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(54) **BI-ILLUMINANT DICHROMATIC REFLECTION MODEL FOR IMAGE MANIPULATION**
DICHROMATISCHES BI-BELEUCHTUNGSREFLEKTIONSMODELL ZUR BILDMANIPULATION
MODÈLE DE RÉFLEXION DICHROMATIQUE À BI-ILLUMINANT POUR MANIPULATION D'IMAGE

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(73) Proprietor: **Tandent Vision Science, Inc.**
San Francisco, California 94111 (US)

(72) Inventors:
• **MAXWELL, Bruce, Allen**
Benton ME 04901 (US)
• **FRIEDHOFF, Richard, Mark**
New York, NY 10019 (US)
• **SMITH, Casey, Arthur**
Ithaca, NY 14850 (US)

(74) Representative: **Reichert & Lindner**
Partnerschaft Patentanwälte
Bismarckplatz 8
93047 Regensburg (DE)

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- **TOMINAGA S ET AL: "ESTIMATING REFLECTION PARAMETERS FROM A SINGLE COLOR IMAGE" IEEE COMPUTER GRAPHICS AND APPLICATIONS, IEEE SERVICE CENTER, NEW YORK, NY, US LNKD-DOI:10.1109/38.865881, vol. 20, no. 5, 1 September 2000 (2000-09-01), pages 58-66, XP000958818 ISSN: 0272-1716**

DescriptionBackground of the Invention

5 **[0001]** Many significant and commercially important uses of modern computer technology relate to images. These include image processing, image analysis and computer vision applications. A challenge in the utilization of computers to accurately and correctly perform operations relating to images is the development of algorithms that truly reflect and represent physical phenomena occurring in the visual world. For example, the ability of a computer to correctly and accurately distinguish between a shadow and a material object edge within an image has been a persistent challenge to scientists. Edge detection is a fundamental task in image processing because without accurate and correct detection of the edges of physical objects, no other processing of the image is possible. If a cast shadow is indistinguishable from the object casting the shadow, it would not be possible for the computer to recognize the object.

10 **[0002]** An early and conventional approach to object edge detection involves an analysis of brightness boundaries in an image. In the analysis it is assumed that a boundary caused by a material object will be sharp, while a boundary caused by a shadow will be soft or gradual due to the penumbra effect of shadows. While this approach can be implemented by algorithms that can be accurately executed by a computer, the results will often be incorrect. In the real world there are many instances wherein shadows form sharp boundaries, and conversely, material object edges form soft boundaries. Thus, when utilizing conventional techniques for shadow and edge recognition, there are significant possibilities for false positives and false negatives for shadow recognition. That is, for example, a material edge that imitates a shadow and is thus identified incorrectly by a computer as a shadow or a sharp shadow boundary that is incorrectly interpreted as an object boundary.

15 **[0003]** Once shadows and object edges are identified, a typical computerized operation is manipulation of the image to, for example, remove shadows from the image. Most scenes depicted in an image have a dominant illuminant, defined as a direct or incident illuminant. The incident illuminant causes shadows. The component of radiance onto a surface in the scene that is not from the incident illuminant, is referred to as an indirect or ambient illuminant. It is the ambient illuminant that is present within a shadow. While much of the energy of the ambient illuminant may come from the incident illuminant, it has generally interacted with the environment.

20 **[0004]** Typical solutions for manipulating images focus on the incident illuminant. Models have been developed for computerized image pixel manipulation based upon the assumption that the ambient illumination has the same spectral characteristics as the incident illumination or is non-existent. One such known solution is the dichromatic reflection model, which describes the variations in appearance caused by the combination of body and surface reflection on a material. Body reflection is what is normally considered the color of the material. The surface reflection is referred to as a highlight or specularly of the material reflecting the illuminant. The known dichromatic reflection model assumes a single incident illuminant and does not account for a non-zero ambient illuminant. Thus, results of image manipulation based upon the dichromatic reflection model are often not color correct.

25 **[0005]** Other useful solutions include color spaces such as hue and chromaticity, and other normalized color spaces that attempt to factor out the effect of changing the intensity of the incident illuminant on the intensity of the reflection from a surface. However, these color models have met with limited success in solving practical vision problems. Consequently, there is a growing realization that simple models of illumination do not correctly reflect the visual world, and thus, do not provide color correct manipulations. Recent research has focused upon empirical models of color change over a single material. This approach is not restricted by any prior assumptions about the behavior of illumination color or reflectance.

30 **[0006]** There is also significant amount of research attempting to determine the complete illumination environment. These methods are based upon multiple images of the same scene and/or knowledge of the scene geometry. In one research project, the existence and importance of complex indirect illumination is acknowledged. However, the method requires both a known geometry of a scene and two images. While these research efforts approach a solution that can extract and represent illumination environments of significant complexity, they cannot be used in environments such as, for example, consumer photography, or with existing photos or in any situation where either taking multiple images of a scene from different points of view or inserting objects into a scene are not readily possible or are unreasonable.

35 **[0007]** The article "Ambient illumination and the determination of material changes" by Ron Gershon, Allan D. Jepson, and John K. Tsotsos, in J. Opt. Soc. Am. A/Vol. 3, No 10/October 1986, pp. 1700-1707, quantifies effects of ambient illumination by a pull factor, which essentially is the inner product between the color vector of reflected light due to ambient illumination and a vector orthogonal to the color vector of the reflected light due to illumination, normalized by the magnitude of the color vector of the reflected light due to the direct illumination.

Summary of the Invention

40 **[0008]** The present invention provides a bi-illuminant dichromatic reflection model (BIDR model) as a representation

of an image to facilitate color correct image manipulation.

[0009] In a first exemplary embodiment of the present invention, an automated, computerized method for manipulating an image comprises the steps of manipulating the image to provide an intensity adjusted image according to the steps of independent claim 1.

5 [0010] In a second exemplary embodiment of the present invention, a computer system comprises a CPU and a memory storing an image file. According to a feature of the present invention, the CPU is arranged and configured to execute a routine to manipulate the image to provide an intensity adjusted image according to independent claim 14.

10 [0011] In accordance with yet further embodiments of the present invention, computer systems are provided, which include one or more computers configured (e.g., programmed) to perform the methods described above. In accordance with other embodiments of the present invention, computer readable media are provided which have stored thereon computer executable process steps operable to control a computer(s) to implement the embodiments described above. The automated, computerized methods can be performed by a digital computer, analog computer, optical sensor, state machine, sequencer or any device or apparatus that can be designed or programed to carry out the steps of the methods of the present invention.

15 Brief Description of the Drawings

[0012]

20 Figure 1 is a block diagram of a computer system arranged and configured to perform operations related to images.

Figure 2 shows an n X m pixel array image file for an image stored in the computer system of figure 1.

25 Figure 3 is a flow chart for modifying a shadow in an image with a manual input, according to a feature of the present invention.

30 Figure 4 is a graph in RGB color space showing colors for a material, from a fully shaded color value to a fully lit color value, as determined by execution of a simplified bi-illuminant dichromatic reflection model according to a feature of the present invention.

35 Figures 5a & b are graphs in RGB color space showing colors for a material, from a fully shaded color value to a fully lit color value, with error bounds forming a cylinder, as determined by execution of the bi-illuminant dichromatic reflection model according to a feature of the present invention.

40 Figure 6a is a flow chart for a color correct brightness adjustment to an intensity adjusted image, according to a feature of the present invention.

45 Figure 6b is a graph in RGB space showing an intensity adjusted pixel value for the intensity adjusted image of figure 6a.

50 Figure 6c is a flow chart for estimating a gamma (γ) value for the pixel of figure 6b using a dynamic range compression algorithm.

55 Figure 7 is a flow chart for removing direct or incident illumination from an image area, according to a feature of the present invention.

Figure 8 is a flow chart for modifying apparent ambient illumination of an image area, according to a feature of the present invention.

Figure 9 is a flow chart for modifying apparent direct or incident illumination of an image area, according to a feature of the present invention.

Figure 10 is a flow chart for modifying apparent level of direct or incident illumination of an image area, according to a feature of the present invention.

Figure 11 is a graph in RGB space showing a color correct gamma correction, according to a feature of the present invention.

Figure 12 is a flow chart for a color correct gamma correction, as shown in figure 11.

Detailed Description of the Preferred Embodiments

5 **[0013]** Referring now to the drawings, and initially to figure 1, there is shown a block diagram of a computer system 10 arranged and configured to perform operations related to images. A CPU 12 is coupled to a device such as, for example, a digital camera 14 via, for example, a USB port. The digital camera 14 operates to download images stored locally on the camera 14, to the CPU 12. The CPU 12 stores the downloaded images in a memory 16 as image files 18. The image files 18 can be accessed by the CPU 12 for display on a monitor 20, or for print out on a printer 22.

10 **[0014]** Alternatively, the CPU can be implemented as a microprocessor embedded in a device such as, for example, the digital camera 14 or a robot. The CPU can also be equipped with a real time operating system for real time operations relating to images, for example, in connection with a robotic operation or an interactive operation with a user.

15 **[0015]** As shown in figure 2, each image file 18 comprises an $n \times m$ pixel array. Each pixel, p , is a picture element corresponding to a discrete portion of the overall image. All of the pixels together define the image represented by the image file 18. Each pixel comprises a digital value corresponding to a set of color bands, for example, red, green and blue color components (RGB) of the picture element. The present invention is applicable to any multi-band image, where each band corresponds to a piece of the electro-magnetic spectrum. The present invention can also be utilized in connection with a grayscale image (a single band). The pixel array includes m columns of n rows each, starting with the pixel $p(1,1)$ and ending with the pixel $p(n, m)$. When displaying or printing an image, the CPU 12 retrieves the corresponding image file 18 from the memory 16, and operates the monitor 20 or printer 22, as the case may be, as a function of the digital values of the pixels in the image file 18, as is generally known.

20 **[0016]** In an image operation, the CPU 12 operates to analyze the RGB values of the pixels of a stored image file 18 to achieve various objectives, such as, for example, manipulation of the image to modify a shadow or to make a color correct brightness adjustment. A fundamental observation underlying a basic discovery of the present invention, is that an image comprises two components, material and illumination. All changes in an image are caused by one or the other of these components.

25 **[0017]** In a first exemplary embodiment of the present invention, shadowed and fully lit regions of an image are manually selected by a user. What is visible to the human eye upon display on the monitor 20 of a stored image file 18 by the CPU 12, is the pixel color values caused by the interaction between specular and body reflection properties of material objects in, for example, a scene photographed by the digital camera 14 and illumination flux present at the time the photograph was taken. As noted above, the illumination flux comprises an ambient illuminant and an incident illuminant. The incident illuminant is light that causes a shadow and is found outside a shadow perimeter. The ambient illuminant is light present on both the bright and dark sides of a shadow, but is more perceptible within the dark region.

30 **[0018]** Figure 3 is a flow chart for modifying a shadow in an image with a manual input, according to a feature of the present invention. In two input steps the user selects a point or region on a fully lit (Bright) material of an image 18 selected by the user (step 100) and a point or region on a fully shadowed (Dark) part of the same material in the same image 18 (step 102). These steps 100, 102 can be implemented by an interactive clicking by the user on the monitor 20 operating to display the subject image file 18. A user can select such regions because human eye physiology is capable of distinguishing between shadows and actual physical objects.

35 **[0019]** In step 104, the CPU 12 operates on the user input selections to calculate a spectral ratio, $S = \text{Dark}/(\text{Bright} - \text{Dark})$, where Dark, for example, is a pixel in the fully shadowed material of the region selected by the user, and Bright is a pixel in the fully lit portion of that material selected by the user. A normalized version of the spectral ratio can be used in the methods according to the present invention. According to a feature of the present invention, the spectral ratio is used to manipulate pixel values for a color correct adjustment. Based upon the fundamental observation of the present invention that an image comprises two components, material and illumination, the computer system 10 can be operated to differentiate between material aspects and illumination flux through recognition of a spectral shift caused by the interplay between the incident or direct illuminant and the ambient illuminant. When one of material and illumination is known in an image, the other can be readily deduced. The spectrum for the incident illuminant and the ambient illuminant can be different from one another. A spectral shift caused by a shadow, i.e., a decrease of the intensity of the incident illuminant, will be substantially invariant over different materials present in a scene depicted in an image.

40 **[0020]** Pursuant to a feature of the present invention, this spectral shift information is detected by determination of an illuminant ratio, or a characteristic spectral ratio formed by the interplay of the incident illuminant and the ambient illuminant. A spectral ratio is a ratio based upon a difference in color or intensities between two areas of a scene depicted in an image, which may be caused by different materials, an illumination change or both.

45 **[0021]** An automated, computerized method for determining a characteristic spectral or illuminant ratio due to illumination flux, for an image, is disclosed in co-pending U.S. Application Serial No. 11/341,742, filed on January 27, 2006, entitled: "Method and System For Identifying Illumination Flux In An Image". As disclosed in the co-pending U.S. Application Serial No. 11/341,742, to improve the accuracy and correctness of the characteristic ratio for an image, the spectral

ratio information for illumination boundaries is determined on a local level, that is, an illuminant ratio is determined for each of several preselected local areas of a scene depicted in an image. An analysis of a boundary is then executed utilizing the spectral ratio for the specific location of the boundary within the image. The determination of locally relevant spectral ratios accommodates complexities that may be encountered in a real world image, for example, the interplay of several different sources of light in a room, inter-reflections, and so on.

