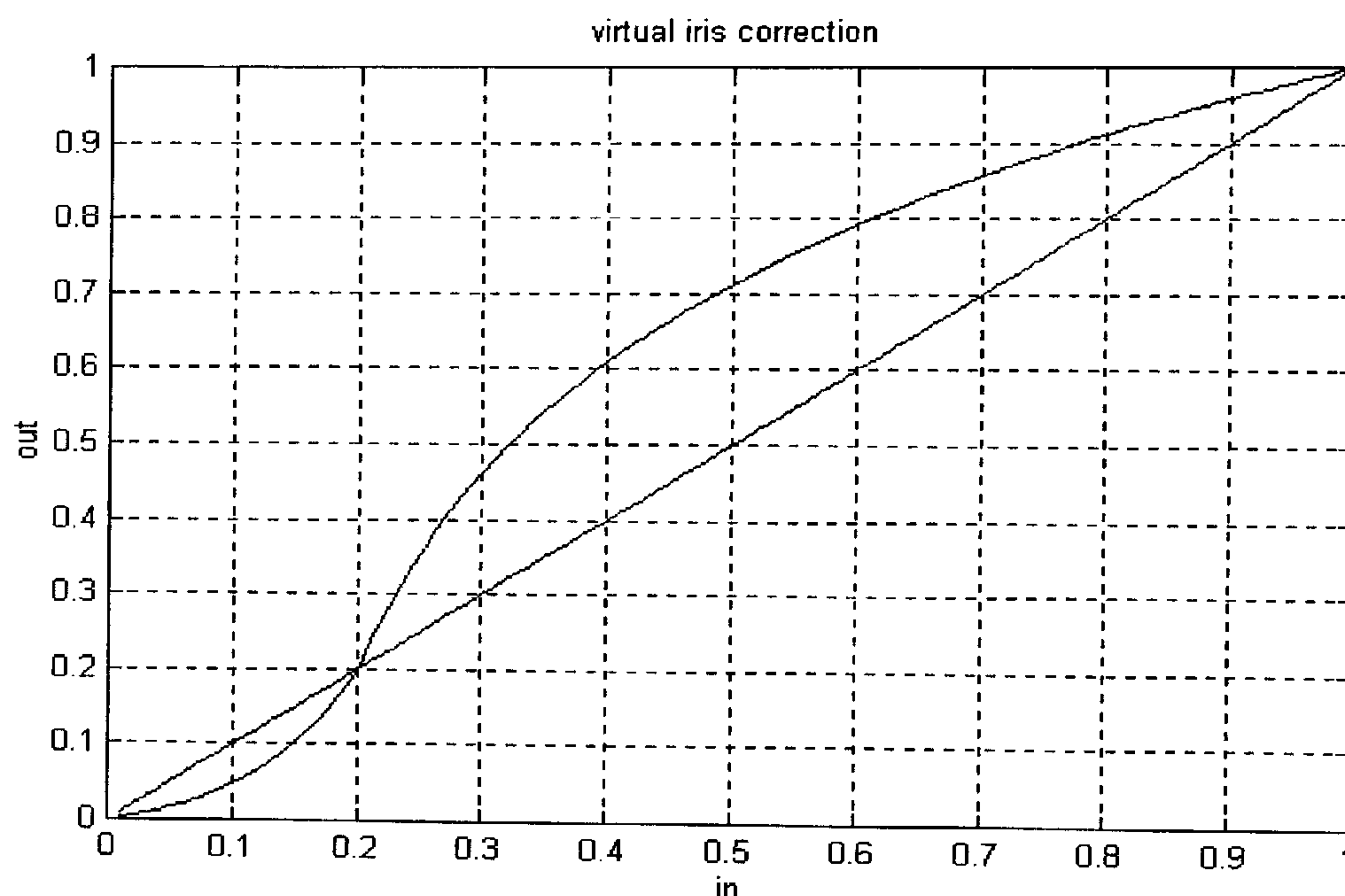




(86) Date de dépôt PCT/PCT Filing Date: 2000/04/10
(87) Date publication PCT/PCT Publication Date: 2000/10/19
(45) Date de délivrance/Issue Date: 2006/10/03
(85) Entrée phase nationale/National Entry: 2001/09/21
(86) N° demande PCT/PCT Application No.: CA 2000/000400
(87) N° publication PCT/PCT Publication No.: 2000/062528
(30) Priorité/Priority: 1999/04/13 (US60/129,041)

(51) Cl.Int./Int.Cl. *H04N 1/60* (2006.01),
H04N 1/407 (2006.01), *H04N 9/69* (2006.01)
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(54) Titre : AMPLIFICATION VIRTUELLE DE LA LUMINOSITE EN COULEURS REELLES
(54) Title: VIRTUAL TRUE COLOR LIGHT AMPLIFICATION



(57) **Abrégé/Abstract:**

Apparatus is provided for enhancing a digital image without distortion of the color. A digital format (13) contains an image. A processor (14) implements a method for extracting color dot information from the digital format and enhancing the image while varying the effective light gathering power. The image enhancement is performed in RGB color space and comprises determining the maximum strength of the R, G, and B of each dot's RGB triplet and similarly for all dots. The dot maximums are scaled through a scaling function which is constrained in domain and range to the system's dynamic range. The corresponding scaling factor that is applied to a dot maximum is also applied to each of R, G and B in the triplet. Preferably, a continuous scaling function is provided which smoothly approaches the minimum and maximum of the system's dynamic range for providing an aesthetically pleasing enhancement while maintaining true color. In a forensic embodiment, a portion of the image can be selected in RGB color space and normalized to substantially the entire dynamic range, thereby emphasizing the area of interest, all without affecting the ratios of R, G and B for maintaining true color.

1 ABSTRACT OF THE INVENTION

2 Apparatus is provided for enhancing a digital image without
3 distortion of the color. A digital format (13) contains an image. A processor
4 (14) implements a method for extracting color dot information from the digital
5 format and enhancing the image while varying the effective light gathering
6 power. The image enhancement is performed in RGB color space and
7 comprises determining the maximum strength of the R, G, and B of each dot's
8 RGB triplet and similarly for all dots. The dot maximums are scaled through a
9 scaling function which is constrained in domain and range to the system's
10 dynamic range. The corresponding scaling factor that is applied to a dot
11 maximum is also applied to each of R, G and B in the triplet. Preferably, a
12 continuous scaling function is provided which smoothly approaches the
13 minimum and maximum of the system's dynamic range for providing an
14 aesthetically pleasing enhancement while maintaining true color. In a forensic
15 embodiment, a portion of the image can be selected in RGB color space and
16 normalized to substantially the entire dynamic range, thereby emphasizing the
17 area of interest, all without affecting the ratios of R,G and B for maintaining
18 true color.

1 **"VIRTUAL TRUE COLOR LIGHT AMPLIFICATION"**

2

3 **FIELD OF THE INVENTION**

4 The present invention related to methods for enhancing digital
5 color images. More particularly, the method applies a scaling function to vary
6 the strength of RGB dots within an image without exceeding the inherent
7 dynamic range for the image.

8

9 **BACKGROUND OF THE INVENTION**

10 If one were to photograph the stain glass windows of a Cathedral,
11 the resulting image would be typically too dark for modern tastes. The beauty of
12 the actual stained glass is lost. Further, a photographer can increase depth of
13 field of an image by reducing the device's aperture, but light collection is
14 sacrificed and can also result in a dark image. Further, as a still image device is
15 capable of only recording the image using a predetermined aperture and
16 exposure time, images having a large disparity between light and dark can only
17 make a compromise; adjusting to expose the film, or record, based on either the
18 dark areas or the light areas in an attempt to properly reveal the detail therein.
19 Images resulting from any of the above can benefit from image enhancement.

20 The usual response by the viewer is to wish to brighten darkened
21 areas and thus reveal the details otherwise obscured to the naked eye. Current
22 techniques produce one or two undesirable effects when brightening: either the
23 colors are washed out into near grays (imagine a nearly black and white and
24 badly faded Stain Glass window); or the brighter areas become very distorted in

1 terms of color and some, completely washed out. The distorted areas tend to be
2 the ones of the most interest, such as the details of a face.

3 Conventional digital image processing has these same problems
4 when a substantial level of brightening is required. The 'standard' enhancement
5 is to brighten the image (fade it out) and then afterwards, amplify the colors.
6 This solution is only an approximate solution and only works on images that
7 aren't too bad in the first place. The image becomes badly color-distorted if a
8 substantial amount of brightening is used.

9 In US Patent 5,982,926 to Kuo et al. ("Kuo"), Kuo suggests that a
10 color image, particularly one originating from video, can be enhanced much
11 more effectively by first transforming the RGB color space to HSV color space.
12 All operations thereafter are performed on the HSV transformed color space.
13 Once in HSV color space, Kuo then isolates and removes the color information
14 (Hue) from the remaining image components (saturation and intensity). Kuo
15 suggests that the components of saturation and intensity can be enhanced
16 without introducing distortion into the color or Hue component. Kuo's color
17 image is represented by a plurality of pixels in HSV color space. Once
18 transformed, Kuo inverse transforms HSV back to RGB color space, all the while
19 claiming this to be efficient. In the preferred embodiment, Kuo adjusts intensity
20 (V) and saturation (S). In summary, Kuo first transforms RGB to HSV color
21 space, applies two sequential transformation functions to V and S respectively,
22 and finally inverse transforms the altered HSV back to RGB for display.

23 Respectfully, Applicant asserts that manipulation of the saturation
24 does affect the color and thus the Kuo technique does not result in true color
25 enhancement. Color photos have three degrees of freedom, being R,G and B,

1 where as black and white photos only have one. Any transformation of the three
2 values results in three more values, each of which contains a color component
3 and not merely a single color value (i.e. hue) and two other independent
4 structural components (i.e. saturation and intensity). Hue may be a more
5 extreme sense of color than saturation, but saturation is still a color component.
6 Adjusting a dot's saturation results in a change in the proportions of RGB in the
7 dot and hence its color. If the saturation is changed, say as part of brightening
8 the image, the result is not the same as if the recording device or camera had
9 obtained the image directly from the real world subject under brighter conditions,
10 or more exposure.

11 Further, note that Kuo emphasizes and attempts to minimize the
12 computational overhead or expense. Unfortunately, Kuo introduces two RGB-
13 HSV and HSV-RGB transformations in addition to whatever adjustments
14 (preferably two) Kuo makes to the HSV pixel. A transformation from RGB to
15 HSV color space, and back again, involves the use of computation-intensive
16 mathematical functions.

17 In US 3,684,825 to Dischert, a circuit comprising an amplifier and a
18 signal intensity shaper is positioned intermediate of R, G and B color image
19 pickup tubes and a output colorplexer. The circuit compresses contrast in the
20 streaming signal so as to prevent clipping of the output colorplexer signal. As
21 color pickup tubes are capable of a contrast ratio of 100:1 and the output system
22 is only capable of 20:1, significant compression is required. To avoid color
23 distortion, Dischert discloses a compression of the gain of each of R, G and B to
24 the output contrast levels, while maintaining their relative proportions.

1 Accordingly, there is demonstrated a need for a computationally
2 efficient process which is capable of maintaining true color for each color dot
3 during enhancement of an digital image.

4 The present invention addresses these problems by providing a
5 technique where, no matter how much image-brightening is needed or what the
6 nature of that brightening is, the color of all dots in the image are preserved in all
7 circumstances.

8

9

SUMMARY OF THE INVENTION

10 The effect of the present invention is to virtually amplify the light
11 captured by the digital image recorder. This means that once the captured
12 image is processed using the present invention, each dot within the processed
13 image is modified to be the same as if the digital image recorder, had used a
14 different light gathering power or procedure for that dot, including simulating the
15 use of a larger aperture or a longer light gathering duration. This modified light
16 gathering procedure may be applied uniformly across the entire processed
17 image or may vary from dot to dot. By ensuring that the dynamic range of the
18 digital recorder is never exceeded, by operating in the primary RGB color space,
19 and by identically treating each of R,G, and B in a color dot, the virtual light
20 amplification process preserves the true color of the original image.

21 In a preferred embodiment, and remaining in RGB space, a triplet
22 of RGB values is extracted for each dot of the digital image. The maximum of
23 the RGB triplet is determined for each dot. The maximum of all of the dot
24 maximums, or an image maximum, is determined and a scaling function is

1 defined which provides scaling factors for each dot maximum. The scaling
2 factors, or a function defining same, are determined and applied to the values of
3 the dot maximums and most particularly, the image maximum, so that no
4 resulting value exceeds the known dynamic range of the system. The very same
5 scaling factor, applied to a dot maximum, is also applied to each of the remaining
6 R, G or B of that dot so as to maintain the original proportions or ratios between
7 R,G and B, and thereby maintain the true color.

8 The enhancement is very efficient, only requiring three simple
9 multiplications, by the same scaling factor, to enhance each color dot. Further,
10 and more preferably, by forming a look-up table of scaling factors for the
11 determined dot maximums, then the calculation of the scaling factor is performed
12 only once. Typically the dynamic range is 0-255 (a maximum of 256 different
13 light strengths) and therefore, for a usual image having in the order of 250,000
14 dots, at least 1000 of them have the same strength and thus the same scaling
15 factor can be applied to an average of 1000 dots, saving that many calculations.
16 Larger images, which are becoming common, will save even more calculations.

17 Accordingly in a broad aspect of the invention a method is provided
18 for adjusting a digital image without introducing color distortion. The image is
19 formed of a plurality of color dots, each dot having at least three independent
20 values representing the strength of the three primary colors R, G, and B. Each
21 of the RGB values lies between a minimum and a maximum of the dynamic
22 range for the system.

1 The method comprises the steps of:

- 2 • determining the dot maximum of the three RGB values in RGB
3 color space;
- 4 • applying a predetermined scaling factor to each dot maximum,
5 the scaling factor being such that the scaled dot maximum is
6 always less than or equal to the maximum of the dynamic range
7 of the system; and
- 8 • applying the same predetermined scaling factor used for a dot
9 maximum to each of that dot's two remaining R,G or B values.

10 When adjusted in the above method, the adjusted image
11 comprises a plurality of new scaled RGB values for each dot wherein the ratios
12 between R,G and B for a dot remain the same after scaling as they were before
13 scaling – thereby maintaining true color.

14 Preferably the scaling factors are obtained from a continuous
15 scaling function. The scaling function normalizes at least a portion of the range
16 of the image to a portion of the dynamic range without ever exceeding the
17 maximum of the dynamic range. Due to the lower magnitude of the dynamic
18 range than number of dots in an image, computation efficiency is improved by
19 first establishing a look-up table of scaling factors.

20 The preferred scaling function is a lazy "S" curve form which
21 produces an aesthetically pleasing enhancement of most digital images.

1 In another preferred embodiment, one can select only a portion of
2 the image, usually an underexposed area, and normalize subset image range to
3 substantially the entire dynamic range of the system for enhancing the detail
4 therein, all without ever exceeding the system's dynamic range for any dots and
5 while maintaining true color by being mindful of the ratios of R,G, and B for each
6 dot.

7 BRIEF DESCRIPTION OF THE DRAWINGS

8 In the Figures, several digital images are presented. As this
9 application is directed to the enhancement of color digital images without
10 suffering a distortion in color, the results cannot be properly reproduced herein in
11 the gray scale printing medium. Original color images have been provided to the
12 respective Patent Offices.

