Title: COLOUR PIXEL CONFIGURATION FOR AN AUTOSTEREOSCOPIC DISPLAY

Abstract: In an autostereoscopic display apparatus comprising a spatial light modulator comprising an array of colour pixels 1044-1058 arranged in rows and columns and a spatially multiplexing parallax element 1072 capable of directing light from successive columns of pixels 1044-1058 towards successive ones of plural viewing windows, the green pixels are arranged in every column of the array. The green pixels have an area which is of the order of half the area all the other pixels combined. Several different choices for the other pixels are possible including red and blue pixels interlaced along the rows and columns, interlaced red, blue and white pixels or interlaced red, blue and magenta pixels. Preferably the display apparatus is switchable between a first mode in which the spatially multiplexing parallax element is effective and a second mode in which the spatially multiplexing parallax element has no effect.
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.
Colour Pixel Configuration For An Autostereoscopic Display

The present invention relates to colour filter patterns for a directional display apparatus. Such an apparatus may be used in a switchable two dimensional (2D)/three dimensional (3D) autostereoscopic display apparatus. Such systems may be used in computer monitors, telecommunications handsets, digital cameras, laptop and desktop computers, games apparatuses, automotive and other mobile display applications.

Normal human vision is stereoscopic, that is each eye sees a slightly different image of the world. The brain fuses the two images (referred to as the stereo pair) to give the sensation of depth. Three dimensional stereoscopic displays replay a separate, generally planar, image to each of the eyes corresponding to that which would be seen if viewing a real world scene. The brain again fuses the stereo pair to give the appearance of depth in the image.

Fig. 1a shows in plan view a display surface in a display plane 1. A right eye 2 views a right eye homologous image point 3 on the display plane and a left eye 4 views a left eye homologous point 5 on the display plane to produce an apparent image point 6 perceived by the user behind the screen plane.

Fig. 1b shows in plan view a display surface in a display plane 1. A right eye 2 views a right eye homologous image point 7 on the display plane and a left eye 4 views a left eye homologous point 8 on the display plane to produce an apparent image point 9 in front of the screen plane.

Fig. 1c shows the appearance of the left eye image 10 and right eye image 11. The homologous point 5 in the left eye image 10 is positioned on a reference line 12. The corresponding homologous point 3 in the right eye image 11 is at a different relative position 3 with respect to the reference line 12. The separation 13 of the point 3 from the reference line 12 is called the disparity and in this case is a positive disparity for points which will lie behind the screen plane.

For a generalised point in the scene there is a corresponding point in each image of the stereo pair as shown in Fig. 1a. These points are termed the homologous points. The relative separation of the homologous points between the two images is
-2-

termed the disparity; points with zero disparity correspond to points at the depth plane of the display. Fig. 1b shows that points with uncrossed disparity appear behind the display and fig.1c shows that points with crossed disparity appear in front of the display. The magnitude of the separation of the homologous points, the
distance to the observer, and the observer's interocular separation gives the amount of depth perceived on the display.

Stereoscopic type displays are well known in the prior art and refer to displays in which some kind of viewing aid is worn by the user to substantially separate the views sent to the left and right eyes. For example, the viewing aid may be colour filters in which the images are colour coded (e.g. red and green); polarising

glasses in which the images are encoded in orthogonal polarisation states; or shutter
glasses in which the views are encoded as a temporal sequence of images in synchronisation with the opening of the shutters of the glasses.

Autostereoscopic displays operate without viewing aids worn by the observer.

In autostereoscopic displays, each of the views can be seen from a limited region in space as illustrated in Fig. 2.

Fig. 2a shows a display device 16 with an attached parallax optical element 17. The display device produces a right eye image 18 for the right eye channel. The parallax optical element 17 directs light in a direction shown by the arrow 19 to produce a right eye viewing window 20 in the region in front of the display. An observer places their right eye 22 at the position of the window 20. The position of the left eye viewing window 24 is shown for reference. The viewing window 20 may also be referred to as a vertically extended optical pupil.

Fig. 2b shows the left eye optical system. The display device 16 produces a
left eye image 26 for the left eye channel. The parallax optical element 17 directs
light in a direction shown by the arrow 28 to produce a left eye viewing window 30
in the region in front of the display. An observer places their left eye 32 at the
position of the window 30. The position of the right eye viewing window 20 is shown for reference.

