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(54) **BILATERAL FILTERING IN A DEMOSAICING PROCESS**

BILATERALE FILTERUNG IN EINEM PROZESS ZUR ENTFERNUNG VON MOSAIKEFFEKTEN

FILTRAGE BILATERAL DANS UN PROCESSUS DE DEMOSAIQUAGE

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Description

TECHNICAL FIELD

5 **[0001]** The invention relates generally to manipulating image information and more particularly to methods and systems for reconstructing an image from a mosaic pattern of intensity values for different colors.

BACKGROUND ART

10 **[0002]** A digital color image consists of an array of pixel values representing the color intensities at each point of the image. Typically, three colors are used to generate the image, with the intensity of each of the colors being identified for each pixel. In reconstructing the image, the three intensities are combined on a pixel-to-pixel basis to determine the image that is printed or displayed to a viewer.

[0003] Conventional color photography utilizes three overlapping color sensing layers having sensitivities in different
15 regions of the color spectrum. Typically, red, green and blue are the three selected colors. However, digital cameras are limited to a single array of sensors, so that there is only one "layer." Within this layer, each sensor determines the intensity of a particular color. As a result, the sensor array does not produce a color image in the traditional sense, but rather a collection of individual color samples. The assignment of the colors to the individual pixels within the array is sometimes referred to as the color filter array (CFA) or the color "mosaic pattern." To produce a true color image, with
20 a full set of color samples at each pixel, a substantial amount of computation is required to estimate the missing information. The computational operation is typically referred to as "demosaicing."

[0004] Since only one color is sensed at each pixel, two-thirds of the spectral information is missing. To generate the missing information at a particular pixel, information from neighboring pixels may be used, because there is a statistical dependency among the pixels in the same region of a particular image. A number of demosaicing algorithms are available.
25 "Bilinear interpolation" is an approach that attempts to minimize the complexity of the demosaicing operation. A bilinear interpolation algorithm interpolates color intensities only from the same-color sensors. That is, the red sensors are treated independently from the green and blue sensors, the green sensors are treated independently from the red and blue sensors, and the blue sensors are treated independently from the red and green sensors. To provide a red intensity value at a given pixel, the values measured by the red sensors in a designated size neighborhood (e.g., in a neighborhood
30 of nine sensors having the given pixel as its center) are interpolated. If the mosaic pattern of sensors is a Bayer pattern (i.e., a repeating 2×2 sensor array kernel having two green sensors diagonally positioned within the kernel and having one red sensor and one blue sensor), the bilinear interpolation algorithm may use twelve kernels of convolution to reconstruct the image. However, while the approach of isolating the different colors in the demosaicing operation provides a relatively low level of computational overhead, the reconstructed image lacks the sharpness of conventional color
35 photography. As will be explained below, there is an unfortunate tradeoff between minimizing artifacts and maximizing sharpness.

[0005] Another approach is described in U.S. Pat. No. 5,475,769 to Wober et al. In this approach, the color sensors are no longer treated as being independent of sensors of other colors. As in the bilinear interpolation approach, a defined-size neighborhood of pixels is "moved" about the mosaic pattern and an intensity value is determined for the pixel that
40 is at the center of the neighborhood. Each pixel in the neighborhood is weighted for each color sensitivity relative to the center pixel. The missing color intensity values for each sensor pixel are estimated by averaging the weighted pixels in the neighborhood for each color band. The neighborhood data and the pixel data are arranged in a matrix and vector expression having the form A*W=X, where A is a matrix of neighborhood values, W is a vector representing the weighting coefficients, and X is a vector of color components of the particular wavelength of the center pixel. The weighting
45 coefficients may be determined using a linear minimum mean square error (LMMSE) solution.

[0006] A single pixel array may be viewed as consisting of a number of separate planes of pixels in which each plane has sensors of the same color. Since the pixels do not overlap, the sensors in the various planes are at different locations. Demosaicing approaches that take weighted averages across more than one monochromatic plane make use of the statistical dependencies among the sample locations. In effect, the blurring of an image by the camera optics allows a
50 true object edge (i.e., an edge of one of the objects being imaged) that would exist precisely on the sensors of one of the monochromatic planes to also be seen in the other color planes, since the image is spread by the blurring onto the sensors of the other monochromatic planes.

[0007] While the blurring that is introduced by the camera optics aids in the demosaicing operation to reconstruct an image, the demosaicing operation should not enhance the blurring or add any other artifacts to the reconstructed image.
55 The goal of demosaicing algorithms should be to faithfully reconstruct the image, so as to provide a true-color, sharp print or display. One problem is that the interpolation approaches tend to introduce artifacts at abrupt changes in intensity. As an example of an abrupt transition, a digital picture that is captured in a poorly lit room will have a sharp transition along any source of illumination. Sharp transitions also occur at borders between two bright colors. Because most known

interpolation algorithms provide estimation within a neighborhood that is not dependent upon identifying transitions, the averaging that occurs along the transitions will consider both the high intensity values on one side of the transition and the low intensity values on the opposite side. This space-invariant interpolation dulls the image along the transition. That is, the reconstructed image loses some of its sharpness. The degree of sharpness loss will partially depend on the emphasis on controlling the introduction of artifacts at the abrupt intensity transitions (i.e., there is a sharpness/artifact tradeoff).

[0008]   A space-invariant approach that is designed to increase sharpness may be referred to as the Generalized Image Demosaicing and Enhancement (GIDE) approach of David Taubman. GIDE minimizes an error estimate of the original scene reconstruction on the basis of factors that include sensor characteristics, models of the relevant imaging system and Wide Sense Stationary (WSS) noise, and prior image statistical models. The approach is outlined in a publication by David Taubman entitled, "Generalized Wiener Reconstruction of Images from Colour Sensor Data Using a Scale Invariant Prior," Proceedings of the International Conference on Image Processing (ICIP 2000), Vancouver, Canada, September, 2000. While the approach works well in most instances, there is a tendency to "oversharpen" at the edges of abrupt changes in intensity. That is, if there is an abrupt transition from a first intensity level to a significantly higher second intensity level, the interpolated pixel values for pixels immediately before the transition may drop significantly below the first level, while the pixels located at and immediately after the abrupt transition may be assigned interpolated pixel values that are significantly above the second intensity level. The oversharpening introduces artifacts into the reconstructed image. While the artifacts are less visually displeasurable than those introduced by other approaches, the artifacts are apparent.

[0009]   A space-variant approach is described in U.S. Pat. Nos. 5,373,322 to Laroche et al. and 5,382,976 to Hibbard, each of which is assigned to Eastman Kodak Company. The Laroche et al. patent relates to interpolating chrominance values, while the Hibbard patent uses the same techniques for interpolating luminance values. Regarding Laroche et al., a digital processor obtains gradient values from the differences between chrominance values in the vertical image directions and the horizontal image directions from a particular pixel of interest. The gradient values are compared with each other in order to select one of the directions as the preferred orientation for the interpolation of additional chrominance values. The interpolation is then performed upon values that are selected so as to agree with the preferred orientation. By performing the comparison of the gradient values, edge artifacts are reduced and image sharpness is enhanced.