[0022] In order to facilitate an accurate and correct manipulation of pixel values, to modify, for example, the pixel from a shaded color (Dark) to a correct fully lit color (Bright), the present invention recognizes the characteristic spectral ratio (illuminant ratio) as an analytical representation of image properties and characteristics pursuant to a bi-illuminant dichromatic reflection model. The bi-illuminant dichromatic reflection model (BIDR) combines terms relevant to the ambient illuminant with the dichromatic reflection model described above. The two illuminants of the BIDR model correspond to the incident illuminant and the ambient illuminant. The BIDR model can be stated as follow:

$$I(x, y, z, \theta, \phi, \lambda) = [m_b(\theta_i) c_b(\lambda) + m_s(\theta_i, \phi_i, \theta_e, \phi_e) c_s(\lambda)] I_d(\lambda) + M_a(\lambda) c_b(\lambda) + M_{as}(\theta_e, \phi_e, \lambda) c_s(\lambda),$$

where: $I_{(x, y, z, \theta, \phi, \lambda)}$ is the radiance of a surface point at (x, y, z) in the direction θ, ϕ , for the wavelength λ , $m_b(\theta_i)$ is the spectrum independent body reflectance based on geometric factors,

$c_b(\lambda)$ is the geometry independent body reflectance of a surface for the wavelength λ , $m_s(\theta_i, \phi_i, \theta_e, \phi_e)$ is the spectrum independent surface reflectance based on geometric factors,

$c_s(\lambda)$ is the geometry independent surface reflectance of a surface for the wavelength λ , $I_d(\lambda)$ is the incident illuminant for the wavelength λ .

θ_i is the incident tilt angle of the illuminant onto a surface relative to the surface normal.

ϕ_i is the incident pan angle: the angle between the incident illuminant and a fixed axis on the tangent plane of a surface.

θ_e is the exitent tilt angle: the angle of an outgoing ray relative to the surface normal.

ϕ_e is the exitent pan angle: the angle between an outgoing ray and a fixed axis on the tangent plane of a surface.

All of the above terms comprise the dichromatic reflection model. The remaining terms of the BIDR model relate to the ambient illuminant, where:

$M_a(\lambda)$ is the integral of the ambient illuminant and geometric body reflectance over a hemisphere, excluding the incident illuminant, and

$M_{as}(\theta_e, \phi_e, \lambda)$ is the integral of the ambient illuminant and geometric surface reflectance over the hemisphere, excluding the incident illuminant.

[0023] In the dichromatic reflection model, the radiance, $I_{(x, y, z, \theta, \phi, \lambda)}$, for a surface at a point viewed from the orientation by θ, ϕ is expressed as the sum of two bipartite terms multiplied by the illumination intensity and color $I_d(\lambda)$ to reflect the effect of the incident illuminant. The first reflectance term explains body reflection. $m_b(\theta_i)$ is the amount of incident illuminant energy reflected by the body reflection, referred to as diffuse reflection, as a function of the geometric relationship of the light source and the surface, expressed by the incident angle θ_i . $c_b(\lambda)$ is the fraction of the incident illuminant energy reflected by the body reflection for each wavelength λ and describes what is considered the body color. The second reflection term explains surface reflection. $m_s(\theta_i, \phi_i, \theta_e, \phi_e)$ is the amount of the incident energy reflected by the surface reflection as a function of the geometry as expressed by the incident angles θ_i, ϕ_i and exit angles θ_e, ϕ_e . $c_s(\lambda)$ is the fraction of the incident energy reflected by the surface reflection for each wavelength λ . The power of the dichromatic reflection model is that the model predicts that the appearance, or color, of a uniform color dielectric surface under a single incident illuminant falls within a plane defined by the two color vectors c_b and c_s in RGB space, even with variation in the amount of incident illuminant and specularities on the surface.

[0024] According to a feature of the present invention, the BIDR model adds body and surface reflection terms for the ambient illuminant, which, as noted above may have a significantly different spectrum from the incident illuminant. Unlike the incident illuminant, the ambient illuminant is radiated from the whole hemisphere visible from the surface point.

[0025] Thus, $M_a(\lambda)$ is the integral of the ambient body reflection: $\int m_b(\theta_i) I_a(\theta_i, \phi_i, \lambda) d\theta_i d\phi_i$.

[0026] $M_{as}(\theta_e, \phi_e, \lambda)$: $\int m_s(\theta_i, \phi_i, \theta_e, \phi_e) I_a(\theta_i, \phi_i, \lambda) d\theta_i d\phi_i$. This function represents the integral of the ambient illuminant and geometric surface reflectance over the hemisphere, excluding the incident illuminant.

[0027] The above functions are an integration of all incoming illumination other than incident illuminant, as integrated over $\theta_i, \phi_i \neq \theta_L, \phi_L$. (incident illuminant). The BIDR model according to the present invention can accurately and correctly accommodate and predict tremendous complexity in the appearance of a surface, even a surface of uniform material. If, for example, the ambient environment is both bright and changes quickly across a surface, the ambient illuminant

terms can cause deviations from the plane predicted by the dichromatic reflection model. Indeed, unlike the dichromatic reflection model, the BIDR model according to the present invention predicts a plane in the RGB space that does not necessarily pass through the zero point of the space, but in fact most often exhibits an offset from the zero point that comprises the color of the ambient illumination multiplied by the object color. The offset results in color correct changes when a pixel value is manipulated using the BIDR model of the present invention.

[0028] Given that the ambient illuminant is often an order of magnitude or more than the incident illuminant, the ambient specularly or body surface reflectance $M_{as}(\theta_e, \phi_e, \lambda)$ term has a minimal effect on the appearance of a surface and can be discarded without significantly affecting the quality of the model. The BIDR model then reduces to three terms:

$$I(x, y, z, \theta, \phi, \lambda) = [mb(\theta_i) c_b(\lambda) + m_s(\theta_i, \phi_i, \theta_e, \phi_e) c_s(\lambda)] I_d(\lambda) + M_a(\lambda) c_b(\lambda).$$

[0029] Inasmuch as the appearance of cast shadows on a surface is also relevant to the uses of the BIDR model, a shadow term or factor $s_{x, y, z} \in [0,1]$ can be added to multiply the incident illuminant term:

$$I(x, y, z, \theta, \phi, \lambda) = [mb(\theta_i) c_b(\lambda) + m_s(\theta_i, \phi_i, \theta_e, \phi_e) c_s(\lambda)] I_d(\lambda) s_{x, y, z} + M_a(\lambda) c_b(\lambda).$$

[0030] A fully lit pixel will have a shadow factor, $s = 1$, and a fully shadowed pixel will have an $s = 0$, with the only remaining term in the model at $s = 0$ being the ambient body reflection. The model can be restated by substituting γ_b , the product of the shadow factor $s_{x, y, z}$ and the geometric factor $mb(\theta_i)$, for those non-spectral factors in the body reflection, and γ_s , the product of the shadow factor $s_{x, y, z}$ and the geometric factor $m_s(\theta_i, \phi_i, \theta_e, \phi_e)$, for those non-spectral factors in the surface reflection. The BIDR model is thus restated as: $I_{(x, y, z, \theta, \phi, \lambda)} = c_b(\lambda) I_d(\lambda) \gamma_b + c_s(\lambda) I_d(\lambda) \gamma_s + M_a(\lambda) c_b(\lambda)$.

[0031] In the absence of specularities in a material, the second term of the BIDR model, $c_s(\lambda) I_d(\lambda) \gamma_s$, is zero, and the measured values of a surface will exist on a single theoretical line in, for example, RGB space. With no specularly term, the BIDR model is given by: $I_{(x, y, z, \theta, \phi, \lambda)} = c_b(\lambda) I_d(\lambda) \gamma_b + M_a(\lambda) c_b(\lambda)$. Figure 4 shows a graph in RGB color space for colors for a material, from a fully shaded color value to a fully lit color value, as determined by execution of a simplified bi-illuminant dichromatic reflection model from $\gamma_b = 0$ to $\gamma_b = 1$, according to a feature of the present invention. As shown in figure 4, the model predicts that all of the measured colors of a particular material in shadow, light and penumbra extend along a line in RGB space (the cube shown in figure 4). An adjustment to a pixel value along a line predicted according to the BIDR model yields a color correct result. For a further discussion regarding the generation of BIDR cylinder representations of an image, reference should be made to co-pending U.S. Application Serial No. 11/341,753, filed January 27, 2006, entitled "Method And System For Identifying Illumination Fields In an Image".

[0032] In practice, a camera or other sensor used to record an image typically has noise, and no material in an image is of a completely uniform color. Accordingly, the appearance values of the surface fall within a cylinder having a width determined by variation in material and imaging sensor noise characteristics. The cylinder representing body reflection, according to the incident and ambient illuminants considered in the BIDR model of the present invention, has a unique starting place for every intrinsic color in the scene. The starting point is determined by the product of the ambient illumination and the body color, and the slope of the cylinder in RGB space is determined by the product of the incident illumination and the body color.

[0033] Figures 5a & b are graphs in RGB color space showing colors for a material, from a fully shaded color value to a fully lit color value, with error bounds forming a cylinder. In figure 5a, a cylinder is shown around the RGB line predicted by the BIDR model (a BIDR cylinder), with the dimensions of the cylinder diameter being a function of the noise of the recording device used to record the image, and variations.

[0034] Figure 5b, illustrates a cone shaped BIDR cylinder in recognition that the same absolute distance at the fully shadowed end represents a greater actual color difference than the same absolute distance from the line at the fully lit end of the line. This is due to the fact that the magnitude of the color band intensities at the shadow end are a greater percentage of the actual distance from the line in the shadow end than at the lit end. For example, consider a color at the shadow end of the cylinder of (RGB) = (5, 6, 8) and a color at the lit end of (100, 120, 160). If the CPU 12 modifies the color value for each 10 units toward the color red from both color values, the result is a shadow color value of (15, 6, 8) and a lit color of (110, 120, 160). At the dark end, the color shifted from a distinctly blue color to a distinctly red color, while at the lit end the color remains blue. In order to compensate for the difference, an adjustment is made to the cylinder to be narrower at the shadow end and wider at the lit end such that a same magnitude of color change will have a correspondingly accurate absolute distance from the line.

[0035] When stating the spectral ratio, $S = \text{Dark}/(\text{Bright-Dark})$, in terms of the BIDR model, $S = M_a(\lambda) c_b(\lambda) / [c_b(\lambda)$

$I_d(\lambda) \gamma_b + M_a(\lambda) c_b(\lambda) - M_a(\lambda) c_b(\lambda)$). This equation reduces to $S = M_a(\lambda) / I_d(\lambda) \gamma_b$. Inasmuch as γ_b is scalar, the relative proportions of different color bands in the spectral ratio, for example, RGB values, are constant. Thus, for a given pair of direct and ambient illuminants in an image, the normalized spectral ratio is constant for all Bright and Dark pairs that correspond to the same material when Dark is assumed to have a $\gamma_b = 0$, and the Bright is receiving some incident illuminant. The spectral ratio is therefore a representation of image properties and characteristics that, according to the BIDR model, can be utilized as a basis for manipulation of pixel values for a color correct adjustment, for example, as a prediction of color adjustments that fall within a color correct cylinder in RGB space, as illustrated in figure 5b.

[0036] In addition, the BIDR model can be used as a basis for representing pixel values. Rather than an RGB value, each pixel is represented by a BIDR cylinder in RGB space and a γ value, to indicate where in a specific BIDR cylinder, for example, the cylinder of figure 5b, the color of a specific pixel is located. Moreover, a spectral ratio based upon the Dark and Bright pixels of a specific BIDR cylinder can be calculated as a local characteristic or illuminant ratio for the image, as discussed above. The BIDR cylinder/ γ /spectral ratio representation for a pixel provides a comprehensive and unique form of pixel representation that permits color correct manipulations of the pixel.

[0037] In step 106, the user selects an area from within the regions provided by the user in steps 100, 102, to be manipulated or corrected, and the degree of adjustment. The degree of adjustment is reflected in the value of γ_b , with, for example, $\gamma_b = 0.5$ being selected if the user desired a half-shadow. In step 108, the CPU 12 uses the spectral ratio calculated in step 104 to adjust the intensity and color of the selected region to achieve the degree of adjustment selected by the user.

[0038] Figure 10 is a flow chart for modifying apparent level of direct or incident illumination of an image area, according to a feature of the present invention. The flow chart of figure 10 can be utilized to carry out step 108 of figure 3. In the routine of figure 10, the CPU 12 is given, in addition to the spectral ratio calculated by the CPU 12 from Dark, for example, a pixel in the fully shadowed material of the region selected by the user, and Bright, a pixel in the fully lit portion of that material selected by the user (step 104), the set of pixels comprising the area selected by the user (step 106), a gamma (γ) map for the set of pixels, and a new gamma map set at a level corresponding to the degree of adjustment selected by the user, for example, a $\gamma_b = 0.5$ if the user desired a half-shadow (step 114).

[0039] A method for generating an approximate gamma map for the pixels of the image can comprise a dynamic range compression algorithm as an input. Examples of such algorithms include a Retinex based algorithm, marketed by Hewlett-Packard or a gamma correction algorithm, an industry standard image compression algorithm. Note that a gamma correction process is distinct from a gamma map that indicates a gamma (γ corresponding to γ_b of the BIDR model representation). For a further discussion of gamma map generation, see the description of figures 6b and 6c, below.

[0040] In step 116, the CPU 12 operates to calculate a fully shadowed (Dark) version of each pixel in the selected area, $\text{Dark} = P / (1 + \gamma / S)$, where P is the color vector in RGB space of a pixel in the selected area of the subject image 18, gamma (γ) is the value of gamma for that pixel from the gamma map, and S is the spectral ratio calculated by the CPU 12 in step 104 of figure 3. The use of the spectral ratio as a representation of the BIDR model for the subject image 18 results in a color correct Dark determination corresponding to the end point of the cylinder predicted by the BIDR model for the pixel, as depicted in figure 5b. Thus, the Dark value correctly corresponds to the $M_a(\lambda) c_b(\lambda)$ term for that pixel in the selected area of the subject image 18.

[0041] In step 118, the CPU 12 calculates a color adjusted new value for each pixel in the selected area as a function of the new gamma map designated by the user: $P_{\text{new}} = \text{Dark} + \gamma_{\text{new}} (\text{Dark} / S)$, where γ_{new} is the new value for the pixel from the new gamma map designated by the user. In step 120, the CPU 12 outputs the image area with the modified incident illuminant (step 108 of figure 3).

