a moving image, and the shutter speed difference SSDD is not be smaller than −1/F (seconds). The shutter speed difference SSDD is a difference value between the imaging shutter speed SSD that is not smaller than zero and the optimum shutter speed SSD**0** that is not greater than 1/F (seconds).

In the process of adding motion blur to be performed at the subsequent stage, the smaller the shutter speed difference SSDD (the larger the absolute value of the shutter speed difference SSDD), the greater the motion blur quantity becomes. The closer the shutter speed difference SSDD is to zero, the smaller the motion blur quantity to be added becomes. In other words, the smaller the value of the shutter speed difference SSDD, the larger the value of the motion vector VD serving as an indicator of a motion blur quantity to be added. The closer the shutter speed difference SSDD is to zero, the smaller the value of the motion vector VD.

The filter controller **1657** thus performs a process in accordance with a function gs (SSDD). The function gs (SSDD) increases and converges to K+1 as the shutter speed difference SSDD becomes closer to "−1/F" and converges to "1" as the shutter speed difference SSDD becomes closer to "0". The filter parameter FN obtained as a result is output to the motion blur addition filter **1658**. A value A closer to −1/F, and a value B closer to 0 are set and the magnitude relationship $-1/F<A<<B<0$ holds. The output value of the function gs is set to be K+1 for a value equal to or smaller than the value A and the output value of the function gs is set to be 1 for a value equal to or larger than the value B. This method is referred to as a clipping method.

Instead of the function gs (SSDD), the filter controller **1657** may perform a multiplication process with gs(VD) having the motion vector VD as a variable or gs(SSDD, VD) as two variables as the shutter speed difference SSDD and the motion vector VD in order to calculate the filter parameter FN.

When the number of frames (FN) for the filter averaging process in each partition area is input, the motion blur addition filter **1658** receives from the image accumulator **1656** the image data of the number of frames for the addition of the motion blur to each partition area, and performs the above-described filter averaging process. When the filter averaging process ends, the image data is reconstructed as a frame image, and then output as the output image signal OD.

As described above, the motion blur addition processor **165** performs the motion blur addition process using one of the spatial filtering process and the time filtering process. The motion blur addition process is not limited to the process described above.

The imaging shutter speed Sc is between Sa and Sb as illustrated in FIG. **18**. Depending on the object speed, the optimum shutter speed may be higher or lower than the imaging shutter speed Sc. In a partition area having Va as the value of the object speed, for example, any method of reducing the motion blur is performed in order to generate an image containing a motion blur at a level corresponding to the optimum shutter speed.

As previously discussed with the imaging shutter speed being at Sa, the process selection controller **171** outputs to the sorting unit **163** process selection control information SCS indicating that the motion blur reduction process has been selected. The sorting unit **163** outputs to the motion blur reduction processor **164** the signal of a partition area in the decoded image data DD. The motion blur reduction processor **164** then performs the filtering process in the same manner as described with reference to the imaging shutter speed Sa.

In the partition area having Vb or Vc as the value of the object speed, any motion addition process is performed to generate an image containing a motion blur at a level corresponding to the optimum shutter speed. As previously discussed with reference to the imaging shutter speed Sb as illustrated in FIG. **18**, the process selection controller **171** outputs to the sorting unit **163** process selection control information SCS indicating that the motion blur addition process has been selected. The sorting unit **163** outputs to the motion blur addition processor **165** the signal of a partition area in the decoded image data DD. The motion blur addition processor **165** performs the filtering process in the same manner as described with reference to the imaging shutter speed Sb.

The structure and operation of the image reproducing apparatus **100** corresponding to the image processing apparatus **2** having the second structure discussed with reference to FIG. **3** have been discussed. The image reproducing apparatus **100** performs the correction process in response to jerkiness and blur, thereby controlling the jerkiness degradation and the blur degradation. The image quality of the output image output from the moving image display output unit **190** is thus improved. Even if the information of the shutter speed at the image capturing of the decoded image data DD is unknown, the imaging shutter speed is estimated. The appropriate motion blur correction process is performed based on the evaluated value of the estimated shutter speed.

The image reproducing apparatus **100** having the third structure is generally identical to the image reproducing apparatus **100** illustrated in FIG. **5**. The image reproducing apparatus **100** having the third structure is different in that a motion blur correction processor **160**A is substituted for the

motion blur correction processor **160**. FIG. **25** illustrates the motion blur correction parameter calculator **170** and a motion blur correction processor **160**A in a diagram form similar to that of FIG. **15**.

