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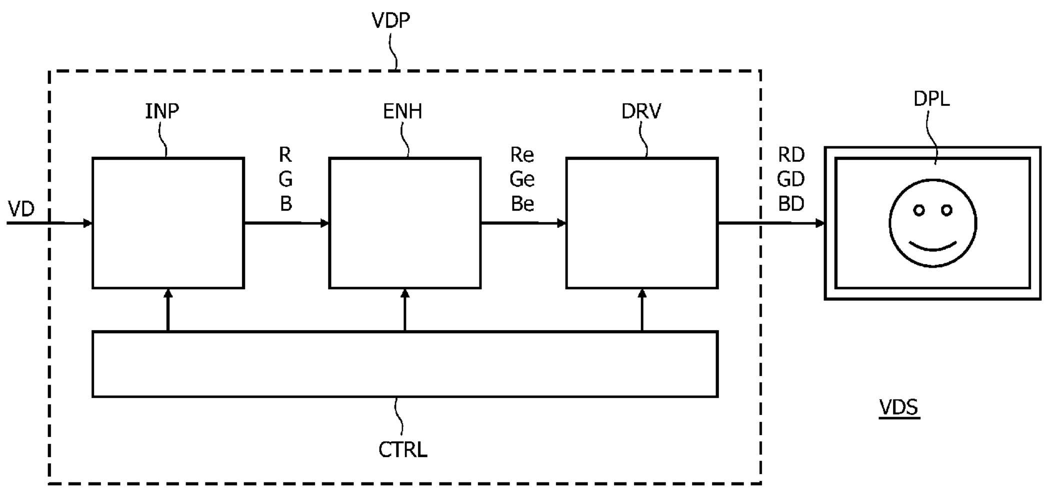
(54) **Title:** METHOD OF DISPLAYING AN IMAGE AND CORRESPOND IMAGE-DISPLAY SYSTEM



(57) **Abstract:** An image-display system (VDS) comprises an image processor (ENH) and a display device (DPL). The image processor (ENH) converts input color-image data (R-G-B) having a basic color gamut into enhanced color-image data (Re-Ge-Be) having an extended color gamut that is wider than said basic color gamut. The display device (DPL), which displays the enhanced color-image data (Re-Ge-Be), has a display color-gamut that is wider than the basic color gamut (BCG).

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METHOD OF DISPLAYING AN IMAGE AND CORRESPOND IMAGE-DISPLAY SYSTEM

FIELD OF THE INVENTION

The present invention relates to an image-display system. The image-display system may comprise, for example, a display device that has relatively wide display color gamut. Liquid-crystal-on-silicon devices (LCOS) and spectrum-sequential liquid-crystal-display devices are examples of such display devices. Other aspects of the invention relate to a method of displaying an image, a computer program for an image-display system, and an image processor.

DESCRIPTION OF PRIOR ART

US patent application published under number US 2003/0098928 describes a color signal processing apparatus for a multi-primary display. The color signal processing apparatus achieves a display white by more than four display primaries. The color signal processing apparatus has a tristimulus value calculation unit, which calculates tristimulus value of an input color signal. A display primary control signal calculation unit calculates a control signal of each display primary to represent the color signal with a number of display primaries. A control unit sets the control signal of each display primary with the control signal calculated by the display primary control signal calculation unit to display the color signal.

SUMMARY OF THE INVENTION

According to an aspect of the invention, an image-display system has the following characteristics. The image-display system comprises an image processor and a display device. The image processor converts input color-image data having a basic color gamut into enhanced color-image data having an extended color gamut that is wider than the basic color gamut. The display device displays the enhanced color-image data.

The invention takes the following aspects into consideration. A display device generally displays a color image by means of a set of primary colors, which are typically red, green, and blue. The display device can display a particular color by making a particular mix of the primary colors. For example, a mix of the red primary color and the blue primary color produces a purple color. A mix of the red primary color and the green primary color produces a yellow color. The primary colors define a display color gamut, which comprises all the colors that the display device can produce by mixing the primary colors. However, in general there is a range of colors that, although visible to the human eye, cannot be produced by any mix of the primary colors. The display device cannot display these colors, which are outside the display color gamut.

Images are generally coded in accordance with a color standard that defines a fixed set of primary colors, which are typically red, green, and blue. Many color standards that are currently used have been defined in the past. These color standards define primary colors that correspond with primary colors that display devices typically used at that time. At the time color standards were defined, display devices were generally cathode-ray tubes. The display color gamut of these display devices comprises a relatively small portion only of colors that are visible to the human eye.

Consequently, many current color standards have a relatively small color gamut. Recommendation 709 of the International Telecommunication Union (ITU Rec. 709) is an example of such a color standard. There are relatively many colors that are visible to the human eye, which color-image data in accordance with ITU Rec. 709 cannot define. These colors are out-of gamut. In such color-image data, an approximate color generally represents an out-of-color gamut. At an image capturing end, an out-of-gamut color is generally rounded off, as it were, to a suitable color that is within the color gamut, which is the approximate color.

Recently, display devices have been developed that have a relatively large color gamut. These display devices can offer a more natural, vivid representation of a color image compared with conventional display devices, if such a display device receives color-image data that has a relatively large color gamut too. For example, the multi-primary display of the aforementioned prior art requires that the tristimulus signal has a relatively large color gamut. Only then can the multi-primary display offer a more natural, vivid representation of a color image compared with a conventional cathode-ray tube display device.

However, a large color gamut display device will not be capable of offering an enhanced viewing experience if the display device receives a color-image data that has a relatively small color gamut, such as, for example, color-image data in accordance with ITU Rec. 709. The viewing experience will be constraint to the color gamut that ITU Rec. 709 offers. A color image, which is displayed, may have originally colors comprised within the color gamut of the display device, but outside the ITU Rec. 709 color gamut. These colors will not benefit, as it were, from the relatively large color gamut that the display device offers.

In principle, it is possible to define a new standard that has a larger color gamut than the ITU Rec. 709, or other conventional standards, and to code color images anew in accordance with such a new standard. However, this takes time and requires a certain investment, which may be prohibitive in certain cases.

In accordance with the aforementioned aspect of the invention, the image-display system comprises an image processor that converts input color-image data having a basic color gamut into enhanced color-image data having an extended color gamut that is wider than the basic color gamut.

The image processor allows a restoration, as it were, of original colors that were out of gamut. The image processor can estimate an original color on the basis of the input color-image data that the image-display system receives. For example, the image processor can identify colors that are likely to be approximate colors. Subsequently, the image processor can estimate the original colors through, for example, extrapolation of colors that the input color-image data faithfully represents. Accordingly, the display device, which has a relatively large color gamut, can display a color image in a natural, vivid fashion even when the input color-image data has a relatively small color gamut. There is no need to code color images anew in accordance with a new standard in order to benefit from a display device that has a relatively large color gamut. For those reasons, the invention allows enhanced viewing experiences even when the input color-image data has a relatively small color gamut.

These and other aspects of the invention will be described in greater detail hereinafter with reference to drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram that illustrates an image-display system.

FIG. 2A and 2B are chromaticity diagrams that illustrate a color enhancement within the image-display system.

FIG. 3 is a block diagram that illustrates a color-enhancement module, which carries out the color enhancement within the image-display system.