13 Figure 1 is a graph representing a linear function as the basis for
14 correcting each R,G or B dot maximum as input to an adjusted output dot
15 maximum, both of which are constrained to the system's dynamic range. This
16 particular function would be a unity function, and would not perform any
17 correction unless the input is normalized to the dynamic range by pre-scaling the
18 maximum of the dot maximums to 1.0;

19 Figure 2 is a brief coding example in Visual Basic for reading a
20 digital screen image, extracting color dots, finding a dot maximum, applying a
21 correction factor for the dot maximum, applying the correction to the entire RGB
22 values for a dot and writing the corrected color dot back to the screen;

1 Figure 3 is a graph illustrating a scaling function designed to modify
2 an image which was intentionally underexposed, such as by using a small
3 aperture so as to obtain improved depth of field;

4 Figure 4 is a graph illustrating a scaling function which enhances
5 the contrast within a specific area of the dot maximums, falling between 0.3 – 0.5
6 of the image's range, by scaling 20% of the range to nearly 100% or
7 substantially the entire dynamic range, and wherein the darker and lighter areas
8 contrasts are diminished;

9 Figure 5 is a graph according to Fig. 4 which enhances the dot
10 maximums in the dark area falling between 0.1 – 0.2 of the image's range;

11 Figure 6 is a graph according to Fig. 4 which enhances the dot
12 maximums in the bright area falling between 0.9 – 1.0 of the image's range;

13 Figure 7a is a brief coding example in Visual Basic for using a GUI
14 interface to select an x1,y1 and x2,y2 window area, reading the digital screen
15 image in the window, extracting color dots, finding a dot maximum, applying a
16 correction factor for the dot maximum, and building a histogram of dot maximum
17 occurrences;

18 Figure 7b is a brief coding example in Visual Basic for generating
19 the histogram according to the third embodiment.

1 Figure 8 is a graph illustrating variable scaling function
2 superimposed over a unity diagonal, the variable function producing an
3 aesthetically pleasing enhancement through the brightening of the image. The
4 scaling function is a smooth curve, such as a third order curve, which de-
5 emphasizes the darker areas and brightens the lighter areas;

6 Figures 9a – 9f are photographs of an Abbey which are
7 respectively, the original, brightened under the prior art, brightened and contrast
8 adjusted under the prior art, brightened and saturation adjusted under the prior
9 art, enhanced according to the first embodiment of the present invention to the
10 full dynamic range and enhanced according to the second embodiment of the
11 present invention;

12 Figures 10a – 10f are photographs of Stone Henge which are
13 respectively, the original, brightened under the prior art, brightened and contrast
14 adjusted under the prior art, brightened and saturation adjusted under the prior
15 art, enhanced according to the first embodiment of the present invention to the
16 full dynamic range and enhanced according to the second embodiment of the
17 present invention;

18 Figures 11a and 11b are respectively an original photo of a satellite
19 and an enhanced photo according to the third embodiment of the present
20 invention;

21 Figures 12a and 12b are respectively an original photo of a blimp
22 and an enhanced photo according to the third embodiment of the present
23 invention;

1 Figures 13a and 13b are respectively an original photo of a car
2 license plate and an enhanced photo according to the third embodiment of the
3 present invention; and

4 Figures 14a, 14b and 14c are respectively an original photo of
5 skiers and ski tracks in the snow and two enhanced photos according to the third
6 embodiment of the present invention, each using a different portion of the photo
7 to build the enhancement.

8

9 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

10 First, an image is captured using some form of digital image
11 recorder. Digital image recorders fall into two categories: physical and virtual.
12 Physical digital image recorders 10 are devices that record a digital image by the
13 measurement of light energy; such as a digital cameras 11. Like a traditional
14 film camera, digital cameras 11 have a 'lens complex' that provides light
15 gathering and the image is recorded by an array of digital sensors so that the
16 value of each dot represent actual measurements of the light. A digital image
17 can also be obtained as a digital scan of a traditional photograph. In a
18 photograph, light gathering was provided by a traditional camera and the image
19 was recorded on film. Accordingly, a physical digital image recorder 10 can be a
20 combination of camera that produced the film/print image and a scanner 12 that
21 digitized it. Other examples include digital movies, digitized movies, digital x-
22 rays, and the like.

23 Virtual digital image recorders 10 are computer renderings that
24 imitate reality. The programs create a 'virtual image' (as in virtual reality) by a

1 logical imitation of the photographic process completely internal to the computer
2 itself. These digital images are what a photograph would have looked like had a
3 'computer model' actually existed. An example is those movies with stunning
4 dinosaur simulations.

5 A lens complex is the apparatus that gathers light in various forms
6 of photography. There is at least one lens and usually a system of such lenses.
7 The lens complex also includes an aperture stop and a shutter which are both
8 controls on the light gathering.

9 The light gathering power of a lens is often measured in terms of
10 the surface area of the objective lens itself. A lens with twice the area of another
11 can gather twice the light. In practice, a lens complex has two controls on the
12 amount of light actually gathered. The first control is the adjustable aperture
13 which varies the amount of light that is collected per unit time. Twice the area
14 means twice the light per unit time. The second control is called the shutter and
15 it varies the amount of time that light enters the body of the camera. Holding the
16 shutter open twice as long means that twice the light energy enters the camera.

17 A true color digital image comprises a grid of dots wherein each dot
18 has three independent measured values representing the strengths of the red,
19 green and blue (RGB) components of the light. This is known as RGB color
20 space. There are various computer file formats 13 used for these images, using
21 various 'compression schemes' to save computer disk storage space.
22 Regardless of compression scheme, all such digital file formats 13 store a grid of
23 dots with RGB values.

1 Currently, the common standard maximum value stored by such
2 files or a system, for each of the R,G, or B value, is 255. Accordingly, each of
3 the RGB components can range in strength from 0 to 255. Some file formats
4 now store values in the range of 0 to 1023, and higher formats are likely.

5

6 Dynamic range

7 Every device, including our digital image recorder, has a 'dynamic
8 range' which is a measure of its ability to record relative energy fluctuations. As
9 stated above, this dynamic range is usually set by the storage means, file or
10 system and is typically 0 – 255. In photography, the trick to success is to use all
11 the dynamic range without exceeding it. In a photo, the trick is to capture both
12 the details in bright areas and details in dark areas without a loss of details
13 anywhere.

14 In film photography, when a significant area of the negative has
15 turned completely opaque it means that the light was so intense in that area that
16 no film crystals were left unchanged. The variations within the washed out area
17 of the photograph are lost and can be said to 'have exceeded the dynamic range
18 of the system'.

19 In digital photography, the strength of the light energy is measured
20 by the photo-electric sensors. These values are stored as a true color format
21 computer file. The dynamic range of the system is exceeded when areas of the
22 grid have been set to the maximum (say 255). Accordingly, variations within the

1 bright areas, hypothetically 256 - 300 can only be recorded as 255 and thus
2 details within such areas are lost.

3 With a limited dynamic range, as is the case with digital images,
4 the amount of light which is captured can significantly affect the image. Consider
5 if one image is obtained containing one particular dot of light which is measured
6 within the dynamic range of the recording device. For example, the light may
7 come from a brown surface. The light dot is measured in terms of three color
8 strengths, the red (R), green (G) and blue (B). If a second image is obtained
9 having had double the exposure time, then twice as much light will go into the
10 recording device for each and every dot, including the dot we are considering. If
11 the range of light remains within the dynamic range of the system, then all the
12 three values of R, G, and B will be doubled – yet the color of the original brown
13 dot remains as brown. Doubling of the incoming light means its strength
14 measurement will be doubled – R is doubled, G is doubled and B is doubled.

15 In the case of digital information, for example, upon a doubling of
16 the light (through a larger aperture or longer exposure), relative RGB values are
17 also doubled. RGB values of 50,30,20 are doubled to 100, 60,40, because $100 = 50 \times 2$, $60 = 30 \times 2$, and $40 = 20 \times 2$.

19 When twice as much energy hits each sensor, then each sensor
20 has twice the stimulation. Twice as much red energy hits the red sensor and the
21 other energy doesn't matter to it. Twice as much green energy hits the green
22 sensor. And twice as much blue energy hits the blue sensor.

1 As the light gathering power increases, the three measurements of
 2 the primary colors of the same dot increase proportionally as shown in the
 3 following Table 1 – hence the color remains the same, only brighter.

4

5 **Table 1. - Effect of Increasing Light Gathering Power on Measurements of RGB**

6	Light						
7	Gathering						
8	Power	Description	Red	Green	Blue	Green/Red	Blue/Red
9	1	"Reference, one unit"	50	30	20	0.600	0.400
10	1.1	Up 10%	55	33	22	0.600	0.400
11	1.2	Up 20%	60	36	24	0.600	0.400
12	1.3	Up 30%	65	39	26	0.600	0.400
13	1.4	Up 40%	70	42	28	0.600	0.400
14	1.5	Up 50%	75	45	30	0.600	0.400
15	2	Double	100	60	40	0.600	0.400
16	2.5	Two and a half times	125	75	50	0.600	0.400
17	3	Triple	150	90	60	0.600	0.400
18	4	Four times	200	120	80	0.600	0.400
19	5	Five times	250	150	100	0.600	0.400

20

21 In Table 1, note that the ratio of Green/Red and the ratio of
 22 Blue/Red remain constant, regardless of the light gathering power.

23 The reference level for light gathering power is artificial, a matter of
 24 convenience. What is the 'correct' measurement of the color of the dot of Table
 25 1? An image collected from an overcast outdoors environment may measure the
 26 color dot at 50,30,20 and the color dot measured in a bright indoor setting could
 27 be 200,120,80 utilizing four times the light gathering power.

28 While it is possible to calibrate light gathering power in terms of the
 29 energy that is collected, it is rarely done in practice. The light gathering power of

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1 our own eyes naturally varies. City lights that seem so very bright at night
2 appear dull in daylight because the eye's iris automatically opens at night and
3 then closes during the day, as is required to deal with the natural extreme
4 variations in light level. Applicant is not aware of a recording device that has a
5 wide enough dynamic range to handle the range from natural daylight to artificial
6 city night lighting with the same light gathering settings. What makes a good
7 image is, in part, that the light gathering ability is varied with the light - so that the
8 recording is not pushed outside of the dynamic range. Both measurements of
9 50,30,20 and 200,120,80 for the same color or dot are valid.

10 For any set of three numbers, such as the intensity values for each
11 of Red, Green, and Blue, there are a total of six possible ratios and they are G/R,
12 B/R, G/B, R/G, R/B, and B/G. Only two of the ratios are unique, the other four
13 ratios are redundant as they are variations of the first two. For example, based
14 upon G/R and B/R, the others are:

15	green/blue	=	(green/red) / (blue/red)
16	red/green	=	1 / (green/red)
17	red/blue	=	1 / (blue/red)
18	blue/green	=	(blue/red) / (green/red)

19 In principle, any two of the six can be chosen. For the purposes of
20 this description, the ratios of green/red and blue/red are chosen.

1 An efficient choice for the value of the strength of the RGB triplet
2 would be to simply take the maximum value from amongst the three RGB
3 values. In the case of 50,30,20 for RGB respectively, red happens to be the
4 maximum value and the calculation of strength and the two ratios becomes:

5 Strength = red = 50
6 Ratio1 = green/red = 30/50 = 0.600
7 Ratio2 = blue/red = 20/50 = 0.400

8 In reverse, one can back-calculate and recover the red, green and
9 blue values as follows:

10 red = Strength = 50
11 green = Strength * Ratio1 = red * green / red = 50 * 0.600 = 30
12 blue = Strength * Ratio2 = red * blue / red = 50 * 0.400 = 20

13 This artificial representation of the RGB triplet is useful because,
14 for any dot, the two ratios are independent of the light gathering power. The
15 amount of light gathered only affects the strength component.

16 Too much light gathering will cause the measurement of the color
17 to become distorted because at least one of the three primary colors RGB will
18 exceed the dynamic range and thus will not be accurately represented.
19 Consider the previous example dot of 50, 30, 20 at some arbitrary reference
20 level of light gathering power. If the image is re-recorded, but at a much higher
21 light gathering power, then at least one color will be pushed beyond the dynamic
22 range.

1 **Table 2. - Increasing Light Gathering Power beyond the Dynamic Range of System**

2	Light						
3	Gathering						
4	Power	Description	Red	Green	Blue	Green/Red	Blue/Red
5	1	Reference	50	30	20	0.600	0.400
6	3	Triple	150	90	60	0.600	0.400
7	5	Five times	250	150	100	0.600	0.400
8	5.1	5.1 times	255	153	102	0.600	0.400
9	5.2	5.2 times	255	156	104	0.612	0.408
10	6	Six times	255	180	120	0.706	0.471
11	7	Seven times	255	210	140	0.824	0.549
12	8	Eight times	255	240	160	0.941	0.627
13	9	Nine times	255	255	180	1.000	0.706
14	10	Ten times	255	255	200	1.000	0.784
15	11	Eleven times	255	255	220	1.000	0.863
16	12	Twelve times	255	255	240	1.000	0.941
17	13	Thirteen times	255	255	255	1.000	1.000
18	1	"Reference, one unit"	50	30	20	0.600	0.400

19 Notice that neither the ratio of green/red nor blue/red are constant
 20 (because they have saturated) past 5.1 times the light gathering power.
 21 Because there is a maximum amount of energy that can be measured by the
 22 recording device (either digital sensors or film) there is a practical limit to the
 23 useful light gathering power for any subject. In Table 2, when light gathering
 24 power exceeds five times the reference power, the dynamic range is almost fully
 25 used. The strength of the dot is 250 and the maximum that can be stored is 255.
 26 That maximum is reached, exactly, at 5.1 times the light gathering power. At 5.1
 27 the strength of the dot is 255 yet the two ratios are still 0.600 and 0.400
 28 respectively. At 5.2 times the light gathering power, even more light enters the
 29 recording device. The red sensor would have stored the number 260 but it
 30 cannot because the dynamic range is surpassed and the value is clipped to 255

1 instead. The correct numbers are stored for both the green and blue sensors,
2 however, the incorrect total color is recorded and this is revealed by noticing that
3 the two ratios now vary from the proper ratios of 0.600 and 0.400. At 6 times the
4 light gathering power, even more light enters and the distortions are
5 correspondingly greater. The ratios are now significantly different and incorrect
6 at 0.706 and 0.471 and these correspond to a significantly different color. At 8.5
7 times the light gathering power, the green sensor also measures clipped values.
8 The light is recorded as having the same strength in both the red and blue
9 primary colors. The blue to red ratio is now 1.000 and the previous distorted
10 color (reddish brown) now further distorts to an orange. Finally, at 12.75 times
11 the light gathering power, all three sensors clip and the color is recorded as three
12 full strength primary colors, meaning white.

13 It is important to avoid collecting light beyond the ability of the
14 recording system (it's dynamic range) because it causes distortion in the color.

15 Any one of the RGB triplet can be chosen as the reference color. If
16 green was the strongest color, and assuming the color was 30,50,20 (having the
17 same reference light gathering power as the previous red example), then having
18 reference to Table 3, the same behavior is exhibited.

1 **Table 3. - Effect of Increasing Light Gathering Power with Green as strongest color**

2	Light						
3	Gathering						
4	Power	Description	Red	Green	Blue	Green/Red	Blue/Red
5	1	Reference	30	50	20	1.667	0.667
6	3	Triple	90	150	60	1.667	0.667
7	5	Five times	150	250	100	1.667	0.667
8	5.1	5.1 times	153	255	102	1.667	0.667
9	5.2	5.2 times	156	255	104	1.635	0.667
10	6	Six times	180	255	120	1.417	0.667
11	7	Seven times	210	255	140	1.214	0.667
12	8	Eight times	240	255	160	1.063	0.667
13	9	Nine times	255	255	180	1.000	0.706
14	10	Ten times	255	255	200	1.000	0.784
15	11	Eleven times	255	255	220	1.000	0.863
16	12	Twelve times	255	255	240	1.000	0.941
17	13	Thirteen times	255	255	255	1.000	1.000

18 As shown, the same situation occurs wherein the green/red and
 19 blue/red ratios become distorted in a very similar manner. In this case, the ratios
 20 red/green and blue/green produce the same numbers (0.600 and 0.400) as in
 21 the previous 50,30,20 illustration for the case of red.