[0010]   U.S. Pat. No. 5,875,040 to Matraszek et al. is another Eastman Kodak Company patent that calculates a direction before pixel interpolation is performed. The Matraszek et al. patent is used to correct defect pixels in a defect region of a source image. The method includes the step of searching for edges in a non-defect region of the image having the defect region. Once the edges of the non-defect region are identified, pixel signals for the defect region are based on the pixel signals for non-defect pixels lying in a direction from the defect pixel which is determined by the direction of the edge. Preferably, both a directional angle and a magnitude are calculated in the detection of the edges. An edge directional angle is defined as being perpendicular to the gradient direction at the pixel being considered. One way of locating the edges is described as selecting the non-defect region as a "sliding" window of limited dimensions adjacent to the defect region, with the window defining a local non-defect region. The patent notes that adjacent does not necessarily mean immediately adjacent, since there may be some preselected distance separating the center of the window or the end of the window from the defect region. The edge of the window can then be located using a gradient field. Using the described method, pixel values can be based upon pixel values from non-defect regions.

[0011]   By properly selecting the direction from which other pixel values are to be selected in the determination of a particular pixel value, the introduction of artifacts can be controlled. However, the process of first determining the direction and then determining the pixel value is computational complex. Numerous iterations may be necessary.

[0012]   What is needed is a method and system for faithfully reconstructing an image from a mosaic pattern of color information without a high level of computational overhead.

[0013]   Kimmel R "Demosaicing: image reconstruction from color CCD samples", IEEE Transactions on Image Processing, Sept 1999, IEEE, vol. 8, no. 9, pages 1221-1228, XP002237072, ISSN: 1057-7149, discloses an iterative scheme for image reconstructions. First, colour samples for a green plane are completed. Colour samples for red and blue planes are then computed based on the reconstructed green plane. Finally, an iterative process is used to refine the reconstructed red, green and blue values. This document does not disclose the use of P_s x P_t different convolution kernels. This document also does not disclose the weighting of kernel values based on photometric similarity between two pixel locations.

SUMMARY OF THE INVENTION

[0014]   According to aspects of the present invention, there are provided a method and a system as set out at claims 1 and 6, respectively.

[0015]   Preservation of intensity transitions is enhanced in a demosaicing operation by utilizing bilateral filtering, which will be explained below. As a result, interpolations among neighboring pixels in a mosaic pattern of color pixels are

based upon factors that include the relative position and photometric similarity of pixel values within a window that is intensity insensitive. By "intensity insensitive "what is meant is that the position of the window is not a function of photometric similarity or dissimilarity within an image. Rather, photometric similarity is a factor after the position of the window has been determined. Thus, within a fixed-orientation window for determining an intensity value for a specific pixel, intensity values of pixels that are physically close are given greater weight than intensity values of more distant pixels and, simultaneously, intensity values that are quantitatively similar are given greater weight than intensity values that are quantitatively dissimilar. By reducing the effect of pixels on one side of an abrupt intensity transition in determining the interpolated intensity values on the opposite side of the abrupt intensity transition, the sharpness of the transition is enhanced in the reconstructed image. Thus, the adverse effects of the conventional tradeoff between sharpness and artifact-free reconstruction are at least partially eliminated.

[0016] In the context of the present invention, a mosaic pattern comprises a plurality of repeated base patterns. In some embodiments, the base pattern may be the 2 x 2 Bayer pattern. At least P_s x P_t different convolution kernels are used, where P_s is the number of possible colour arrangements within a base-pattern shaped window as said base-pattern shaped window is moved with respect to the mosaic pattern, and where P_t is the number of different colours in said mosaic pattern. In some portions of the remainder of this description, the base-pattern shaped window will be referred to as a "given-sized window" or a "given-sized neighborhood".

[0017] While the invention may be used with bilinear interpolation demosaicing, another embodiment is one in which all of the intensity values within a given-sized window of the mosaic pattern are considered in determining the intensity values for pixels in the general center of the neighborhood ("general" center because the precise center may not coincide with the physical location of any pixel, depending on the parameters of the given-sized window). Thus, demosaicing includes utilizing at least P_sxP_t different convolution kernels, where P_s is the number of possible color arrangements within the given-sized neighborhood and where P_t is the number of different colors in the mosaic pattern. For a Bayer pattern P_s=4 and P_t=3, so that there will be twelve convolution kernels.

[0018] In the bilateral filtering, a similarity function that is indicative of the photometric similarity among intensity values of neighboring pixels is algorithmically combined with determinations of the relative position of the neighboring pixel locations. For each pixel in an image to be reconstructed, the similarity function is applied after the neighborhood of relevant pixels has been selected. As a result of the algorithmic combination, statistical dependencies among the intensity values within the selected neighborhood are more reliably estimated. In one embodiment, the similarity function defines coefficients that are multiplied by the determinations of relative position. In this embodiment, the similarity function returns coefficients that are close to "1" for small absolute photometric dissimilarity and tends to "0" as the photometric dissimilarity is increased. Thus, the similarity function will have little effect in image regions with slowly varying intensities, but will inhibit artifacts around highly contrasted transitions within the image.

[0019] The demosaicing process may be considered as forming a number of monochromatic image planes, such as a green image plane, a red image plane and a blue image plane. In one embodiment, each output image plane has the same number of pixels as the original mosaic pattern and each pixel includes an intensity value. Thus, each pixel location is assigned three intensity values (i.e., one intensity value for each mono-chromatic image), with each intensity value being based upon the relative positions of the pixel location to selected other pixel locations and photometric similarities to intensity values of the selected pixel locations. The selected pixel locations are those that are contained within the given-sized window that has the particular pixel location as its general center, since the position and orientation of the window are intensity insensitive. It should be noted that the shape of the window is not important to the practice of the invention.

[0020] The system for carrying out the invention includes a two-dimensional array of sensors in which the sensors are color-specific. While not critical, the sensors may be arranged in the Bayer pattern. Connected to the sensor array is an input that receives signals in a format representative of the mosaic pattern. Demosaicing process software/hardware is enabled to generate intensity values for each of the different colors at each of the discrete pixel locations of the original mosaic pattern. The demosaicing capability includes a bilateral filter that is configured to access the spectral information of the mosaic pattern and to process the spectral information such that intensity values are generated on the basis of both relative position of pixel locations and photometric similarity of spectral information. In one embodiment, the demosaicing capability also includes a multiplier having a first input that is responsive to calculations of relative position between first and second pixel locations within the mosaic pattern and having a second input that is responsive to calculations of photometric similarity between the spectral information contained within the first and second pixel locations. For embodiments in which the mosaic pattern is the Bayer pattern, twelve stored convolution kernels having adaptive coefficients are utilized.

[0021] An advantage of the invention is that known linear reconstruction filters, such as Wiener filters, may be modified to become transition and texture sensitive. Apart from being adaptive, the demosaicing having bilateral filtering requires no iterations. This is in contrast to systems in which edges of abrupt intensity (color or luminance) must be identified before interpolation can occur. The transition and texture sensitivity is achieved by causing the process to become space variant, but with only a small amount of additional computational overhead. Applying bilateral filtering to "correct" artifacts

in demosaicing may be used in applications such as digital cameras in order to enhance sharpness in the reconstruction of a substantially artifact-free image.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022]

Fig. 1 is a schematic representation of a demosaicing operation in accordance with one embodiment of the invention.