FIG. 4 is a diagram that illustrates a detection bitmap, which the color-enhancement module establishes.

FIG. 5A and 5B are diagrams that illustrate a one dimensional extrapolation and a two dimensional extrapolation, respectively, which the color-enhancement module carries out.

DETAILED DESCRIPTION

FIG. 1 illustrates a video-display system VDS. The video-display system VDS displays a sequence of color images, which represents, for example, a movie, in response to an input video-signal VD. The video-display system VDS comprises a video processor VDP and a display device DPL. The video processor VDP comprises an input module INP, a color-enhancement module ENH, a display-driver module DRV, and a control module CTRL.

The display device DPL has a relatively wide color gamut. Spectrum-sequential liquid-crystal-display devices and liquid-crystal-on-silicon (LCOS) devices are examples of display devices that have relatively wide color gamut. The display device DPL may also be a more conventional liquid crystal display device having three primary color sources that offer a wide color gamut. The display device DPL may also comprise more than three primary colors so as to achieve relatively wide color gamut. In contrast, the input video-signal VD may have a relatively narrow color gamut because, for example, the input video-signal VD is compliant with Recommendation 709 of the International Telecommunication Union (ITU Rec. 709). The display device DPL may thus have a color gamut that is wider than the color gamut of the input video-signal VD.

The video-display system VDS basically operates as follows. The input module INP derives red-green-blue image data R-G-B from the input video-signal VD, which may, for example, have a so-called YC format that comprises a luminance component and a chrominance component. The red-green-blue image data R-G-B comprises a red component R, a green component G, and a blue component B for a pixel in an image to be displayed. Respective values of these color components R, G, and B, define a color for the pixel.

For example, the red, green, and blue components R, G, B may be in the form of 8-bit binary words, whose value may range between 0 and 255. Let it be assumed that the red component R has the value 255, whereas the other two components G and B have the value 0. In that case, the color of the pixel will be fully saturated bright red. Conversely, the color of the pixel will be fully saturated bright green or fully saturated bright blue when the red component R or the blue component B has the value 255, respectively, whereas, in each respective case, the other two components have the value 0. There are numerous different mixes between the aforementioned extremes, each representing a different color.

The color-enhancement module ENH, which receives the red-green-blue image data R-G-B, carries out a color enhancement. As a result, the color-enhancement module ENH provides enhanced red-green-blue image data Re-Ge-Be. The color enhancement, which the color-enhancement module ENH carries out, extends the relatively narrow color gamut, which the input video-signal VD has. The color enhancement will be described in greater detail hereinafter.

The display-driver module DRV applies red-green-blue display data RD-GD-BD to the display device DPL on the basis of the enhanced red-green-blue image data Re-Ge-Be, respectively. The display-driver module DRV may apply further signals to the display device DPL so as to cause the display device DPL to correctly display the sequence of images, which the input video-signal VD represents. These further signals may comprise, for example, synchronization signals and biasing voltages.

The control module CTRL causes the input module INP, the color-enhancement module ENH, and the display-driver module DRV to operate in accordance with a set of desired operating parameters. These operating parameters may relate to, for example, an image format, a field and frame frequency, and user preferences. The controller CTRL may be coupled to a human interface via which a user can define his or her preferences.

FIGS. 2A and 2B illustrate the color enhancement, which the color-enhancement module ENH carries out. FIGS. 2A and 2B are chromaticity diagrams, which the Commission Internationale de l'Eclairage (CIE) has defined in 1931. The chromaticity diagrams have an x axis and a y axis. A set of x, y coordinates defines a color within a visible color gamut VCG. FIGS. 2A and 2B illustrate the visible color gamut VCG, which comprises a curved borderline. The curved borderline represents monochromatic colors. That is, each point on this curved borderline corresponds with a particular wavelength in a visible-light spectrum, which ranges from 400 nanometers (nm) to 700 nm. FIGS. 2A and 2B illustrate a white point WP, which corresponds to a white “color”. Each color has a particular saturation. The closer the color is to the curved borderline with respect to the white point WP, the higher the saturation that the color has, or stated otherwise, the more saturated the color is.

FIG. 2A illustrates a basic color gamut BCG, which the input video-signal VD has. The basic color gamut BCG is a triangle, which has three vertices. Each vertex corresponds with a primary color. The basic color gamut BCG has three primary colors: a red primary RP, a green primary GP, and a blue primary BP. The basic color gamut BCG may correspond, for example, with ITU-Rec. 709 mentioned hereinbefore. The red-green-blue image data R-G-B, which is derived from the input video-signal VD, also has the basic color gamut BCG that FIG. 2A illustrates. That is, in this example, the input module INP does not affect the basic color gamut BCG.

The red-green-blue image data R-G-B can only define a color which lies within the triangle that represents the basic color gamut BCG. For example, let it be assumed that the red, green, and blue components R, G, B are in the form of 8-bit binary words as described hereinbefore. The red-green-blue image data R-G-B defines a color that corresponds with the red primary RP when the red component R has the value 255, whereas the other two components have the value 0. Conversely, the red-green-blue image data R-G-B defines a color that corresponds with the green primary GP or the blue primary BP when the green component G or the blue component B has the value 255, whereas, in each respective case, the other two components have the value 0. Any particular combination of the red, green, and blue components, R, G, B, can be converted into a set of x, y coordinates in the chromaticity diagram, which FIG. 2A illustrates, and vice versa. The primary colors RP, GP, BP determine the characteristics of this conversion and, as a result, the basic color gamut BCG to which the input colors are confined. The image capturing end, from which the input video-signal VD originates, fixes the primary colors RP, GP, BP.

FIG. 2A illustrates that the basic color gamut BCG only captures a portion of the visible color gamut VCG. There are numerous colors within the visible color gamut VCG that are not in the basic color gamut BCG. A camera may capture an image which comprises colors that are not in the basic color gamut BCG. Generally, such an out-of-gamut color is clipped, as it were, so as to obtain an approximate color that is within the basic color gamut BCG. For example, a bluish-green color, which is outside the basic color gamut BCG, is clipped so as to obtain another bluish-green color, which is within the basic color gamut BCG.

FIG. 2A illustrates that the basic color gamut BCG has a main portion PM and a boundary portion PB, which is shaded. The color-enhancement module ENH defines these portions on the basis of, for example, control data from the control module CTRL. Optionally, the user may adapt the definition of the main portion PM and a boundary portion PB through the user interface, if any, which is coupled to the control module CTRL.

The boundary portion PB preferably comprises approximate colors, which result from a clipping of an out-of-gamut color at an image capturing end, as described hereinbefore. The boundary portion PB may also comprise colors that are true colors in the sense that they have not been subject to any clipping. FIG. 2A illustrates an input color C1 that is in the boundary portion PB of the basic color gamut BCG. There is relatively high probability that the input color C1 results from a clipping of an out-of-gamut color.

The main portion PM predominantly comprises true colors and preferably, relatively few approximate colors. Ideally, the main portion PM would not comprise any approximate colors. FIG. 2A illustrates an input color C2 that is in the main portion PM of the basic color gamut BCG. There is relatively high probability that the input color C2 is a true color, which has not been subject to any clipping at the image capturing end.