The motion blur correction processor **160**A includes the motion blur reduction processor **164**, the motion blur addition processor **165**, and the selector and synthesizer **167**. The process selection controller **171** and the optimum shutter speed information memory **172** in the motion blur correction parameter calculator **170** are identical to the counterparts discussed with reference to FIG. **15** and subsequent drawings. However, it is noted that process selection control information SCS output from the process selection controller **171** is supplied to the selector and synthesizer **167**. The correction processes of the motion blur reduction processor **164** and the motion blur addition processor **165** remain unchanged.

With reference to FIG. **25**, the sorting unit **163** illustrated in FIG. **15** is not employed. The input decoded image data DD is directly supplied to both the motion blur reduction processor **164** and the motion blur addition processor **165**. The motion blur reduction processor **164** performs the motion blur reduction process on all the partition areas of the input decoded image data DD in accordance with the filter parameter PD of each partition area supplied from the process selection controller **171**. The resulting image data is output to the selector and synthesizer **167**. The motion blur addition processor **165** performs the motion blur addition process on all the partition areas of the input decoded image data DD in accordance with the filter parameter PD of each partition area supplied from the process selection controller **171**. The resulting image data is output to the selector and synthesizer **167**.

The selector and synthesizer **167** receives the image data having undergone the motion blur addition process at all the partition areas of the decoded image data DD (including a partition area having zero correction quantity) and the image data having undergone the motion blur reduction process at all the partition areas of the decoded image data DD (including a partition area having zero correction quantity). The selector and synthesizer **167** selects the image data of each partition area in response to the scene change detection signal SCD supplied from the process selection controller **171**. At each partition area forming one frame, the selector and synthesizer **167** selects between the image data from the motion blur reduction processor **164** and the image data from the motion blur addition processor **165**. The selector and synthesizer **167** then synthesizes the selected image data of the partition areas, and then outputs the synthesized image data as the output image signal OD of one frame.

The motion blur correction processor **160**A also has the same advantages as the motion blur correction processor **160** illustrated in FIG. **15**.

In the above discussion, the specific example of each of the image processing apparatuses **1**, **2**, and **3** is the image reproducing apparatus **100**. The present invention is applicable to a variety of apparatuses. For example, the present invention may be applicable not only to the image reproducing apparatus but also to an imaging apparatus, a communication apparatus, an image recording apparatus, a game playing machine, a video editing apparatus or the like. The information processing apparatus such as a general-purpose personal computer may implement each of the image processing apparatuses **1**, **2**, and **3**. A computer program to be executed by a central processing unit (CPU) that operates as the motion blur correction parameter calculator **12**, the motion blur correction processor **13**, and the shutter speed estimation processor **14** illustrated in FIGS. **1**, **3** and **4** may be provided as an image processing application software program. The computer can thus perform an appropriate image processing. The computer program to be executed by the central processing unit (CPU) includes calculating the motion blur correction parameter for the motion blur correction process on the basis of the motion information indicating the motion of the image between unit images forming the image data, and the shutter speed information at the image capturing of the image data, and correcting the motion blur contained in the image data by performing at least the motion blur reduction process using the motion blur correction parameter. The computer program further includes estimating the shutter speed by analyzing the image data. When the motion blur correction parameter is calculated, the estimated shutter speed is used. The operation of the shutter speed estimation processor **14** is thus performed by the CPU.

The computer program allows the same image processing to be performed by a personal computer, a cellular phone, a personal digital assistant (PDA), and a variety of image processing apparatuses using image data.

The computer program causing the CPU to operate as the motion blur correction parameter calculator **12**, and the motion blur correction processor **13** (and the shutter speed estimation processor **14**) may be pre-stored on a hard disk drive as a recording medium contained in an apparatus such as a computer, or a read-only memory (ROM), a flash memory or the like of a microcomputer having a CPU. The computer program may also be stored temporarily or permanently on removable recording media including a flexible disk, a compact disc read only memory (CD-ROM), a magneto-optical (MO) disc, a digital versatile disc (DVD), Blu-ray disc (registered trademark of Sony), a magnetic disc, a semiconductor memory, and a memory card. Such a removable recording medium may be supplied as package software. The computer program may be installed onto the personal computer from such a removable recording medium. The computer program may also downloaded from a download site via a network such as a local area network (LAN), or the Internet.