Fig. 2 is a plot of intensity as a function of distance across one of the output planes of Fig. 1, with the intensity measures being unfiltered.

Fig. 3 is a plot of the same determination of intensity, but with filtering in accordance with the prior art.

Fig. 4 is the same plot of intensity as Fig. 2, but with bilateral filtering in accordance with the invention.

Fig. 5 is a schematic diagram of selected components of a demosaicing system in accordance with the prior art.

Fig. 6 is a schematic diagram of selected components of one embodiment of a demosaicing system having bilateral filtering in accordance with the invention.

Fig. 7 is a schematic diagram of a second embodiment of a demosaicing system having bilateral filtering in accordance with the invention.

DETAILED DESCRIPTION

[0023]   With reference to Fig. 1, an image sensor array 10 is represented by a mosaic pattern that follows an arrangement referred to as a Bayer pattern. The sensor array is a color-sampling device that acquires its samples using a number of discrete color-specific detectors. The array may have 1500 columns and 1500 rows, but the values of M and N are not critical to the invention.

[0024]   The image that is captured using the sensor array 10 may be considered as being decomposed into four input image planes 12, 14, 16 and 18. Each input image plane satisfies two conditions. First, the planes have the identical number of samples within a horizontal and vertical sampling interval. Second, all of the samples in a given input image plane must have identical color properties, although multiple image planes can have the same color properties. For example, the image planes 12 and 18 include green samples, as indicated by the letter "G." Image plane 14 includes all of the samples that are specific to the color blue, as indicated by the letter "B," while image plane 16 includes all of the red samples from the sensor array 10, as indicated by the letter "R." While the illustrated embodiment shows a Bayer pattern, any regular sampling lattice can be decomposed into a set of image planes as shown in Fig. 1.

[0025]   In Fig. 1, there are a total of three different colors (P_t=3) and there are four possible color arrangements (P_s=4) within a two-by-two neighborhood of pixels. The number of possible color arrangements is consistent with the four imaging planes 12, 14, 16 and 18. In this illustrated embodiment, demosaicing utilizes twelve convolution kernels ($P_s \times P_t$=12). The twelve convolution kernels are selected on the basis of which of the input image planes contains the sample for the pixel that is at the present center of the movable neighborhood in which interpolation occurs and on the basis of which monochromatic output plane 20, 22 and 24 is presently being constructed. Each monochromatic output plane contains interpolated intensity values that are derived from the intensity values of the input image planes 12, 14, 16 and 18. Techniques for deriving the output intensity values are known in the art. For example, linear interpolation may be used. However, in one embodiment, the Generalized Image Demosaicing and Enhancement (GIDE) approach is employed. In this approach, the scene statistics and physical properties of the acquisition device (e.g., the focusing optics for the sensor array 10) are considered in producing convolution kernels.

[0026]   A concern with the known approaches to deriving the intensity values of the monochromatic output planes 20, 22 and 24 is that artifacts are often introduced into the final image that is formed from the output planes. Notably, artifacts are often introduced as a result of abrupt intensity transitions within the captured image. Referring now to Fig. 2, a graph of intensity as a function of distance across a sensor array 10 is shown as including two abrupt transitions 26 and 28 on opposite sides of a plateau 30. The response shown in Fig. 2 may occur when the pixels corresponding to the plateau 30 image a light source, while the pixels on opposite sides of the plateau image dark areas. The flat regions of the response of Fig. 2 are unsmooth, since some noise is generated in capturing the imaging signal.

[0027]   One source of artifacts is most clearly understood when referring to bilinear interpolation. As previously noted, bilinear interpolation bases pixel values upon neighboring pixel values for sensors of the same color. As an example, for a pixel within the red image plane 16 of Fig. 1, only pixel values of the same image plane are considered in an interpolation step. Since the Bayer pattern has alternating rows of red pixels and blue pixels, a diagonally extending abrupt intensity transition will have an easily detectable remnant of the mosaic pattern when the edge of the abrupt intensity transition is closely viewed in the reconstructed image. This remnant will appear as a diagonal pattern of alternating red and blue pixels along the transition.

[0028]   A second source of artifacts will be described with reference to Figs. 2 and 3. The abrupt transitions 26 and

28 of Fig. 2, as captured by the sensor array 10 of Fig. 1, are blurred if the intensity values of the monochromatic output planes 20, 22 and 24 are determined using a simple averaging approach to interpolation. For example, the interpolated intensity values prior to the abrupt transition 26 will be determined to be inaccurately high, since they will be averaged with the intensity values with at least some of the pixels corresponding to the plateau 30. Similarly, the initial intensity values of the plateau 30 will be inaccurately low, since they will be averaged with the pixels immediately prior to the abrupt transition 26. A similar "smoothing" will occur at the abrupt downward transition 28. The resulting response 32 is represented in Fig. 3. Such a response is most likely to occur if demosaicing is used with linear filtering.

[0029]   The GIDE approach and other interpolation approaches address this "smoothing" concern in a manner that presents another type of color artifact. This artifact may be referred to as "oversharpening." Still referring to Figs. 2 and 3, a pixel that precedes the abrupt transition 26 may be "depressed" in order to overcome the error that would be introduced by simple averaging. Similarly, a pixel which immediately follows the abrupt transition 26 may be inflated in order to overcome the averaging difficulties. However, often overcompensation will occur, so that pixels immediately before the abrupt transition will be assigned values that are too low, while pixels immediately following the transition will be assigned values that are statistically too high. Similar ascending and descending humps in the response will occur on opposite sides of the second abrupt transition 28, but in the opposite order.

[0030]   In accordance with the invention, the artifacts are avoided by incorporating demosaicing convolution kernels into the framework of bilateral filtering. Thus, in addition to utilizing relative position as a basis for interpolating intensity values, photometric similarity is considered. Referring to Fig. 4, the use of bilateral filtering preserves the abrupt transitions 26 and 28 on opposite sides of the plateau 30. Consequently, a sharper final image is rendered by the process. The use of such filtering to perform denoising (as opposed to demosaicing) is described by C. Tomasi and R. Manduchi in the publication entitled "Bilateral Filtering for Gray and Color Images," Proceedings of the 1998 IEEE International Conference on Computer Vision. Bombay. India.

[0031]   "Relative position" as used herein refers to the consideration of the coordinates of two pixels for which intensity values are being considered. Referring to Fig. 1, the relative position of a first pixel i,j with respect to a second pixel a, b may be determined simply on the basis of the coordinate i-a, j-b. In a demosaicing operation, a "movable" window is used and the pixel i,j for which an intensity value is being interpolated is located at the general center and is compared with the intensity value for each other pixel (ξ) in the neighborhood. In accordance with the invention, the shape of the window is not critical and the position and orientation of the movable window are insensitive to the abrupt transitions. That is, the window for a given pixel is intensity insensitive.

[0032]   "Photometric similarity" as used herein refers to the extent to which two pixel values are quantitatively similar. Referring to Fig. 2, the pixel values in the region prior to the abrupt upward transition 26 are photometrically similar. Similarly, the intensity values for the pixels aligned with the plateau 30 are photometrically similar. However, the intensity values for pixels on opposite sides of the abrupt transition 26 are photometrically dissimilar.