FIG. 2B illustrates that the color-enhancement module ENH processes input colors that are in the boundary portion PB, on the one hand, and input colors that are in the main portion PM, on the other hand, differently. The color-enhancement module ENH provides an enhanced color that substantially corresponds with an input color, which the input video-signal VD defines, when the input color is within the main portion PM of the basic color gamut BCG. That is, the color-enhancement module ENH substantially reproduces the input color in that case. FIG. 2B illustrates an enhanced color Ce2 that the color-enhancement module ENH provides in response to the input color C2, which is in the main portion PM of the basic color gamut BCG. The enhanced color Ce2 substantially corresponds with the input color C2.

On the other hand, the color-enhancement module ENH provides an enhanced color that has a higher saturation than an input color, when the input color is within the boundary portion PB of the basic color gamut BCG. That is, the color-enhancement module ENH provides a more saturated color, which is closer to the curved borderline of the visible color gamut VCG, in that case. FIG. 2B illustrates an enhanced color Ce1 that the color-enhancement module ENH provides in response to the input color C1, which is in the boundary portion PB of the basic color gamut BCG. The enhanced color Ce1 is closer to the curved borderline than the input color, which corresponds with a higher saturation.

FIG. 2B further illustrates that the enhanced red-green-blue image data R-G-B, which the color-enhancement module ENH provides, has an extended color gamut ECG. The extended color gamut ECG is a triangle, which has three vertices, like the basic color gamut BCG. Each vertex corresponds with an enhanced primary color. The extended color gamut ECG has three enhanced primary colors: an enhanced red primary ERP, an enhanced green primary EGP, and an enhanced blue primary EBP. The extended color gamut ECG is wider than the basic color gamut BCG, which FIG. 2A illustrates.

FIG. 2B illustrates that the extended color gamut ECG has an inner portion PI and a peripheral portion PP, which is shaded. The inner portion PI corresponds with the main portion PM of the basic color gamut BCG, which FIG. 2A illustrates. The peripheral portion PP comprises the boundary portion PB of the basic color gamut BCG and, in addition, more saturated colors, which are not within the basic color gamut BCG. The peripheral portion PP thus comprises a greater variety of colors, which may have a higher saturation compared with colors within the boundary portion PB of the basic color gamut BCG.

An input color that is within the main portion PM of the basic color gamut BCG will result in an enhanced color that is within the inner portion PI of the extended color gamut ECG. An input color that is within the boundary portion PB of the basic color gamut BCG will generally result in enhanced color that is within the peripheral portion PP of the extended color gamut ECG.

FIG. 2B illustrates that the color-enhancement module ENH stretches, as it were, the boundary portion PB of the basic color gamut BCG so as to become the peripheral portion PP of the extended color gamut ECG. It is as if the color-enhancement module ENH were to pull the vertices of the triangle, which corresponds with the basic color gamut BCG, away from each other towards the triangle that corresponds with the extended color gamut ECG. In doing so, vertices of a triangle that correspond with the main portion PM remain fixed. That is, the color-enhancement module ENH stretches the boundary portion PB of the basic color gamut BCG only, but not the main portion PM. The color-enhancement module ENH selectively enhances color dynamics.

FIG. 3 illustrates an example of the color-enhancement module ENH in the form of a functional diagram. In FIG. 3, blocks represent operations, or functions, that the color-enhancement module ENH carries out. A suitably programmed computer may carry out an operation. In such a software-based implementation, a block corresponds with a software module in the form of, for example, a subroutine. Alternatively, a dedicated circuit may carry out an operation. In such a software-based implementation, a block corresponds with such a circuit. The various blocks will be described hereinafter as if they were functional entities for reasons of ease of description.

The color-enhancement module ENH, which FIG. 3 illustrates, comprises an input memory MEMI, an input switch SWI, an output switch SWO, and an output memory MEMO. Two transfer paths extend between the input switch SWI and the output switch SWO : a neutral transfer path NTP and an enhancement transfer path ETP. The enhancement transfer path ETP comprises an extrapolator EXTR, an intra-boundary detector IBD, a scaler SCL, and an adder ADD. The enhancement transfer path ETP couples the input memory MEMI to the output memory MEMO when the input switch SWI and the output switch SWO have positions as shown in FIG. 3. The neutral transfer path NTP couples the input memory MEMI to the output memory MEMO when the input switch SWI and the output switch SWO have opposite positions. The color-enhancement module ENH further comprises a control path CTP. The control path CTP comprises a boundary detector BDET, a bitmap memory BMEM, and a transfer controller TC.

The color-enhancement module ENH operates as follows. The input memory MEMI temporarily stores the red-green-blue image data R-G-B, which the input module INP has derived from the input video-signal VD as FIG. 1 illustrates. As mentioned hereinbefore, the red-green-blue image data R-G-B comprises a red component R, a green component G, and a blue component B for a pixel in an image to be displayed. The boundary detector BDET detects whether respective color components for respective pixels of the image are in a range comprised between a lower level LL and an upper level UL or not. The boundary detector BDET provides a detection bit DB for each respective component.

The detection bit DB is 0 when the component has a value which is comprised in the main range, which extends between a lower level LL and an upper level UL. Conversely, the detection bit DB is 1 when the component concerned has a value that is outside the main range. That is, detection bit DB is 1 when the component concerned has a value that is in a lower boundary range or in an upper boundary range. The lower boundary range extends between a minimal value, which the component may have, and the lower level LL. The upper boundary range extends between a maximum value, which the component may have and the upper level UL.

For example, let it be assumed that the red, green, and blue components R, G, B are in the form of 8-bit binary words. Let it further be assumed that these components have been coded between a minimum value, which is 16, and a maximum value, which is 235. These values are typical for digital versatile disk (DVD) video signals. The lower level LL and the upper level UL for the boundary detector BDET can be set to, for example, 25 and 226, respectively. The boundary detector BDET will provide a detection bit DB whose value is 0 when a red component R has a value that is comprised between 25 and 226, which is the main range. Conversely the boundary detector BDET will provide a detection bit DB whose value is 1 when the red component R has a value that is smaller than 25 or greater than 226. In those cases, the red component R is in the lower boundary range or in the upper boundary range, respectively. The same principle applies for a green component G and a blue component B.

The bitmap memory BMEM stores respective detection bits that the boundary detector BDET provides. Let it be assumed that the boundary detector BDET has carried out a boundary detection, as described hereinbefore, for the red component R of each respective pixel in an image. Let it further be assumed that each respective detection bit has been stored in the bitmap memory BMEM. The bitmap memory BMEM will then comprise a red detection bitmap for the image. Likewise, the boundary detector BDET may cause the data memory to comprise a green detection bitmap and a blue detection bitmap.

FIG. 4 illustrates such a detection bitmap, which is stored in the bitmap memory BMEM. The detection bitmap BMP may be a red detection, a green detection, or a blue detection bitmap. The detection bitmap BMP is a matrix that has a plurality of lines L[1], .., L[n] and a plurality of columns C[1], .., C[m]. The lines and columns define a matrix of cells. Each cell has a unique combination of a line number and a row number. A cell in the matrix corresponds with a pixel of the image to be displayed. In case of a red detection bitmap, the cell comprises the detection bit for the red component R of the corresponding pixel. In case of a green detection bitmap and a blue detection bitmap, the cell comprises the detection bit for the green component G and the blue component B, respectively, of the corresponding pixel.