The present application contains subject matter related to that disclosed in Japanese Priority Patent Application JP 2008-161581 filed in the Japanese Patent Office on Jun. 20, 2008, the entire content of which is hereby incorporated by reference.

It should be understood by those skilled in the art that various modifications, combinations, sub-combinations and alterations may occur depending on design requirements and other factors insofar as they are within the scope of the appended claims or the equivalents thereof.

What is claimed is:

1. An image processing apparatus, comprising:

correction parameter calculation means for calculating a motion blur correction parameter for motion blur correction on the basis of motion information indicating a motion of an image between unit images, the unit images forming image data, and shutter speed information obtained at the image capturing of the image data; and

motion blur correction processing means for correcting a motion blur quantity contained in the image data by performing at least a process of reducing a motion blur in accordance with the motion blur correction parameter, wherein the motion blur correction parameter indicates a degree of correction to be applied to the image data.

2. The image processing apparatus according to claim **1**, wherein the motion blur correction processing means performs a process of adding a motion blur on the image data and the process of reducing a motion blur in accordance with the motion blur correction parameter.

3. The image processing apparatus according to claim 1, wherein the motion blur correction processing means adaptively selects in response to each partition area of the image data one of the process of adding the motion blur and the process of reducing the motion blur on the image data, in accordance with the motion blur correction parameter.

4. The image processing apparatus according to claim 1, further comprising motion vector generating means for generating from the image data a motion vector as the motion information.

5. The image processing apparatus according to claim 1, wherein the correction parameter calculation means acquires an optimum shutter speed corresponding to a speed of an object from each partition area of the image data by referencing mapping information mapping the object speed to an imaging shutter speed at which image quality degradation of an output image is reduced, and

calculates the motion blur correction parameter as selection control information for selecting between a process of adding a motion blur and a process of reducing a motion blur on the image data by comparing information regarding an input imaging shutter speed with the optimum shutter speed, and

wherein the motion blur correction processing means selectively performs on the image data the process of adding the motion blur and the process of reducing the motion blur in accordance with the motion blur correction parameter.

6. The image processing apparatus according to claim 1, wherein the correction parameter calculation means calculates the motion blur correction parameter indicating one of the degree of addition of the motion blur and the degree of reduction of the motion blur, respectively used by the motion blur correction processing means in the process of adding the motion blur and the process of reducing the motion blur on the image data.

7. The image processing apparatus according to claim 6, wherein the motion blur correction parameter indicating one of the degree of addition of the motion blur and the degree of reduction of the motion blur comprises one of an imaging shutter speed and a difference between the imaging shutter speed and an optimum shutter speed.

8. The image processing apparatus according to claim 6, wherein the motion blur correction parameter indicating one of the degree of addition of the motion blur and the degree of reduction of the motion blur comprises movement speed information of a partition area.

9. An image processing method, comprising the steps of:

calculating a motion blur correction parameter for motion blur correction on the basis of motion information indicating a motion of an image between unit images, the unit images forming image data, and shutter speed information obtained at the image capturing of the image data; and

correcting a motion blur quantity contained in the image data

by performing at least a process of reducing a motion blur in accordance with the motion blur correction parameter, wherein the motion blur correction parameter indicates a degree of correction to be applied to the image data.

10. A non-transitory computer readable medium having stored thereon executable instructions that, when executed by at least one processor, cause the at least one processor to:

calculate a motion blur correction parameter for motion blur correction on the basis of motion information indicating a motion of an image between unit images, the unit images forming image data, and shutter speed information obtained at the image capturing of the image data; and

correct a motion blur quantity contained in the image data by performing at least a process of reducing a motion blur in accordance with the motion blur correction parameter, wherein the motion blur correction parameter indicates a degree of correction to be applied to the image data.

11. An image processing apparatus, comprising:

a correction parameter calculating unit calculating a motion blur correction parameter for motion blur correction on the basis of motion information indicating a motion of an image between unit images, the unit images forming image data, and shutter speed information obtained at the image capturing of the image data; and

a motion blur correction processing unit correcting a motion blur quantity contained in the image data by performing at least a process of reducing a motion blur in accordance with the motion blur correction parameter, wherein the motion blur correction parameter indicates a degree of correction to be applied to the image data.

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