[0033]   Incorporating linear interpolation convolution kernels into the framework of bilateral filtering provides a result in which for every pixel position (i,j) in the input image I captured by the sensor array 10 of Fig. 1, a filtered output h(i,j) is returned according to the following equation:

$$h(i,j) \; = \; \frac{\Sigma_a \Sigma_b I(a,b) k(i-a, j-b) s[I(i,j)-I(a,b)]}{\Sigma_a \Sigma_b k(i-a, j-b) s[I(i,j)-I(a,b)]} \tag{1}$$

where $k(\cdot,\cdot)$ is a predefined two-dimensional spatial kernel which considers relative positions and $s(\cdot)$ is a predefined one-dimensional similarity function that incorporates photometric similarity. Thus, k(i-a,j-b) is responsive to the relative position between the pixel position (i,j), and a nearby pixel position (a,b), while s[I(i,j)-I(a,b)] is responsive to the degree to which intensity values at positions (i,j) and (a,b) are similar. In one embodiment, the spatial kernels are determined by GIDE, so that the incorporation into the bilateral filtering may be referred to as BiGIDE. However, other demosaicing kernels may be used.

[0034]   While the embodiment that uses Equation 1 has advantages, other algorithms that incorporate convolution kernels into the framework of bilateral filtering may be used. However, if Equation 1 is employed, particular interest is given to similarity functions that return a value close to "1" for small absolute dissimilarity values and that return values tending to "0" as the photometric dissimilarity increases. For example, in Fig. 2, the intensity values along the plateau 30 are photometrically similar, so that the similarity function returns a value at or near "1." On the other hand, intensity values on opposite sides of the abrupt transition 26 are photometrically dissimilar, so that the similarity function returns a value that is substantially closer to "0." In its simplest form, the similarity function may be Gaussian, with a crest of "1" that corresponds to a determination that two intensity values are identical. In this case, the similarity function will play only a small role in the demosaicing of image regions in which intensity values vary only slowly, but will function to reduce

incorporation of artifacts in high contrasted regions of the image.

[0035] Fig. 5 illustrates a prior art arrangement that enables demosaicing by linear convolution, but without bilateral filtering. A summation device 34 is used to accumulate values for forming one of the monochromatic output planes 20, 22 and 24 of Fig. 1. The summation device outputs C values for each coordinate position i,j in the sensor array 10, where C is the desired number of color planes in the output image process. Each output color plane is indexed by the symbol c, which assumes integer values ranging from one to C. Typically, C is equal to 3. For each output value, the summation device receives an input for each of the pixels a,b in the sensor array 10 that is located within a movable window having pixel i,j at its general center. The selection of the appropriate convolution kernel (k) that is utilized will depend upon the position p and the color c of the output. In the embodiment of Fig. 1, there will be twelve convolution kernels $k_{p,c}$, as previously explained.

[0036] The prior art application of Fig. 5 includes a multiplier 36 that is used in determining the value of $h_c(i,j)$. The intensity values at each of the pixels within the window having pixel i,j as its general center are multiplied by the result from the appropriate kernel $k_{p,c}$. This result is responsive to relative positioning. This process repeats for each pixel of the monochromatic output plane 22 and also repeats in forming the other two monochromatic output planes 20 and 24 of Fig. 1.

[0037] While relative positions are considered in providing the input to the multiplier 36 from kernel $k_{p,c}$, photometric similarity is not considered. Referring now to Fig. 6, the invention adds a differencing circuit 38 and a similarity function device 40, so that the system provides a determination of interpolated intensity values $h_c(i,j)$ that is responsive to both relative positions and photometric similarities within the movable window that defines the neighborhood having pixel i, j at its general center. The differencing circuit 38 determines the photometric "distance" between the intensity value at pixel i,j and the intensity value at a pixel a,b within the neighborhood. This sequentially occurs for each pixel within the neighborhood having pixel i,j as its general center.

[0038] The output of the differencing circuit 38 is the photometric distance that is received by the similarity function device 40. In one embodiment, the similarity function that is employed by the device 40 is Gaussian, with a crest of "1" that is output as a result of determining that the intensity values at pixel i,j and pixel a,b are identical. However, the output of the similarity function device tends toward "0" as the absolute of the output of the differencing circuit 38 increases.

[0039] A multiplier 42 has a first input from the similarity function device 40 that is responsive to photometric similarity and has a second input that is responsive to the relative positions of the pixels i,j and a,b. This second input may be identical to the one described with reference to Fig. 5. When the similarity function device 40 has an output of "1" (i.e., when the intensity at pixel i,j is equal to the intensity at pixel a,b), the input to the summation device 34 will be identical to the input that was described with reference to Fig. 5. On the other hand, if the intensity values at the two pixels are photometrically "distant," the physical proximity of the two pixels will have less effect than in the prior art arrangement.

[0040] The embodiment of Fig. 6 utilizes normalization. Thus, this embodiment incorporates all of the features of Equation 1, since the denominator of Equation 1 is designed to achieve normalization. The output of the multiplier is directed to the multiplier 36 and to a second summation device 43. The denominator of Equation 1 is the output of the second summation device 43, while the numerator is the output of the first summation device 34. A divider 45 receives the two outputs of the summation device and calculates $h_c(i,j)$. Normalization is not critical to the invention, so that the second summation device and the divider can be eliminated. In Fig. 6, the various components may be implemented in computer software (e.g., in different modules of an application program), in hardware, or in a combination of software and hardware.

[0041] Fig. 7 illustrates a second embodiment of the invention. In this system 44, a convolution system such as the one described in Fig. 5 is used to generate pre-demosaiced image $\hat{I}(i,j)$, the values of which are used selectively as inputs to the differencing module 38. Thus, pre-demosaicing of an image occurs in order to provide the color-specific values. If three color planes are being formed, the convolution system will provide three different intensity values for each pixel. The color component of $\hat{I}(i,j)$ selected as input to the differencing module 38 is the same mosaic color as that of the entry I(a,b), and is designated m(a,b). The selected color component is designated $\hat{I}_{m(a,b)}(i,j)$. Thus, for example, if the pixel (a,b) in the mosaic image is red (m(a,b) = red), then the red component of $\hat{I}(i,j)$ is considered. The remaining operations are identical to those that were described with reference to Fig. 6.

Claims

1. A method of manipulating image information comprising the steps of:

receiving said image information as intensity values (10) acquired from a mosaic pattern of pixel locations in which different pixel locations are specific to different colors, wherein the mosaic pattern comprises a plurality of repeated base patterns;
demosaicing said image information by:

i) utilizing at least P_s x P_t different convolution kernels ($k_{p,c}$), where P_s is the number of possible colour arrangements within a base-pattern shaped window as said base-pattem-shaped window is moved with respect to the mosaic pattern, where P_t is the number of different colors in said mosaic pattern, each of P_s and P_t being greater than 1, where each convolution kernel ($k_{p,c}$) comprises kernel values, and where for each convolution kernel ($k_{p,c}$), one of the kernel values is a central kernel value,
and by

ii) generating C monochromatic output planes by determining interpolated intensity values (20, 22, 24) for said pixel locations of said mosaic pattern, each determination of an interpolated intensity value ($h_c(i,j)$) being specific to a particular pixel location (i,j) and to a particular color of the C colors, and including the steps of:

selecting from the convolution kernels ($k_{p,c}$) a convolution kernel that corresponds to the particular color of the output plane and to the position of said pixel location (i, j) within the base pattern;
weighting (42) each kernel value, of the selected convolution kernel ($k_{p,c}$), by the photometric similarity (38, 40) between the pixel location (i,j) corresponding to the central kernel value and the pixel location (a, b) corresponding to the kernel value being weighted, and by the relative position between the pixel location (i, j) and the pixel location (a, b).

