HIGH FIDELITY ANAGLYPHS UTILIZING A FAR-RED PRIMARY COLOR

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ABSTRACT
Four primary colors may be used to render anaglyphs with a full color gamut. The first image of a stereoscopic pair may be rendered in three primary colors while the second image of a stereoscopic pair may be rendered in a fourth primary color. The first image may be rendered in green and blue primary colors and a third primary color which may be a yellow, orange or red. The second image of the anaglyph may be rendered in a red or far-red primary color. A first color filter for viewing the first image may transmit light with wavelengths shorter than an edge wavelength $\lambda_e$, where $\lambda_e$ may be between about 610 nm and 650 nm. A second color filter for viewing the second image may transmit light with wavelengths longer than the edge wavelength $\lambda_e$.
HIGH FIDELITY ANAGLYPHS UTILIZING A FAR-RED PRIMARY COLOR

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of PCT/US2008/000855 filed Jan. 23, 2008, which claims priority to U.S. Ser. No. 60/881,863 filed Jan. 23, 2007, which applications are hereby incorporated by reference herein.

TECHNICAL FIELD

[0002] The technical field relates to imaging and viewing in three dimensions.

BACKGROUND

[0003] Stereoscopic images generally consist of two images which are related by a small change in the lateral perspective. When viewed through an enabling apparatus, stereoscopic images may provide the perception of stereoscopic depth. Anaglyphs are stereoscopic images wherein different sets of primary colors are used to render the first and second images of the stereo pair. Usually the spectra of the first and second images do not overlap significantly. Then the first and second images may be viewed selectively using two complementary color viewing filters. The first viewing filter $F_1$ may be used to view the first image while the second viewing filter $F_2$ may be used to view the second image. The first filter $F_1$ substantially transmits the primary colors of the first image and blocks the primary colors of the second image. The second filter $F_2$ substantially transmits the primary colors of the second image and blocks the primary colors of the first image.

[0004] Anaglyphs are often rendered in three primary colors where the first image is rendered in two primary colors while the second image is rendered in one primary color. In red/cyan anaglyphs, the first image is rendered in green and blue primary colors while the second image is rendered in a red primary color. Other types of anaglyphs include blue/yellow and green/magenta anaglyphs. Herein these anaglyphs are called three-color anaglyphs.

[0005] Anaglyphs are often used to display stereoscopic images due to their relatively low cost and wide compatibility with display devices. However, conventional anaglyphs have some well known disadvantages. Firstly, conventional anaglyphs generally exhibit a reduced color gamut when viewed through the colored viewing filters. Secondly, conventional anaglyphs generally exhibit retinal rivalry which may cause user discomfort. The prior art contains many methods to improve the color gamut of anaglyphs. The prior art also contains many methods to reduce the retinal rivalry in anaglyphs. However, these anaglyphs still have reduced color gamuts and exhibit retinal rivalry.

[0006] It is commonly known that viewing a subject through colored filters may reduce the observed color gamut of the subject. In general, a color filter which transmits only a single primary color does not allow any color hue to be fully perceived through the filter. For example, an image rendered in a pure red primary color may appear to be nearly a grayscale image when viewed through the red filter.

[0007] On the other hand, a filter which transmits two primary colors may allow only the hues associated with the two primary colors to be perceived through the filter. The hue consisting of both primary colors may appear to be nearly a gray color through the filter. For example, a cyan filter (which transmits green and blue light) may allow only blue and green hues or blue and greenish-yellow hues to be perceived through the filter depending on how close the green primary color is to yellow. An image rendered in pure cyan hues may appear to be nearly a grayscale image when viewed through a cyan filter. These phenomena may be confirmed by viewing a digital color spectrum through pure cyan and pure red filters. Software programs for editing digital images often provide a suitable digital color spectrum in their color selection tools.

[0008] Since the second image in an anaglyph, may be generally perceived as a grayscale image, the color gamut observed in a stereo view of an anaglyph may be generally similar to the color gamut of the first image rendered in two primary colors. The first image in an anaglyph generally contributes more to color perception than the second image.

[0009] Methods exist in the prior art to increase the color gamut of anaglyph images by using leaky viewing filters. It is widely known that the range of perceived hues in anaglyphs may be expanded to some degree by allowing one or both of the viewing filters to partially transmit or leak a small amount of additional primary colors through the filters. For example, a red filter which also transmits a small amount of green light may allow a dark green hue and an unsaturated red hue to be perceived through the red filter. Or a cyan filter which also transmits a small amount of red light may allow a dark red hue and an unsaturated cyan hue to be perceived through the filter.