[0042] Referring once again to figure 3, the CPU 12 can smooth, feather or implement other known techniques to the modified image (step 110) and then output the modified image, for example for display on the monitor 20 or print out on the printer 22 (step 112).

[0043] Figure 6a shows a flow chart for a color correct brightness adjustment to an intensity adjusted image, according to a feature of the present invention. The CPU 12 is given an original image area, an intensity adjusted image area, a gamma map and a spectral ratio S for the original image area (step 200). The intensity adjusted image area can be the output of a known dynamic range compression algorithm, such as, for example, the Retinex-based dynamic range compression algorithm marketed by Hewlett-Packard or a Foveon statistics-based dynamic range compression algorithm. These algorithms brighten darker areas of an image for a more pleasing appearance, by adjusting the intensity but not the color of pixels: $f^*(R, G, B) \Rightarrow (fR, fG, fB)$. The routine of figure 6a is meant to shift the colors as well as the intensity for each pixel for a color correct image adjustment. The gamma (γ) map can be estimated by ascertaining a difference between the intensity adjusted image and the original image.

[0044] To that end, reference is made to figures 6b and 6c. Figure 6b is a graph in RGB space showing an intensity adjusted pixel value for the intensity adjusted image input to the CPU 12 in the routine of figure 6a. The graph shows the RGB value of the original pixel P and the intensity adjusted value for the pixel A . The graph also shows the position of a fully shadowed version of the pixel Dark , and a color correct fully lit version B , as predicted by the BIDR model according to a feature of the present invention. As can be clearly seen in the graph of figure 6b, the color of A is displaced

in RGB space from the color correct value for the intensity adjusted pixel, B. The result of execution of the routine of figure 6a by the CPU 12 is an adjustment of A to the value of B, for a color correct depiction of the scene in the image.

[0045] Figure 6c is a flow chart for estimating a gamma (γ) value for the pixel of figure 6b using a dynamic range compression algorithm. In step 400, the CPU 12 is provided with the input information corresponding to the input to the CPU 12 in step 200 of figure 6a, absent the gamma value to be determined by the routine of figure 6c. In step 402, for each pixel in the image 18, the CPU 12 calculates a ratio of the scalar value of the intensity adjusted pixel of the image divided by the scalar value of the original pixel value P: $R = \|A\| / \|P\|$.

[0046] In step 404, for each pixel, the CPU 12 determines a Q, as the value of the minimum of R or the value of $(1 + \|S\|) / \|S\|$. In step 406, for each pixel, the CPU 12 calculates a gamma value: $\gamma = [(1 + \|S\|) / Q] - \|S\|$. After completing steps 402-406 for each pixel, the CPU outputs a gamma map of the image, with a gamma value for each pixel. The gamma value indicates the percent of incident or direct illuminant on the pixel.

[0047] In step 202, the CPU 12 calculates a fully shadowed version (Dark) for each pixel as performed by the CPU 12 in step 116 of figure 10, utilizing the algorithm $\text{Dark} = P / (1 + \gamma/S)$ wherein γ is the estimated value in the map generated from execution of the routine of figure 6c. In step 204, the CPU 12 uses the Dark version of each pixel, the spectral ratio and the estimated γ to calculate the color and intensity of each pixel such that the corrected pixel has an intensity that matches the intensity adjusted image with a correct color. Initially the CPU 12 calculates a bright version of each pixel: $P_{\text{bright}} = P_{\text{original}} * (1 + S) / (\gamma + S)$. P_{bright} is the color correct version of P_{original} . Next, the CPU 12 determines an RGB vector relative to intensity change for each pixel: $V = P_{\text{bright}} - \text{Dark}$.

[0048] Thereafter, the CPU 12 calculates a fraction representing the difference between the goal intensity, that is , the intensity of the intensity adjusted image, and the intensity of the P_{bright} : $\text{fraction} = (P_{\text{goal intensity}} - P_{\text{bright intensity}}) / V_{\text{intensity}}$. The adjustment required to the intensity of P_{bright} to reach the intensity of the intensity adjusted image is $\text{Adjustment} = \text{fraction} * V$. The final pixel value is then: $P_{\text{final}} = P_{\text{bright}} + \text{Adjustment}$.

[0049] After the CPU 12 completes step 204 for each pixel in the image area, the CPU 12 outputs a color correct intensity adjusted image (step 206).

[0050] Figure 7 is a flow chart for removing direct or incident illumination from an image area, according to a feature of the present invention. In step 208, the CPU 12 is given an original image area, which can be, for example, an area of an image file 18 selected by a user, a gamma map for the image area, and a characteristic spectral ratio S for the image area.

[0051] In step 210, the CPU calculates a shadowed version (Dark) of each pixel in the image area, again as performed by the CPU 12 in step 116 of figure 10, utilizing the algorithm $\text{Dark} = P / (1 + \gamma/S)$. Upon completion of step 210 for all pixels, the CPU 12 outputs an image with all materials lit only by the ambient illuminant (step 212).

[0052] Figure 8 shows a flow chart for modifying apparent ambient illumination of an image area, according to a feature of the present invention. In step 214, the CPU 12 is given an original image area, a gamma map, a characteristic spectral ratio S for the image area, and an ambient illuminant modifier vector V. The ambient illuminant modifier vector is a vector in, for example, RGB space that, when multiplied by the actual vector of a fully shadowed pixel in the image (Dark), provides a modified version of the pixel with a new apparent ambient illumination.

[0053] In step 216, the CPU 12 uses the spectral ratio and gamma map to calculate a fully shadowed (Dark) version of each pixel in the image area, again using the algorithm: $\text{Dark} = P / (1 + \gamma/S)$. In steps 218, 220, the CPU 12 multiplies each Dark pixel by V to yield Dark_{new} and thereby obtain a new apparent ambient illuminant (step 218), and also multiply S by V to obtain S_{new} (step 220).

[0054] In step 222, The CPU 12, using S_{new} and the gamma map, calculates a new color for each pixel: $P_{\text{new}} = \text{Dark}_{\text{new}} + \gamma(\text{Dark}_{\text{new}}/S_{\text{new}})$. Upon completion of step 222 for all pixels, the CPU 12 outputs an image area with a modified apparent ambient illuminant (step 224).

[0055] Figure 9 is a flow chart for modifying apparent direct or incident illumination of an image area, according to a feature of the present invention. In step 300, the CPU is given an original image area, a gamma map and spectral ratio for the image area and an incident or direct illuminant modifier vector V. The direct illuminant modifier vector is a vector in, for example, RGB space that can be used to modify the spectral ratio for use in modifying the apparent direct illumination in the image area.

[0056] In step 302, the CPU 12 calculates a Dark version of each pixel, as completed in the routines of the previous figures. In step 304, a new spectral ratio is determined by the CPU 12 using the vector V, $S_{\text{new}} = S * 1/V$. The new spectral ratio permits a manipulation of pixel values to in effect, modify the apparent incident illumination. In step 306, the CPU 12 uses S_{new} and the gamma map to calculate a new color for each pixel: $P_{\text{new}} = \text{Dark} + \gamma(\text{Dark}/S_{\text{new}})$. Upon completion of step 306 for all pixels, the CPU 12 outputs an image area with a modified apparent direct or incident illuminant.

[0057] Figure 11 is a graph in RGB space showing a color correct gamma correction, according to a feature of the present invention. The graph shows the RGB value of the original pixel C and the intensity adjusted value for the pixel B_1 after gamma correction. The graph also shows the position of a fully shadowed version of the pixel, Dark, and a color correct fully lit version P, as contained within a BIDR cylinder, as predicted by the BIDR model according to a feature of

the present invention. As can be clearly seen in the graph of figure 11, the color of B_1 is displaced in RGB space from the color correct value for the pixel P. The pixel B_2 is the color correct intensity adjusted value for the pixel P (and thus of the original pixel C) after gamma correction, according to the present invention.

[0058] Gamma correction is an industry standard method for brightening an image for display on a monitor or in print.

According to the standard, an image is adjusted such that for each pixel in the image, the intensity is measured on a scale of 0 to 1, and the brightened intensity is equal to the original intensity raised to a power of $(1.0/\text{gamma})$, where gamma is a value greater than or equal to 1.0. The gamma used in the industry standard is not to be confused with gamma used above in this document to represent the fraction of incident light on a surface. To avoid confusion, the brightening factor used herein can be defined as lambda (λ). Gamma correction brightens all pixels some amount irrespective of illumination. Like other forms of dynamic range compression, gamma correction brightens shadows without making them more similar in color to the color correct unshaded counterparts. As will be described, the concepts of the BIDR model of the present invention can be applied to brighten shadows and adjust the color to provide a color correct, and thus, more visually pleasing image.

[0059] Figure 12 is a flow chart for a color correct gamma correction, as shown in figure 11. In step 600, the CPU 12 is provided an original image, from an image file 18, a brightening power, λ , and a normalized spectral ratio for the image, S. In step 602, for each pixel C, the CPU 12 finds the brightened intensity(B_1) as $\text{intensity}(C)^{1.0/\lambda}$, as in a standard and normal gamma correction. Then, in step 604, the CPU 12 calculates two ratios. R_1 is some small percentile (such as the 5th, 10th, 20th, or 40th) value of $\text{intensity}(B_1)/\text{intensity}(C)$. R_2 is some large percentile (such as 60th, 80th, or 95th) value of $\text{intensity}(B_1)/\text{intensity}(C)$. R_1 represents a minimum degree of brightening, and pixels with a smaller ratio are assumed to be fully lit; R_2 represents a maximum degree of brightening, and pixels with a larger ratio are assumed to be fully shadowed.

[0060] In step 606, the CPU 12 calculates the intensity of the DARK pixel (intensity(D)) of the BIDR cylinder as $\text{intensity}(D) = \text{intensity}(B_1)/R_2$. If $\text{intensity}(D) > \text{intensity}(C)$, then the value C is updated to be $C * \text{intensity}(D)/\text{intensity}(C)$. Next, in step 608, the CPU 12 calculates the intensity of the bright pixel P on the BIDR cylinder C as $\text{intensity}(C)/R_1$ if $\text{intensity}(B_1)/\text{intensity}(C) > R_1$; otherwise, the intensity(P) is set to $\text{intensity}(C)$. The intensity(P) will be less than the $\text{intensity}(B_1)$ because gamma correction brightens all pixels, even pixels in full incident illumination. The ratio R_1 is a measurement of the excess brightening beyond full incident illumination.

[0061] Knowing the normalized spectral ratio \hat{S} , the original color C, and the intensity(D), the CPU 12 calculates the dark color D in step 610. The dark color D is the color such that $D = (k\hat{S}C)/(1+k\hat{S})$ for some scalar k. There is one value of k that satisfies the equation with the correct intensity for D. The value can be found by a direct algebraic solution or by successive approximation.

[0062] With the dark color D, the intensity(P), and the normalized spectral ratio \hat{S} , the CPU 12 calculates the fully lit color P in step 612. The color P is the color with the proper intensity such that $P = (D + D\hat{S}k)/(\hat{S}k)$ for some scalar k. The scalar k can be found as $k = (D_R/\hat{S}_R + D_G/\hat{S}_G + D_B/\hat{S}_B)/(3 * \text{intensity}(P) - D_R - D_G - D_B)$. In step 614, the CPU 12 brightens the color P to have the same intensity as B_1 , resulting in the color corrected brightened color B_2 . Following these steps for each pixel in the image produces a gamma corrected image with appropriately colored shadows (step 616).

[0063] The scope of the invention is set by the appended claims.

Claims

1. A method for manipulating an image to provide a color correct intensity adjusted image, comprising the steps of:

determining a characteristic spectral ratio formed by the interplay of an incident illuminant and an ambient illuminant and substantially invariant over different materials present in a scene depicted in the image, the characteristic spectral ratio being an analytical representation of image properties and characteristics pursuant to a bi-illuminant dichromatic reflection model, the bi-illuminant dichromatic reflection model obtained by combining terms relevant to an ambient illuminant with a dichromatic reflection model; and
utilizing the characteristic spectral ratio to manipulate the image to generate a color correct intensity adjusted image.

2. The method of claim 1, wherein the image is manipulated to generate a manipulated image having correct color of material depicted in the image, the correct color being set at any selected degree of adjustment within the range extending from fully shaded color value to fully lit color value and determined as a function of the correct color values represented by the bi-illuminant dichromatic reflection model.

3. The method of claim 1 or 2 wherein the spectral ratio equals $\text{Dark}/(\text{Bright} - \text{Dark})$, where Dark indicates color values of a shaded pixel and Bright color values of a fully lit pixel.

4. The method of one of the previous claims comprising the further step of normalizing the spectral ratio.
5. The method of one of the previous claims, wherein the step of utilizing the characteristic spectral ratio to manipulate the image comprises the steps of:

5
10 providing a gamma map and a new gamma map for the image;
calculating a Dark version of each pixel of the image as a function of the spectral ratio and the gamma map; and
calculating a new pixel value for each pixel as a function of the Dark version, the spectral ratio and the new gamma map to modify an apparent level of incident illuminant in the image.

6. The method of one of the claims 1 to 4, wherein the step of utilizing the characteristic spectral ratio to manipulate the image comprises the steps of:

15 providing a gamma map and an intensity adjusted image;
calculating a Dark version of each pixel of the image as a function of the spectral ratio and the gamma map; and
calculating a new pixel value for each pixel as a function of the Dark version, the spectral ratio, the gamma map and the intensity adjusted image to provide a color correct brightness adjustment to the image.

7. The method of one of the claims 1 to 4, wherein the step of utilizing the characteristic spectral ratio to manipulate the image comprises the steps of:

20 providing a gamma map; and
calculating a Dark version of each pixel of the image as a function of the spectral ratio and the gamma map to remove an incident illuminant from the image and provide an image lit solely by an ambient illuminant.