2. The method of claim 1 wherein said step of receiving said image information includes receiving data (10) representative of intensities of three colors (P_t=3) within a mosaic pattern in which P_s=4.

3. The method of claim 1, wherein said step of receiving said image information includes utilizing an array of pixel sensors (10) in which said base pattern is
RG
GB.

4. The method of claim 1 wherein said step of determining interpolated intensity values (20, 22, 24) includes applying a similarity function (40) which is indicative of said photometric similarity among intensity values (I(a, b)) of said pixel locations (a,b) within said convolution kernel ($k_{p,c}$), said similarity function being algorithmically combined with determinations of relative positions, of said particular pixel location (i,j) with respect to other pixel locations (a,b) in said convolution kernel ($k_{p,c}$), to define said interpolated intensity values,

5. The method of claim 1 wherein said step of determining interpolated intensity values (20, 22, 24) includes determining:

relative positions of said particular pixel location (i,j) with respect to each other pixel location (a,b) in said convolution kernel ($k_{p,c}$);
said photometric similarities of said particular pixel location (i,j) relative to each other pixel location in said convolution kernel ($k_{p,c}$); and
an interpolated intensity value that is responsive to said determinations of said relative positions and said photometric similarities.

6. A system for manipulating image information comprising:

means for receiving said image information as intensity values (10) acquired from a mosaic pattern of pixel locations in which different pixel locations are specific to different colors, wherein the mosaic pattern comprises a plurality of repeated base patterns;
means for demosaicing said image information by:

i) utilizing at least P_s x P_t different convolution kernels ($k_{p,c}$), where P_s is the number of possible colour arrangements within a base-pattern shaped window as said base-pattem-shaped window is moved with respect to the mosaic pattern, where P_t is the number of different colors in said mosaic pattern, each of P_s and P_t being greater than 1, where each convolution kernel ($k_{p,c}$) comprises kernel values, and where for each convolution kernel ($k_{p,c}$), one of the kernel values is a central kernel value,
and by

ii) generating C monochromatic output planes by determining interpolated intensity values (20, 22, 24) for said pixel locations of said mosaic pattern, each determination of an interpolated intensity value ($h_c(i,j)$) being specific to a particular pixel location (i, j) and to a particular color of the C colors, and including the steps of:

selecting from the convolution kernels ($k_{p,c}$) a convolution kernel that corresponds to the particular color of the output plane and to the position of said pixel location (i, j) within the base pattern;

weighting (42) each kernel value, of the selected convolution kernel ($k_{p,c}$), by the photometric similarity (38, 40) between the pixel location (i, j) corresponding to the central kernel value and the pixel location (a, b) corresponding to the kernel value being weighted, and by the relative position between the pixel location (i, j) and the pixel location (a, b).

7. The system of claim 6 wherein said means for demosaicing includes a multiplier (42) with a first input ($k_{p,c}$(i-a, j-b)) that is responsive to relative position between the pixel location (i,j) corresponding to the central kernel value and the pixel location (a,b) corresponding to the kernel value being weighted and having a second input that is responsive to said photometric similarity (40) of spectral information of said pixel locations.

8. The system of claim 6 wherein the means for demosaicing comprises a bilateral filter that is configured to apply a similarity function as a basis of said photometric similarity (40), said similarity function providing coefficients that decay toward zero with dissimilarity of spectral information.

Patentansprüche

1. Ein Verfahren, Bildinformation zu bearbeiten, welches die Schritte umfasst:

die Bildinformation als von einem Mosaikmuster von Pixelpositionen erlangte Intensitätswerte (10) zu empfangen, in dem verschiedene Pixelpositionen für verschiedene Farben spezifisch sind, wobei das Mosaikmuster mehrere wiederholte Grundmuster umfasst;

das Entfernen des Mosaikeffekts der Bildinformation durch:

i) das Verwenden von mindestens P_s x P_t verschiedenen Faltungskernen ($k_{p,c}$), wobei P_s die Anzahl an möglichen Farbanordnungen innerhalb eines grundmusterförmigen Fensters ist, während das grundmusterförmige Fenster in Bezug auf das Mosaikmuster bewegt wird, wobei P_t die Anzahl an verschiedenen Farben im Mosaikmuster ist und P_s und P_t jeweils größer als 1 sind, wobei jeder Faltungskern ($k_{p,c}$) Kernwerte umfasst und für jeden Faltungskern ($k_{p,c}$) einer der Kernwerte ein zentraler Kernwert ist, und durch

ii) das Generieren C-monochromatischer Ausgabeebenen, durch das Bestimmen interpolierter Intensitätswerte (20, 22, 24) für die Pixelpositionen des Mosaikmusters, wobei jede Bestimmung eines interpolierten Intensitätswertes (h_c (i, j)) für eine spezielle Pixelposition (i, j) und eine spezielle Farbe der C-Farben spezifisch ist, und die Schritte einschließt:

von den Faltungskernen ($k_{p,c}$) einen Faltungskern auszuwählen, welcher der speziellen Farbe der Ausgabeebene und der Position der Pixelposition (i, j) innerhalb des Grundmusters entspricht; das Gewichten (42) von jedem Kernwert des ausgewählten Faltungskerns ($k_{p,c}$) anhand der photometrischen Ähnlichkeit (38, 40) zwischen der Pixelposition (i, j), die dem zentralen Kernwert entspricht, und der Pixelposition (a, b), die dem gewichteten Kernwert entspricht, und anhand der relativen Lage zwischen der Pixelposition (i, j) und der Pixelposition (a, b).

2. Verfahren nach Anspruch 1, wobei der Schritt, die Bildinformation zu empfangen, das Empfangen von Daten (10), die repräsentativ für Intensitäten von drei Farben (P_t=3) innerhalb eines Mosaikmusters sind in dem P_s=4 ist.

3. Verfahren nach Anspruch 1, wobei der Schritt, die Bildinformation zu empfangen, das Verwenden einer Anordnung von Pixelsensoren (10) umfasst, in der das Grundmuster ist
RG
GB.

4. Verfahren nach Anspruch 1, wobei der Schritt des Bestimmens von interpolierten Intensitätswerten (20, 22, 24) das Anwenden einer Ähnlichkeitsfunktion (40) einschließt, die indikativ für die photometrische Ähnlichkeit unter Intensitätswerten (I(a, b)) der Pixelpositionen (a, b) innerhalb des Faltungskerns ($k_{p, c}$) ist, wobei die Ähnlichkeitsfunktion algorithmisch mit Bestimmungen von relativen Positionen der speziellen Pixelposition (i, j) in Bezug auf andere Pixelpositionen (a, b) im Faltungskern ($k_{p, c}$ kombiniert ist, um die interpolierten Intensitätswerte zu definieren.