22 Accordingly, regardless of which of the RGB triplet is the
 23 maximum, there is a symmetry and strength is defined as the maximum strength
 24 value of (Red, Green, and Blue) and color ratios result (red/Strength,
 25 green/Strength, blue/Strength). One of the three ratios will be exactly equal to 1
 26 because strength is always equal to one of the numerators. In the case of Red
 27 from Table 1, RGB = 50,30,20 so that strength = max of (50,30,20) which is 50
 28 and the color ratios are (50/50, 30/50, 20/50) = (1, 0.600, 0.400).

1 Thus, for Red, Green and Blue respectively:

2	<u>Color</u>	<u>Strength</u>	<u>R/S</u>	<u>G/S</u>	<u>B/S</u>
3	50,30,20	Red	1	0.6	0.4
4	30,50,20	Green	0.6	1	0.4
5	30,20,50	Blue	0.6	0.4	1

6 As considered before, when a camera gathers more light
 7 compared to another setting for the same image, a given dot has the qualities
 8 that the ratios of the measured primary colors remain the same - if we are within
 9 the dynamic range of the recording system. Instead of thinking of the dot as an
 10 RGB triplet we can think of the dot as a strength and ratios. Again, for our dot,
 11 50,30,20 at its reference strength of 50, the color ratios are 1, 0.600 and 0.400.

12

13 Enhancing the Image

14 As long as the color ratios are unaltered, the image can be
 15 adjusted without adversely affecting the colors. For instance, should insufficient
 16 light have been gathered by the recording device, we can virtually amplify the
 17 light power or strength while maintaining the color.

18 To virtually amplify or scale the light by a correction factor of 2, the
 19 strength is doubled without varying the color ratios: For example, doubling the
 20 strength of our dot of (50,30,20) to 100 results in a color dot of $50 * 2 *$
 21 $(1,0.6,0.4) = (100,60,40)$. Simply, the same result can be achieved by simply
 22 multiplying the R,G, and B by 2.

23 This virtual true color light amplification is accomplished by
 24 multiplying or scaling all three primary colors by the same number. No colors

1 become distorted, as long as the output values stay within the dynamic range.
2 The dynamic range is exceeded if a R, G, or B value is calculated that is greater
3 than the range used by the file format for the image (such as 255).

4 One can ensure that no value, resulting from the triple
5 multiplication scaling, can exceed the dynamic range, by deriving the correction
6 from an algebraic scaling expression or function.

7 Having reference to Fig. 1, the X-axis represents the strength of an
8 image dot (Maximum of red, green, and blue). The scales of 0 – 1 represent the
9 limits of the dynamic range (such as 0 – 255). For the linear diagonal shown, a
10 strength of 50 ($50/256 = 0.2$) for a dot is scaled by unity for an output value of
11 0.2. Accordingly, the unity diagonal corresponds to a 'no operation' situation
12 where the output is identical to the input. However, once the scaling function
13 deviates from unity, the output values will be different from the input values,
14 resulting in a change to the image.

15 To scale the dynamic range from 0 to 1.0 is to simply divide a
16 current strength (maximum of the RGB triplet) value by the maximum number
17 that can be stored with this dynamic range. Suppose that number is 255. An
18 arbitrary dot will have a dot maximum strength having a number between 0 and
19 255. To scale the dot maximum to 0 and 1.0 one divides the strength by 255.

20 Both the input and the output axis represent the values of the
21 maximum of the RGB triplet; the dot maximum. The input is the dot maximum
22 under consideration. The output corresponds to the adjusted dot maximum for
23 the RGB triplet that will be calculated as a result of the method.

1 Dot Maximum

2 One method to find the maximum of an input RGB triplet is to
3 choose one as maximum, testing each of the others, and resetting the maximum
4 to that other if higher. The following 3 lines of pseudo code illustrated the
5 selection of a dot maximum:

```
6                   strength = red  
7                   strength is set to red value  
8                   IF strength < green THEN strength = green  
9                   if strength is less than green value then reset it to the green value  
10                  IF strength < blue THEN strength = blue  
11                  if strength is less than blue value then reset it to the blue value
```

12 Having reference to Fig. 1, any scaling or correction is constrained
13 to the 1 X 1 graph shown. The input axis is constrained to the domain from 0 to
14 1 and the output axis is constrained to the range of 0 to 1. This means that the
15 strength of an adjusted or corrected dot will not exceed the dynamic range.

16 Any scaling function that can be plotted within the constrained
17 graph can be used for virtual true color light amplification. The properties of a
18 particular graph will affect the final aesthetics and application. A particular
19 function is chosen as appropriate for the application; whether it be to adjust the
20 brightness of an entire image, or a portion of the image, or other adjustment.

21 Two implementations of the scaling function correction include
22 forming a lookup table of corrections (a finite number dictated by the dynamic
23 range); and another less efficient means is to calculate each dot independently
24 in turn. One can understand that in an image, the value of the strength of a
25 particular dot may be repeated many times for many other dots. Thus, for

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1 efficient calculation, in the case of a look-up table, a correction can be calculated
 2 only once but applied many times.

3 For the look-up table approach, once the parameters needed to
 4 specify a particular scaling function are known - all the corrections (usually 256
 5 of them, this depends on the limit of the dynamic range) are then calculated by
 6 means of a subroutine and the results stored in a look up table so that each is
 7 only calculated once. The correction is then simply looked up in this way (a
 8 pseudo coded example is:)

9 **corr = corra(strength)**
 10 where corr is the particular correction for the current dot;
 11 corra() is the lookup table or array that stores the corrections;
 12 and
 13 strength is the dot maximum of the RGB for the current dot.

14 The other (less efficient) way is to have a function calculate the
 15 correction for a particular dot, each one in turn. An example would be

16 **corr = correct(strength)**
 17 where corr is the particular correction for the current dot;
 18 correct () is the correction function which executed by
 19 simply 'calling' its name in this way; and
 20 strength is the dot maximum of the RGB for the current dot.

21 A given point along the graphed scaling function, which provides
 22 an input and output value, is to be used to derive the correction multiplier or
 23 factor. A correction factor is equal to output value / input value.

24 So as to maintain the respective color ratios, all three of the RGB
 25 triplet values are multiplied by this same correction **corr** as determined for and
 26 specified by the dot maximum.

1 Accordingly, $\text{red} = \text{red} * \text{corr}$; $\text{green} = \text{green} * \text{corr}$; $\text{blue} = \text{blue} *$
2 corr where red, green, blue end up holding the values for the current dot before
3 and after correction. The effect of coupling these four considerations is that of
4 Virtual True Color Light Amplification. The Dynamic Range is never exceeded
5 and the color is always preserved.

6

7 Practical Implementation

8 An image can be read in various ways. Applicant has avoided the
9 need to review the various graphical computer file formats 13 by illustrating the
10 method on a displayed image. Applicant is aware that, currently, Visual Basic (a
11 programming language 14 operable under the Windows operating system – all
12 trademarks of Microsoft Corporation) and most other modern programming
13 languages 14 have simple commands that allow for image reads. In Visual
14 Basic, one command is `pbox.Picture = LoadPicture(file_in)` where pbox is a
15 'picture box object', used for displaying pictures, Picture is a 'method' which
16 assigns a picture to the object, LoadPicture() is the function that reads Picture
17 Files, and file_in is the name of the file 13 that is to be read. Once this
18 command is issued by Visual Basic, the image file 13 is read in and displayed on
19 the screen in the programming 'tool' called the 'picture box object'. There is a
20 similar method to save a picture.

21 Having reference to Fig. 2, the simplified code illustrates a Visual
22 Basic implementation of the virtual true color light amplification method applied
23 to an image. This simplified technique requires, at a minimum, a 16 bit video

1 card 15 and a 24 bit card is preferable. The code of Fig. 2 is directed to
2 extracting color values from the video card 15 itself. This is not the most efficient
3 technique and could be improved significantly by storing the image in the main
4 RAM memory 16. This would eliminate accessing the video card 15 at all and
5 eliminate the extraction steps of stripping R, G and B values from a combined
6 color variable such as that returned by Visual Basic function
7 pbox.Point(icol,irow). Accessing memory 16 could result in about a 7 times
8 efficiency gain.

9 Simply, the process permits a rectangular displayed image of dots
10 to be adjusted. For example, the image may be dark, only having a maximum
11 strength for any of the dot maximums being about 128, or half the dynamic range
12 for the system. In the simplest case, the image range is scaled to the dynamic
13 range as a linear function. Accordingly, by normalizing the maximum of 128 to
14 255, the strength of all dot maximums will be doubled. Accordingly, the scaling
15 function is merely a constant of 2 and the look up result, for any dot maximum, is
16 2. For each column of the image, the values of the color are extracted for blue,
17 green and red. The dot maximum is set as red and the green and blue are
18 tested to reset the strength to the maximum amongst the three. The correction
19 is looked up in the table, in this case being a constant of 2. Each of the values
20 for RGB are scaled by 2, the maximum scaled value being $128 * 2$ or 256 – the
21 maximum of the dynamic range. The modified dot is written back to the display,
22 all colors having been preserved and without having exceeding the dynamic
23 range.

1 Applications – Effect of the Scaling Function

2 The virtually infinite selection of scaling functions, as applied to the
3 image, results in different effects to suit various differing objectives. Sometimes
4 the quality of the image dictates which function is used (such as a function
5 designed simply for brightening a dark image), or a more particular function
6 which enhances only specified strengths within an image (such as extracting
7 detail from a narrow portion with minimal concern regarding the effect on the
8 other portions of the image).

9

10 Applications – Virtual Lens

11 Both the aperture and the shutter cause problems in and of
12 themselves. If the subject of the photograph is moving, the shutter can only be
13 open for a short period of time or the image will be blurred by the motion itself.

14 When the aperture is opened up, the depth of field (which means
15 the range of distance that is in focus) decreases. Even when focusing correctly,
16 a wide open aperture means that only a small range of distance will be in focus.
17 This 'distortion' is due to the spherical shape of the lens itself. When the
18 aperture is small, the depth of field is better because only the nearly flat center of
19 the lens was used. The smallest aperture setting provides the largest depth of
20 field.

21 In practice, photography (and light gathering in general) is a trade
22 off of these two effects. A motionless scene can have a large depth of field, by
23 choosing a small aperture and a slow shutter speed. A racing car can only be

1 photographed at the cost of the depth of field, the shutter cannot be open for
2 long and so the aperture must be opened to gather more light.

3 Suppose that a 'normal' quality lens is used to photograph
4 something that is moving quickly but the photographer does not want to lose the
5 depth of field. Without the process of the present invention there is no way to do
6 this. Accordingly, by setting the controls to gather too little light, in terms of
7 normal photographic thinking, the uncorrected image will be too dark but the
8 depth of field is preserved. Suppose the photographer had collected a quarter
9 (25%) of the amount of light that would make full use of the dynamic range. The
10 image will be nearly black, with the highest value recorded being 63 whereas the
11 dynamic range limit is 255. This image can be corrected to bring out the detail in
12 the dark areas.

13 Accordingly, in a first embodiment, and having reference to Fig. 3,
14 the graph is a straight line which terminates at the point $(x, 1.0)$ where x is the
15 maximum of the entire measured image. This maximum value can be found
16 using a modified histogram approach. In this example, x would be 0.25 but it
17 could be any value between 0 and 1. In the preferred embodiment of the
18 invention, virtual light is added in the same way that opening the aperture more
19 would have except that it will have a depth of field associated with a superior
20 lens. This process can also be used to make up for 'blunders' where
21 inappropriate lens settings resulted in a too dark photograph.

1 Virtual Iris

2 In a second embodiment, and having reference to Fig. 8, a graph
3 can be chosen so that the darkest parts of the image will remain dark, the duller
4 parts will brighten but also so that the bright parts of the image remain nearly
5 unaffected. Fig. 8, and similarly shaped smooth non-linear graphs, have the
6 effect of imitating the iris when used with the virtual true color light amplification
7 of the present invention. The output image happens to more closely resemble
8 one's visual memory of the experience. Applicant refers to this enhancement as
9 "virtual iris".

10 The gentle nature of this non-linear graph ensures that a quality
11 input image will result in an attractive processed image. The important aspects
12 to maintain this aesthetic result is that the graph remains smooth, the slope of
13 the graph is never zero and is also smoothly changing, and that there is a net
14 brightening effect in total.

15 In Fig. 8, the scaling function approaches the asymptote of the
16 minimum and maximum of the system's dynamic range. The more the function
17 approaches a tangent to the minimum and maximum of the dynamic range, the
18 more severe the correction.

19

1 Virtual Detail Enhancement

2 Simply, any one frame of a photo is the result of only one aperture
3 and shutter setting. In investigative work, this has the annoying limitation that
4 details in certain areas of the photograph will be subtle. In a third embodiment, a
5 process is provided for bringing out detail in that certain subtle area.

6 Having reference to Fig. 4, an area of interest is chosen and a
7 histogram approach is applied to find that the minimum strength dot within the
8 area is 0.30 and the maximum strength dot is 0.50. This area utilizes only 20%
9 of the dynamic range, which means that the contrasts will be subtle – or virtually
10 indistinguishable to the eye.

11 Applying a three part linear scaling function as shown in Fig. 4
12 turns these small contrasts into large ones as the output from that specified area
13 now varies over 80% of the dynamic range.

14 The small sloped lines below 0.30 and above 0.50 on the input
15 have the effect of washing out the detail in darker and brighter parts of the
16 image. But the resulting color, at each dot, will never be corrupted and the
17 brighter parts of the image provide a good reference.

18 Any area of the photograph can be chosen. Having reference to
19 Fig. 5, details in a very dark area are revealed, such as writing obscured in
20 shadow. Fig. 6 illustrates how to bring out the details in a bright area, such as
21 tracks in the snow. Any number of areas can have their detail enhanced by
22 simply choosing the area of interest and applying the correction.

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1 More particularly, any areas or portions of the image can be
2 optimized. First, the area needs to be identified. In a Graphics User Interface,
3 this is easily done using the mouse in a 'click and drag' operation. This can be
4 done in Object Oriented Programming by using the Operating System (Windows)
5 to identify when the mouse button has been clicked. In Visual Basic there are
6 built in subroutines (for every program) that are executed as soon as the mouse
7 button is depressed or released.

8 A user can select any rectangular area within the image. The
9 'coordinates' are stored in common memory as xdown, ydown, xup and yup. See
10 the photographic examples #1 and #2 for the superimposed rectangle on the
11 image.

12 In both the Virtual Lens and the Virtual Detail Enhancement, I
13 referred to a 'modified histogram approach'. A histogram is simply the
14 measurement of the number of occurrences against the value of the
15 occurrences.

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1 For example, as shown in Table 4, in terms of a set of RGB triplets:

2 **Table 4 - Standard Histogram Approach**

3 "Red, Green, and Blue values taken as independent"

4	Dot #	Red	Green	Blue	Value	# Events
5	1	1	1	1		
6	2	0	0	1	0	2
7	3	2	2	1	1	11
8	4	4	3	1	2	3
9	5	4	4	4	3	7
10	6	3	2	1	4	5
11	7	5	1	1	5	2
12	8	3	3	1		
13	9	4	3	1	Total	30
14	10	3	3	5		

15 In this example, there are 10 dots each having 3 values (red, green
 16 and blue) and each of these 30 values range in value from 0 to 5. The normal
 17 histogram is calculated by adding up the number of times each value (0, 1, 2, 3,
 18 4, and 5) occurs in total.

1 The modified histogram approach, where strength = max (red,
2 green, blue), described by Table 5 as follows:

3 **Table 5 - Modified Histogram Approach**

4 "Red, Green, and Blue values taken as a unit, Histogram on maximum"

5	Dot #	Red	Green	Blue	Strength	Value	# Events
6	1	1	1	1	1		
7	2	0	0	1	1	0	0
8	3	2	2	1	2	1	2
9	4	4	3	1	4	2	1
10	5	4	4	4	4	3	2
11	6	3	2	1	3	4	3
12	7	5	1	1	5	5	2
13	8	3	3	1	3		
14	9	4	3	1	4	Total	10
15	10	3	3	5	5		

16 Simply, it is the occurrence of numbers as found in the maximum
17 strength that is used to build the histogram and not the values of red, green and
18 blue separately.