FIG. 4 illustrates in fact a portion of the detection bitmap BMP in greater detail. This portion concerns the lines L[i-2], .., L[i+4] and the columns C[j-4], .., C[j+2]. A majority of detection bits in this portion are 0. There are five detection bits that are 1, namely the detection bits for the relevant component of the pixels that can be designated as P[i,j], P[i+1,j-1], P[i+1,j-2], P[i+2,j-1], and P[i+3,j+1]. Let it be assumed that the detection bitmap BMP that FIG. 4 illustrates is a red detection bitmap. In that case, the red component R[i,j] of pixel P[i,j] has a value that is outside the main range. The red components R[i+1,j-2], R[i+1,j-1], R[i+2,j-1], and R[i+3,j+1] of pixels P[i+1,j-2], P[i+1,j-1], P[i+2,j-1], and P[i+3,j+1], respectively, also have respective values that are outside the main range.

The transfer controller TC causes the output memory MEMO to have an enhanced red component Re for each pixel for which the input memory MEMI comprises a red component R. Two cases may occur : the red detection bitmap indicates that the red component R concerned is within the main range or outside the main range. The relevant detection bit DB is 0 in the first mentioned case and is 1 in the last mentioned case.

Let it be assumed that the detection bit DB for the red component R is 0. In that case, the transfer controller TC causes the input switch SWI and the output switch SWO to have positions opposite to those illustrated in FIG. 3. As a result, the input memory MEMI applies the red component R to the neutral transfer path NTP and the output memory MEMO receives the enhanced red component Re from the neutral transfer path NTP. The enhanced red component Re is similar to the red component R because the neutral transfer path NTP substantially maintains color characteristics.

Let it now be assumed that the detection bit DB for the red component R is 1. In that case, the transfer controller TC causes the input switch SWI and the output switch SWO to have positions as illustrated in FIG. 3. As a result, the input memory MEMI applies the red component R to the enhancement transfer path ETP and the output memory MEMO receives the enhanced red component Re from the enhancement transfer path ETP. The enhancement transfer path ETP modifies color characteristics in the following fashion.

The extrapolator EXTR establishes an extrapolated red component Rx on the basis of respective red components of neighboring pixels. In doing so, the extrapolator EXTR preferably excludes any red component for which the detection bit is 1. That is, the extrapolator EXTR preferably bases an extrapolation exclusively on red components whose respective values are within the main range.

For example, let it be assumed that FIG. 4 represents the red detection bitmap BMP of interest. The extrapolator EXTR will establish an extrapolated red component Rx[i,j] for pixel P[i,j] because the red component R[i,j] of that pixel is outside the main range. In doing so, the extrapolator EXTR will not take into account the red components R[i+1,j-2], R[i+1,j-1], R[i+2,j-1], and R[i+3,j+1] because the detection bits for these red components are 1. The red components, which are not taken into account, are relatively close. Consequently, the extrapolator EXTR needs to base the extrapolation on red components that are relatively distant. In such a case, the extrapolator EXTR preferably bases the extrapolation on relatively many red components, in order to achieve a satisfactory extrapolation precision. That is, the extrapolator EXTR preferably has a relatively large extrapolation base in case there are relatively many neighboring pixels of which the red component is outside the main range. Conversely, the extrapolation base can be relatively modest if there are relatively few neighboring pixels of which the component is outside the main range.

FIG. 5A illustrates a one-dimensional extrapolation, which provides an extrapolated red component Rx[i,j] for pixel P[i,j]. The one-dimensional extrapolation is based on respective red components of neighboring pixels that are on the same line : red components R[i,j-2], R[i,j-1], R[i,j+1], and R[i,j+2]. These neighboring pixels are close to the lower level LL of the main range. FIG. 5A illustrates the minimum value MIN for the red, green, and blue components R, G, B of the red-green-blue image data R-G-B.

FIG. 5A illustrates that the extrapolated red component Rx[i,j] has a value that is below the minimum value MIN. For example, let it be assumed that the minimum value MIN is 0. In that case, the extrapolated red component Rx[i,j] may have a negative value. A value below the minimum value MIN corresponds with a higher saturation of the opposite color, which is cyan in that case of red, magenta in the case of green, and yellow in the case of blue. Consequently, providing a value below the minimum value MIN has the effect of extending the color gamut.

FIG. 5A illustrates a first-order extrapolation, which is relatively simple but has a modest precision. A higher-order extrapolation can achieve a better precision. Such an extrapolation needs to be based on further red components of other neighboring pixels on the same line. That is, a higher-order extrapolation necessitates a larger extrapolation base.

FIG. 5B illustrates a two-dimensional extrapolation. The two-dimensional extrapolation has a larger extrapolation base than the one-dimensional extrapolation, which FIG. 5A illustrates. The two-dimensional extrapolation is further based on respective red components of neighboring pixels that are on the same row : red components R[i-2,j], R[i-1,j], R[i+1,j], and R[i+2,j]. The two-dimensional extrapolation offers a better precision compared with the one-dimensional extrapolation. An even better precision can be achieved if the two-dimensional extrapolation is based on further red components in a diagonal direction. A yet better precision can be achieved if the extrapolator EXTR carries out a higher order-extrapolation.

The intra-boundary detector IBD, which FIG. 3 illustrates, derives an intra boundary value IBV from a red component R whose value is outside the main range. The intra boundary value IBV reflects a distance that the red component R has with respect to the main range, which the lower level LL and the upper level UL define. The intra boundary value IBV is relatively low if the red component R is relatively close to the main range ; the red component R is barely outside the main range. For example, the value may be just one unit higher than the upper level UL or just one unit lower than the lower level LL. Conversely, the intra boundary value IBV is relatively high if the red component R is relatively far from the main range. For example, the value may be equal to the maximum value or the minimum value that the red component R may have. The intra boundary value IBV may be equal to, for example, the lower level LL minus the value of the red component R, if the red component R is below the lower level LL. The intra boundary value IBV may be equal to the value of the red component R minus the upper level UL, if the red component R is below the upper level UL.

The scaler SCL multiplies the intra boundary value IBV with an appropriate scaling factor so as to obtain a scaled intra boundary value IBVs. The scaling factor determines the extent to which the intra boundary value IBV contributes to the enhanced red component Re. The scaler SCL can be omitted altogether if the appropriate scaling factor is equal to 1.

The adder ADD adds the scaled intra boundary value IBVs to the extrapolated red component Rx. This addition provides the enhanced red component Re, which is stored in the output memory MEMO.

The operations described hereinbefore equally apply to green components and blue components. That is, in a similar fashion, the transfer controller TC causes the output memory MEMO to have an enhanced green component Ge and an enhanced blue component Be for each pixel for which the input memory MEMI comprises a green component G and a blue component B, respectively.

In the operations described hereinbefore, the lower level LL and the upper level UL play an important role. These parameters determine whether the color-enhancement module ENH will modify a particular color component or not. The color-enhancement module ENH may receive the upper level UL and the lower level LL from the controller CTRL, which FIG. 1 illustrates.