The system comprises a display and an optical steering mechanism. The light
from the left image 26 is sent to a limited region in front of the display, referred to as the viewing window 30. If an eye 32 is placed at the position of the viewing window 30 then the observer sees the appropriate image 26 across the whole of the display 16. Similarly the optical system sends the light intended for the right image 18 to a separate window 20. If the observer places their right eye 22 in that window then the right eye image will be seen across the whole of the display. Generally, the light from either image may be considered to have been optically steered (i.e. directed) into a respective directional distribution.

The optical system serves to generate a directional distribution of the illumination at a window plane at a defined distance from the display. The variation in intensity across the window plane of a display constitutes one tangible form of a directional distribution of the light.

The respective images are displayed at the display plane, and observed by an observer at or near the window plane. The variation in intensity across the window plane is not defined by the variation in intensity across the image; however the image seen by an observer at the window plane may be referred to as the image at the viewing window for ease of explanation.

In this application the term "SLM" (Spatial Light Modulator) is used to include devices which modulate the transmitted or reflected intensity of an external light source, examples of which include Liquid Crystal Displays, and also devices which generate light themselves, examples of which include Electroluminescent displays.

In this application the term "3D" is used to refer to a stereoscopic or autostereoscopic image in which different images are presented to each eye resulting in the sensation of depth being created in the brain. This should be understood to be distinct from "3D graphics" in which a 3D object is rendered on a 2D dimensional display and each eye sees the exact same image.

One type of prior art switchable 2D/3D display system uses a switchable backlight unit in order to achieve switching between different directional distributions as described in Proc.SPIE vol.1915 Stereoscopic Displays and
Applications IV(1993) pp177-186, "Developments in Autostereoscopic Technology at Dimension Technologies Inc.", 1993. In a first mode, the light distribution from the backlight is substantially uniform and a 2D directional distribution from the display is generated. In a second display mode, light lines are produced by the backlight. These light lines are modulated by LCD pixels so that the windows of an autostereoscopic intensity distribution for viewing a 3D image are formed. The switching could, for example, be accomplished by means of a switchable diffuser element, controlled by a voltage applied across the diffuser. Such diffusers are well known in the prior art.

Another type of display apparatus which is capable of switching between a 2D mode of operation and a 3D autostereoscopic mode of operation is disclosed in WO-03/015424 which is described in more detail below.

One type of prior art pixel configuration for 3D autostereoscopic displays uses the stripe configuration shown in Fig. 7a which is well known for use in a 2D display. In this configuration, a spatial light modulator comprises an array of pixels comprising columns of red pixels 1228, green pixels 1234 and blue pixels 1238. To generate an autostereoscopic display, a lens array 100 or other parallax element is aligned with pairs of colour sub-pixels as shown. The lens array 100 is shown in cross section while the pixels are shown in plan view for ease of explanation in the figures of this document. As a result of the cylindrical lens array 100 being placed over the surface of this pixel configuration then each eye of the observer will see half of the horizontal pixels. This is illustrated in Fig. 7b for the right eye image comprising columns of red 102, blue 104 and green 106 image pixels. In this case, the horizontal gap 108 between the pixels is substantially zero because the lenticular screen serves to distribute the light from the respective pixel across the whole of the aperture of the lens.

The use of colour pixels in a two view autostereoscopic display is shown in more detail in Fig. 8. The lens 1214 of the lens array 1208 serves to cover pixel columns 1228 and 1234. The column 1228 contains red right eye data and the column 1234 contains green left eye data. The pixels 1222 are imaged to the right
eye by the lens 1214 and appear to fill the aperture of lens 1214. In the adjacent lens 1216, the blue pixel column 1238 is imaged to the right eye and the red pixel column 1230 is imaged to the left eye. Similarly for the lens 1218 the green pixel column 1236 is imaged to the right eye and the blue pixel column 1240 is imaged to the left eye.

In the 2D mode, a colour pixel 1200 is made from adjacent colour sub-pixels 1202, 1204 and 1206. However, the 3D image colour pixel is formed from pixels that have twice the spacing for example 1224, 1242 and 1207.

As shown in Fig. 7b, the horizontal resolution of a conventional stripe image produced by attaching a parallax optic such as a lenticular screen or parallax barrier to a conventional stripe panel is half the full panel resolution. The disadvantage of this approach is that the stereo image may appear to contain aliasing artifacts, for example appearing to contain vertical stripes.