19 This is in keeping with the nature of this patent application which is
20 that red, green, and blue values are to be treated as a unit having a strength and
21 ratios and not as three independent values.

22 The histogram is built by considering only those dots within the
23 range of rows = xdown to xup and columns = ydown to yup.

24 Having reference to Fig. 7a, example code is provided by which to
25 apply the modified histogram.

26 At this point, the histogram is formed and its running total is known
27 with respect to the strength of the RGB triplets of the marked area. The

1 beginning and the ending significant strengths are determined, as reflected by
2 the histogram data.

3 To avoid errors such as dead or saturated recording elements and
4 otherwise 'stray values' that are not representative of the area, one can limit the
5 relevant dots to the 2% and the 98% of the number of occurrences to represent
6 the smallest and largest relevant RGB strengths.

7 The number of strengths counted by the histogram, in total, is
8 equal to the last running total value, and the 2% and 98% values are, therefore,
9 easily found. Code is shown in Fig. 7b which determines the range of strength
10 index (hmin and hmax) corresponding to the range of strengths within the box
11 selected by the user.

12 Having reference also to Fig. 4, the modified histogram approach
13 found 0.30 (of the dynamic range maximum) and 0.50 (of the dynamic range
14 maximum) to be the minimum and maximum strength values of the portion of the
15 image selected by the user. (See photographic examples #1, #2, for the boxes).

16 It was also assumed that the range calculated from the modified
17 histogram approach should be modified so that it varied over the majority of the
18 dynamic range.

19 So, what should this input range of hmin and hmax be turned into?
20 We want it to occupy most of the dynamic range. A good guess is 80% of the
21 dynamic range with a little left over for the darker and lighter areas so they can
22 still be used as a reference.

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1 In application code, the output strength range of the selected area
 2 was originally set to 0.1 to 0.9 of the dynamic range maximum. It was later reset
 3 to 0.2 to 0.9 as these numbers simply seemed better after observing many
 4 images.

5 The code used to calculate the look up table based on the modified
 6 histogram approach for determining the input strength range and the (nearly)
 7 arbitrary output range of 0.2 to 0.9 follows.

8 The graph of Fig. 4 can be thought of, in the general sense, as
 9 having 3 line segments each with two end points.

10	Table 6: Line Segments:		
11	Line Segment	Start	Stop
12	#1	(0,0)	(xmin,0.20)
13	#2	(xmin,0.20)	(xmax,0.90)
14	#3	(xmax,0.90)	(1.0,1.0)

15 where xmin and xmax have been calculated by the modified
 16 histogram approach. That is to say:

$$17 \quad \text{xmin} = \text{hmin} / \text{drmx}$$

$$18 \quad \text{xmax} = \text{hmax} / \text{drmx}$$

19 Both input axes are measured in terms of the dynamic range. The
 20 input values are in terms of the strength (max of RGB) of the dot. The graph
 21 never leaves the 0 to 1 'box'. These constraints must always be met by any
 22 scaling function in any specific process.

1 All that remains, here, is that the output value be calculated by a
2 program equivalent to that described for Fig. 2 above and that the lookup table
3 does not hold the graph, exactly, but the ratio of the output to the input.

4 Each line segment can be expressed with algebra in the 'slope
5 intercept' form, of which the general form is: $y = m \cdot x + b$. For each of the three
6 line segments, linear equations and scaling factors are determined. An array of
7 corrections or scaling factors can be formed from the three equations. Dividing
8 the output values by the system dynamic range produces the ratio of output to
9 input.

10 This virtual detail enhancement technique, or forensic flash due to
11 its ability to delve into the normally obscured areas, maximizes the dynamic
12 range of any target so that the details are enhanced. This is not restricted to the
13 target area but any part of the photograph that has similar strengths to the user's
14 choice will also be so enhanced. Any target area can be selected and so there
15 can be many valuable corrections performed on the same photograph. Those
16 areas which were stronger than the strength range picked by the user remain as
17 useful references due to the 'true color' nature of the correction.

18

1 Examples

2 Virtual Flash - Virtual Iris

3 The examples illustrated in Figs. 9 and 10 illustrate corrections to
4 the limitations that occur from the physical light gathering devices or image
5 recorders. The one aperture and shutter setting per frame means that a
6 photograph is likely to vary from one's memory of the experience of being there.
7 The eye's iris adjusts itself when experiencing contrasts. In a park on a sunny
8 day, the iris opens up when moving from sunlight to the shade so that you
9 remember all the grass as being green whereas photos often show shaded
10 grass as black.

11

12 Photo #1 (Figs. 9a – 9f) Tourist photo of an Abbey

13 This example illustrates how various prior art processes and the
14 present invention enhance the image. The approach with the prior art processes
15 is to "play" with the image until the brightness looks about right for what you
16 want. It is a subjective thing and the expert user is someone who is good at
17 making the necessary compromises. In Fig. 9a, the original image, scanned
18 from a photograph, is very dark but still uses all/most of dynamic range (of the
19 dot maximums (hits) being outside the strengths of 5 and 254) of a system of
20 256.

21 Figs. 9b - 9d illustrate prior art image brightening techniques. Fig.
22 9b does so by increasing the image brightness by 80%. While the image of Fig.
23 9b is brighter, the colors are badly faded and the sky has also experienced

1 change in color. Fig. 9c illustrates the prior art brightened image of Fig. 9b with
2 contrast set to 50%. Contrast is increased in an attempt to try to restore the
3 colors lost in brightening. Notice how much of the detail of the image is lost.
4 The process has pushed many of the dots past the edge - outside of the
5 dynamic range. Fig. 9d illustrates the brightened image of Fig. 9b with the
6 saturation set to 50%. Increase in saturation is another technique for restoring
7 the colors. As a result, the sky is almost returned to what it was but the rest of
8 the image has significant and unsightly color distortions.

9 Applying the techniques of the present invention, the photo fares
10 much better particularly in Fig. 9f. In Fig. 9e, the image range of 5 to 254 is
11 linearly mapped to 0 to 255. The effect is small because the original image was
12 nearly full range already. It does, however, ensure that we have the full dynamic
13 range in the output image. In Fig. 9f, the scaling function of Fig. 8 was applied
14 for obtaining a superior image. All the colors are true to the image, as it was
15 scanned, and are vibrant, just as they would have been to the eye with no loss of
16 detail.

17

18 Photo #2 (Figs. 10a – 10f) Tourist photo of Stone Henge

19 In the original frame of Fig. 10a, the stones are in the shadows due
20 to the extreme lighting conditions. In Fig. 10f, the virtual iris process of the
21 present invention compensates in a similar way that the iris does automatically,
22 turning the poor photo into a good one.

1 More particularly, in Fig. 10a, the subject is very dark and again
2 uses all/most of dynamic range (only 1% of the hits being outside of a strength of
3 6 and 253). This image had been "pre-processed" by others to bring out detail -
4 notice how the sky is nearly white but clouds are still available (reproduction of
5 the Figures in this application does not necessarily preserve the actual presence
6 of the clouds). The prior art had taken it "as far" as its could but the subject was
7 still too dark. Fig. 10b illustrates prior art brightening of the image by 60%.
8 While image is brighter, the colors are badly faded and the stones have lost all
9 their color. Some of the detail is also lost by this process alone. Note, even in
10 the gray-scale rendering, the whitening of the "red" rock left of the stones and at
11 the left extreme of Fig. 10b image. Fig. 10c is the brightened image of Fig. 10b
12 with contrast set to 40%. Notice that the stones have, in areas, regained some
13 color but not in other areas. Also notice how much more of the detail of the
14 image is lost. Fig. 10d is the brightened image of Fig. 10b with saturation set to
15 15%. There is improved color that is "sort of right in a way" but it also adds
16 artificial colors, such as some reds and yellows. Even in photos where not much
17 correction is needed, manipulation of saturation for each dot ends up with
18 different RGB ratios than were recorded. At best, one ends up with a
19 compromise solution.

20 Applying the techniques of the present invention, in Fig. 10e the
21 image range of 6 to 253 is linearly mapped to 0 to 255 to ensure the full dynamic
22 range in the output image. In Fig. 10f, the scaling function of Fig. 8 was again
23 applied for obtaining the superior, true color image with no loss of detail.

24

1 Forensic Flash - Virtual Detail Enhancement

2 Photo #3 (Figs. 11a,11b) Satellite

3 In Fig. 11a, the satellite is in the shadows and the surface is very
4 dark. This often happens in space because of the extreme contrast in lighting.
5 Important 'docking' holes cannot be seen. Using the forensic flash correction
6 technique of the third embodiment, a window or box was selected within the dark
7 area and the histogram approach used to build a correction graph suited for that
8 area.

9 In Fig. 11b, the processed image now shows the detail in the dark
10 area. The docking holes, marked with white circles, are now revealed.

11

12 Photo #4 (Fig. 12a,12b) Blimp

13 In the original image of Fig. 12a, the underside of the blimp is in the
14 shadows. This often happens in photography when the lens is directed into the
15 sky. Specifically, the identification markings cannot be seen as the tail is too
16 dark.

17 Under the principles of the third embodiment, the tail area is
18 selected and the histogram approach used to build a correction graph suited for
19 that area. As a result, as shown in Fig. 12b, the processed image shows the
20 lettering in the previously obscured, dark area. The blimp is now identified as
21 COLUMBIA N3A.

22

1 Photo #5 (Fig. 13a,13b) Car Plate

2 In the original frame of Fig. 13a, the car's license plate is mostly
3 shrouded in shadows. The car cannot be identified because the plate cannot be
4 read. Using the third embodiment, the plate is selected and the histogram
5 approach used to build a correction graph suited for that area.

6 As a result, and referring to Fig. 13b, the processed image shows
7 that the car does not have a normal plate at all but, instead, the words: Classic
8 Mustang.

9

10 Photo #6 (Fig.14a, 14b, 14c) Tracks in the Snow

11 In Fig. 14a, there are two people skiing. Their tracks are
12 identifiable, but subtle. Using the forensic flash correction technique of the third
13 embodiment, a window or box was selected within the overexposed area of the
14 tracks in the snow and the histogram approach used to build a correction graph
15 suited for that area.

16 In Fig. 14b, the processed image now shows the detail in the
17 overexposed area. The tracks in the snow are distinctly visible.

18 Similarly, a window or box was selected in the dark area of the face
19 of the skier in the photograph. Figure 14c is the result of the histogram approach
20 used to build a correction graph uniquely suited to this area of the photo. The
21 features of the skier are more clearly visible than in the original photo shown in
22 Fig. 14a.

1 Summary

2 The key concepts are here expressed as the combination of the
3 following six factors: correcting in RGB color space, the correction graph; the
4 definition of the correction axes; constraint of domain and range to the system's
5 dynamic range; properties of the graph; and application of the same correction
6 factor to each of R, G and B in the triplet.

7 The correction must be applied to the RGB color space to maintain
8 true color. Any correction graph can be used that embodies the above
9 characteristics. Both the input and the output axes represent the maximum of
10 the RGB triplet. The input is the maximum of the RGB triplet under
11 consideration and the output corresponds to the maximum of the RGB triplet that
12 is calculated as a result of virtual true color light amplification. The correction is
13 constrained to the dynamic range. This means that the strength of the
14 calculated dot is constrained to the dynamic range. Any graph that can be
15 plotted within the constraints can be used for the process. The properties of a
16 particular graph will affect the emphasis of the correction. Again, all three of the
17 RGB values must be multiplied by the scaling factor derived from the graph. A
18 given point on the graph has an input and output value. The correction equals
19 the ratio (division) of these two and all three of the RGB triplet values are
20 multiplied by this ratio of output to input.

21 The result of these considerations is a suite of processes all of
22 which preserve the essential color of each and every dot in the input digital
23 image while varying the effective light gathering power which can easily be on a
24 dot to dot basis.

WO 00/62528

PCT/CA00/00400

1 All that differs between the above embodiments is to vary the
2 graph within the imposed constraints. With virtual true color light amplification, a
3 new and useful result is dependent only upon identifying an image enhancing
4 need and identifying a reasonable graph to fit that need.

1 **THE EMBODIMENTS OF THE INVENTION FOR WHICH AN**
2 **EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS**
3 **FOLLOWS:**

- 4 1. A color digital image enhancement apparatus comprising:
- 5 a first digital data storage means having a dynamic range and in
- 6 which is stored a digital image comprising a multiplicity of color dots;
- 7 a reading means for reading each stored color dot from the first
- 8 digital data storage;
- 9 an extracting means for extracting an R, G, and B strength value
- 10 for each stored color dot;
- 11 a dot maximum determining means for determining a dot
- 12 maximum from between each of the R, G, or B strength values for each color
- 13 dot;
- 14 a scaling factor obtaining means for establishing a scaling factor
- 15 corresponding to each determined dot maximum as a ratio between the
- 16 dynamic range of the digital data storage and each determined dot maximum;
- 17 a scaling factor applying means for applying the scaling factors
- 18 to each color dot, the particular scaling factor for each determined dot
- 19 maximum being applied to the corresponding dot maximum for each color dot
- 20 and being applied equally to each of the R, G, or B strength values of the
- 21 color dot for obtaining scaled R, G, or B strength values for each color dot
- 22 wherein the scaled strength value for the dot maximum remains within the
- 23 dynamic range of the image stored in the first digital data storage; and
- 24 a second digital data storage means for storing the scaled R, G,
- 25 or B strength values for each color dot.

1 2. The color digital image enhancement apparatus in
2 accordance with claim 1 wherein:

3 the extracting means further determines a maximum value and a
4 minimum value for the dot maximums for establishing an image strength
5 range therebetween, and

6 a scaling factor obtaining means obtains a scaling function for
7 the color dots which determines the scaling factors for expanding at least a
8 portion of the image strength range to a greater portion of the dynamic range
9 of the first digital data storage.

10

11 3. The color digital image enhancement apparatus in
12 accordance with claim 2 further comprising a third digital data storage for
13 storing a look up table of the scaling factors corresponding to each dot
14 maximum for at least a portion of the dynamic range, the number of scaling
15 factors being equal to or less than a total number of color dots in the digital
16 image so that the scaling factor applied to each color dot are looked up from
17 the lookup table.

18

19 4. The color digital image enhancement apparatus in
20 accordance with claim 2 wherein the extracting means further normalizes the
21 image strength range to the dynamic range.

22

23 5. The color digital image enhancement apparatus in
24 accordance with claim 4 wherein a portion of the image strength range is
25 normalized to the substantial portion of the dynamic range.

26

1 6. The color digital image enhancement apparatus in
2 accordance with any one of claims 2 – 5 wherein the digital image stored in
3 the first digital data storage means has a first digital format having a first
4 dynamic range and the digital format of the enhanced image stored in the
5 second digital data storage means has a second, larger dynamic range and
6 wherein the extracting means further determines a maximum value and a
7 minimum value for the dot maximums is determined for establishing an image
8 strength range within the first dynamic range; and normalizes the at least a
9 portion of the image's strength range to a portion of the second dynamic
10 range is normalized to a substantial portion of the second dynamic range.

11

12 7. The color digital image enhancement apparatus in
13 accordance with any one of claims 2 to 6 wherein the scaling function is linear
14 and continuous.

15

16 8. The color digital image enhancement apparatus in
17 accordance with any one of claims 2 to 6 wherein the scaling function is non-
18 linear and continuous.