5. Verfahren nach Anspruch 1, wobei der Schritt des Bestimmens von interpolierten Intensitätswerten (20, 22, 24) die Bestimmung einschließt:

relative Positionen der speziellen Pixelposition (i, j) in Bezug zu jeder anderen Pixelposition (a, b) im Faltungskern ($k_{p, c}$);
photometrische Ähnlichkeiten der speziellen Pixelposition (i, j) relativ zu jeder anderen Pixelposition im Faltungskern ($k_{p, c}$); und
ein interpolierter Intensitätswert, der auf die Bestimmungen der relativen Positionen und photometrischen Ähnlichkeiten reagiert.

6. Ein System, um Bildinformation zu bearbeiten, umfassend:

Mittel, um die Bildinformation als von einem Mosaikmuster von Pixelpositionen erlangte Intensitätswerte (10) zu empfangen, in dem verschiedene Pixelpositionen für verschiedene Farben spezifisch sind, wobei das Mosaikmuster mehrere wiederholte Grundmuster umfasst;
Mittel zum Entfernen des Mosaikeffekts der Bildinformation durch:

i) das Verwenden von mindestens P_s x P_t verschiedenen Faltungskernen ($k_{p, c}$), wobei P_s die Anzahl an möglichen Farbanordnungen innerhalb eines grundmusterförmigen Fensters ist, während das grundmusterförmige Fenster in Bezug auf das Mosaikmuster bewegt wird, wobei P_t die Anzahl an verschiedenen Farben im Mosaikmuster ist und P_s und P_t jeweils größer als 1 sind, wobei jeder Faltungskern ($k_{p, c}$) Kernwerte umfasst und für jeden Faltungskern ($k_{p, c}$) einer der Kernwerte ein zentraler Kernwert ist, und durch
ii) das Generieren C-monochromatischer Ausgabeebenen, durch das Bestimmen interpolierter Intensitätswerte (20, 22, 24) für die Pixelpositionen des Mosaikmusters, wobei jede Bestimmung eines interpolierten Intensitätswertes (h_c (i, j)) für eine spezielle Pixelposition (i, j) und eine spezielle Farbe der C-Farben spezifisch ist und die Schritte einschließt:

von den Faltungskernen ($k_{p, c}$) einen Faltungskern auszuwählen, welcher der speziellen Farbe der Ausgabeebene und der Position der Pixelposition (i, j) innerhalb des Grundmusters entspricht;
das Gewichten (42) von jedem Kernwert des ausgewählten Faltungskerns ($k_{p, c}$) anhand der photometrischen Ähnlichkeit (38, 40) zwischen der Pixelposition (i, j), die dem zentralen Kernwert entspricht, und der Pixelposition (a, b), die dem gewichteten Kernwert entspricht, und anhand der relativen Lage zwischen der Pixelposition (i, j) und der Pixelposition (a, b).

7. System nach Anspruch 6, wobei das Mittel für das Entfernen des Mitnahmeeffekts einen Multiplikator (42) mit einem ersten Eingang ($k_{p, c}$(i-a, j-b)) einschließt, der auf die relative Lage zwischen der Pixelposition (i, j), die dem zentralen Kernwert entspricht, und der Pixelposition (a, b), die dem gewichteten Kernwert entspricht, reagiert und der einen zweiten Eingang aufweist, der auf die photometrische Ähnlichkeit (40) der Spektralinformation von Pixelpositionen reagiert.

8. System nach Anspruch 6, wobei das Mittel für das Entfernen des Mosaikeffekts einen doppelseitigen Filter umfasst, der konfiguriert ist, eine Ähnlichkeitsfunktion als Basis der photometrischen Ähnlichkeit (40) anzuwenden, wobei die Ähnlichkeitsfunktion Koeffizienten bereitstellt, die mit einer Ungleichheit der Spektralinformation in Richtung auf Null abnehmen.

Revendications

1. Un procédé de manipulation d'informations d'image comprenant les étapes consistant à :

recevoir lesdites informations d'image telles que des valeurs d'intensité (10) acquises à partir d'un motif en mosaïque d'emplacements de pixel dans lequel différents emplacements de pixel sont spécifiques à des couleurs différentes, dans lequel le motif en mosaïque comprend une pluralité de motifs de base répétés ;
démosaïquer lesdites informations d'image en :

i) utilisant au moins P_s x P_t différents noyaux de convolution ($k_{p,c}$), où P_s est le nombre d'agencements de couleurs possibles dans une fenêtre en forme de motif de base à mesure que ladite fenêtre en forme de

motif de base est déplacée par rapport au motif en mosaïque, où P_t est le nombre de couleurs différentes dans ledit motif en mosaïque, chacun de P_s et de P_t étant plus grand que 1, où chaque noyau de convolution ($k_{p,c}$) comprend des valeurs de noyau, et où pour chaque noyau de convolution ($k_{p,c}$), l'une des valeurs de noyau est une valeur de noyau centrale,

et en

ii) générant C plans de sortie monochromatiques en déterminant des valeurs d'intensité interpolées (20, 22, 24) pour lesdits emplacements de pixel dudit motif en mosaïque, chaque détermination d'une valeur d'intensité interpolée ($h_c(i, j)$) étant spécifique à un emplacement de pixel particulier (i, j) et à une couleur particulière des C couleurs, et comprenant les étapes consistant à :

sélectionner parmi les noyaux de convolution ($k_{p,c}$) un noyau de convolution qui correspond à la couleur particulière du plan de sortie et à la position dudit emplacement de pixel (i, j) dans le motif de base ; pondérer (42) chaque valeur de noyau, du noyau de convolution sélectionné ($k_{p,c}$), par la similarité photométrique (38, 40) entre l'emplacement de pixel (i, j) correspondant à la valeur de noyau centrale et l'emplacement de pixel (a, b) correspondant à la valeur de noyau qui est pondérée, et par la position relative entre l'emplacement de pixel (i, j) et l'emplacement de pixel (a, b).

2. Le procédé selon la revendication 1, dans lequel ladite étape consistant à recevoir lesdites informations d'image comprend la réception de données (10) représentatives des intensités de trois couleurs (P_t=3) dans un motif en mosaïque dans lequel P_s=4.

3. Le procédé selon la revendication 1, dans lequel ladite étape consistant à recevoir lesdites informations d'image comprend l'utilisation d'un réseau de capteurs de pixel (10) dans lequel ledit motif de base est
RG
GB.

4. Le procédé selon la revendication 1, dans lequel ladite étape consistant à déterminer des valeurs d'intensité interpolées (20, 22, 24) comprend l'application d'une fonction de similarité (40), qui est indicative de ladite similarité photométrique parmi les valeurs d'intensité ($I(a, b)$) desdits emplacements de pixel (a, b) dans ledit noyau de convolution ($k_{p,c}$), ladite fonction de similarité étant combinée de manière algorithmique avec les déterminations des positions relatives, dudit emplacement de pixel particulier (i, j) par rapport aux autres emplacements de pixel (a, b) dans ledit noyau de convolution ($k_{p,c}$), pour définir lesdites valeurs d'intensité interpolées.