In this kind of two-view spatially multiplexed autostereoscopic image, the horizontal pixel resolution of the stereoscopic image is half of the 2D horizontal pixel resolution. The reduction of horizontal resolution may lead to stereoscopic aliasing artefacts, ie the image appearing stripy for an observer positioned at a nominal viewing distance. One way to avoid this effect is to double the spatial frequency of the pixels so that the spatial frequency of pixels visible in one viewing window is restored to that of the corresponding 2D display. This requires the pixels to be half the original size. This creates a number of manufacturing difficulties. Firstly, reducing the pixel size itself increases difficulty and cost. Secondly, for a display of a given overall size, twice the number of connections is needed which is difficult, particularly for small displays. Thirdly, it requires a smaller separation between the spatial light modulator and the parallax element to maintain the width of the viewing windows at a given viewing distance. In practice, it is difficult to manufacture a device with a sufficiently small separation.

One type of spatial light modulator for use with autostereoscopic display is described in EP-A-0,625,861. The pixels are aligned in a manner so that the columns of the pixels are substantially contiguous so as to provide uniform viewing windows
when combined with a parallax optic with power in a first direction only.

Another type of spatial light modulator is described in EP-A-0,833,184 in which the viewing windows have substantially uniform intensity when combined with a parallax optic with power in a first direction only.

A colour spatial light modulator of the type described in EP-A-0,625,861 is disclosed in EP-A-0,752,610 which teaches compensation of colour balance in displays with more than three sub pixels by using a compensating reduction in efficiency of the device.

According to the present invention, there is provided an autostereoscopic display apparatus comprising:

- a spatial light modulator comprising an array of colour pixels arranged in rows and columns; and
- a spatially multiplexing parallax element capable of directing light from successive columns of pixels towards successive ones of two or more viewing windows,

wherein green pixels are arranged in every column of the array of colour pixels, the green pixels having an area which is of the order of half the area of all the other pixels combined.

As a result, a green pixel is visible at each aperture of the parallax element as viewed from each one of the viewing windows. In other words, as compared to the conventional striped configuration shown in Fig.7a, the spatial frequency of the green pixels along the rows increases, but the spatial frequency of the other pixels along the rows remains the same, at least for a given spatial frequency along the columns. However due to the fact that the sensitivity of the human eye to green light is greater than the sensitivity to red or blue light, this is sufficient to enhance the spatial resolution of the viewed image as a whole.

The fact that light from a green pixel is directed towards each of the successive viewing windows provides autostereoscopic display. This allows the separation of the parallax element from the pixel plane to be increased for a fixed spatial luminance frequency at the plane of the parallax element. This in turn
increases manufacturability to reduce cost and/or minimise viewing nominal window
distance. The brightness of the display can be increased and the gaps between the
viewing windows can be reduced which can advantageously reduce 3D image cross
talk and increase viewing freedom. The visibility of stripes from the parallax
element can be reduced to improve image appearance.

The appearance of 3D images can be improved by reducing the visibility of
image stripes in the stereo image. Stereoscopic aliasing artefacts can be reduced to a
level equivalent to at least a double-resolution panel without the need to double the
resolution of the panel.

The practical consequence is that the manufacturing difficulties created with
the use of the conventional striped configuration are eased.

Firstly, the increase in total number of pixels is less than the increase in
spatial luminance frequency, so that the cost increase is minimised. The number of
connections is reduced compared to a double-resolution panel. Similarly, if more
than two windows are required, then the resolution does not have to increase by a
factor of more than two to maintain non-stripy images.

Secondly, the separation of the spatial light modulator and the parallax
element for high resolution displays may be unexpectedly and advantageously
increased, because the pixel resolution need not be increased as much to maintain
luminance resolution and image appearance. This allows the use of thicker substrates,
which are easier to manufacture at high yields and more compatible with standard
manufacturing techniques and increased display yield, reducing display cost, as well
as increasing the maximum number of panels that can be processed on a single
substrate. Conversely, the nominal viewing distance of the display can be reduced
without reducing the separation of the pixel plane and optical element.

The green pixels have an area which is of the order of half the area of all the
other pixels combined to maintain the colour balance between the different colours.
In practice the area of the green pixels is usually substantially half the area of the
other pixels, although in principle there could be some variation, for example in
dependence on the relative luminosity of the pixels.
The other pixels besides the green pixels may consist of interlaced red and blue pixels, interlaced red, blue and white pixels, or interlaced red, blue and magenta pixels. The pixels may be arranged in a number of different ways to provide different advantages as described in more detail below with reference to specific embodiments.