19

1 9. The color digital image enhancement apparatus in
2 accordance with any one of claims 2 – 8 further comprising:

3 image selecting means for enabling selection of a subset of
4 color dots from the digital image and wherein the dot maximum determining
5 means determines the strength range of dot maximums for the subset; and

6 wherein the scaling factor obtaining means establishes:

7 a first scaling function for those color dots having dot
8 maximums within the subset strength range, the first scaling function
9 scaling R, G, and B strength values for the subset to a substantial
10 portion of the dynamic range;

11 a second scaling function for those color dots having dot
12 maximums darker than the subset strength range; and

13 a third scaling function for those color dots having dot
14 maximums brighter than the subset strength range, the first second
15 and third scaling functions acting to expand the strength range of
16 scaled dot maximums for the subset and compress the strengths for
17 the remaining color dots.

18

19 10. The color digital image enhancement apparatus in
20 accordance with claim 9 wherein each of the first, second and third scaling
21 functions are continuous.

22

23 11. The color digital image enhancement apparatus in
24 accordance with claim 9 or 10 wherein each of the first, second and third
25 scaling functions are substantially linear.

26

1 12. The color digital image enhancement apparatus in
2 accordance with claim 9, 10, or 11 wherein the first, second and third scaling
3 functions are continuous with each other.

4

5 13. The color digital image enhancement apparatus in
6 accordance with any one of claims 9 - 12 wherein the selected subset of color
7 dots is an underexposed portion of the digital image.

8

9 14. The color digital image enhancement apparatus in
10 accordance with any one of claims 9 - 13 wherein the subset of color dots is
11 selected by selecting a rectangular area of color dots within the image.

12

13 15. The color digital image enhancement apparatus accordance
14 to claim 13 or 14 wherein the digital image is an underexposed image having
15 a statistically significant maximum value of the dot maximums being less than
16 the dynamic range, further characterized in that:

17 the scaling function is established which enhances the image's
18 strength range to substantially the entire dynamic range of the digital image;
19 and

20 the scaling function is applied to each dot maximum for
21 expansion of the image's strength range.

22

1 16. The color digital image enhancement apparatus in
2 accordance with any one of claims 1 to 15 wherein:

3 the scaling factors for each dot maximum for at least a portion of
4 the dynamic range are stored in a lookup table, the number of scaling factors
5 being equal to or less than the number of color dots in the digital image; and

6 the scaling factor for a dot maximum is looked up from the
7 lookup table which corresponds to the dot maximum for each color dot and is
8 applied to each color dot.

9

10 17. The color digital image enhancement apparatus in
11 accordance with any one of claims 1 to 16 wherein the first digital data
12 storage is a computer file.

13

14 18. The color digital image enhancement apparatus in
15 accordance with any one of claims 1 to 17 wherein the second digital data
16 storage is a computer file.

17

18 19. The color digital image enhancement apparatus in
19 accordance with any one of claims 1 to 18 wherein the first digital data
20 storage is RAM.

21

22

23 20. The color digital image enhancement apparatus in
24 accordance with any one of claims 1 to 19 wherein the second digital data
25 storage is RAM.

26

1 21. A computer program product comprising:
2 a first memory having computer readable code embodied
3 therein, for execution by a processor for extracting a digital image from a first
4 digital storage having a dynamic range and in which is stored a digital image
5 comprising a multiplicity of color dots and storing an enhanced digital image
6 on a second digital storage, said code comprising:
7 a reading code means for reading each stored color dot from the
8 first digital data storage;
9 an extracting code means for extracting an R, G, and B strength
10 value for each stored color dot;
11 a dot maximum determining code means for determining a dot
12 maximum from between each of the R, G, or B strength values for each color
13 dot;
14 a scaling factor obtaining code means for establishing a scaling
15 factor corresponding to each determined dot maximum as a ratio between the
16 dynamic range of the digital data storage and each determined dot maximum;
17 a scaling factor applying code means for applying the scaling
18 factors to each color dot, the particular scaling factor for each determined dot
19 maximum being applied to the corresponding dot maximum for each color dot
20 and being applied equally to each of the R, G, or B strength values of the
21 color dot for obtaining scaled R, G, or B strength values for each color dot
22 wherein the scaled strength value for the dot maximum remains within the
23 dynamic range of the image stored in the first digital data storage; and
24 a storing code means for storing the scaled R, G, or B strength
25 values for each color dot in the second digital data storage.
26

1 22. A memory for storing data for access by an application
2 program being executed on a processor comprising:

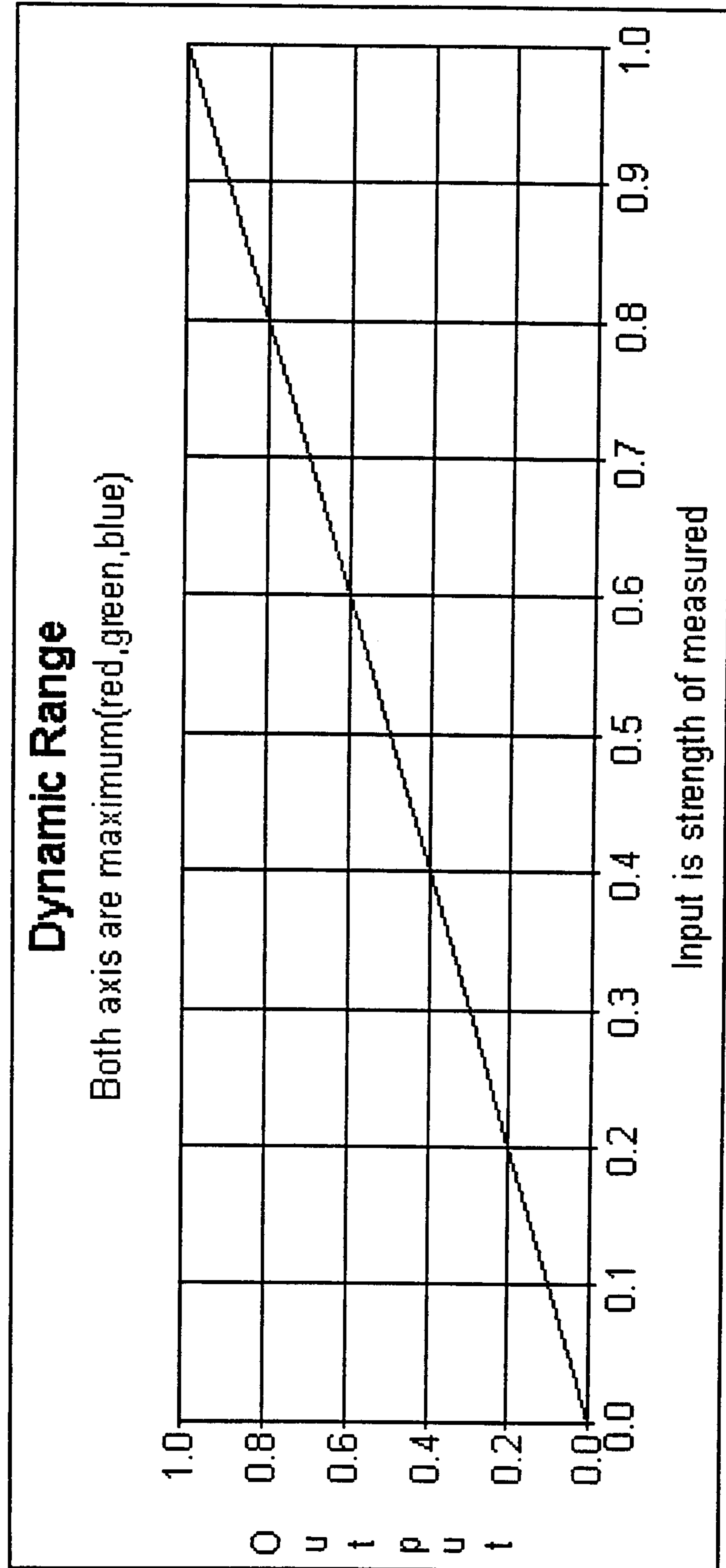
3 a first data structure stored in said memory and used by said
4 application program and including an array of a multiplicity of color dots
5 representing a digital image having a dynamic range and an R, G, and B
6 strength value for each color dot, each color dot having a dot maximum from
7 between each of the R, G, or B strength values;

8 a second data structure stored in the memory including a look
9 up table used by the application program wherein the look up table comprises
10 a plurality of scaling factors corresponding to each determined dot maximum,
11 each scaling factor being a ratio between the dynamic range of the digital data
12 storage and each determined dot maximum, the number of scaling factors
13 being equal to or fewer than the multiplicity of color dots in the first data
14 structure so that the scaling factor corresponding to each determined dot
15 maximum can be applied to the corresponding dot maximum for each color
16 dot and being applied equally to each of the R, G, or B strength values of the
17 color dot for obtaining scaled R, G, or B strength values for each color dot
18 wherein the scaled strength value for the dot maximum remains within the
19 dynamic range of the image stored in the first data structure; and

20 a third data structure stored in the memory and used by the
21 application program to received the scaled R, G, or B strength values for each
22 of the multiplicity of color dots.

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Fig. 1



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pbox.Picture = LoadPicture(file_in)

a rectangular picture of columns and rows is displayed

For icol = 1 To pbox.ScaleWidth

loops through the columns of the image,

For irow = 1 to pbox.ScaleHeight

loops through the rows of the image

color = pbox.Point(icol,irow)

the color of the point at current column, row.

blue = color / 65536

This sets blue to the most significant byte (division by $256 * 256$)

color = color mod 65536

This keeps only the 2 least significant bytes (mod of $256 * 256$)

green = color / 256

This sets green to the (next) most significant byte (division by 256)

red = color mod 256

This sets red to the least significant byte (modulus of 256)

strength = red

If strength < green Then strength = green

If strength < blue Then strength = blue

the dot maximum is found

corr = corra(strength)

Lookup correction for that value of dot maximum then correct RGB in the dot

red = red * corr

green = green * corr

blue = blue * corr

Red, green, blue are now corrected to desired values

pbox.PSet(icol,irow),RGB(red,green,blue)