8. The method of one of the claims 1 to 4, wherein the step of utilizing the characteristic spectral ratio to manipulate the image comprises the steps of:

25 providing a gamma map and an ambient illuminant modifier vector;
30 calculating a Dark version of each pixel of the image as a function of the spectral ratio and the gamma map;
calculating a new Dark version of each pixel as a function of the Dark version and the ambient illuminant modifier vector;
calculating a new spectral ratio as a function of the spectral ratio and the ambient illuminant modifier vector; and
35 calculating a new pixel value for each pixel of the image as a function of the new Dark version and the new spectral ratio to provide a modified apparent ambient illuminant for the image.

9. The method of one of the claims 1 to 4, wherein the step of utilizing the characteristic spectral ratio to manipulate the image comprises the steps of:

40 providing a gamma map and an incident illuminant modifier vector;
calculating a Dark version of each pixel of the image as a function of the spectral ratio and the gamma map;
calculate a new spectral ratio as a function of the spectral ratio and the incident illuminant modifier vector; and
calculating a new pixel value for each pixel of the image as a function of the new spectral ratio to provide a modified apparent incident illuminant for the image.

- 45 10. The method of one of the previous claims, wherein, when an intensity adjustment for an intensity adjusted image causes an intensity beyond the range of a fully lit color value, the intensity is adjusted with reference to a fully lit color value determined according to the bi-illuminant dichromatic reflection model.

- 50 11. The method of claim 1, wherein at least one pixel of the image is manipulated by deriving a cylinder representation of the at least one pixel as a function of the characteristic spectral ratio, and utilizing the cylinder representation of the at least one pixel to manipulate the at least one pixel.

- 55 12. The method of claim 11 wherein the step of deriving the cylinder representation of the at least one pixel is carried out by calculating the spectral ratio for an area of the image corresponding to the cylinder and containing the at least one pixel, and determining a γ value for the at least one pixel.

13. The method of claim 12 wherein the step of utilizing the cylinder representation of the at least one pixel to manipulate

the at least one pixel is carried out by calculating a new color value for the at least one pixel as a function of the spectral ratio and the γ value.

- 5 14. A computer system (10) which comprises: a CPU (12);
and a memory (16) storing an image file (18);
the CPU (12) arranged and configured to execute a routine to manipulate the image to provide an intensity adjusted image,
determine a characteristic spectral ratio formed by the interplay of an incident illuminant and the ambient illuminant
10 and substantially invariant over different materials present in a scene depicted in the image, the characteristic spectral ratio being an analytical representation of image properties and characteristics pursuant to a bi-illuminant dichromatic reflection model, the bi-illuminant dichromatic reflection model obtained by combining terms relevant to an ambient illuminant with a dichromatic reflection model; and
utilize the characteristic spectral ratio to manipulate the intensity adjusted image to generate a color correct intensity adjusted image.
- 15 15. The computer system (10) of claim 14 wherein the CPU (12) executes a routine to manipulate the image to provide an intensity adjusted image by executing a gamma correction method.
- 20 16. The computer system (10) of claim 14, wherein the CPU (12) is arranged and configured to execute a routine to adjust the intensity with reference to a fully lit color value determined according to the bi-illuminant dichromatic reflection model, when an intensity adjustment for an intensity adjusted image causes an intensity beyond the range of a fully lit color value.

25 **Patentansprüche**

1. Verfahren zum Manipulieren eines Bildes, um ein farbkorrektes, intensitätsangepasstes Bild bereitzustellen, die folgenden Schritte umfassend:

30 Bestimmen eines charakteristischen Spektralverhältnisses, das durch das Zusammenspiel eines Einfallslichtmittels und eines Umgebungsleuchtmittels gebildet wird und über unterschiedliche Materialien, die in einer auf dem Bild dargestellten Szene vorhanden sind, im Wesentlichen unveränderlich ist, wobei das charakteristische Spektralverhältnis eine analytische Darstellung von Bildeigenschaften und Charakteristiken entsprechend einem dichromatischen Doppelleuchtmittelreflexionsmodell ist, wobei das dichromatische Doppelleuchtmittelreflexionsmodell erhalten wird, indem Bedingungen, die für ein Umgebungsleuchtmittel relevant sind, mit einem
35 dichromatischen Reflexionsmodell kombiniert werden; und
Verwenden des charakteristischen Spektralverhältnisses, um das Bild zu manipulieren, um ein farbkorrektes, intensitätsangepasstes Bild zu erzeugen.

- 40 2. Verfahren nach Anspruch 1, wobei das Bild manipuliert wird, um ein manipuliertes Bild zu erzeugen, das korrekte Farbe von auf dem Bild dargestelltem Material aufweist, wobei die korrekte Farbe bei einem beliebigen ausgewählten Anpassungsgrad innerhalb der Spanne, die sich von einem vollschattierten Farbwert zu einem vollbeleuchteten Farbwert erstreckt, festgelegt ist und in Abhängigkeit der korrekten Farbwerte bestimmt wird, die durch das dichromatische Doppelleuchtmittelreflexionsmodell dargestellt sind.

- 45 3. Verfahren nach Anspruch 1 oder 2, wobei das Spektralverhältnis Dunkel/(Hell-Dunkel) gleicht, wobei Dunkel Farbwerte eines schattierten Pixels und Hell Farbwerte eines vollbeleuchteten Pixels angibt.

- 50 4. Verfahren nach einem der vorhergehenden Ansprüche, umfassend den weiteren Schritt des Normalisierens des Spektralverhältnisses.

- 55 5. Verfahren nach einem der vorhergehenden Ansprüche, wobei der Schritt des Verwendens des charakteristischen Spektralverhältnisses zum Manipulieren des Bildes die folgenden Schritte umfasst:
Bereitstellen einer Gammakarte und einer neuen Gammakarte für das Bild;

Berechnen einer Dunkel-Version jedes Pixels des Bildes in Abhängigkeit des Spektralverhältnisses und der Gammakarte; und
Berechnen eines neuen Pixelwertes für jedes Pixel in Abhängigkeit der Dunkel-Version, des Spektralverhält-

nisses und der neuen Gammakarte, um ein erkennbares Niveau von Einfallsluchtmittel in dem Bild zu modifizieren.

- 5 6. Verfahren nach einem der Ansprüche 1 bis 4, wobei der Schritt des Verwendens des charakteristischen Spektralverhältnisses zum Manipulieren des Bildes die folgenden Schritte umfasst:
Bereitstellen einer Gammakarte und eines intensitätsangepassten Bildes;

Berechnen einer Dunkel-Version jedes Pixels des Bildes in Abhängigkeit des Spektralverhältnisses und der Gammakarte; und

- 10 Berechnen eines neuen Pixelwertes für jedes Pixel in Abhängigkeit der Dunkel-Version, des Spektralverhältnisses, der Gammakarte und des intensitätsangepassten Bildes, um dem Bild eine farbkorrekte Helligkeitsanpassung bereitzustellen.

- 15 7. Verfahren nach einem der Ansprüche 1 bis 4, wobei der Schritt des Verwendens des charakteristischen Spektralverhältnisses zum Manipulieren des Bildes die folgenden Schritte umfasst:

Bereitstellen einer Gammakarte; und

- 20 Berechnen einer Dunkel-Version jedes Pixels des Bildes in Abhängigkeit des Spektralverhältnisses und der Gammakarte, um ein Einfallsluchtmittel aus dem Bild zu entfernen und ein Bild bereitzustellen, das ausschließlich durch ein Umgebungsleuchtmittel beleuchtet wird.

8. Verfahren nach einem der Ansprüche 1 bis 4, wobei der Schritt des Verwendens des charakteristischen Spektralverhältnisses zum Manipulieren des Bildes die folgenden Schritte umfasst:

- 25 Bereitstellen einer Gammakarte und eines Umgebungsleuchtmittelmodifizierungsvektors;
Berechnen einer Dunkel-Version jedes Pixels des Bildes in Abhängigkeit des Spektralverhältnisses und der Gammakarte;

- Berechnen einer neuen Dunkel-Version jedes Pixels in Abhängigkeit der Dunkel-Version und des Umgebungsleuchtmittelmodifizierungsvektors;

- 30 Berechnen eines neuen Spektralverhältnisses in Abhängigkeit des Spektralverhältnisses und des Umgebungsleuchtmittelmodifizierungsvektors; und

- Berechnen eines neuen Pixelwertes für jedes Pixel des Bildes in Abhängigkeit der neuen Dunkel-Version und des neuen Spektralverhältnisses, um ein modifiziertes erkennbares Umgebungsleuchtmittel für das Bild bereitzustellen.

- 35 9. Verfahren nach einem der Ansprüche 1 bis 4, wobei der Schritt des Verwendens des charakteristischen Spektralverhältnisses zum Manipulieren des Bildes die folgenden Schritte umfasst:

- 40 Bereitstellen einer Gammakarte und eines Einfallsluchtmittelmodifizierungsvektors;
Berechnen einer Dunkel-Version jedes Pixels des Bildes in Abhängigkeit des Spektralverhältnisses und der Gammakarte;

- Berechnen eines neuen Spektralverhältnisses in Abhängigkeit des Spektralverhältnisses und des Einfallsluchtmittelmodifizierungsvektors; und

- 45 Berechnen eines neuen Pixelwertes für jedes Pixel des Bildes in Abhängigkeit des neuen Spektralverhältnisses, um ein modifiziertes erkennbares Einfallsluchtmittel für das Bild bereitzustellen.

- 50 10. Verfahren nach einem der vorhergehenden Ansprüche, wobei, wenn eine Intensitätsanpassung für ein intensitätsangepasstes Bild eine Intensität außerhalb der Spanne eines vollbeleuchteten Farbwertes bewirkt, die Intensität unter Bezugnahme auf einen vollbeleuchteten Farbwert angepasst wird, der gemäß dem dichromatischen Doppellichtmittelreflexionsmodell bestimmt wird.

- 55 11. Verfahren nach Anspruch 1, wobei zumindest ein Pixel des Bildes manipuliert wird, indem eine Zylinderdarstellung des zumindest einen Pixels in Abhängigkeit des charakteristischen Spektralverhältnisses abgeleitet wird und die Zylinderdarstellung des zumindest einen Pixels verwendet wird, um das zumindest eine Pixel zu manipulieren.

12. Verfahren nach Anspruch 11, wobei der Schritt des Ableitens der Zylinderdarstellung des zumindest einen Pixels durchgeführt wird, indem das Spektralverhältnis für einen Bereich des Bildes entsprechend dem Zylinder und das zumindest eine Pixel enthaltend berechnet wird und ein γ -Wert für das zumindest eine Pixel bestimmt wird.

13. Verfahren nach Anspruch 12, wobei der Schritt des Verwendens der Zylinderdarstellung des zumindest einen Pixels, um das zumindest eine Pixel zu manipulieren, durchgeführt wird, indem ein neuer Farbwert für das zumindest eine Pixel in Abhängigkeit des Spektralverhältnisses und des γ -Wertes berechnet wird.

5 14. Computersystem (10), umfassend:

eine CPU (12); und

einen Speicher (16), der eine Bilddatei (18) speichert;

wobei die CPU (12) angeordnet und konfiguriert ist zum;

10 Ausführen einer Routine zum Manipulieren des Bildes, um ein intensitätsangepasstes Bild bereitzustellen;

Bestimmen eines charakteristischen Spektralverhältnisses, das durch das Zusammenspiel eines Einfallsluchtmittels und des Umgebungsleuchtmittels gebildet wird und über unterschiedliche Materialien, die in einer auf dem Bild dargestellten Szene vorhanden sind, im Wesentlichen unveränderlich ist, wobei das charakteristische

15 Spektralverhältnis eine analytische Darstellung von Bildeigenschaften und Charakteristiken entsprechend einem dichromatischen Doppelleuchtmittelreflexionsmodell ist, wobei das dichromatische Doppelleuchtmittelreflexionsmodell erhalten wird, indem Bedingungen, die für ein Umgebungsleuchtmittel relevant sind, mit einem dichromatischen Reflexionsmodell kombiniert werden; und

Verwenden des charakteristischen Spektralverhältnisses, um das intensitätsangepasste Bild zu manipulieren, um ein farbkorrektes, intensitätsangepasstes Bild zu erzeugen.

20 15. Computersystem (10) nach Anspruch 14, wobei die CPU (12) eine Routine zum Manipulieren des Bildes ausführt, um ein intensitätsangepasstes Bild bereitzustellen, indem ein Gammakorrekturverfahren ausgeführt wird.

25 16. Computersystem (10) nach Anspruch 14, wobei die CPU (12) angeordnet und konfiguriert ist, um eine Routine auszuführen, um die Intensität unter Bezugnahme auf einen vollbeleuchteten Farbwert anzupassen, der gemäß dem dichromatischen Doppelleuchtmittelreflexionsmodell bestimmt wird, wenn eine Intensitätsanpassung für ein intensitätsangepasstes Bild eine Intensität außerhalb der Spanne eines vollbeleuchteten Farbwertes hinaus bewirkt.

30 **Revendications**

1. Procédé de manipulation d'une image pour fournir une image à réglage d'intensité correcte de couleur, comprenant les étapes :

35 de détermination d'un rapport spectral caractéristique formé par l'interaction d'un illuminant incident et d'un illuminant ambiant et sensiblement invariant sur des matériaux différents présents dans une scène illustrée dans l'image, le rapport spectral caractéristique étant une représentation analytique de propriétés et de caractéristiques d'image conformément à un modèle de réflexion dichromatique bi-illuminant, le modèle de réflexion dichromatique bi-illuminant étant obtenu en combinant des termes relatifs à un illuminant ambiant avec un

40 modèle de réflexion dichromatique ; et
d'utilisation du rapport spectral caractéristique pour manipuler l'image afin de générer une image à réglage d'intensité correcte de couleur.