[0010] Transmitting part of the primary colors of the opposite image through the viewing filters may cause the user to see ghost images or double images in the stereo view. The double images may reduce the ability of the user to fuse the stereo pair and may reduce the perceived stereoscopic depth in the stereo view. Therefore, when using leaky filters, the benefit of the extra hues created by the leak must be balanced against the disadvantage of perceiving less stereoscopic depth.

[0011] Conventional cyan filters for viewing red/cyan anaglyphs are often designed to leak a small amount of a red primary color through the filter. This allows a weak reddish hue to be perceived through the cyan filter. However the leaked red primary color creates a ghost of the second image in the view of the first image. Furthermore since the second image may be offset from the first image due to stereoscopic parallax, the red light from the second image is often not at the proper location to contribute correctly to the color of the first image. Similar disadvantages occur when using leaky filters with blue/yellow and green/magenta anaglyphs.

BRIEF SUMMARY OF THE INVENTION

[0012] One embodiment of the present invention describes a method of displaying anaglyphs comprising an anaglyph including a first image and a second image and a short pass filter $F_1$ with a long edge wavelength in the region from about 610 nm to about 650 nm and a long pass filter $F_2$ with a short edge wavelength in the region from about 610 nm to about 650 nm and a primary color $Q_1$, with a short edge wavelength in the region from about 610 nm to about 650 nm and rendering the first image in three or more primary colors $\{P_1, \ldots, P_n\}$ and rendering the second image in the primary color $Q_1$ and the first filter $F_1$ substantially transmitting the primary colors $\{P_1, \ldots, P_n\}$ and blocking the primary color $Q_1$ and the second filter $F_2$ substantially transmitting the primary color $Q_1$ and blocking the primary colors $\{P_1, \ldots, P_n\}$ and the first image viewable through the filter $F_1$ and
the second image viewable through the filter $F_2$, whereby the first image may have a two-dimensional color gamut.

[0013] An alternative embodiment of the present invention describes a method of displaying anaglyphs comprising an anaglyph including a first image and a second image and a short pass filter $F_1$, with a long edge wavelength in the region from about 610 nm to about 650 nm three or more primary colors $\{P_1, \ldots, P_m\}$, primary color $P_2$ including a substantially amount of light with wavelengths in the region from about 580 nm to about 620 nm and rendering the first image in primary colors $\{P_1, \ldots, P_m\}$ and rendering the second image in a primary color $Q_1$ and the first filter $F_1$, substantially transmitting the primary colors $\{P_1, \ldots, P_n\}$ and blocking the primary color $Q_1$ and the second filter $F_2$, substantially transmitting the primary color $Q_1$ and blocking the primary colors $\{P_1, \ldots, P_n\}$ and the first image viewable through the filter $F_2$, and the second image viewable through the filter $F_2$, whereby the first image may have a two-dimensional color gamut.

[0014] An alternative embodiment of the present invention describes an apparatus for viewing anaglyphs comprising a short pass filter $F_1$, with a long edge wavelength in the region from about 610 nm to about 650 nm and a long pass filter $F_2$, with a short edge wavelength in the region from about 610 nm to about 650 nm and wherein anaglyphs viewed through the first and second viewing filters may have a color gamut including yellow and orange hues.

[0015] The present invention is directed to the use of primary colors and special filters to display and view digital anaglyphs with wide color gamut.

[0016] The present invention provides methods for expanding the color gamut of anaglyphs by distributing the red wavelengths of light between two primary colors, a near-red primary color and a far-red primary color. The first image of an anaglyph may be rendered in near-red, green, and blue primary colors while the second image may be rendered in a far-red primary color. The color gamut of an anaglyph of the present invention may be essentially full-color without creating ghost images in the stereo view.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

[0017] FIG. 1 depicts the spectra of conventional red $Q_1$, green $P_2$, and blue $P_3$ primary colors and the spectra of conventional red and cyan viewing filters where the cyan filter leaks a small amount of the red primary color.

[0018] FIG. 2 depicts the spectra of far-red $Q_1$, red $P_2$, green $P_3$, and blue $P_3$ primary colors, and the spectra of first and second viewing filters.

[0019] FIG. 3 depicts far-red $Q_1$, orange $P_1$, green $P_2$, and blue $P_3$ primary colors on a CIE chromacity diagram; the two-dimensional color gamut of the $\{P_1, P_2, P_3\}$ primary colors; and the conventional white point $W_c$.