Put the adjusted and corrected dot back into the image on the screen

Next irow

Get next row dot in the column

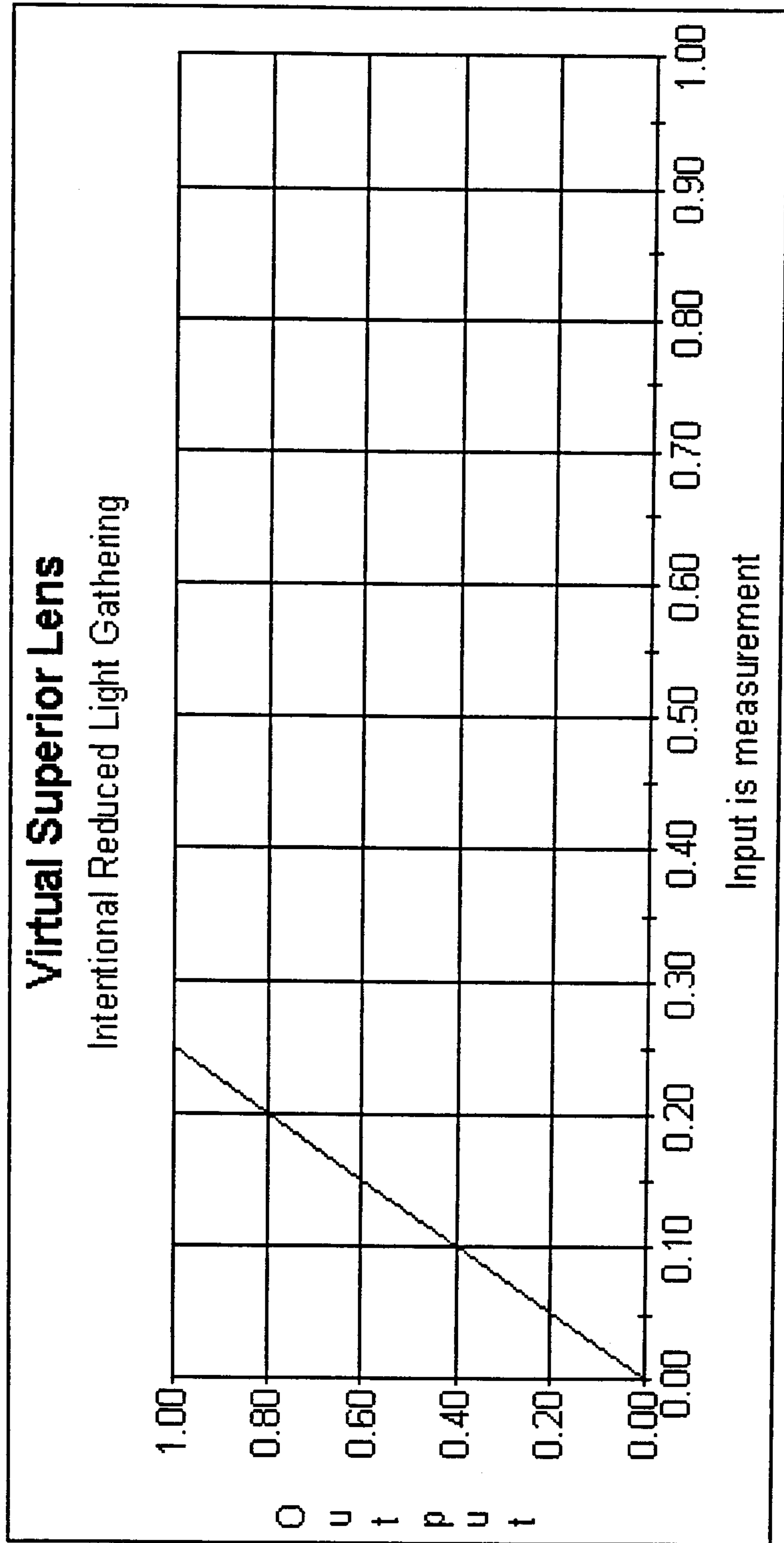
Next icol

Get next image column of dots

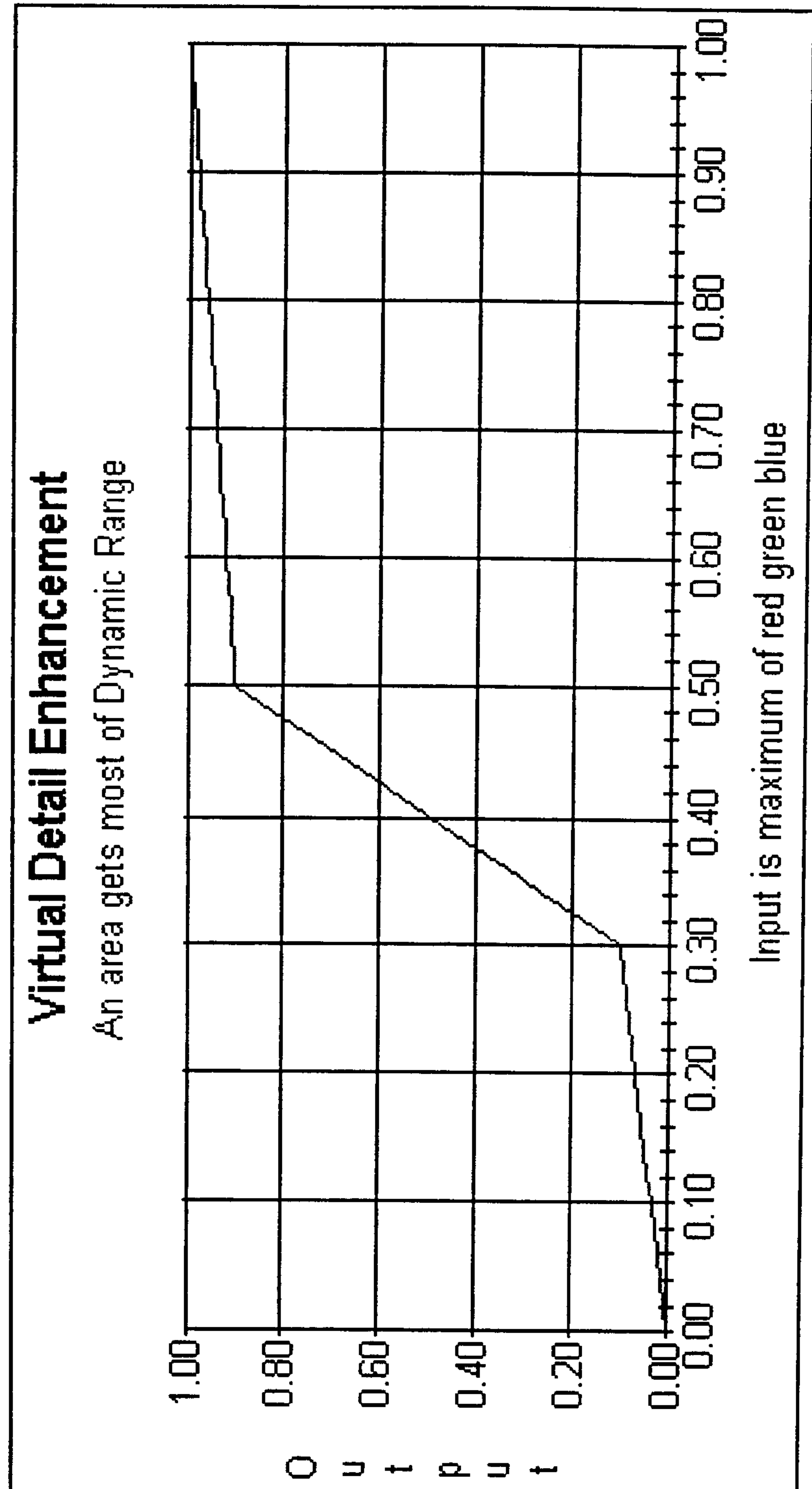
Fig. 2

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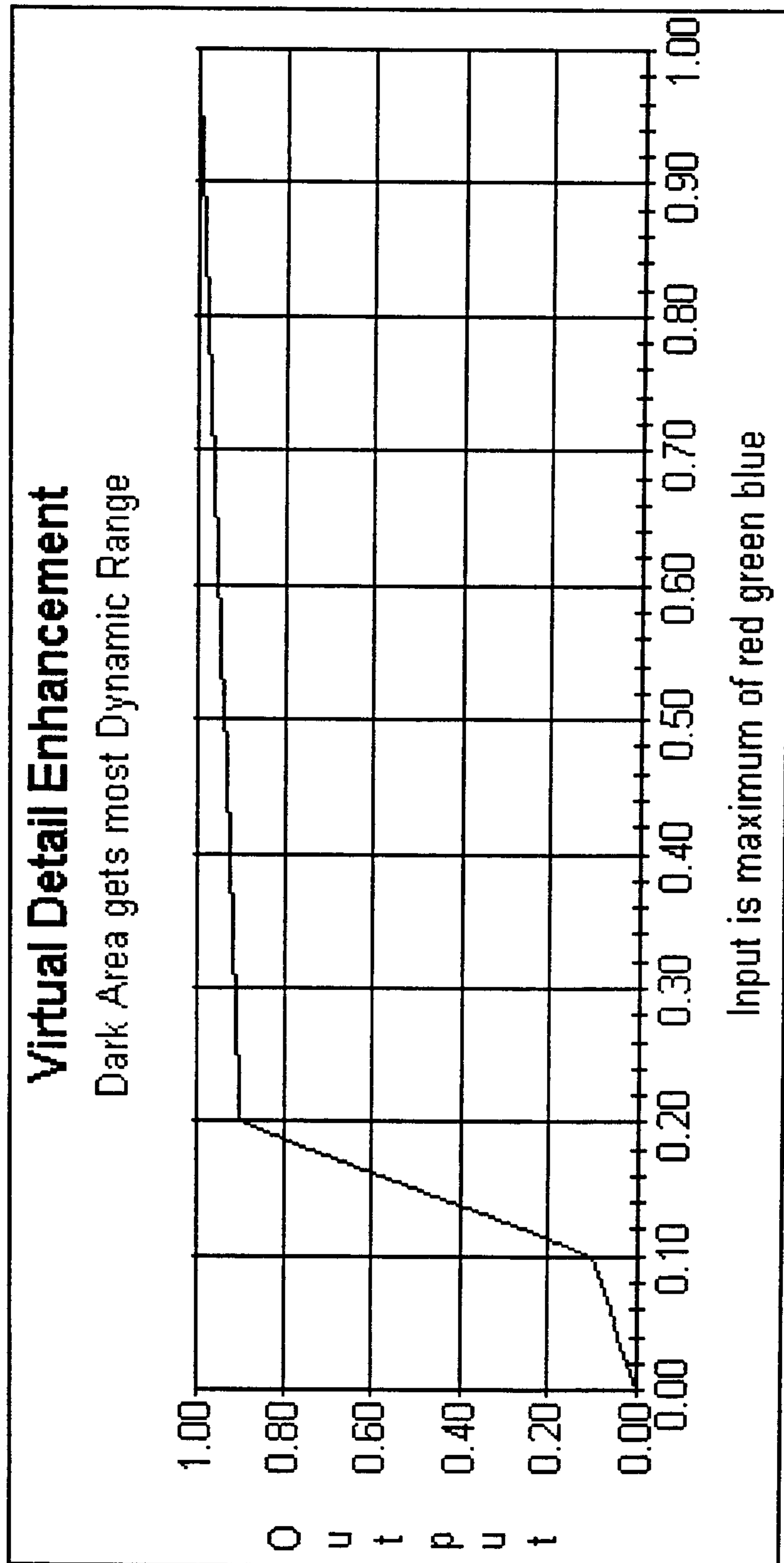
Fig. 3



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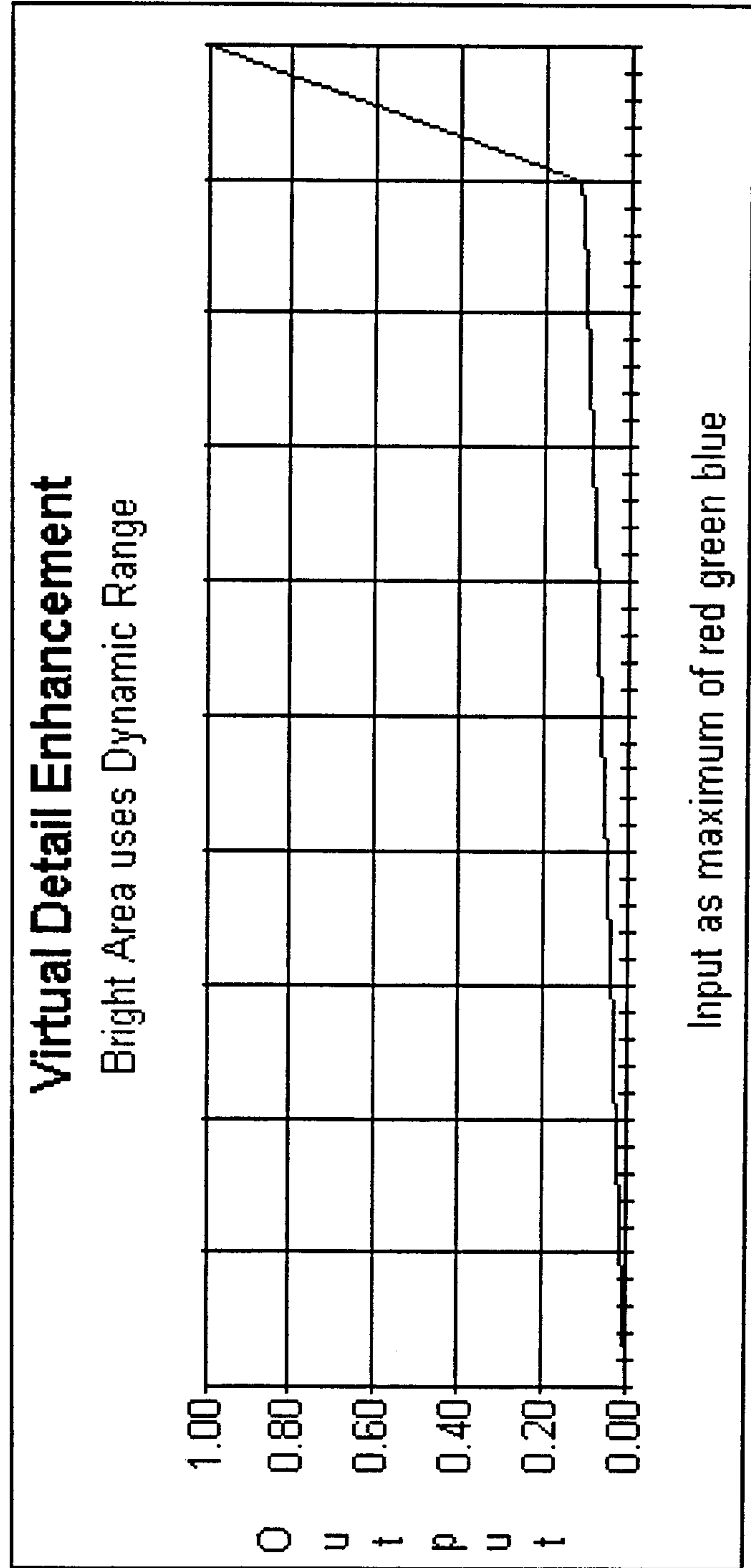
Fig. 4

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Fig. 5

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Fig. 6



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Assuming the area was selected so that xdown is less than xup

x1 = xdown +1

x2 = xup -1

y1 = ydown +1

y2 = yup -1

This Statement Ends the loop limit determination

For icol = x1 To x2

For irow = y1 to y2

The next 5 lines determine the color values (RGB)

color = pbox.Point(icol,irow)

blue = color / 65536

color = color mod 65536

green = color / 256

red = color mod 256

Find the dot Maximum

strength = red

If strength < green Then strength = green

If strength < blue Then strength = blue

The next line builds the histogram

hist(strength) = hist(strength) + 1

hist is an array (look up table) that stores the histogram counts

Next irow

Next icol

Find the minimum and maximum strengths, in some statistical sense, recorded stored in the histogram look up table (the array hist()). Creating a second look up table with the running totals of the histogram:

hsum(0) = hist(0)

hsum is the look up table used to hold the running total of the histogram

first (zeroth) running total is the first (zeroth) histogram element

For indx = 1 To drmx

indx is an index that runs from 1 (not 0) to the dynamic range maximum

hsum(indx) = hsum(indx - 1) + hist(indx)

the running total is calculated as previous running total plus next value

Next indx

Fig. 7a

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Code for histogram look-up table

hsum(0) = hist(0)

hsum is the look up table used to hold the running total of the histogram

first (zeroth) running total is the first (zeroth) histogram element

For indx = 1 To drmx

Indx is an index that runs from 1 (not 0) to the dynamic range maximum

hsum(indx) = hsum(indx - 1) + hist(indx)

the running total is calculated as previous running total plus next value

Next indx

p002 = 0.02 * hsum(drmx) wherein

result is 2% of the total count and hsum(drmx) is the last running total (the total) of the histogram counts

p098 = 0.98 * hsum(drmx)

result is 98% of the total count, The next step is to find the index values corresponding to the 2% and 98% occurrence in the histogram.

i002 = -1; i098 = -1

these variables will hold the indices at the 2% and 98% level, for now they are set to -1

For indx = 0 to drmx

the loop runs over all the strength values

if hsum(indx) < p002 then i002 = indx

when the running total is less than 2% total then store it (stop storing it when it is over 2%)

if hsum(indx) < p098 then i098 = indx

when the running total is less than 98% total then store it (stop storing it when it is over 98%)

Next indx

Now, the histogram minimum and maximum values are set with a check to ensure that they are reasonable.