The color-enhancement module ENH can provide enhanced color components Re, Ge, Be having values below the minimum value for the corresponding color components R, G, B, which the color-enhancement module ENH receives. FIGS. 5A and 5B illustrate this. An enhanced color component that has a value below the minimum value provides a more saturated color, which is beyond the basic color gamut BCG illustrated in FIG. 2A. For example, let it be assumed that the minimum value is 0. In that case, an enhanced red component Re that has a negative value provides more saturated cyan, which is the opposite of red. Stated boldly, negative red means more saturated cyan. Negative green means more saturated magenta, which is the opposite of green. Negative blue means more saturated yellow, which is the opposite of blue. Accordingly, the lower level LL can be associated with making more saturated colors, which corresponds with a color gamut extension as illustrated in FIG. 2B.

The color-enhancement module ENH can also provide enhanced color components Re, Ge, Be having values above the maximum value for the corresponding color components R, G, B, which the color-enhancement module ENH receives. An enhanced color component that has a value above the maximum value provides brighter color, which need not necessarily be beyond the basic color gamut BCG illustrated in FIG. 2A. Accordingly, the upper level UL can be associated with making brighter colors, which may remain within an original color gamut.

The display device DPL, which FIG. 1 illustrates, has certain display capabilities, which include a relatively wide color gamut as mentioned hereinbefore. The red-green-blue display data RD-GD-BD needs to have a certain desired dynamic range in order to fully benefit from the display capabilities of the display device DPL. The enhanced red-green-blue image data Re-Ge-Be, which the color enhancement module ENH provides, has a certain dynamic range, which may include negative values. The display-driver module DRV maps, as it were, the dynamic range of the enhanced red-green-blue image data Re-Ge-Be on the desired dynamic range of the red-green-blue display data RD-GD-BD. Such a dynamic-range mapping may include, for example, a level shift and amplification.

CONCLUDING REMARKS

The detailed description hereinbefore with reference to the drawings illustrates the following characteristics, which are cited in claim 1. An image-display system (VDS) comprises an image processor (color-enhancement module ENH, which forms part of the video processor VDP) that converts input color-image data (input video-signal VD from which red-green-blue image data R-G-B is derived) having a basic color gamut (BCG) into enhanced color-image data (enhanced red-green-blue image data Re-Ge-Be from which red-green-blue display data RD-GD-BD is derived) having an extended color gamut (ECG) that is wider than the basic color gamut (BCG). A display device (DPL) displays the enhanced color-image data (Re-Ge-Be).

The detailed description hereinbefore further illustrates the following optional characteristics, which are cited in claim 2. The image processor (color-enhancement module ENH) establishes an enhanced color (Ce1, Ce2) in response to an input color (C1, C2). (FIG. 2B illustrates enhanced colors Ce1 and Ce2, which comprise an enhanced red component Re, an enhanced green component Ge and an enhanced blue component Be). The enhanced color has a higher saturation than the input color when the input color is in the boundary portion (PB) of the basic color gamut (BCG). (FIG. 2B illustrates this : enhanced color Ce1 has a higher saturation than input color C1 because the latter is in the boundary portion PB). The enhanced color substantially corresponds with the input color when the input color is not in the boundary portion (PB) of the basic color gamut (BCG). (FIG. 2B illustrates this :

enhanced color Ce2 substantially corresponds with input color C2 because the latter is in not the boundary portion PB). These characteristics allow a distinction between input colors that are likely to truly represent colors with an original image, on the one hand, and input colors that are likely to be approximations of out-of-gamut colors in the original image. The first-mentioned input colors are maintained, which avoids unnatural effects. The last-mentioned colors are enhanced in the sense that estimations are made of out-of gamut colors in the original image. For those reasons, the aforementioned characteristics allow color enhanced images that have a natural appearance.

The detailed description hereinbefore further illustrates the following optional characteristics, which are cited in claim 3. The image processor (color-enhancement module ENH) detects whether a color component (R, G, B) has a value that is below a lower level (LL). If so, the image processor provides an enhanced color component (Re, Ge, Be) having a value that is lower than the lowest value (MIN), which the color component (R, G, B) may have. (FIGS. 5A and 5B illustrate this). These characteristics allow an extension of the color gamut with relatively simple hardware or software, or both. This is particularly true for input color-image data in the RGB format, which is generally used in video-display systems. For those reasons, the aforementioned characteristics allow cost-efficient implementations.

The detailed description hereinbefore further illustrates the following optional characteristics, which are cited in claim 4. The image processor (ENH) comprises an extrapolation module (EXTR) that establishes the enhanced color (Ce1) when the input color (C1) is in the boundary portion (PB) of the basic color gamut (BCG). The extrapolation module (EXTR) establishes the enhanced color (Ce1) on the basis of an extrapolation of respective input colors for neighboring pixels in the input color-image data (R-G-B). These characteristics allow a relatively precise estimation of out-of gamut colors in the original image. Consequently, these characteristics further contribute to color-enhanced images that have a natural appearance.

The detailed description hereinbefore further illustrates the following optional characteristics, which are cited in claim 5. The extrapolation module (EXTR) establishes the extrapolation on the basis of respective colors for neighboring pixels in two dimensions (FIG. 5B illustrates this). These characteristics contribute to a relatively precise estimation of out-of gamut colors in the original image. Consequently, these characteristics further contribute to color-enhanced images that have a natural appearance.

The detailed description hereinbefore further illustrates the following optional characteristics, which are cited in claim 6. The image processor (ENH) comprises an intra-boundary-detection module (IBD) arranged to establish, when the input color (C1) is in the boundary portion (PB) of the basic color gamut (BCG), a relative position of the input color in the boundary portion (PB). The image processor (ENH) takes the relative position into account when establishing the enhanced color (Ce1). These characteristics contribute to a relatively precise estimation of out-of-gamut colors in the original image. Consequently, these characteristics further contribute to color enhanced images that have a natural appearance.

The aforementioned characteristics can be implemented in numerous different manners. In order to illustrate this, some alternatives are briefly indicated.

The input color-image data can be in an YCC-format or YUV-format, wherein Y designates luminance and CC/UV designates chrominance/hue. The input color-image data can also be in an xyY-format, wherein xy designates coordinates in the chromaticity diagram and Y brightness, a tristimulus XYZ-format, or any other possible color format, The image processor, which corresponds to the color-enhancement module ENH in the detailed description, can be arranged to process any of these or other possible color formats. That is, the image processor may carry out a color enhancement in the YCC, YUV, xyY, or XYZ domain. The image-display system may be arranged so that the image processor can be disabled or effectively bypassed, allowing a user to switch on and off a color-gamut extension. The image-display system may also comprise a video-analyzing circuit that decides to switch on or off the color-gamut extension on the basis of the input color-image data received.

The color-enhancement module ENH, which FIG. 3 illustrates, may be arranged so that a color component whose value is above the upper limit UL is processed differently than a color component whose value is below the lower limit LL. This can be advantageous because, as explained in before, these respective types of processing provide different effects, namely making a color brighter, on the one hand, and extending the color gamut, on the other hand. It is also possible to dispense with the upper limit UL and retain the lower limit LL only, which is associated with color-gamut extension. The intra-boundary detector and the scaler may be dispensed with. In such a variant, the color enhancement is substantially based on extrapolation. Conversely, the extrapolator may be dispensed with. In this variant, the color enhancement is substantially based on dynamic-range expansion in a particular range of color-component values.