[0020] FIG. 4 depicts far-red $Q_1$, red $P_2$, green $P_2$, and blue $P_3$ primary colors on a CIE chromacity diagram; the two-dimensional color gamut of the $\{P_1, P_2, P_3\}$ primary colors; and the conventional white point $W_c$.

[0021] FIG. 5 depicts red $Q_1$, green $P_2$, and blue $P_3$ primary colors on a CIE chromacity diagram; the one-dimensional color gamut of the $\{P_2, P_3\}$ primary colors; and the conventional white point $W_c$.

DETAILED DESCRIPTION OF THE INVENTION

[0022] Viewing filters for viewing red/cyan anaglyphs may include a first filter $F_1$, which has the characteristics of a short pass filter, and a second filter $F_2$, which has the characteristics of a long pass filter. These viewing filters often comprise adsorbing dyes in a plastic medium. Short pass and long pass filters may be characterized by edge wavelengths. Generally, a short pass filter transmits light with wavelengths shorter than an edge wavelength while a long pass filter transmits light with wavelengths longer than an edge wavelength. Herein an edge wavelength is defined to be approximately the wavelength where a spectrum begins to increase rapidly from near zero. Typically, edge wavelengths will have spectral values between about 5 percent to about 15 percent of the maximum transmission value. Herein a range of wavelengths may be considered edge wavelengths of a spectrum.

[0023] A primary color may also be characterized by edge wavelengths. Herein if an edge wavelength is on the short side of a spectrum, the edge wavelength is sometimes called a short edge wavelength. Herein if an edge wavelength is on the long side of a spectrum, the edge wavelength is called a long edge wavelength. Primary colors may have both short and long edge wavelengths. Similarly, filters may have both short and long edge wavelengths.

[0024] Conventional red and green primary colors typically have edge wavelengths around 580-590 nm. Consequently, the red and cyan filters for viewing red/cyan anaglyphs typically have edge wavelengths around 580-590 nm. These red and cyan filters often comprised of polyester dye films. Red dye films are generally available with edge wavelengths up to about 600 nm for general color filtering applications.

[0025] FIG. 1 depicts the spectra of red $Q_1$, green $P_2$, and blue $P_3$ primary colors representative of the primary colors used in the prior art for rendering red/cyan anaglyphs. The cyan filter spectra 102 overlaps the red primary color by a small amount 108 and is representative of conventional leaky cyan filters used for viewing red/cyan anaglyphs. The red filter spectra 104 has a edge wavelength near about 580 nm and is representative of conventional red filters used for viewing red/cyan anaglyphs. The alternate red spectra 106 has an edge wavelength near 600 nm (not shown) and represents the maximum edge wavelengths which are commonly available in plastic dye filters for general lighting applications. The spectra 106 is rarely used for viewing anaglyphs of the prior art because the luminance of the red image decreases as the edge wavelength increases.

[0026] One embodiment of the present invention is directed to distributing the spectrum of red light between the first and second images of an anaglyph by creating two red primary colors. One red primary color $P_1$ has wavelengths in the shorter end of the red spectrum while a second red primary color $Q_1$ has wavelengths in the longer end of the red spectrum. The first image may be displayed using three primary colors $\{P_1, P_2, P_3\}$ consisting of red, green, and blue primary colors respectively while the second image may be displayed using a far-red primary color $Q_1$. Herein this type of anaglyph is called a far-red anaglyph. The edge wavelength $\lambda_e$ between the primary color $P_1$ and the primary color $Q_1$ may be in the region from about 600 nm to about 650 nm. If the edge wavelength $\lambda_e$ is near 600-620 nm, primary color $P_1$ may be a yellow or orange primary color. If the edge wavelength $\lambda_e$ is near 620-650 nm, primary color $P_1$ may be an orange or red primary color. It is within the scope of the present invention for the spectra of the $P_1$ and $Q_1$ primary colors to overlap each other by a small amount.

[0027] Another embodiment of the present invention is directed to a set of viewing filters $F_1$ and $F_2$ for viewing far-red
anaglyphs. The first filter $F_1$ substantially transmits visible light with wavelengths shorter than an edge wavelength $\lambda_e$ and blocks light with wavelengths longer than the edge wavelength $\lambda_e$. Herein, a filter transmits a primary color if a substantial portion of the luminance of the primary color is transmitted by the filter. Conversely, a filter blocks a primary color if only a small fraction of the luminance of the primary color is transmitted by the filter. The first filter $F_1$ may transmit the primary colors $\{P_1, P_2, P_3\}$ and may block the primary color $Q_1$. Conversely, the second filter $F_2$ may transmit the primary color $Q_1$. It is within the scope of the present invention for the filters $F_1$ and $F_2$ to leak a small amount of the luminance of additional primary colors through the viewing filters. It is also within the scope of the present invention for the filters $F_1$ and $F_2$ to overlap each other by a small amount.