hmin = i002 + 1

hmin is set to 2% level strength index + 1 for reasons of symmetry

If hmin < 1 then hmin = 1

hmin is forced to be no less than 1

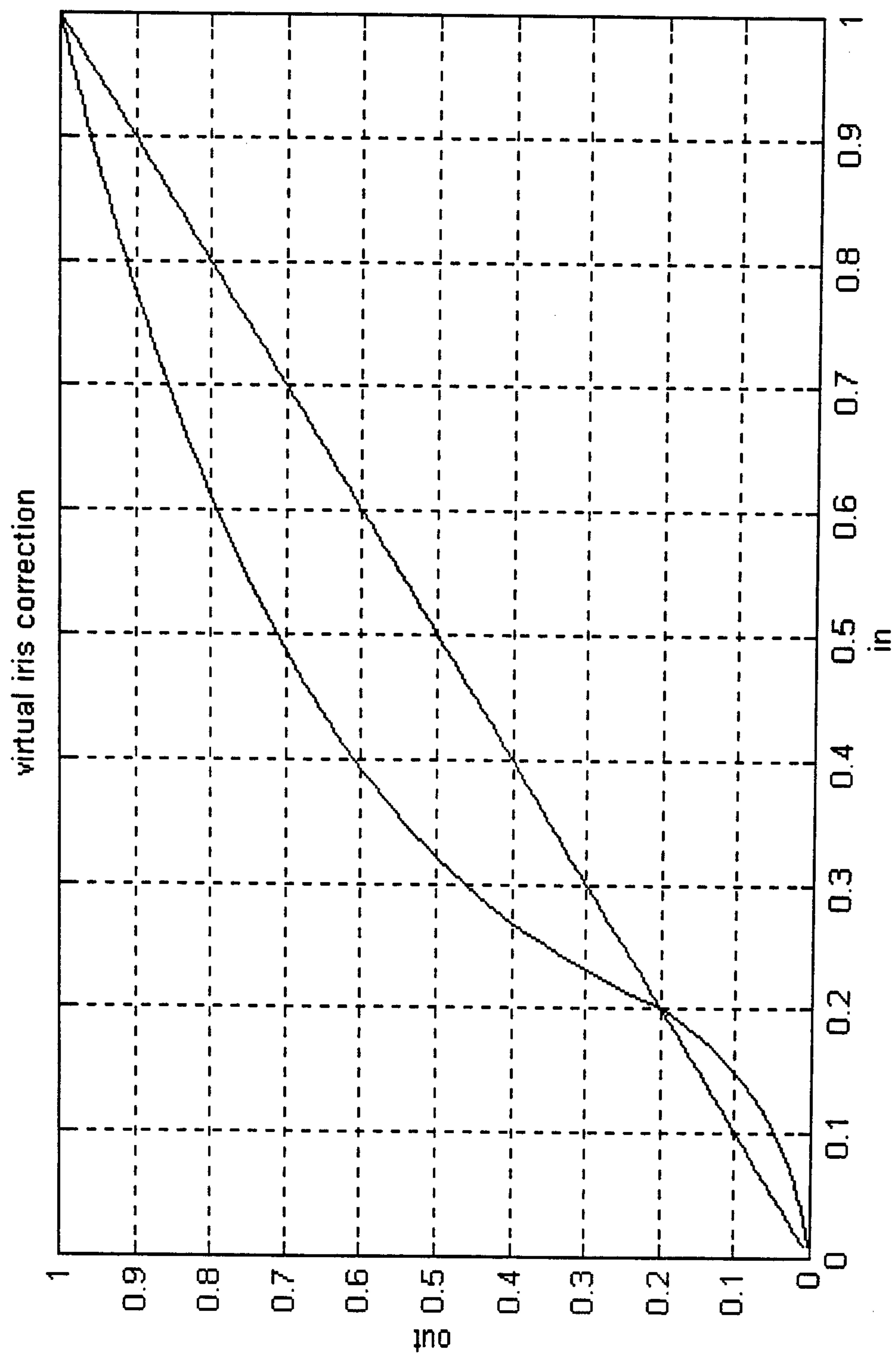
hmax = i098

hmax is set to 98% occurrence level of strength index

If hmax > drmx - 1 then hmax = drmx - 1

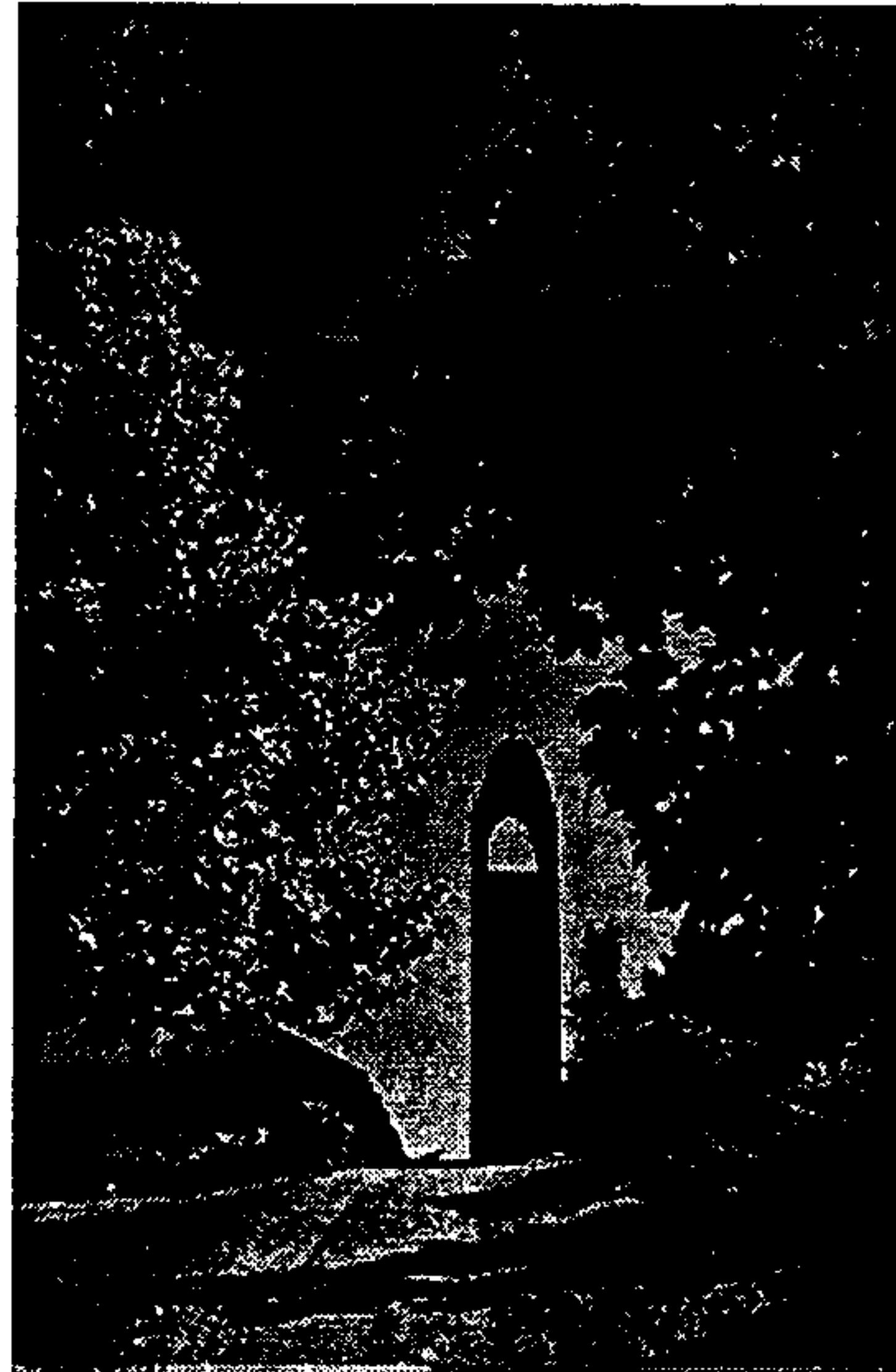
hmax is forced to be no more than dynamic range limit - 1 (254)

Fig. 7b

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Input Image

**Fig. 9b**

PRIOR ART

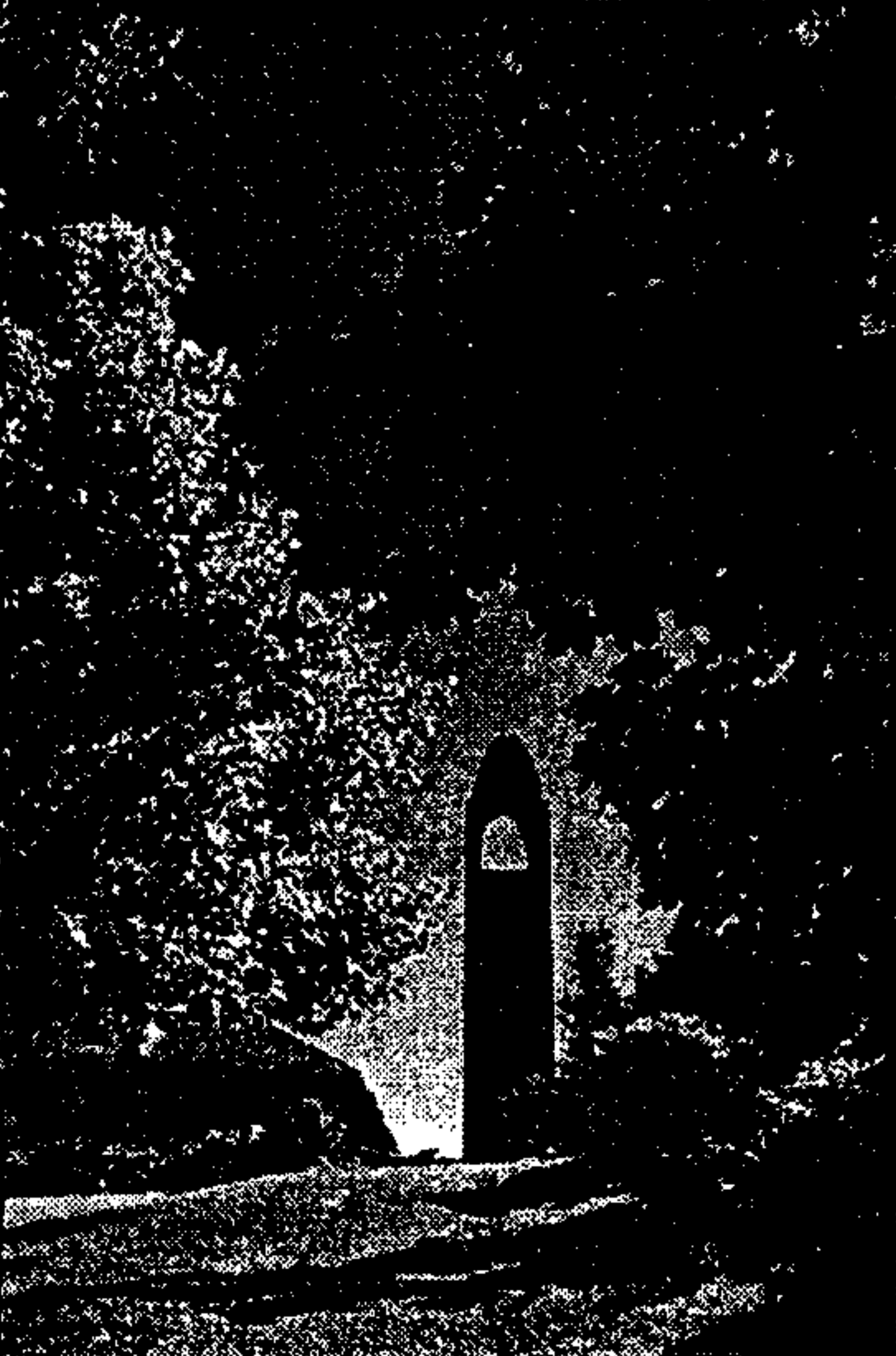
Brightened

**Fig. 9c**

PRIOR ART

Bright 80%
Contrast**Fig. 9d**

PRIOR ART

Bright 80%
Saturation**Fig. 9e**

Virtual Flash

Output Image
Full Dyn Range**Fig. 9f**

Virtual Flash

Output Image
Apply Fig. 8
curve

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Input Image

**Fig. 10b**PRIOR ART
Brightened**Fig. 10c**PRIOR ART
Bright 60%
Contrast**Fig. 10d**PRIOR ART
Bright 60%
Saturation 15%**Fig. 10e**

Virtual

Output Image
Full Dyn
Range**Fig. 10f**

Virtual Flash

Output Image
Apply Fig. 8
curve

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Fig. 11a

Input Image

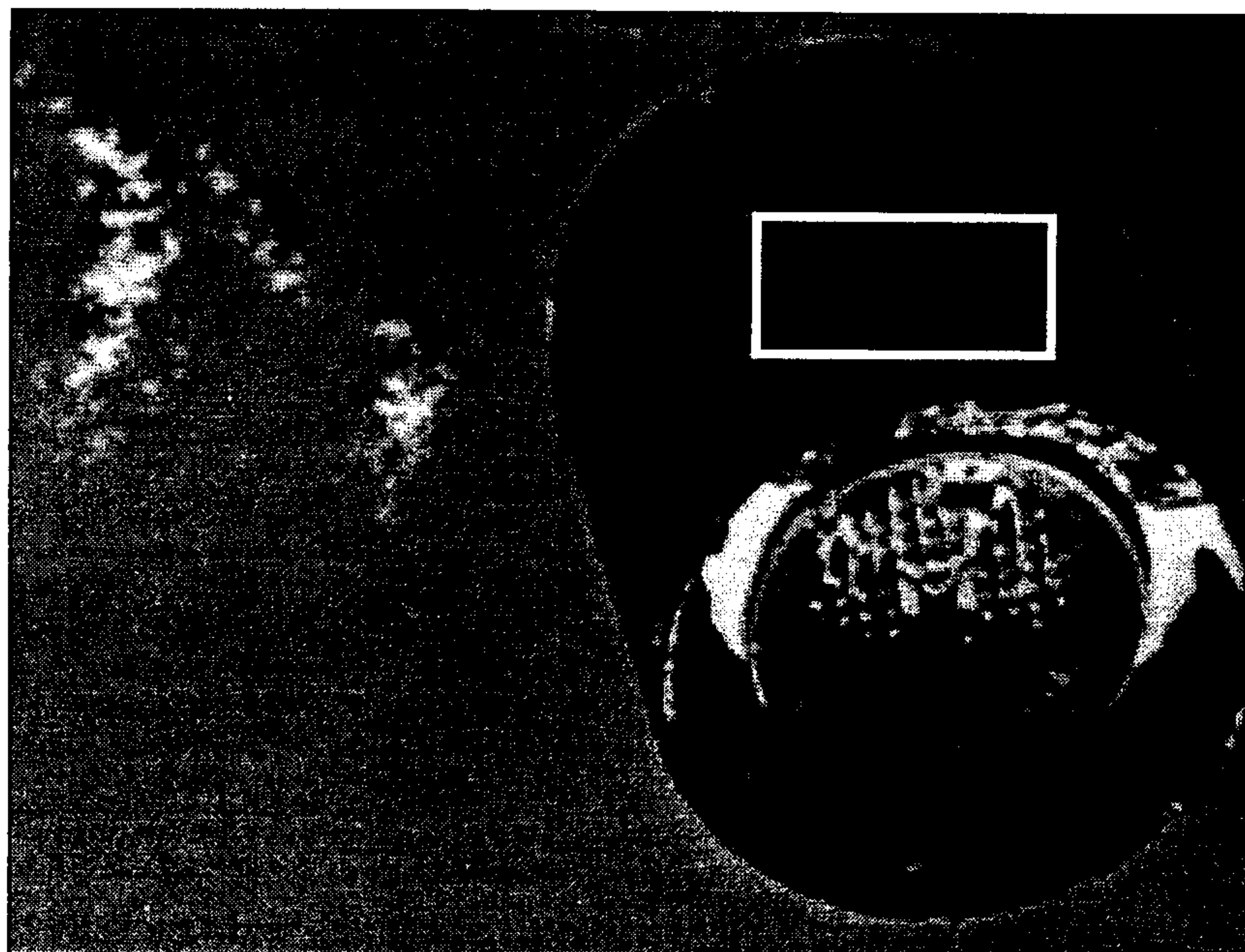
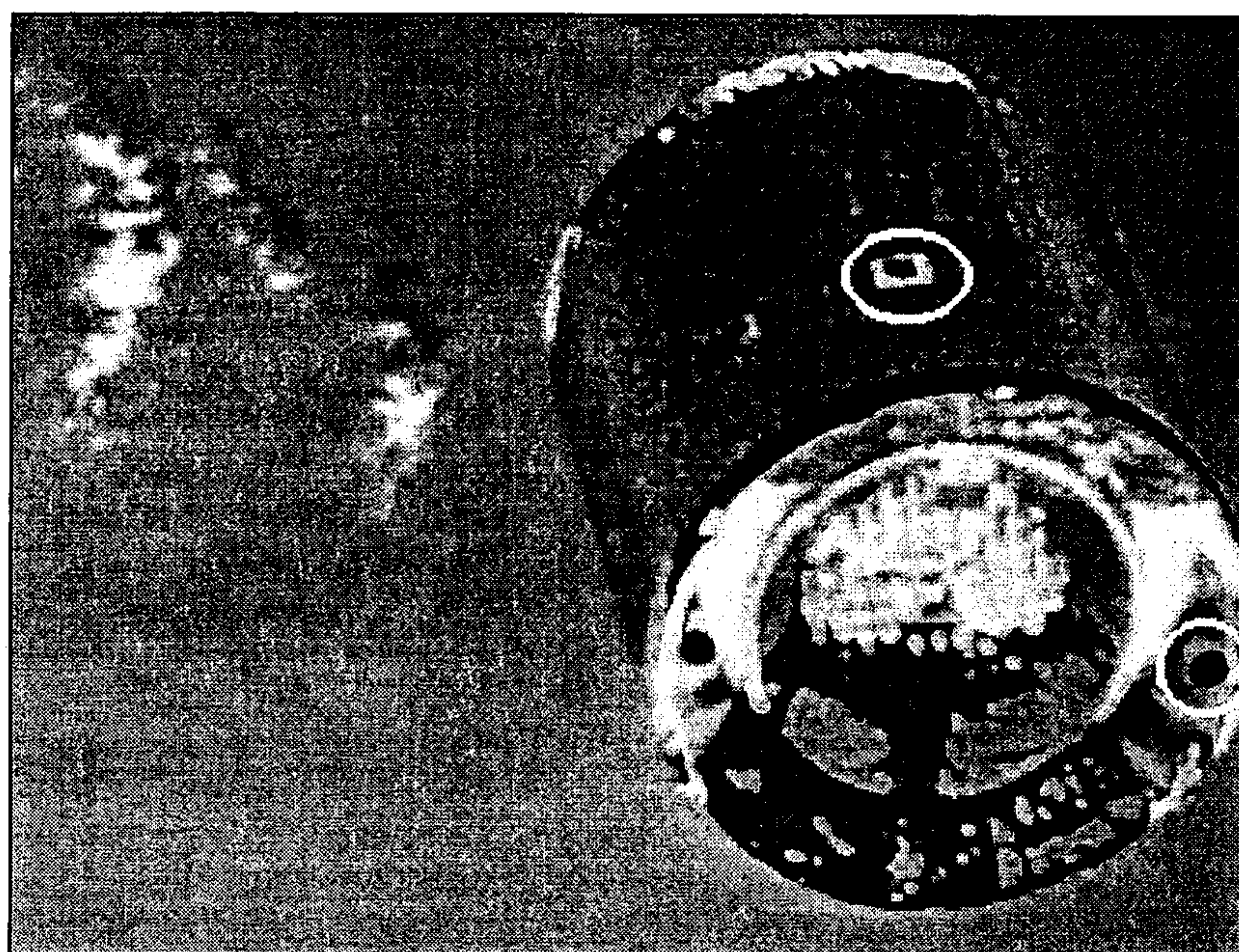