The present invention may be advantageously applied to a display apparatus which is switchable between a first mode in which the spatially multiplexing parallax element is effective to direct light from successive columns of pixels towards an alternate one of two viewing windows and a second mode in which the spatially multiplexing parallax element has no effect.

Thus, in the first mode the display apparatus provides a 3D autostereoscopic effect, whereas in the second mode, the display apparatus provides a 2D display. In the second mode, the spatial luminance resolution of the 2D images is enhanced. The spatial luminance resolution increase may be in the lateral direction, so that the readability of Roman fonts may be increased.

Desirably, the spatially multiplexing parallax element is a lenticular array. Alternatively any other type of parallax element may be used. Suitable parallax elements include lenticular screens, parallax barriers, holographic optical elements and polarisation selective elements in combination with a suitably polarised illumination source.

In another form according to the present invention, there is provided an autostereoscopic display apparatus comprising:

a spatial light modulator comprising rows and columns of pixels, where each column contains pixels for green image data and the area of the green pixel is a fraction less than one of the area of the pixels for blue and red data; and

a spatially multiplexing parallax element, which may be for example a lenticular screen or parallax barrier, separated by a distance t from the pixel plane such that the spatial light modulator and spatially multiplexing parallax element cooperate to produce an image which has at least one green pixel at each aperture of the parallax optic when seen from each of the viewing windows.
The display apparatus may be switchable between a first mode in which the directional distribution of the SLM illumination is modified and a mode in which it is unmodified.

Different features of the hereinafter described embodiments of the invention can provide the following advantages singly or in any combination:

- An increase in luminance frequency can be achieved without as significant a reduction in aperture ratio due to the finite area of electrodes and drive transistors. Thus the display brightness can be enhanced. The present invention also reduces the visibility of the zones between windows due to smaller relative size of the the finite black mask width between pixels for the same increase in luminance frequency.

- As the pixel area is larger than the comparative double resolution panel, the width of the gap between the windows can be reduced compared to a double resolution panel. This produces higher quality viewing windows with wider viewing freedom for a moving observer.

- The number of source lines can be reduced for increased spatial frequency, and thus the cost of connectors and drive electronics can be reduced as well as increasing manufacturing yield.

- The vertical resolution of the panel can be maintained

- The panel can be conveniently interfaced to existing operating systems

- In panels using white or magenta pixels, the display brightness can be increased

- The number of views in a multiple view system can be increased without further degradation of image quality

- The graphics processing power may be reduced compared to a panel with more pixels, and so the cost and complexity may be reduced.

Embodiments of the present invention will now be described, by way of none-limitative example, with reference to the accompanying drawings, in which:

Fig. 1a shows the generation of apparent depth in a 3D display for an object behind the screen plane;

Fig. 1b shows the generation of apparent depth in a 3D display for an object
in front of the screen plane;

Fig. 1c shows the position of the corresponding homologous points on each image of a stereo pair of images;

Fig. 2a shows schematically the formation of the right eye viewing window in front of an autostereoscopic 3D display;

Fig. 2b shows schematically the formation of the left eye viewing window in front of an autostereoscopic 3D display;

Fig. 3 shows a switchable 2D/3D system;

Fig. 4 shows a 3D autostereoscopic display in which the directional distribution is switched by means of an electronically controlled polarisation switching element;

Fig. 5 shows a further 3D autostereoscopic display in which the directional distribution is switched by means of an electronically controlled polarisation switching element between a lens array and an output polariser;

Fig. 6 shows a further 3D autostereoscopic display in which the directional distribution is switched by means of an electronically controlled polarisation switching element between an output polariser and a lens array;

Fig. 7a shows a prior art colour filter pattern;

Fig. 7b shows the appearance of Fig. 7a when used in conjunction with a two view parallax optic in the right eye of an observer;

Fig. 8 shows the arrangement of data on a two view lenticular display of the type shown in Fig. 7a;

Fig. 9 shows a graph of a known computational model for perceived contrast sensitivity against spatial frequency;

Fig. 10 shows the effect of higher green pixel luminance on the spatial luminance distribution of colour pixellated displays;

Fig. 11a shows a pixel configuration of a first pixel configuration and the respective position of a lenticular screen parallax optic;