**[0028]** FIG. 2 depicts the spectra of far-red $Q_1$, red $P_3$, green $P_2$, and blue $P_1$ primary colors which are representative of the primary colors of the present invention. Also depicted are the spectra 202 of filter $F_1$ and the spectra 204 of filter $F_2$, which are representative of the viewing filters of the present invention. The primary colors $P_1$ and $Q_1$ have edge wavelengths near $\lambda_e$ as depicted in FIG. 2. As drawn, the primary color $P_1$ may have either an orange hue or red hue depending on the value of $\lambda_e$. The spectrum 202 of filter $F_1$ overlaps the primary colors $\{P_1, P_2, P_3\}$ and does not overlap the primary color $Q_1$. The filter $F_1$ transmits the primary colors $\{P_1, P_2, P_3\}$ and blocks the primary color $Q_1$. The spectrum 204 of filter $F_2$ overlaps the primary color $Q_1$, and does not overlap the primary colors $\{P_1, P_2, P_3\}$, significantly. The filter $F_2$ transmits the primary color $Q_1$, and blocks the primary colors $\{P_1, P_2, P_3\}$.

**[0029]** In far-red anaglyphs, by distributing the red light between the first and second images, the color gamut of the first image of anaglyph viewed through the first filter may be expanded up to a full spectrum of hues without creating a ghost image of the second image in the field of view of the user’s first eye.

**[0030]** The primary colors $\{P_1, P_2, P_3\}$ and $Q_1$ may be provided in digital displays or in printed media. In the prior art, some types of digital displays may provide more than three primary colors in order to increase the color gamut or brightness of the display. These primary colors may be defined by dichroic interference filters. By modifying the design (spectra) of the dichroic filters, the $\{P_1, P_2, P_3, Q_1\}$ primary colors of the present invention may be provided in a display device.

**[0031]** Some display methods may provide multiple primary colors using multiple LED or laser light sources. These light sources produce narrow bands or light. A typical red primary color may have a maximum output at a wavelength near about 610-630 nm. Then a second red primary color may be provided by another LED or laser LED with a maximum output at a wavelength near about 630-670 nm.

**[0032]** The spectra of the viewing filters $F_1$ and $F_2$ of the present invention may be produced with absorbing dyes. Polyester films or other plastic films may form the medium or substrate for the absorbing dyes for filters $F_1$ and $F_2$, whereby the viewing filters for far-red anaglyphs may be produced at relatively low cost. The viewing filters may also be made of doped glass, interference layers or by other methods. The color gamut observed in a stereo view of an anaglyph may be generally similar to the color gamut of the first image of the anaglyph rendered in two primary colors. Therefore, expanding the color gamut of the first image in an anaglyph may expand the color gamut observed in the anaglyph. The color gamut of a set of primary colors is the set of colors which may be rendered using the set of primary colors. The color gamut of a set of primary colors may be depicted by plotting the $xy$ chromaticity coordinates of the primary colors on a CIE chromacity diagram. A property of a CIE chromacity diagram is that the color gamut of a set of primary colors may be depicted by connecting the points representing the primary colors with line segments in the chromacity diagram. The color gamut includes the area bounded by the line segments.

**[0033]** The color gamut of the first image of a far-red anaglyph viewed through the first filter may be a two-dimensional triangle. FIG. 3 depicts the color gamut 302 of the first image for a yellow or orange primary color $P_1$. If primary color $P_1$ is yellow, the color gamut 302 may include blue, cyan, green, and yellow hues. If primary color $P_1$ is orange, the color gamut may include blue, cyan, green, yellow, and orange hues. FIG. 4 depicts the color gamut 402 of the first image for a red primary color $P_1$. If primary color $P_1$ is a red primary color, the color gamut 402 may include blue, cyan, green, yellow, orange, and magenta hues. The white point $W_c$, depicted in FIGS. 3 and 4, is located at the conventional location without viewing through a colored filter. The white point may be shifted toward the middle of the color gamut when viewing through a color filter.

**[0034]** On the other hand, the color gamut of the first image of a three-color anaglyph may be a one-dimensional line segment. FIG. 5 depicts the color gamut 502 of the first image of a red/cyan anaglyph. For a three-color anaglyph, the white point $W_c$, viewed through the cyan filter generally moves close to the midpoint of color gamut line segment causing the cyan hues to appear nearly white.