45 2. Procédé selon la revendication 1, dans lequel l'image est manipulée pour générer une image manipulée ayant une couleur correcte de matériau illustré dans l'image, la couleur correcte étant fixée à tout degré de réglage souhaité dans la plage allant d'une valeur de couleur totalement ombrée à une valeur de couleur totalement éclairée et déterminé en fonction des valeurs de couleur correcte représentées par le modèle de réflexion dichromatique bi-illuminant.

50 3. Procédé selon la revendication 1 ou 2, dans lequel le rapport spectral est égal à Sombre/ (Vif - Sombre), où Sombre indique des valeurs de couleur d'un pixel ombré et Vif des valeurs de couleur d'un pixel totalement éclairé.

4. Procédé selon l'une des revendications précédentes, comprenant l'étape supplémentaire de normalisation du rapport spectral.

55 5. Procédé selon l'une des revendications précédentes, dans lequel l'étape d'utilisation du rapport spectral caractéristique pour manipuler l'image comprend les étapes :

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de fourniture d'une carte gamma et d'une nouvelle carte gamma pour l'image ;
de calcul d'une version Sombre de chaque pixel de l'image en fonction du rapport spectral et de la carte gamma ;
et
de calcul d'une nouvelle valeur de pixel pour chaque pixel en fonction de la version Sombre, du rapport spectral
et de la nouvelle carte gamma pour modifier un niveau apparent d'illuminant incident dans l'image.

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6. Procédé selon l'une des revendications 1 à 4, dans lequel l'étape d'utilisation du rapport spectral caractéristique pour manipuler l'image comprend les étapes :

10 de fourniture d'une carte gamma et d'une image à réglage d'intensité ;
de calcul d'une version sombre de chaque pixel de l'image en fonction du rapport spectral et de la carte gamma ; et
de calcul d'une nouvelle valeur de pixel pour chaque pixel en fonction de la version Sombre, du rapport spectral,
de la carte gamma et de l'image à réglage d'intensité pour assurer un réglage de luminosité correcte de couleur
à l'image.

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7. Procédé selon l'une des revendications 1 à 4, dans lequel l'étape d'utilisation du rapport spectral caractéristique pour manipuler l'image comprend les étapes :

20 de fourniture d'une carte gamma ; et
de calcul d'une version Sombre de chaque pixel de l'image en fonction du rapport spectral et de la carte gamma
pour éliminer un illuminant incident de l'image et fournir une image éclairée seulement par un illuminant ambiant.

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8. Procédé selon l'une quelconque des revendications 1 à 4, dans lequel l'étape d'utilisation du rapport spectral caractéristique pour manipuler l'image comprend les étapes :

de fourniture d'une carte gamma et d'un vecteur modificateur d'illuminant ambiant ;
de calcul d'une version Sombre de chaque pixel de l'image en fonction du rapport spectral et de la carte gamma ;
de calcul d'une nouvelle version Sombre de chaque pixel en fonction de la version Sombre et du vecteur
modificateur d'illuminant ambiant ;
de calcul d'un nouveau rapport spectral en fonction du rapport spectral et du vecteur modificateur d'illuminant
ambiant ;
de calcul d'une nouvelle valeur de pixel pour chaque pixel de l'image en fonction de la nouvelle version Sombre
et du nouveau rapport spectral pour fournir un illuminant ambiant apparent modifié pour l'image.

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9. Procédé selon l'une des revendications 1 à 4, dans lequel l'étape d'utilisation du rapport spectral caractéristique pour manipuler l'image comprend les étapes :

40 de fourniture d'une carte gamma et d'un vecteur modificateur d'illuminant incident ;
de calcul d'une version Sombre de chaque pixel de l'image en fonction du rapport spectral et de la carte gamma ;
de calcul d'un nouveau rapport spectral en fonction du rapport spectral et du vecteur modificateur d'illuminant
incident ; et
de calcul d'une nouvelle valeur de pixel pour chaque pixel de l'image en fonction du nouveau rapport spectral
pour fournir un illuminant incident apparent modifié pour l'image.

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10. Procédé selon l'une des revendications précédentes, dans lequel, lorsqu'un réglage d'intensité pour une image à réglage d'intensité entraîne une intensité au-delà de la plage d'une valeur de couleur totalement éclairée, l'intensité est réglée en référence à une valeur de couleur totalement éclairée déterminée selon le modèle de réflexion dichromatique bi-illuminant.

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11. Procédé selon la revendication 1, dans lequel au moins un pixel de l'image est manipulé en dérivant une représentation en cylindre de l'au moins un pixel en fonction du rapport spectral caractéristique, et en utilisant la représentation en cylindre de l'au moins un pixel pour manipuler l'au moins un pixel.

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12. Procédé selon la revendication 11, dans lequel l'étape de dérivation de la représentation en cylindre de l'au moins un pixel est réalisée en calculant le rapport spectral pour une aire de l'image correspondant au cylindre et contenant l'au moins un pixel, et en déterminant une valeur γ pour l'au moins un pixel.

13. Procédé selon la revendication 12, dans lequel l'étape d'utilisation de la représentation en cylindre de l'au moins

un pixel pour manipuler l'au moins un pixel est réalisée en calculant une nouvelle valeur de couleur pour l'au moins un pixel en fonction du rapport spectral et de la valeur γ .

14. Système d'ordinateur (10) qui comprend :

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une unité centrale (12) ; et
une mémoire (16) stockant un fichier d'image (18) ;
l'unité centrale (12) étant conçue et configurée pour exécuter une routine pour manipuler l'image afin de fournir
10 une image à réglage d'intensité,
déterminer un rapport spectral caractéristique formé par l'interaction d'un illuminant incident et de l'illuminant
ambiant et sensiblement invariant sur des matériaux différents présents dans une scène illustrée dans l'image,
le rapport spectral caractéristique étant une représentation analytique de propriétés et de caractéristiques
d'image conformément à un modèle de réflexion dichromatique bi-illuminant, le modèle de réflexion dichroma-
15 tique bi-illuminant étant obtenu en combinant des termes relatifs à un illuminant ambiant à un modèle de réflexion
dichromatique ; et
utiliser le rapport spectral caractéristique pour manipuler l'image à réglage d'intensité afin de générer une image
à réglage d'intensité correcte de couleur.

15. Système d'ordinateur (10) selon la revendication 14, dans lequel l'unité centrale (12) exécute une routine pour
20 manipuler l'image afin de fournir une image à réglage d'intensité en exécutant un procédé de correction gamma.

16. Système d'ordinateur (10) selon la revendication 14, dans lequel l'unité centrale (12) est conçue et configurée pour
exécuter une routine pour régler l'intensité en référence à une valeur de couleur totalement éclairée déterminée
selon le modèle de réflexion dichromatique bi-illuminant, lorsqu'un réglage d'intensité pour une image à réglage
25 d'intensité entraîne une intensité au-delà de la plage d'une valeur de couleur totalement éclairée.

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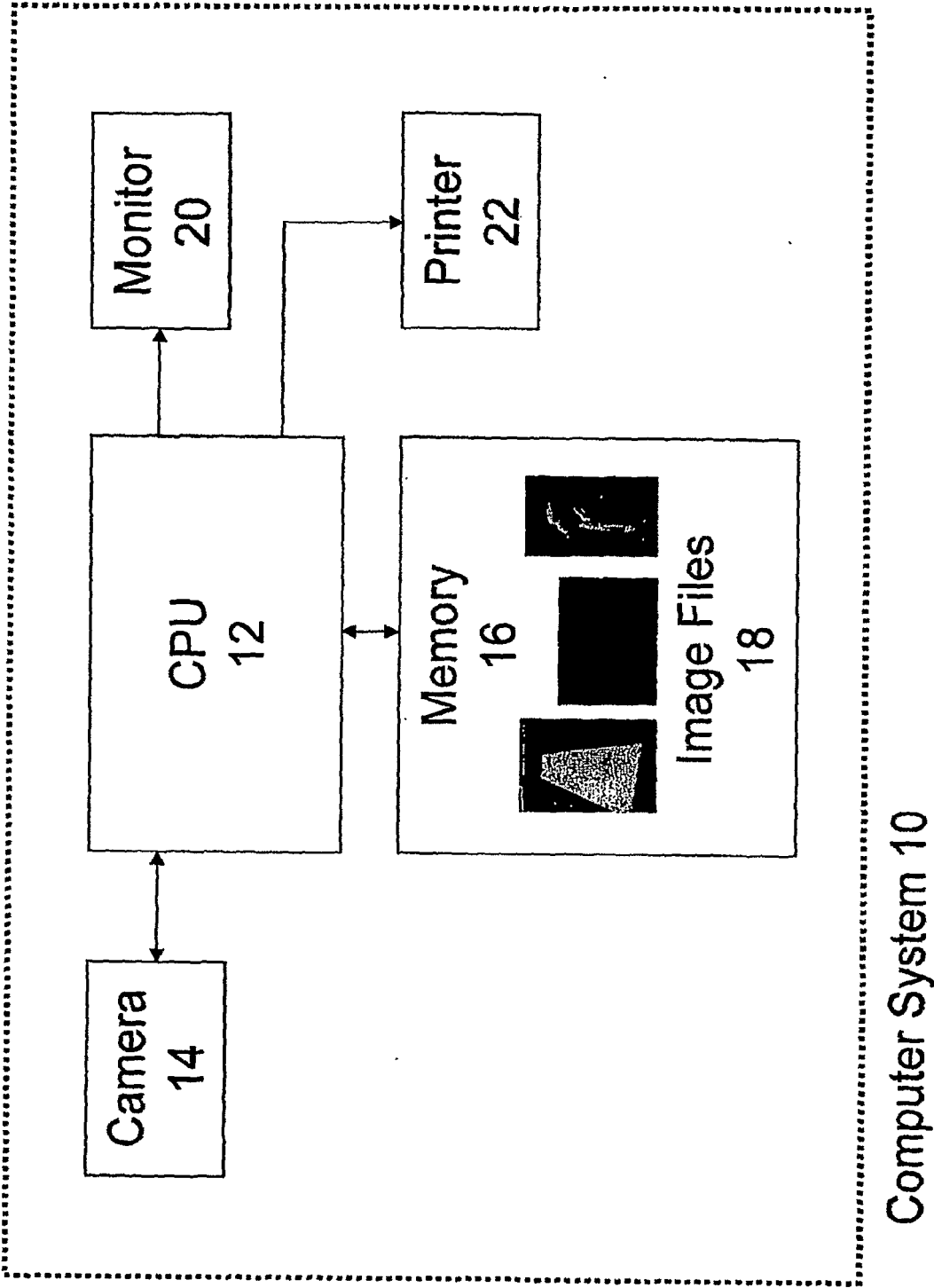