5. Le procédé selon la revendication 1, dans lequel ladite étape consistant à déterminer des valeurs d'intensité interpolées (20, 22, 24) comprend la détermination :

des positions relatives dudit emplacement de pixel particulier (i, j) par rapport à chaque autre emplacement de pixel (a, b) dans ledit noyau de convolution ($k_{p,c}$) ; desdites similarités photométriques dudit emplacement de pixel particulier (i, j) par rapport à chaque emplacement de pixel dans ledit noyau de convolution ($k_{p,c}$) ; et d'une valeur d'intensité interpolée qui est sensible auxdites déterminations desdites positions relatives et desdites similarités photométriques.

6. Un système pour manipuler des informations d'image, comprenant :

un moyen pour recevoir lesdites informations d'image telles que des valeurs d'intensité (10) acquises à partir d'un motif en mosaïque d'emplacements de pixel dans lequel différents emplacements de pixel sont spécifiques à des couleurs différentes, dans lequel le motif en mosaïque comprend une pluralité de motifs de base répétés ; un moyen pour démosaïquer lesdites informations d'image en :

i) utilisant au moins $P_s \times P_t$ différents noyaux de convolution ($k_{p,c}$), où P_s est le nombre d'agencements de couleurs possibles dans une fenêtre en forme de motif de base à mesure que ladite fenêtre en forme de motif de base est déplacée par rapport au motif en mosaïque, où P_t est le nombre de couleurs différentes dans ledit motif en mosaïque, chacun de P_s et de P_t étant plus grand que 1, où chaque noyau de convolution ($k_{p,c}$) comprend des valeurs de noyau, et où pour chaque noyau de convolution ($k_{p,c}$), l'une des valeurs de noyau est une valeur de noyau centrale, et en

ii) générant C plans de sortie monochromatiques en déterminant des valeurs d'intensité interpolées (20, 22, 24) pour lesdits emplacements de pixel dudit motif en mosaïque, chaque détermination d'une valeur

d'intensité interpolée (h_c(i,j)) étant spécifique à un emplacement de pixel particulier (i, j) et à une couleur particulière des C couleurs, et comprenant les étapes consistant à :

sélectionner parmi les noyaux de convolution ($k_{p,c}$) un noyau de convolution qui correspond à la couleur particulière du plan de sortie et à la position dudit emplacement de pixel (i, j) dans le motif de base ;
pondérer (42) chaque valeur de noyau, du noyau de convolution sélectionné ($k_{p,c}$), par la similarité photométrique (38, 40) entre l'emplacement de pixel (i, j) correspondant à la valeur de noyau centrale et l'emplacement de pixel (a, b) correspondant à la valeur de noyau qui est pondérée, et par la position relative entre l'emplacement de pixel (i, j) et l'emplacement de pixel (a, b).

7. Le système selon la revendication 6, dans lequel ledit moyen pour démosaïquer comprend un multiplicateur (42) avec une première entrée ($k_{p,c}$(i-a, j-b)) qui est sensible à la position relative entre l'emplacement de pixel (i, j) correspondant à la valeur de noyau centrale et l'emplacement de pixel (a, b) correspondant à la valeur de noyau qui est pondérée, et ayant une seconde entrée qui est sensible à ladite similarité photométrique (40) des informations spectrales dudit emplacement de pixel.

8. Le système selon la revendication 6, dans lequel le moyen pour démosaïquer comprend un filtre bilatéral qui est configuré pour appliquer une fonction de similarité comme base de ladite similarité photométrique (40), ladite fonction de similarité fournissant des coefficients qui décroissent vers zéro avec une dissimilarité des informations spectrales.
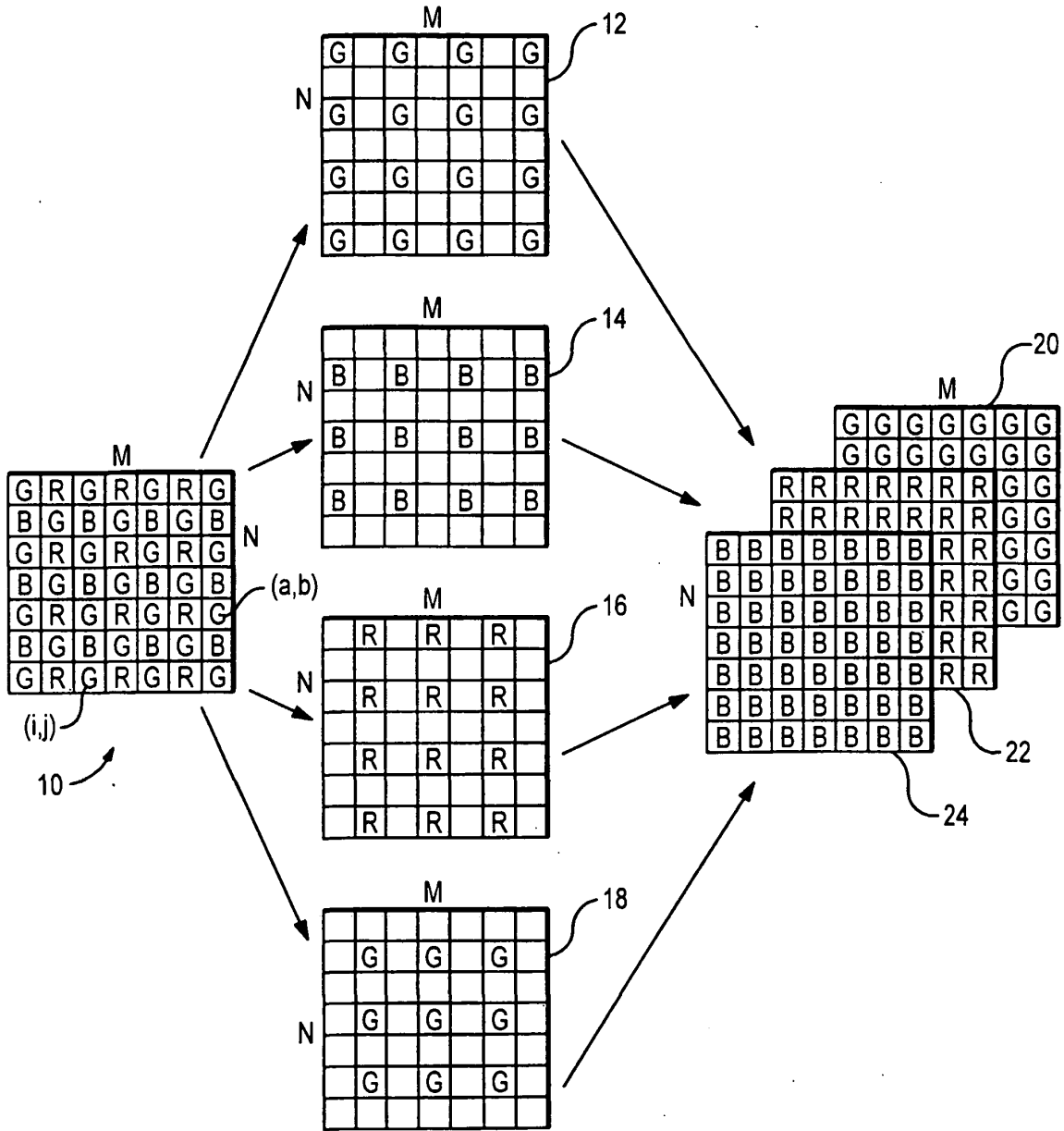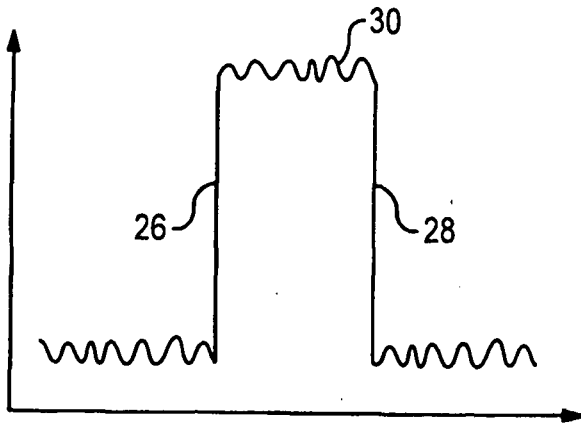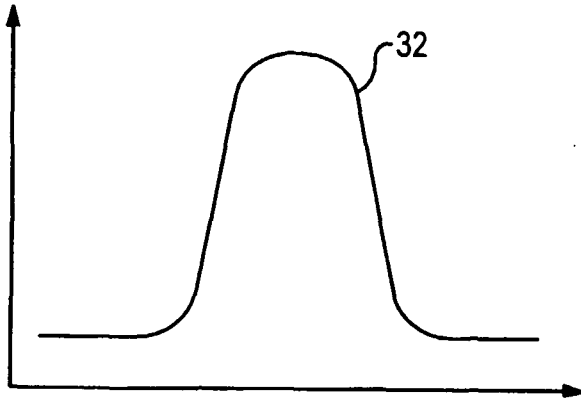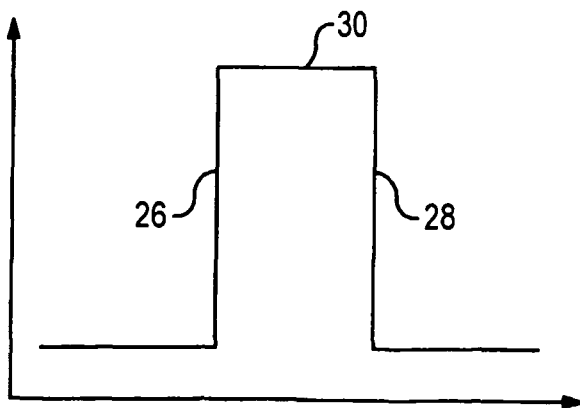
FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