The processing of the color components of a pixel may depend on the hue of the pixel. For example, pixels that have a substantially red color may be processed differently than pixels that have a substantially yellow color. That is, when processing a particular color component of a pixel, the other color component of the pixel are taken into account.

The invention can be used to advantage in an image-display system that comprises a display device with a relatively wide color gamut. Examples of such display devices have been given hereinbefore in the detailed description. Other examples include direct-view LCD's with a backlight-source that comprises light-emitting-diodes (LED's) or one or more lasers. LCD's may also comprise modified color filter patterns which provide a wider color gamut. The display device may also be based on projection with a light source that comprises one or more gas-discharge lamps, LED's or lasers. Scanning laser systems and organic LED displays are yet further examples. In phosphor-based displays, such as plasma display panels (PDP) or cathode-ray tubes (CRT), new phosphor materials can provide a wider color gamut.

There are numerous ways of implementing functions by means of items of hardware or software, or both. In this respect, the drawings are very diagrammatic, each representing only one possible embodiment of the invention. Thus, although a drawing shows different functions as different blocks, this by no means excludes that a single item of hardware or software carries out several functions. Nor does it exclude that an assembly of items of hardware or software or both carry out a function.

The remarks made herein before demonstrate that the detailed description, with reference to the drawings, illustrates rather than limits the invention. There are numerous alternatives, which fall within the scope of the appended claims. Any reference sign in a claim should not be construed as limiting the claim. The word "comprising" does not exclude the presence of other elements or steps than those listed in a claim. The word "a" or "an" preceding an element or step does not exclude the presence of a plurality of such elements or steps.

Claims.

1. An image-display system (VDS) comprising:

- an image processor (ENH) arranged to convert input color-image data (R-G-B) having a basic color gamut (BCG) into enhanced color-image data (Re-Ge-Be) having an extended color gamut (ECG) that is wider than the basic color gamut (BCG); and

- a display device (DPL) arranged to display the enhanced color-image data (Re-Ge-Be).

2. An image-display system (VDS) as claimed in claim 1, the display device (DPL) being arranged to display the enhanced color-image data by means of a display-driver module (DRV) applying red-green-blue display date RD-GD-BD to the display device (DPL) on the basis of the enhanced color-image data.

3. An image-display system (VDS) as claimed in anyone of claims 1 and 2, the image processor (ENH) being further arranged to establish an enhanced color (Ce1, Ce2) in response to an input color (C1, C2), the enhanced color (Ce1) having a higher saturation than the input color (C1) when the input color is in the boundary portion (PB) of the basic color gamut (BCG), the enhanced color (Ce2) substantially corresponding with the input color (C2) when the input color is not in the boundary portion (PB) of the basic color gamut (BCG).

4. An image-display system (VDS) as claimed in claim 3, the image processor (ENH) being arranged to detect whether a color component (R, G, B) has a value that is below a lower level (LL), and, if so, to provide an enhanced color component (Re, Ge, Be) having a value that is lower than the lowest value (MIN), which the color component (R, G, B) may have.

5. An image-display system (VDS) as claimed in claim 3, the image processor (ENH) comprising:

- an extrapolation module (EXTR) for establishing the enhanced color (Ce1) when the input color (C1) is in the boundary portion (PB) of the basic color gamut (BCG), the extrapolation module (EXTR) being arranged to establish the enhanced color

(Ce1) on the basis of an extrapolation of respective input colors for neighboring pixels in the input color-image data (R-G-B).

6. An image-display system (VDS) as claimed in claim 5, the extrapolation module (EXTR) being arranged to establish the extrapolation on the basis of respective colors for neighboring pixels in two dimensions.

7. An image-display system (VDS) as claimed in claim 3, the image processor (ENH) comprising:

- an intra-boundary-detection module (IBD) arranged to establish, when the input color (C1) is in the boundary portion (PB) of the basic color gamut (BCG), a relative position of the input color in the boundary portion (PB),

the image processor (ENH) being arranged to take the relative position into account when establishing the enhanced color (Ce1).

8. An image-display system (VDS) as claimed in anyone of claims 1 and 2, the display device (DPL) being arranged to display the enhanced color-image data (Re-Ge-Be) on the basis of a number of different primary colors, which number exceeds the number of different color components comprised in the input color-image data (R-G-B).

9. A method of displaying an image comprising:

- a color-enhancement step in which an input color-image data (R-G-B) having a basic color gamut (BCG) is converted into enhanced color-image data (Re-Ge-Be) having an extended color gamut ECG that is wider than the basic color gamut (BCG); and
- a display step in which the enhanced color-image data (Re-Ge-Be) is displayed on a display device (DPL).

10. A computer program for an image-display system, the computer program comprising a set of instructions that, when loaded into the image-display system, causes the image-display system to carry out:

- a color-enhancement step in which an input color-image data (R-G-B) having a basic color gamut (BCG) is converted into enhanced color-image data (Re-Ge-Be) having an extended color gamut ECG that is wider than the basic color gamut (BCG); and

- a display step in which the enhanced color-image data (Re-Ge-Be) is displayed on a display device (DPL).

11. An image processor (ENH) arranged to convert input color-image data (R-G-B) having a basic color gamut (BCG) into enhanced color-image data (Re-Ge-Be) having an extended color gamut ECG that is wider than the basic color gamut (BCG).