Figure 1: Computer System Configured to Operate on Images

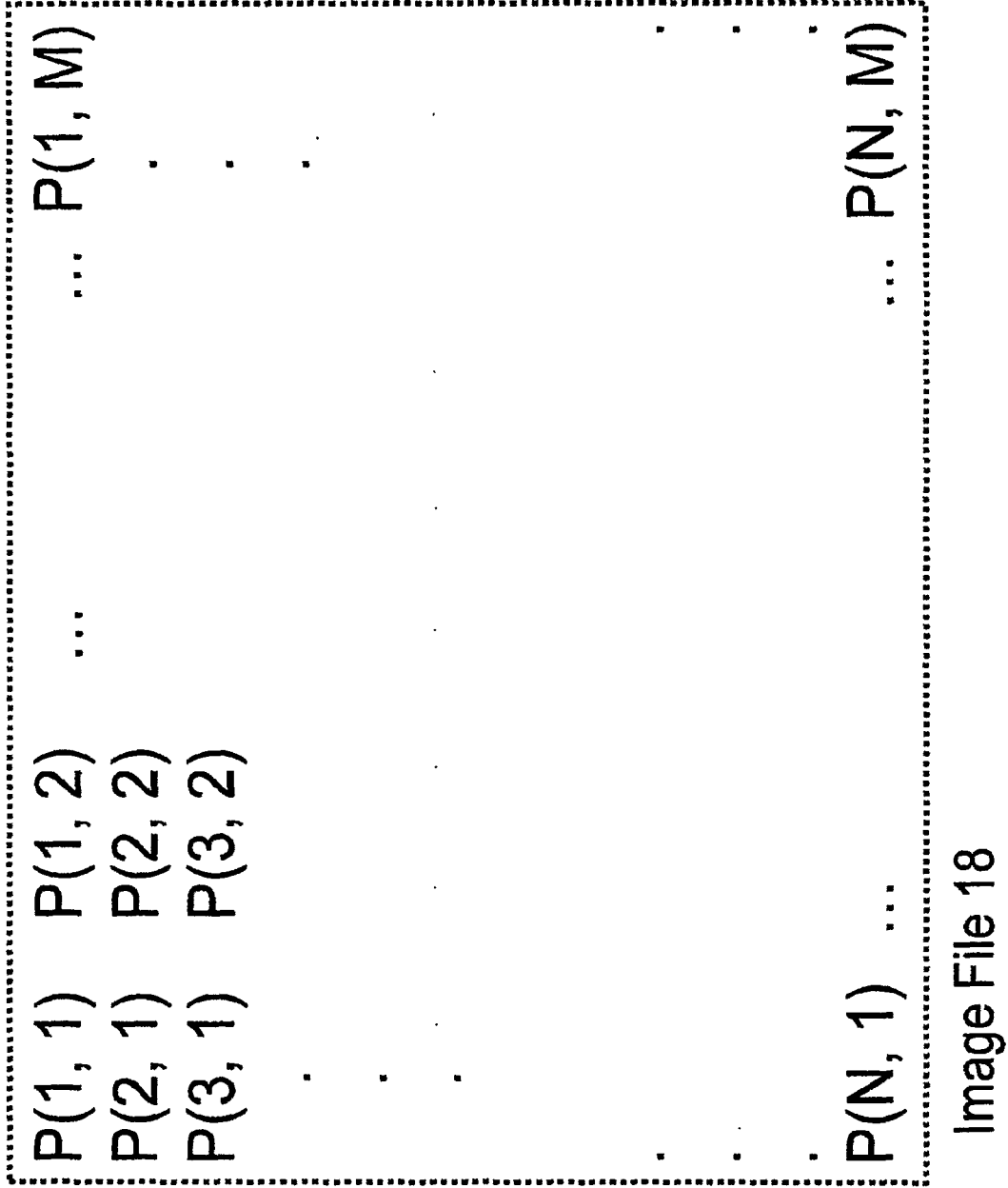


Figure 2: Pixel Array for Storing Image Data

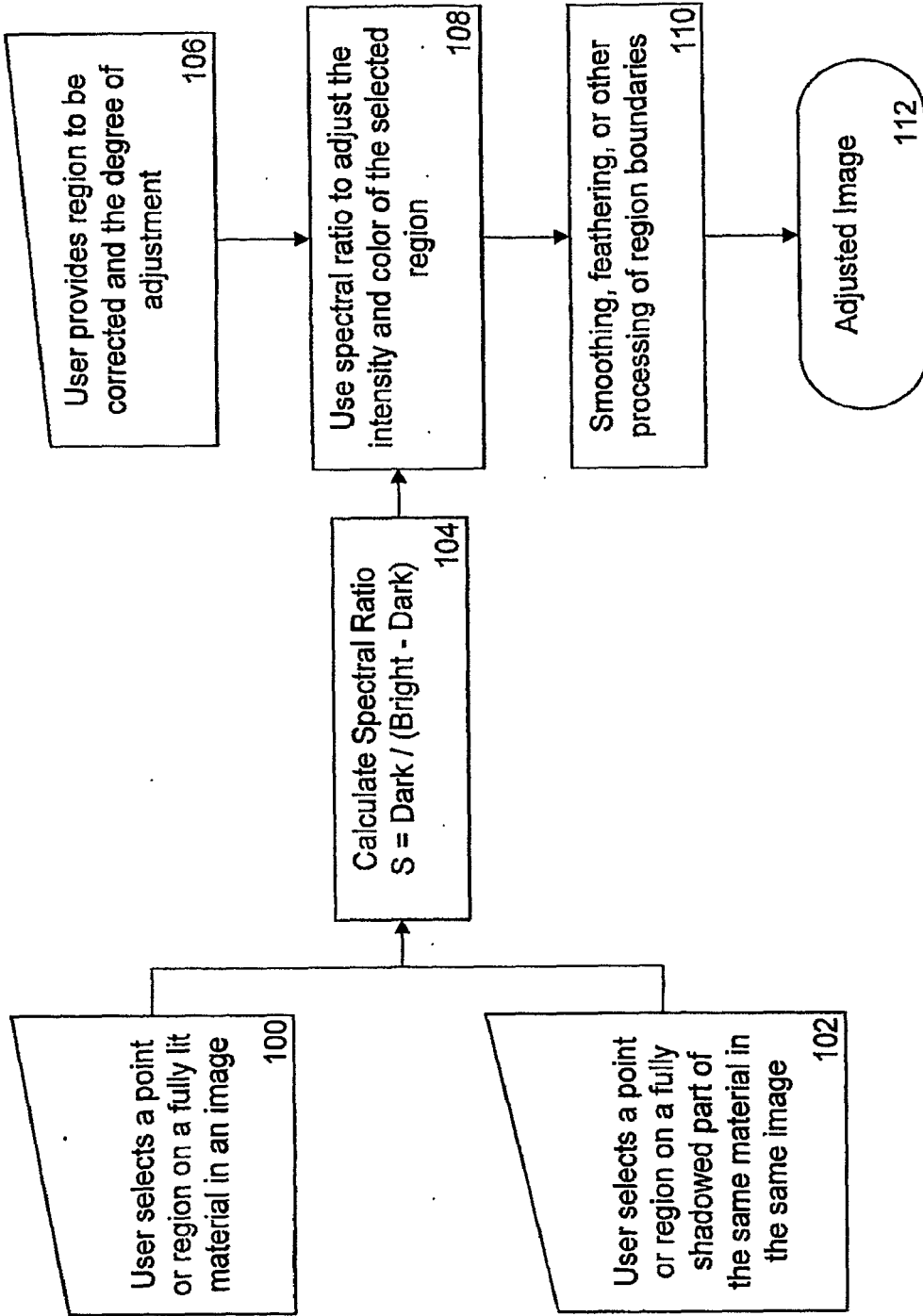


Figure 3: Modifying a Shadow with Manual Input

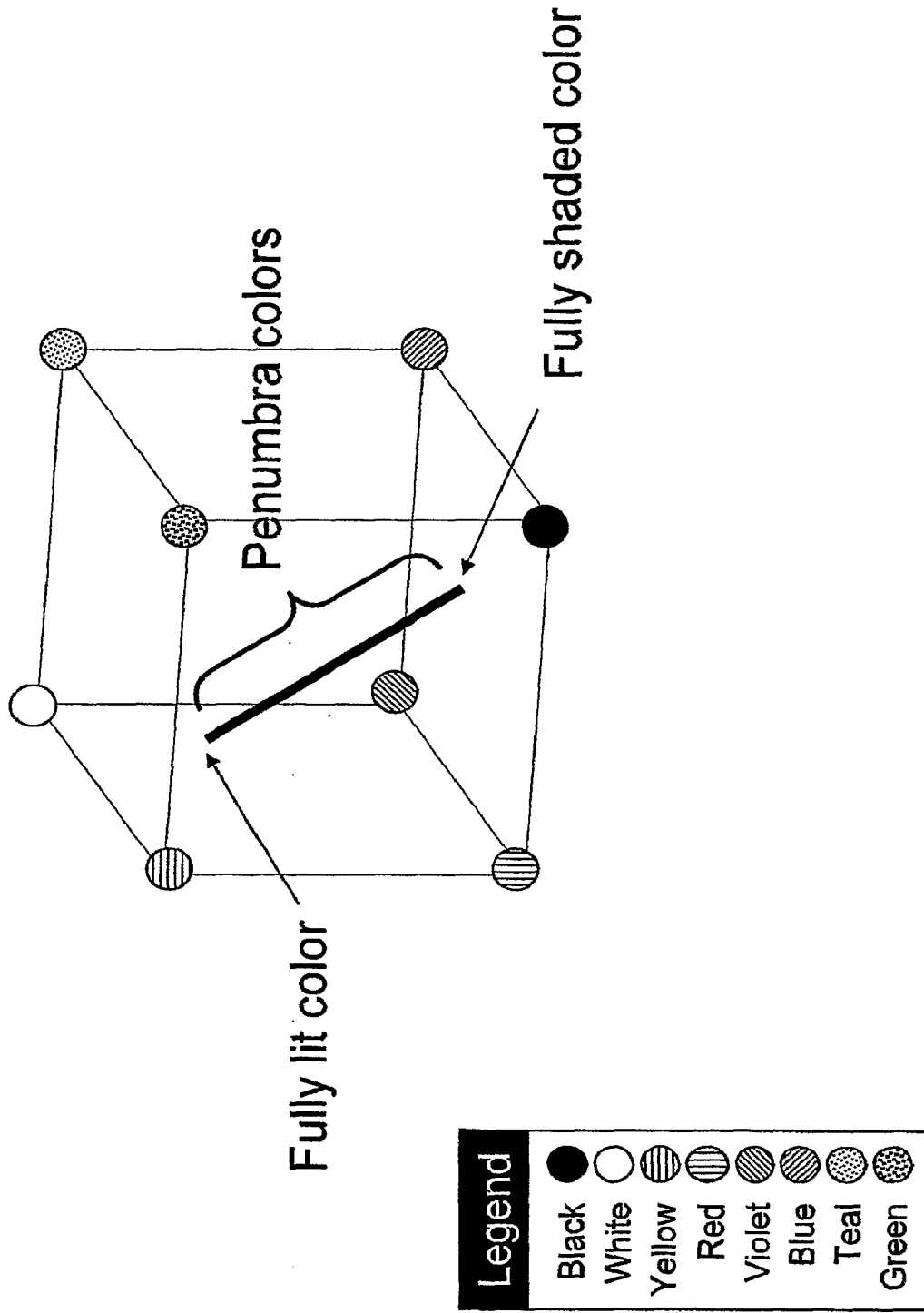


Figure 4: Representation of Body Reflection in RGB Space

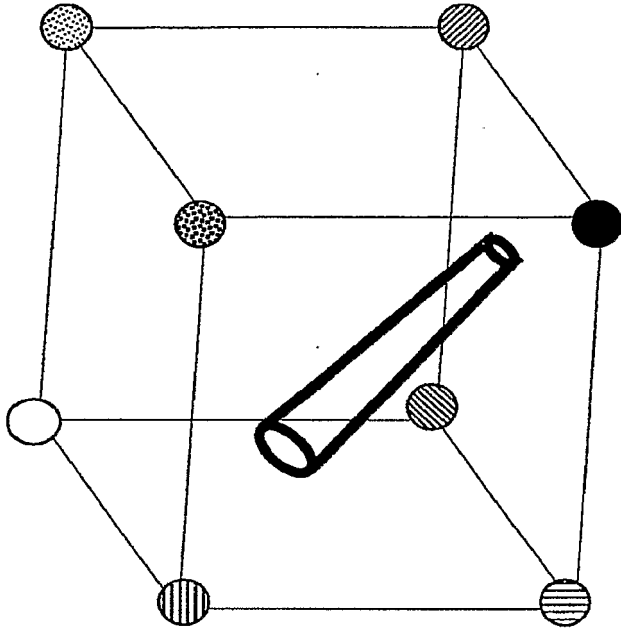


Figure 5A: Body reflection with uniform error bounds

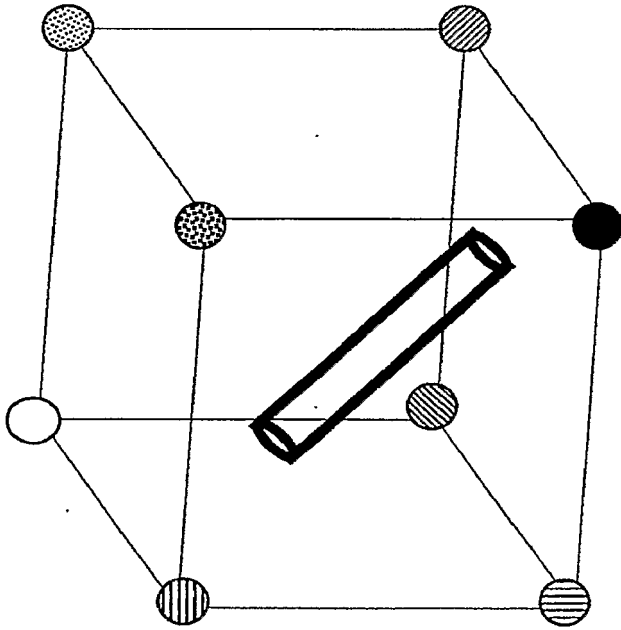


Figure 5B: Body reflection with non-uniform error bounds that are tighter at the dark end.