Fig. 11b shows the appearance of Fig. 11a when used in conjunction with a parallax optic in the right eye of an observer;
Fig. 12a shows a second pixel configuration and the respective position of a lenticular screen parallax optic;

Fig. 12b shows the appearance of Fig. 12a when used in conjunction with a parallax optic in the right eye of an observer;

Fig. 13a shows a third pixel configuration and the respective position of a lenticular screen parallax optic;

Fig. 13b shows the appearance of Fig. 13a when used in conjunction with a parallax optic in the right eye of an observer;

Fig. 14 shows a fourth pixel configuration and the respective position of a lenticular screen parallax optic;

Fig. 15 shows the appearance of Fig. 14a when used in conjunction with a parallax optic in the right eye of an observer;

Fig. 16 shows an alternative alignment of pixels with the parallax optic for the colour filter arrangement of Fig. 11a;

Fig. 17a shows a further pixel configuration and the respective position of a lenticular screen parallax optic;

Fig. 17b shows the appearance of Fig. 17a when used in conjunction with a parallax optic in the right eye of an observer;

Fig. 18a shows the use of a known pixel shape in combination with the pixel configurations in order to reduce the intensity variations across the window plane;

Fig. 18b shows the appearance of Fig. 18a when used in conjunction with a parallax optic in the right eye of an observer;

Fig. 19 shows a pixel configuration using an additional white pixel;

Fig. 20 shows a pixel configuration using an additional magenta pixel;

Fig. 21 shows the interface of a known data signal with a panel comprising pixels as described in Fig. 20.

Fig. 22 shows an embodiment of the invention in which more than two views are produced.

The present embodiments are 2D/3D switchable directional display devices of the type disclosed in WO-03/015424, but with a particular configuration for the
colour pixels, as described in detail below. First the overall construction of particular display devices will be described. Further details of the constructions and their operation, which may be applied to the present invention, are disclosed in WO-03/015424, which is incorporated herein by reference.

Fig. 3 shows one type of switchable directional display, as described in WO-03/015424. A backlight 1034 produces an optical output 1036 which is incident on an input linear polariser 1038, and a LCD TFT substrate 1040. The light passes through the pixel plane 1042 comprising an array of LCD pixels 1044-1058. The substrate 1040 and the pixels 1044-1058 together constitute a spatial light modulator.

Each pixel comprises a separate region of addressable liquid crystal material, a colour filter and is surrounded by a black mask 1060 to form a pixel aperture 1062. The light then passes through the LCD counter substrate 1064 and through a carrier substrate 1066 to fall on a birefringent microlens 1072 which is a lenticular array comprising a layer of birefringent material 1068 and an isotropic lens microstructure 1070. The light then passes through a lens substrate 1074 and a polarisation modifying device 1076.

Fig. 4 shows a further type of switchable directional display, as described in WO-03/015424 in which the directional distribution is switched by means of a switchable polariser element. A backlight 1034 produces an optical output 1036 which is incident on an input linear polariser 1038, and a LCD TFT substrate 1040. The light passes through the pixel plane 1042 comprising an array of LCD pixels. The light then passes through the LCD counter substrate 1064, an LCD output polariser 1414 and through a carrier substrate 1066 to fall on a birefringent microlens 1072 comprising a layer of birefringent material and an isotropic lens microstructure.

The light then passes through a lens substrate 1074 and a polarisation modifying device 1416.

The polarisation modifying device 1416 may be embodied as for example a twisted nematic liquid crystal layer sandwiched between surfaces treated with transparent electrodes and liquid crystal alignment layers 1418 as well known in the art. A sensing device 1424 may be used to monitor the electrical driving of the
polarisation switching layer 1416. The second substrate 1420 of the cell 1416, 1418 has a polariser 1422 attached to its second surface.

The polariser 1414 may be a linear polariser with a transmission direction aligned at 45 degrees to the birefringent optical axis of the microlens 1072. The birefringent axis of the microlens is the direction of the extraordinary axis of the birefringent material used in the birefringent microlens 1072. The polarisation state incident on to the birefringent microlens will resolve on to the two axes of the birefringent material. In a first axis, the refractive index of the birefringent material is substantially index matched to the isotropic index of the birefringent microlens 1072 and so the lens has substantially no imaging function. In a second axis, which may be orthogonal to the first axis, the refractive index of the birefringent material has a different refractive index to the isotropic material and thus the lens has an imaging function.