**[0035]** When viewing through a colored filter, the white point may move toward the center of the color gamut of the filter. In the case of a one-dimensional color gamut, the shift of the white point toward the center of the gamut may reduce the number of observed hues whereas in the case of a two-dimensional color gamut, the shift of the white point toward the center of the gamut may increase the number of observed hues.

**[0036]** The two-dimensional color gamuts of the anaglyphs of the present invention may be greater than the one-dimensional color gamuts of anaglyphs of the prior art. The color gamut of a far-red-anaglyph of the present invention may be full-color while the viewing filters may be produced by inexpensive methods.

**[0037]** Some embodiments of the present invention provide that the first image may be rendered in three or more primary colors $\{P_1, \ldots, P_n\}$ and the second image may be rendered in a far-red or red primary color $Q_1$. Then the color gamut of the anaglyphs of the present invention may be greater than the color gamut of anaglyphs of the prior art.

**[0038]** As noted above, the present invention is applicable to primary colors and special filters and is believed to be particularly useful for displaying and viewing anaglyphs with wide color gamuts. The present invention should not be considered limited to the particular examples described above.
but rather should be understood to cover all aspects of the invention as fairly set out in the attached claims. Various modifications, equivalent processes, as well as numerous structures to which the present invention may be applicable will be readily apparent to those of skill in the art to which the present invention is directed upon review of the present specification. The claims are intended to cover such modifications and devices.

I claim:

1. A method of displaying anaglyphs comprising:
   an anaglyph including a first image and a second image;
   a short pass filter $F_1$ with a long edge wavelength in the region from about 610 nm to about 650 nm;
   a long pass filter $F_2$ with a short edge wavelength in the region from about 610 nm to about 650 nm;
   a primary color $Q_1$ with a short edge wavelength in the region from about 610 nm to about 650 nm;
   rendering the first image in three or more primary colors $\{P_1, \ldots, P_m\}$;
   rendering the second image in the primary color $Q_1$;
   the first filter $F_1$ substantially transmitting the primary colors $\{P_1, \ldots, P_m\}$ and blocking the primary color $Q_1$;
   the second filter $F_2$ substantially transmitting the primary color $Q_1$ and blocking the primary colors $\{P_1, \ldots, P_m\}$;
   the first image viewable through the filter $F_1$; and
   the second image viewable through the filter $F_2$ whereby
   the first image may have a two-dimensional color gamut.

2. The method of claim 1 wherein the spectrum of primary color $P_1$ includes a substantial amount of light with wavelengths in the region from about 580 nm to about 650 nm.

3. The method of claim 1 wherein the primary color $P_1$ is yellow, orange or red.

4. A method of displaying anaglyphs comprising:
   an anaglyph including a first image and a second image;
   a short pass filter $F_1$ with a long edge wavelength in the region from about 610 nm to about 650 nm;
   a long pass filter $F_2$ with a short edge wavelength in the region from about 610 nm to about 650 nm;
   three or more primary colors $\{P_1, \ldots, P_m\}$, primary color $P_1$ including a substantial amount of light with wavelengths in the region from about 580 nm to about 650 nm;
   rendering the first image in primary colors $\{P_1, \ldots, P_m\}$;
   the first filter substantially transmitting the primary colors $\{P_1, \ldots, P_m\}$ and blocking the primary color $Q_1$;
   the second filter substantially transmitting the primary color $Q_1$ and blocking the primary colors $\{P_1, \ldots, P_m\}$;
   the first image viewable through the filter $F_1$; and
   the second image viewable through the filter $F_2$ whereby
   the first image may have a two-dimensional color gamut.

5. The method of claim 4 wherein the primary color $Q_1$ has a short edge wavelength in the region from about 610 nm to about 650 nm.

6. The method of claim 4 wherein the primary color $P_1$ is yellow, orange or red.

7. An apparatus for viewing anaglyphs comprising:
   a short pass filter $F_1$ with a long edge wavelength in the region from about 610 nm to about 650 nm;
   a long pass filter $F_2$ with a short edge wavelength in the region from about 610 nm to about 650 nm;
   wherein anaglyphs viewed through the first and second viewing filters may have a color gamut including yellow or orange hues.

8. The apparatus of claim 7 wherein the first filter includes material which substantially absorbs light with wavelengths longer than about 650 nm and the second filter includes material which substantially absorbs light with wavelengths shorter than about 610 nm.

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