$I(a,b)$

38

$\hat{I}_{m(a,b)}(i,j)$

40

36

42

$k_{p,c}(i\text{-}a,\ j\text{-}b)$
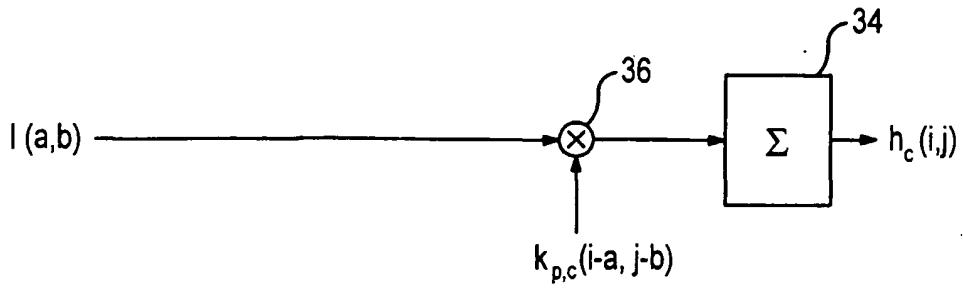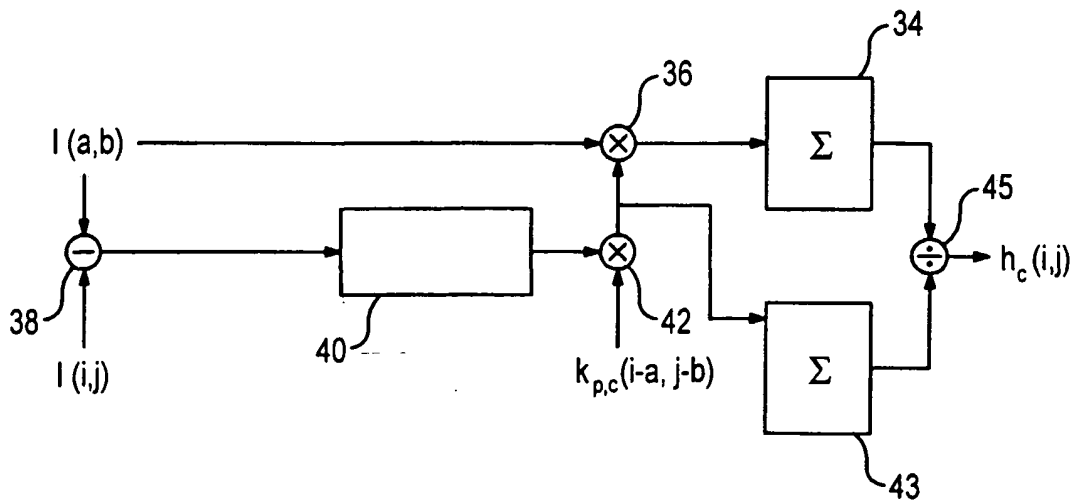
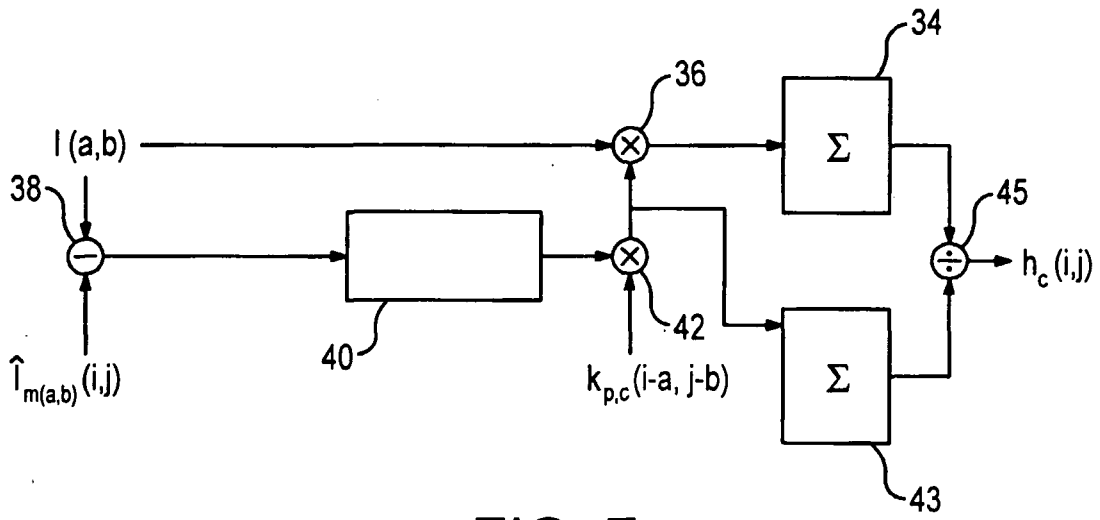34

Σ

45

$\div$ $h_c(i,j)$

Σ

43

FIG. 7

REFERENCES CITED IN THE DESCRIPTION

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