Fig. 11b

Forensic Flash
Output Image



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Fig. 12a

Input Image

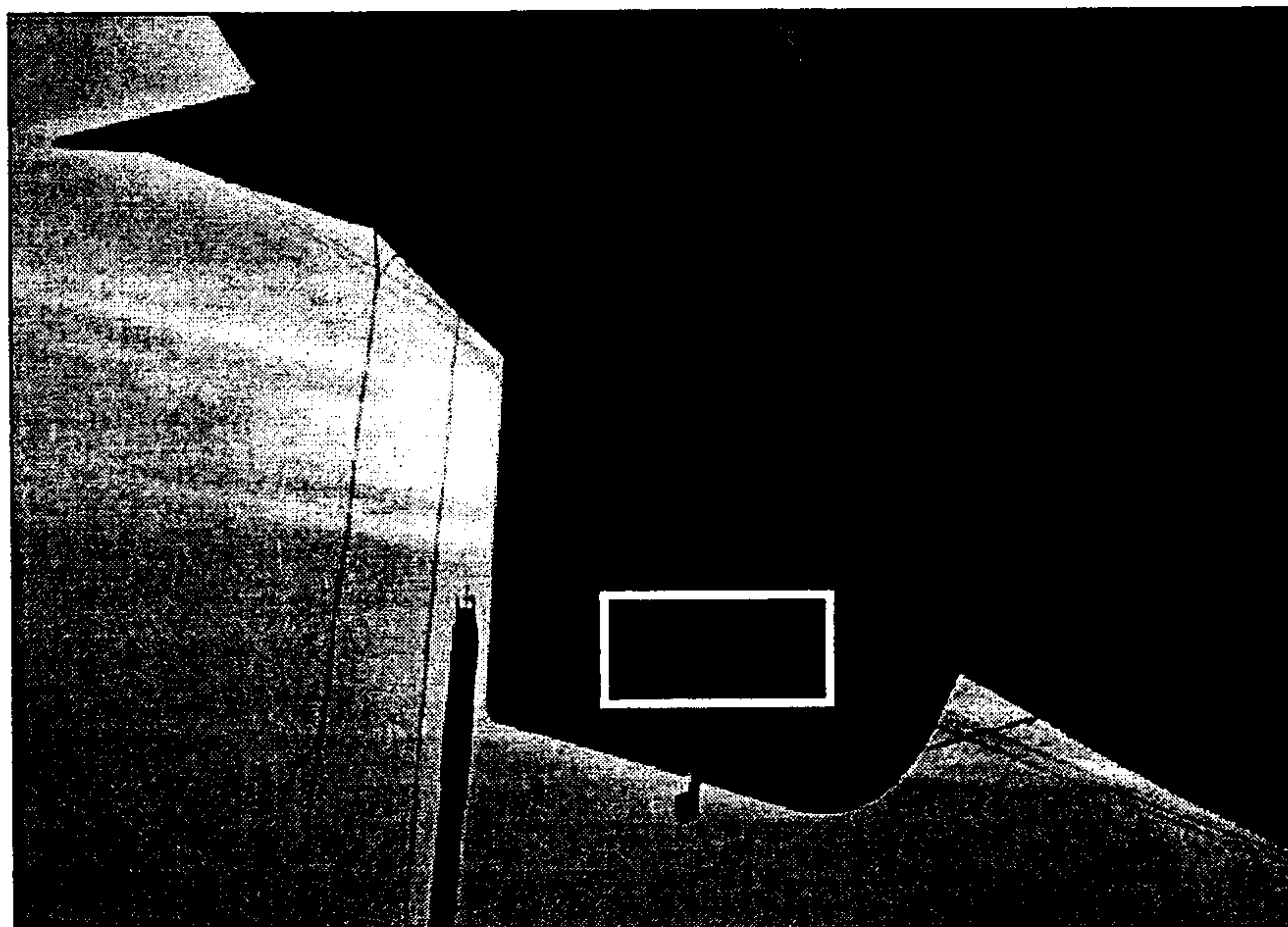
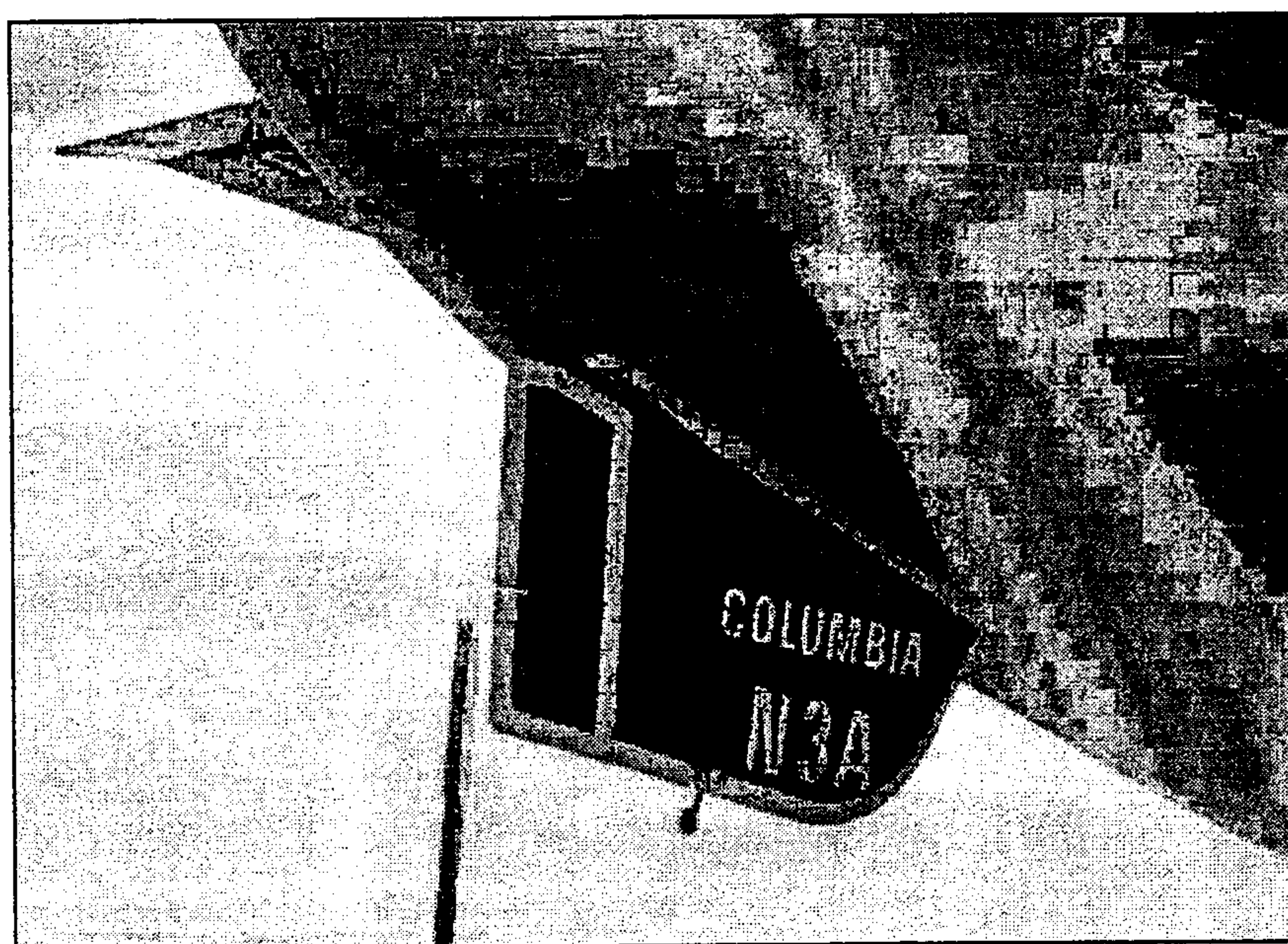


Fig. 12b

Forensic Flash
Output Image



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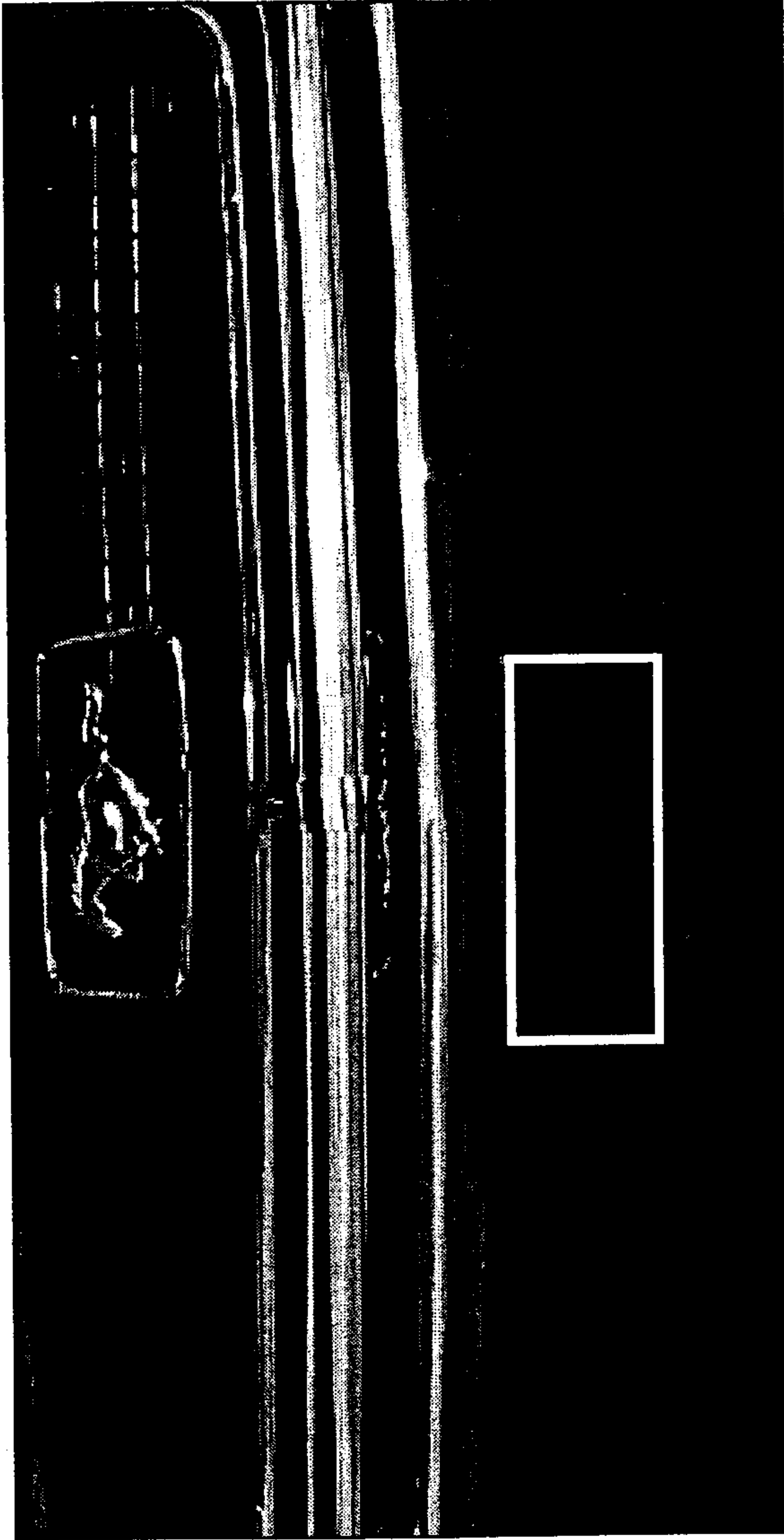


Fig. 13a
Input Image

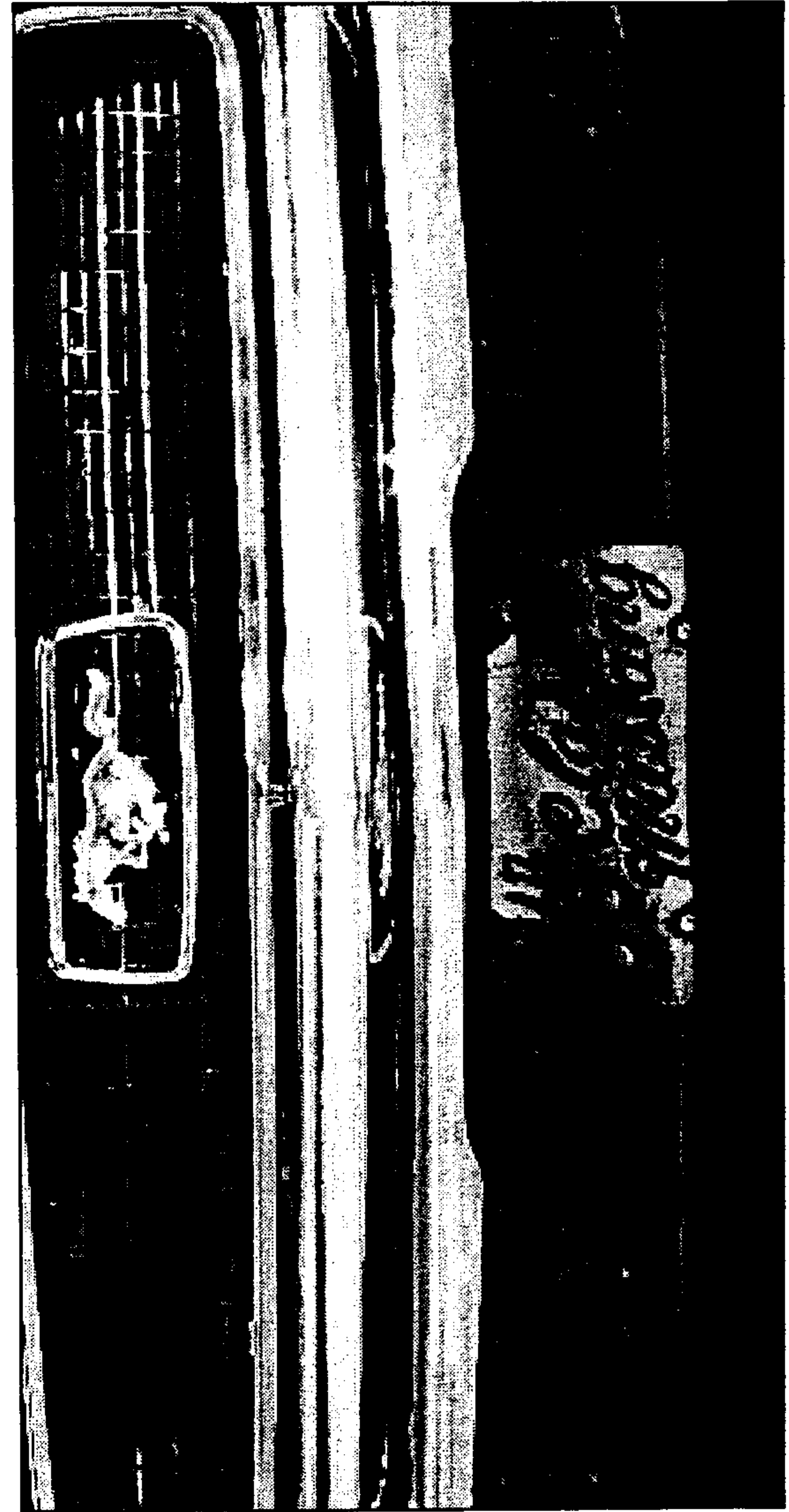


Fig. 13b
Forensic Flash
Output Image

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Fig. 14a

Input Image



Fig. 14b

Forensic Flash

Output Image
Pick Snow



Fig. 14c

Forensic Flash

Output Image
Pick Face



virtual iris correction