Legend	
●	Black
○	White
▨	Yellow
▩	Red
▧	Violet
▦	Blue
▥	Teal
▤	Green

Figure 5A, 5B: Representation of Body Reflection with Noise

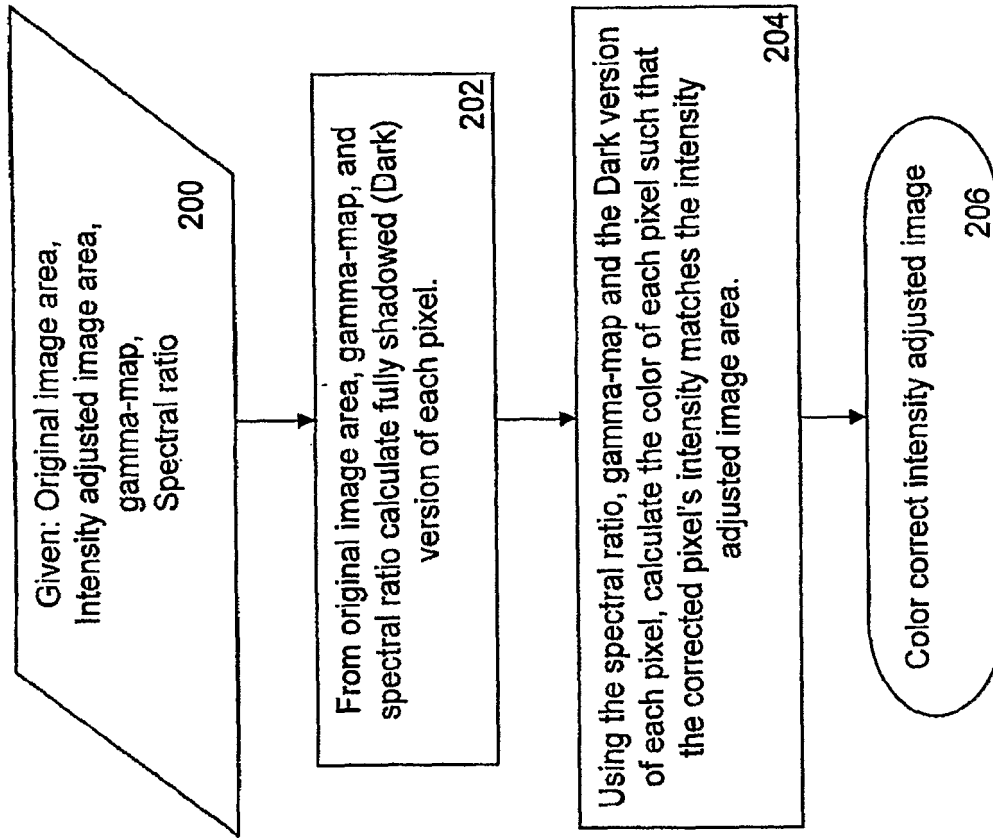


Figure 6A: Color Correct Brightness Adjustment

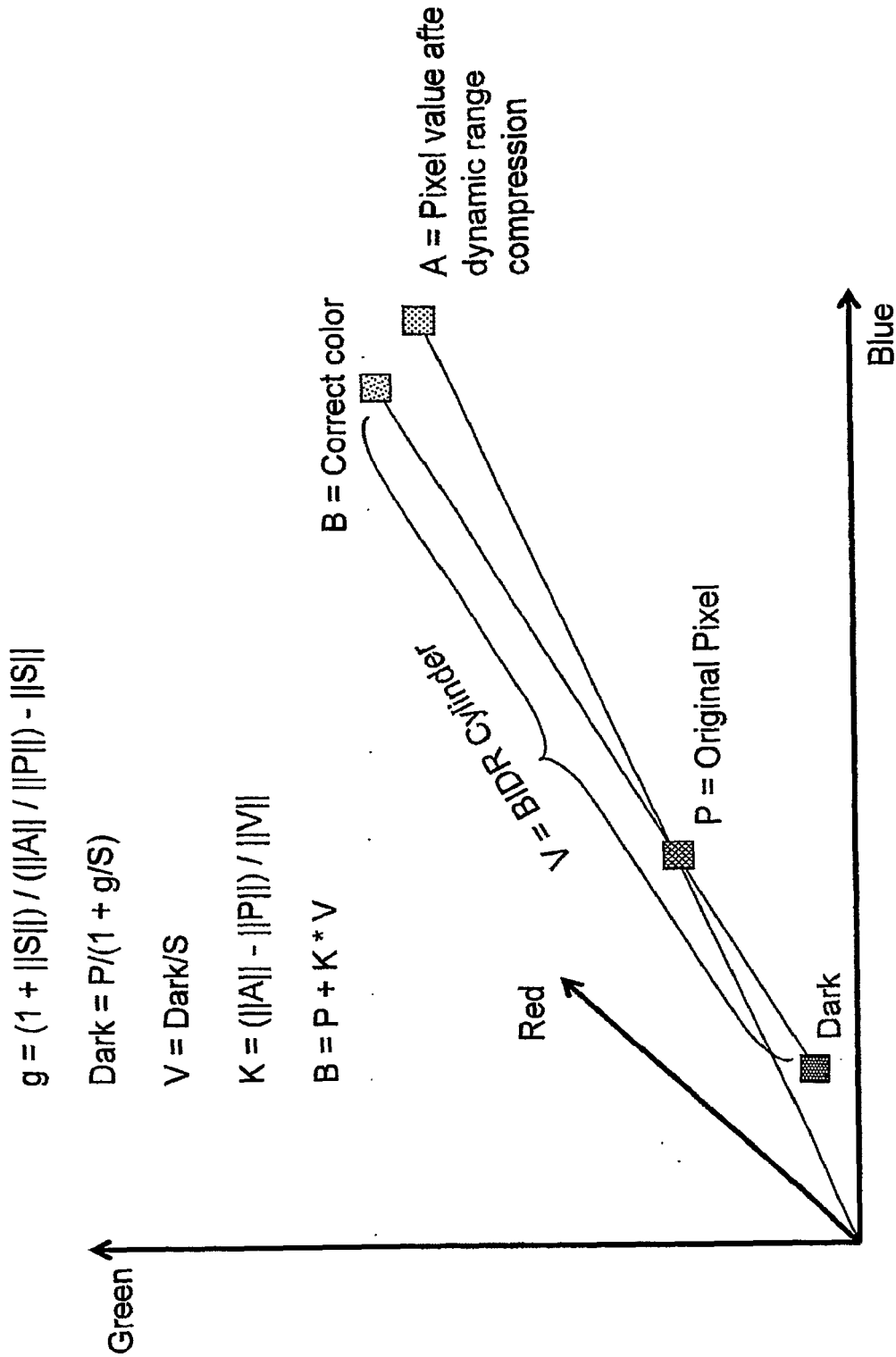


Figure 6B. Method of estimating percent of direct illumination (g) from a dynamic range compressed image.