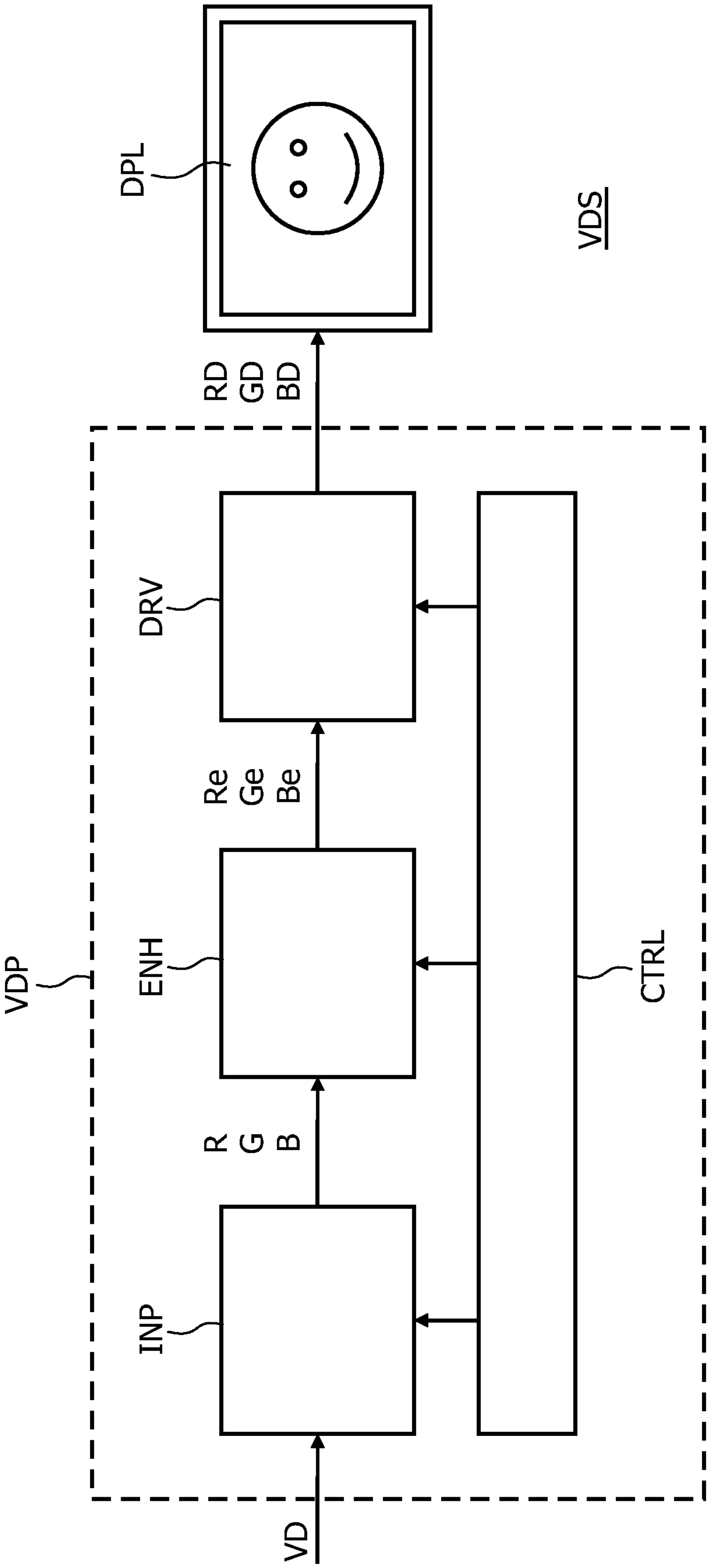

FIG. 1

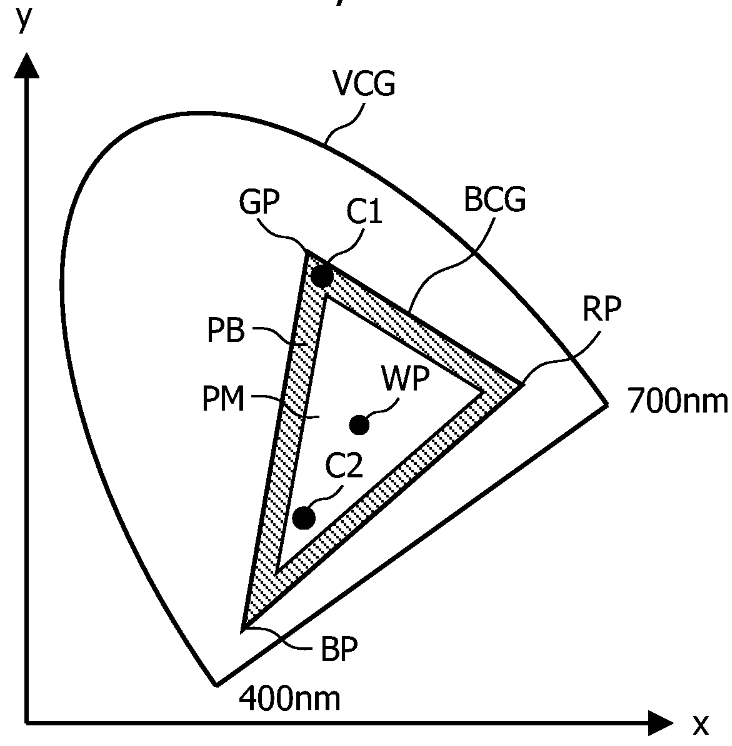
y
VCG
GP
C1
BCG
RP
PB
PM
WP
700nm
C2
BP
400nm
x

FIG. 2A

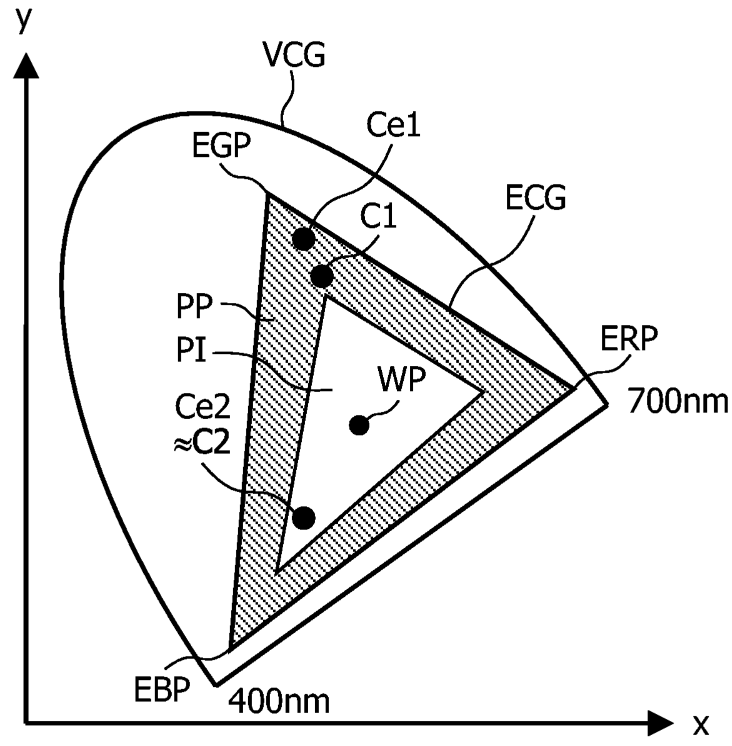
y
VCG
Ce1
EGP
C1
ECG
PP
PI
ERP
WP
700nm
Ce2
≈C2
EBP
400nm
x