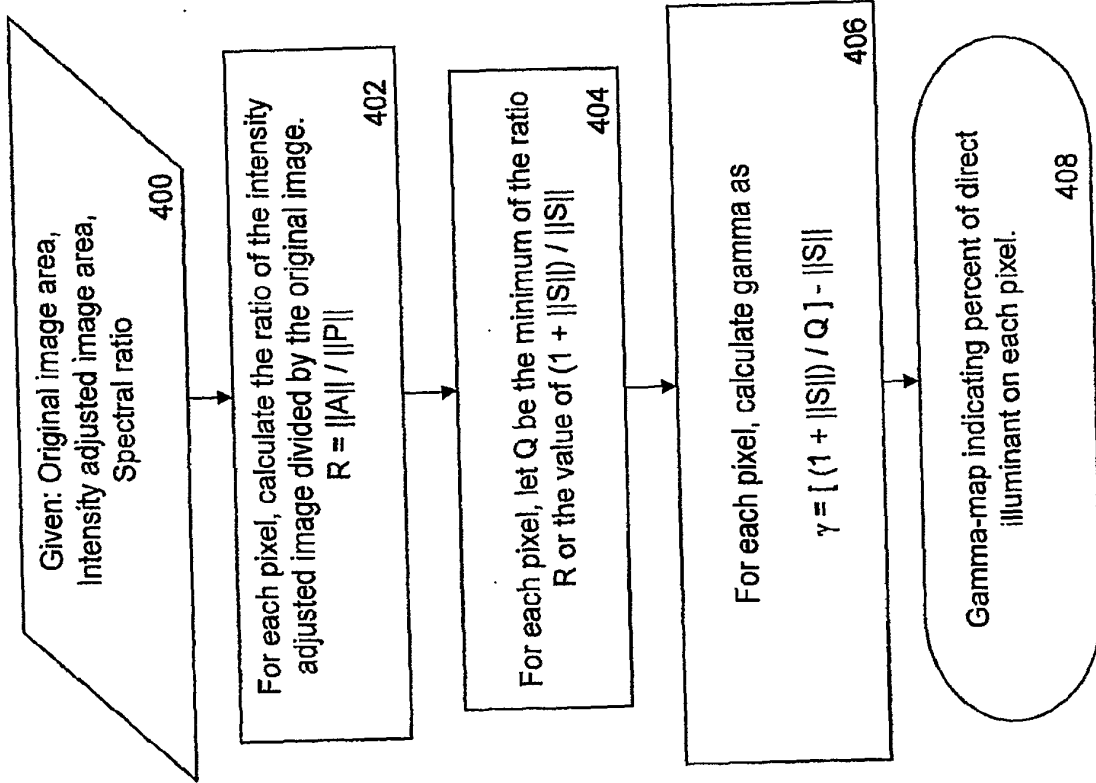


Figure 6C: Estimating Gamma Using a Dynamic Range Compression Algorithm

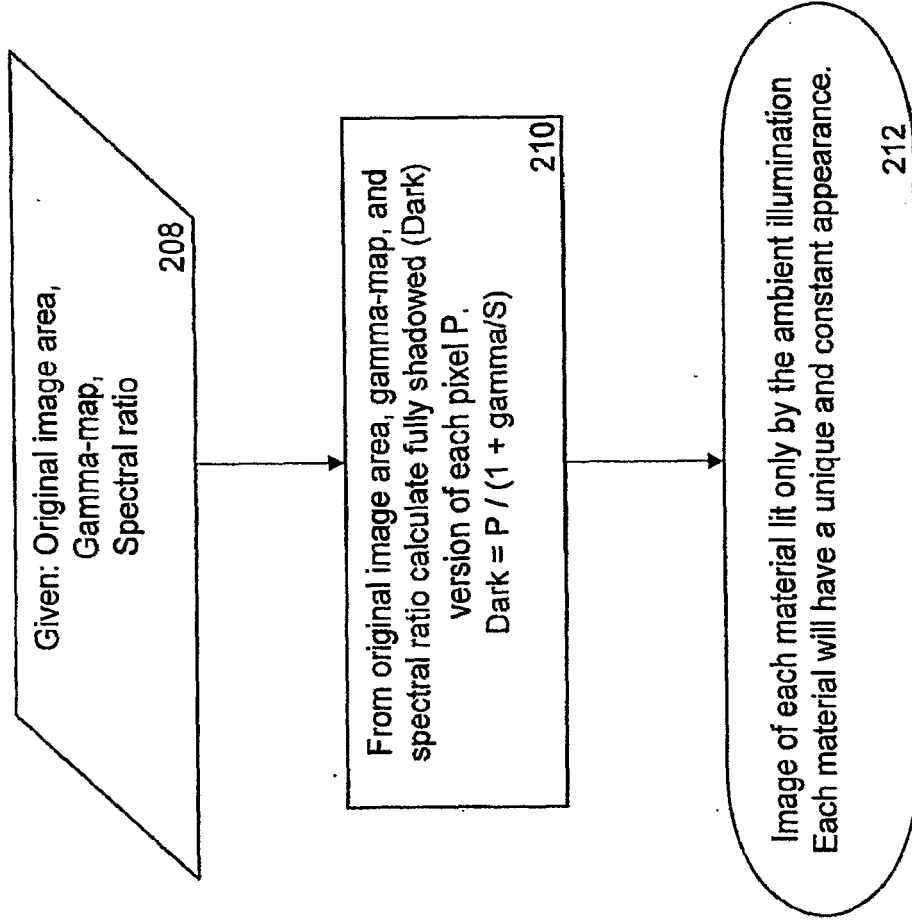


Figure 7: Removing Direct Illumination From an Image Area

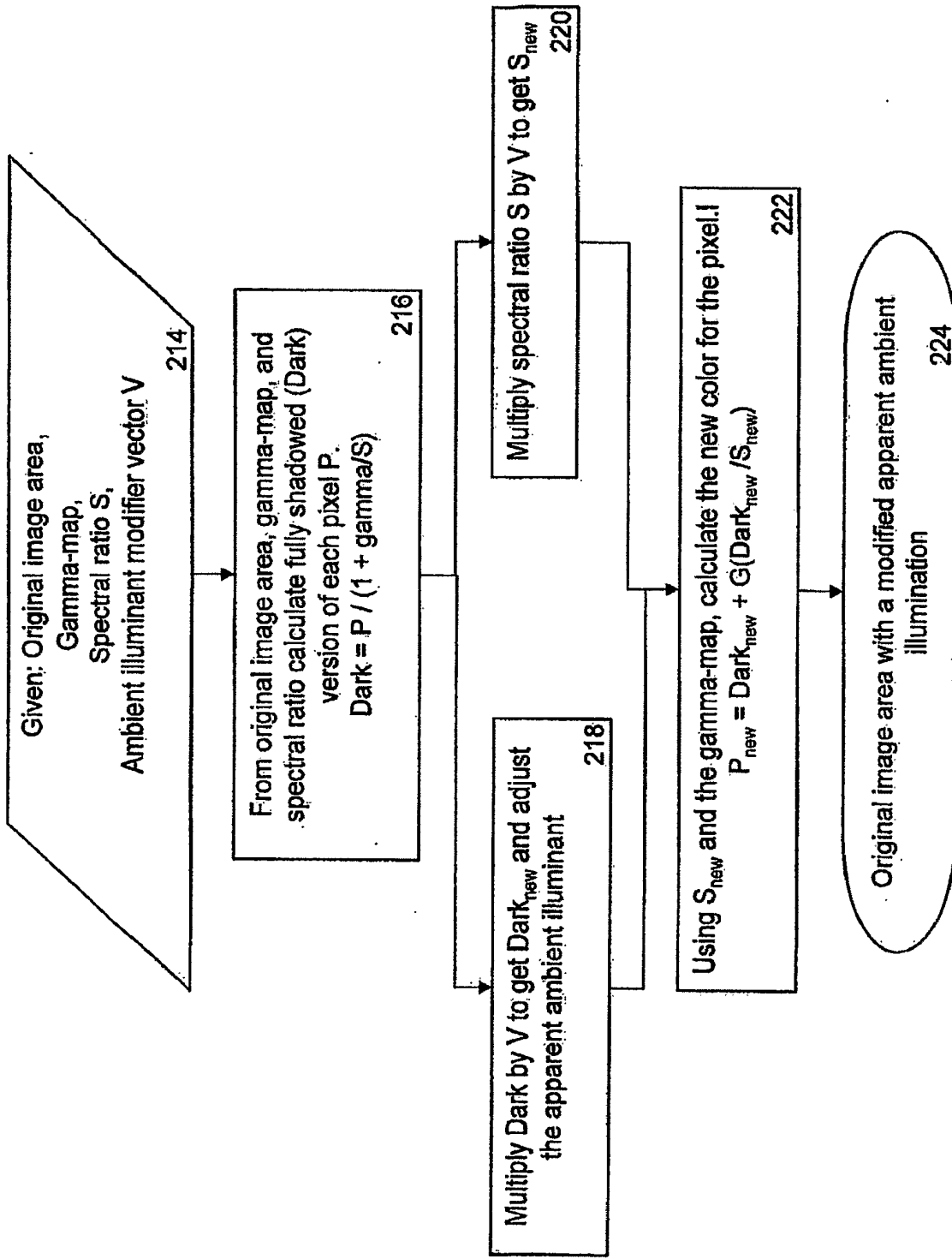


Figure 8: Modifying the Apparent Ambient Illumination of an Image Area

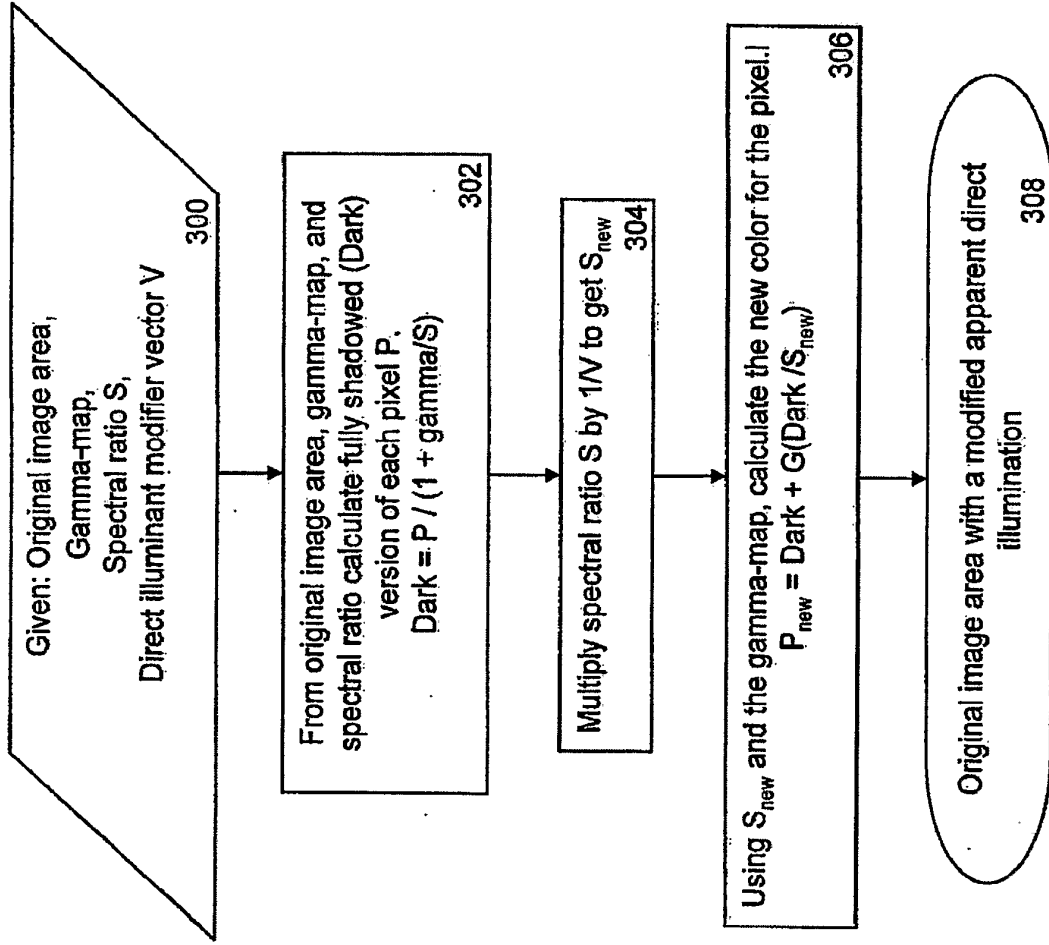


Figure 9: Modifying the Apparent Ambient Illumination of an Image Area

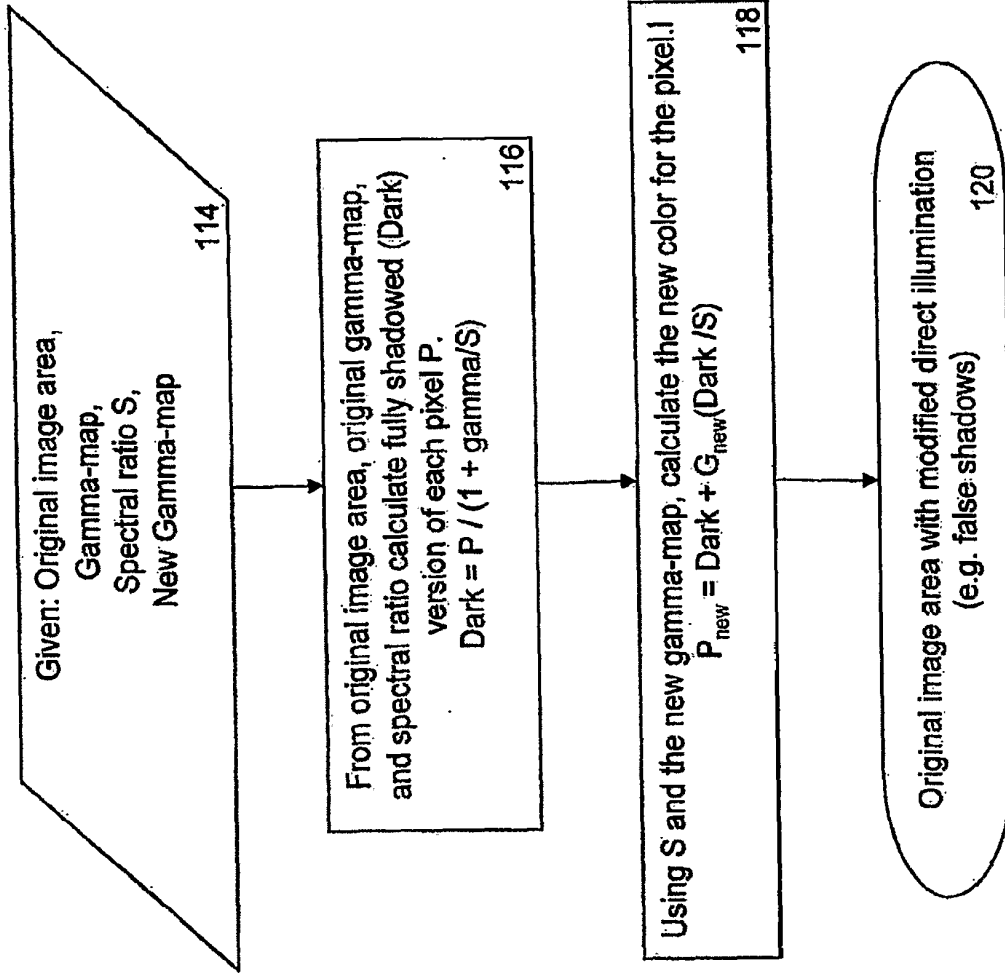


Figure 10: Modifying the Apparent Level of Direct Illumination of a Image Area

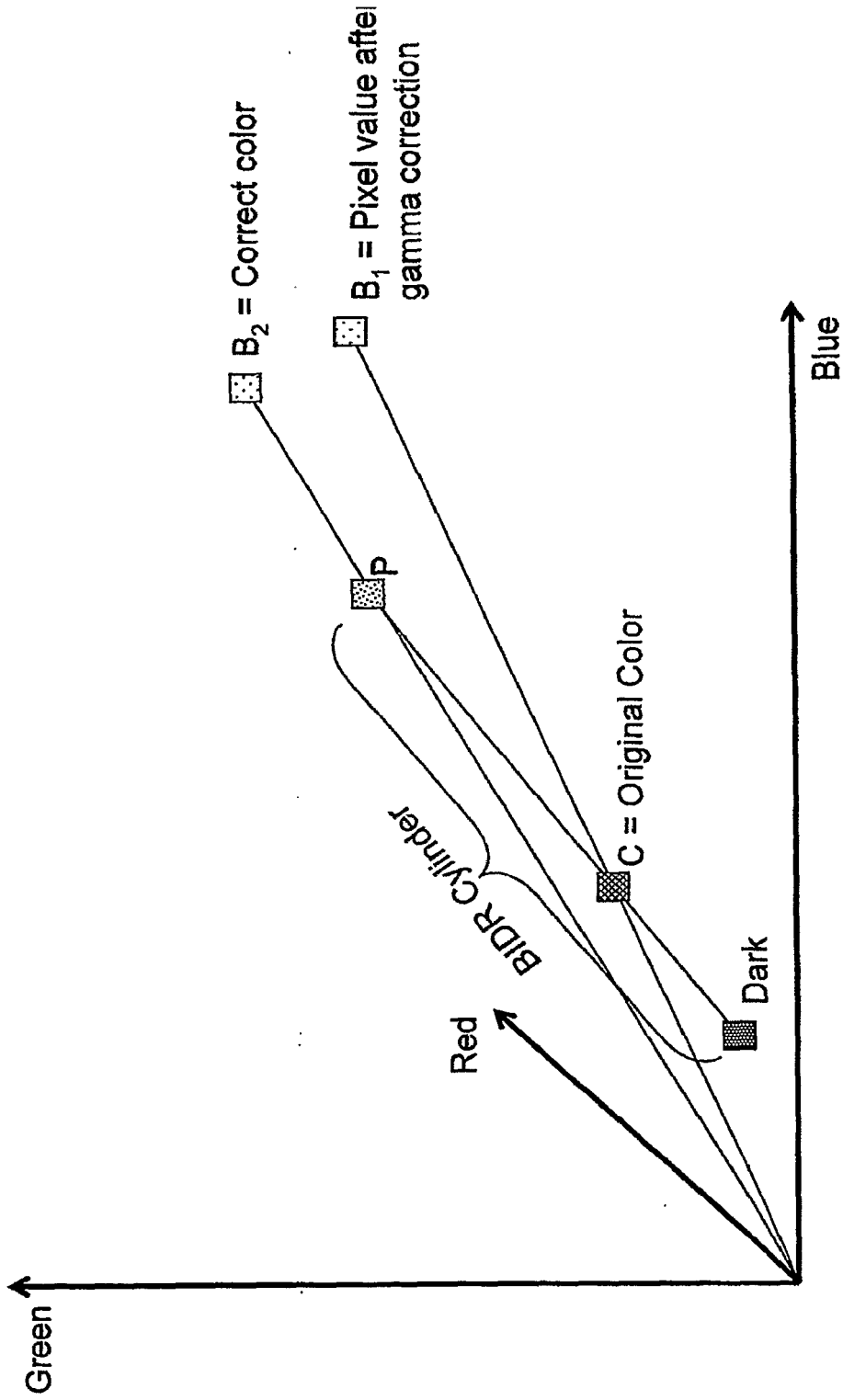


Figure 11. Diagram of color correct gamma correction.

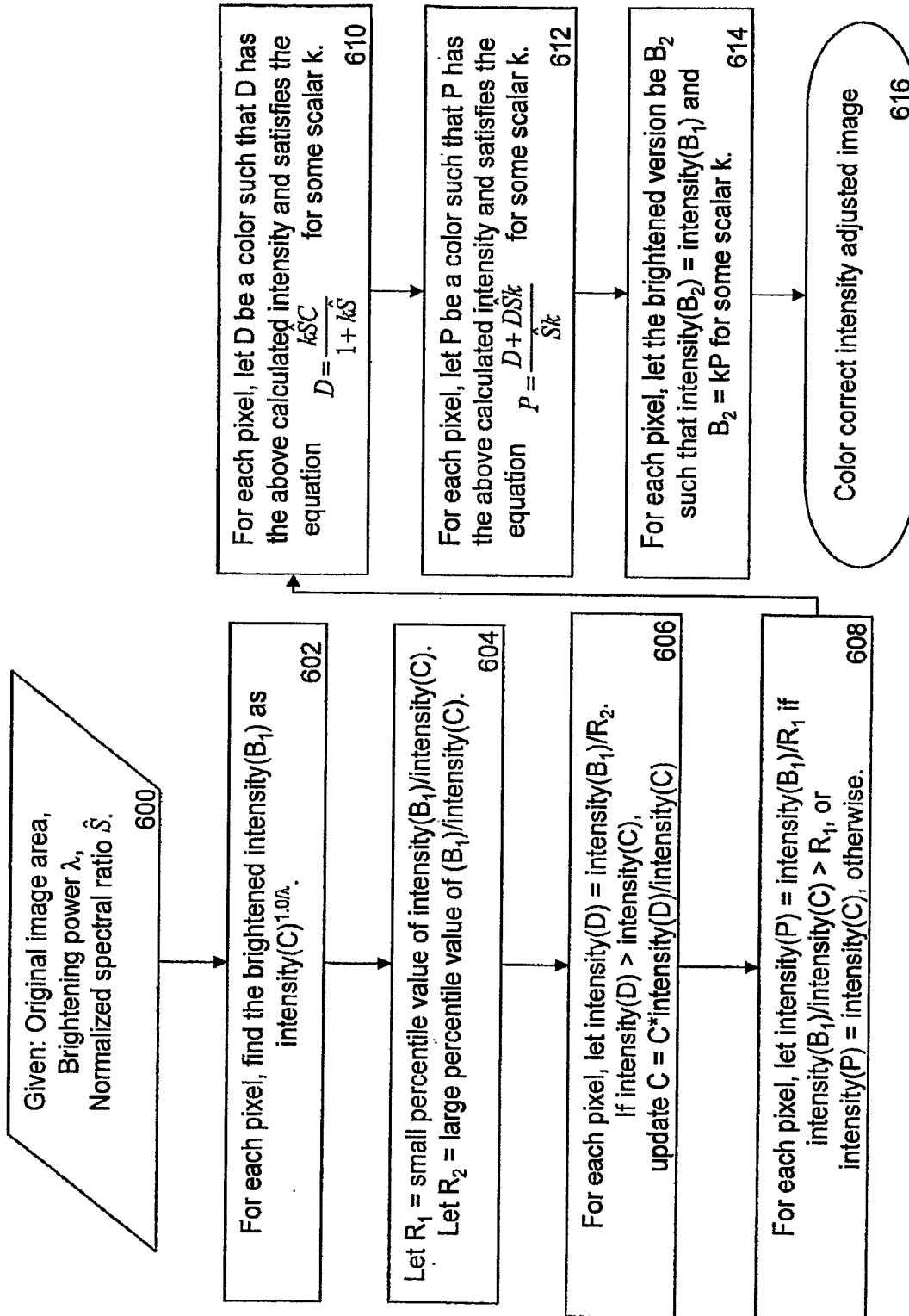


Figure 12: Color Correct Gamma Correction

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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- US 34175306 A [0031]

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- **RON GERSHON ; ALLAN D. JEPSON ; JOHN K. TSOTSOS.** Ambient illumination and the determination of material changes. *J. Opt. Soc. Am. A*, October 1986, vol. 3 (10), 1700-1707 [0007]