FIG. 2B

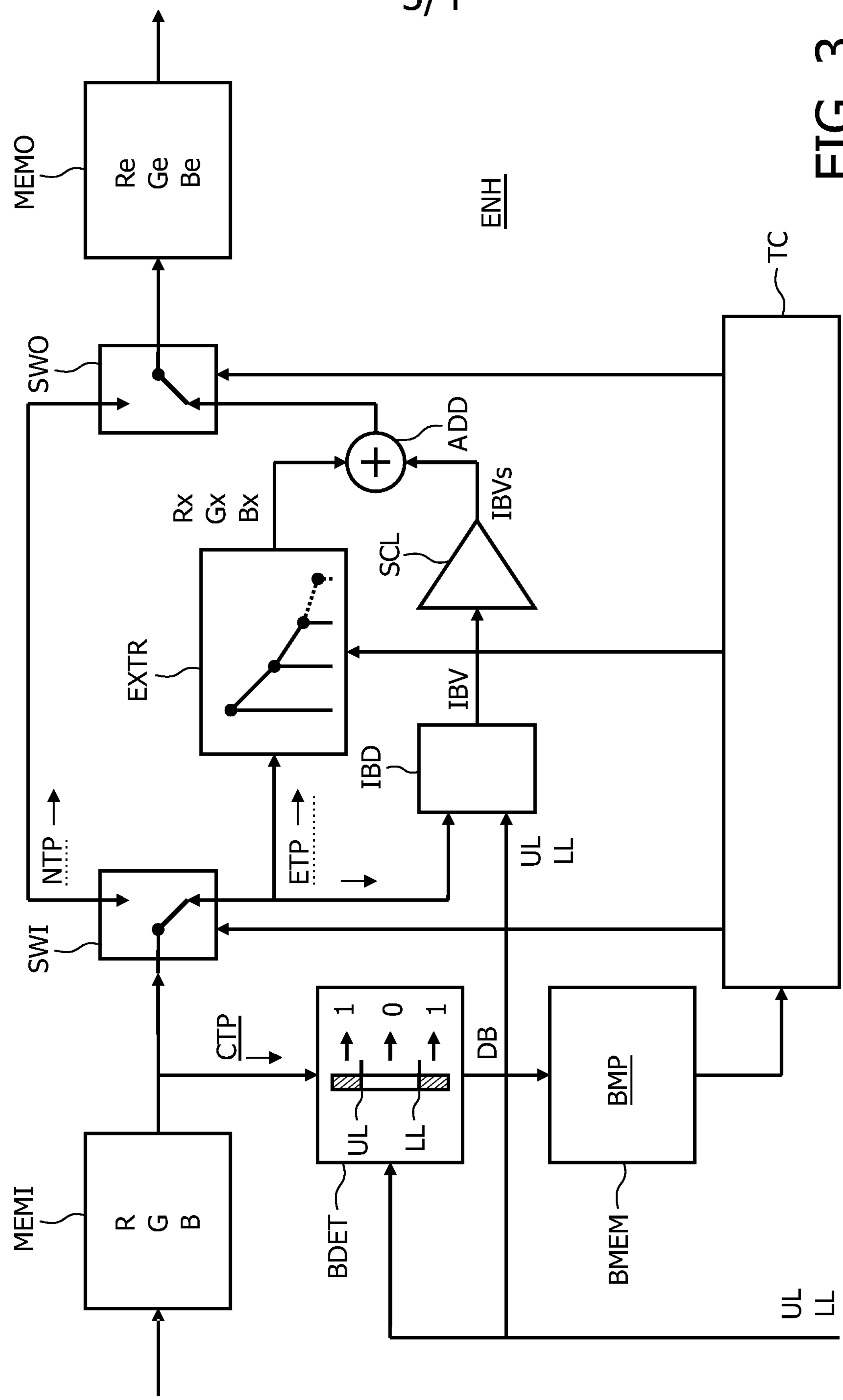
MEMO
Re
Ge
Be
ENH
SWO
ADD
Rx
Gx
Bx
IBVs
SCL
EXTR
TC
IBV
IBD
NTP
ETP
UL
LL
SWI
CTP
1
0
1
DB
BMP
MEMI
R
G
B
BDET
BMEM
UL
LL
UL
LL

FIG. 3

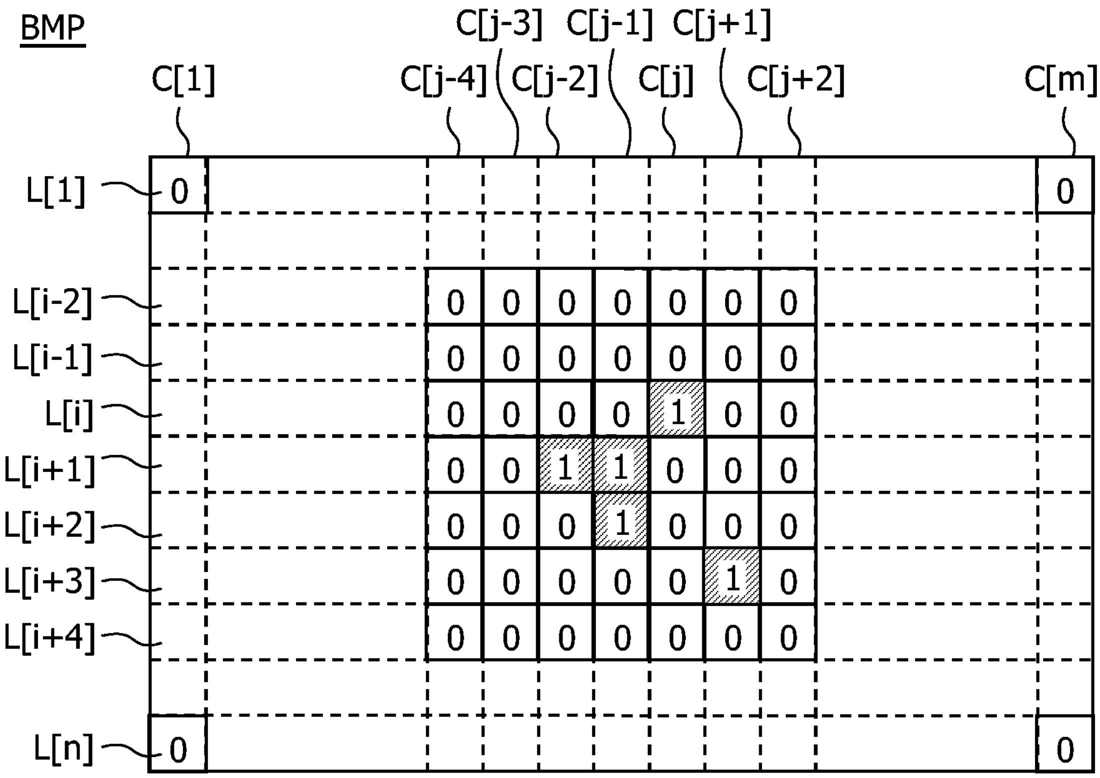

FIG. 4

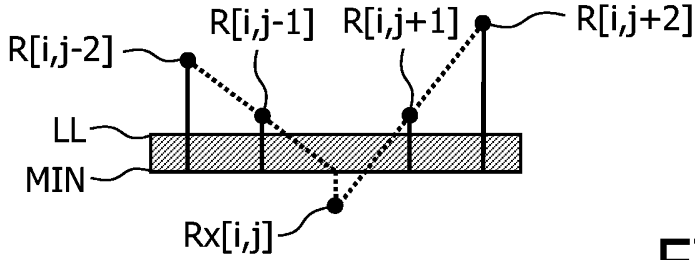

FIG. 5A

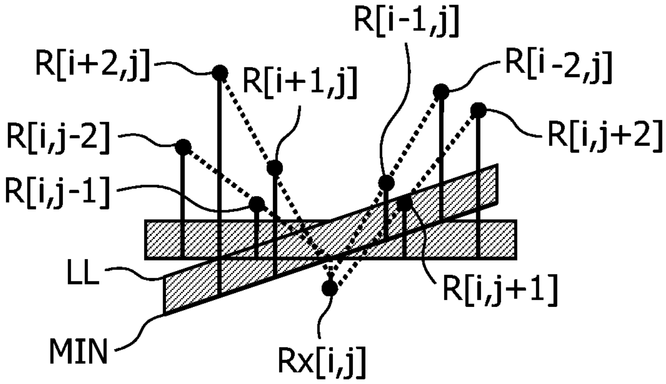

FIG. 5B