In a 2D mode of operation, no voltage is applied across the liquid crystal layer 1416, and an incident polarisation state is rotated. In a 3D mode of operation, a voltage is applied across the cell, and the incident polarisation state is substantially unrotated.

If the switch 1416 is set so that the polarisation state transmitted through the polariser 1422 is parallel to the first axis, then the display will have a 2D directional distribution. If the switch 1416 is set so that the polarisation state transmitted through the polariser 1422 is parallel to the second axis, then the display will have an autostereoscopic 3D directional distribution. The sensing device 1424 thus determines the display mode of the optical switching apparatus by determining the electrical driving of the polarising element.

Fig. 5 shows a further type of switchable directional display, as described in WO-03/015424, in which the directional distribution is switched by means of a switchable polariser element. This is similar in structure to the architecture of Fig. 4 except that the polariser 1414 is omitted and the orientation of polarisation angles is different. Such a device operates in a similar way to the device of Fig. 3 except that the mechanically reconfigurable polariser is replaced by an electrically switched
polariser 1416 which may be for example a twisted nematic liquid crystal layer
sandwiched between surfaces 1418 comprising transparent electrodes and alignment
layers and an absorbing linear polariser 1422.

As described for Fig. 4, the device may be switched between 2D and 3D
directional distributions by selecting the polarisation state that is transmitted by the
final polariser 1422.

Fig. 6 shows a further type of switchable directional display, as described in
WO-03/015424, in which the directional distribution is switched by means of a
switchable polariser element positioned between a display output polariser and a
birefringent microlens array 1072. The output linear polarisation of the display
transmitted by polariser 1414 is transmitted through a switch substrate 1432,
transparent electrodes and alignment layers 1418 sandwiching a twisted nematic
layer 1430, a lens counter substrate 1066, a birefringent microlens 1072 and a lens
substrate 1074.

In the 2D mode, the polarisation switch 1430 rotates the incident polarisation
so that it is incident on to the ordinary axis of the material in the birefringent
microlens. The ordinary index is matched to the index of the isotropic material and
thus the lens has no effect. In the 3D mode, an electric field is applied to the liquid
crystal layer 1430 so that the polarisation state is not rotated and the light is incident
on the extraordinary axis of the birefringent microlens. The lens then has an optical
effect which produces the autostereoscopic directional distribution.

The sensing device 1424 thus determines the display mode of the optical
switching apparatus by determining the electrical driving of the polarising element.

Various configurations of the colour pixels are described below, any of which
may be applied to any of the display devices described above. Equally the following
configurations of the colour pixels may be applied to any other type of
autostereoscopic display apparatus, which for example might not be switchable or
might be switchable in a different manner from the display devices disclosed in WO-
03/015424.

As described in detail above one could apply the known striped pixel
configuration shown in Fig. 7a to a 3D autostereoscopic display, but this would reduce the resolution to half the resolution of the same pixel configuration in a 2D display. If the spatial frequency of the pixels is not increased this can cause the display to appear to have vertical stripes.

One origin of the appearance of these stripes may be due to the human contrast sensitivity function as shown for example in Fig. 9, taken from the known relationship described in J. L. Mannos, D. J. Sakrison, "The Effects of a Visual Fidelity Criterion on the Encoding of Images", IEEE Transactions on Information Theory, pp. 525-535, Vol. 20, No 4, (1974). This relationship describes the variation of visual contrast sensitivity 110 against spatial frequency 112 of a luminance function. The luminance spatial frequency for a stripe panel may be defined as the spatial frequency of the triplet of colour sub-pixels.

For a typical display using a stripe panel of pixel pitch 80 μm, viewed from 400mm, the spatial frequency of the green channel for example is 29 cycles per degree and is shown by the arrow 114. When a lenticular screen is added and the device is viewed in the 3D mode then the spatial frequency is halved to 14.5 cycles per degree and the arrow 116 has been marked. In this case, the relationship predicts that contrast sensitivity function has increased from 0.2 to 0.8. In the 3D mode the contrast sensitivity function is thus close to the peak of the human contrast sensitivity function. Clearly this value can be reduced by increasing the distance of the observer from the display, but the image will be less easily viewed and so this approach is not desirable.

Fig. 10 shows schematically the horizontal luminance function in images with RGB stripe pixel patterns. An array of pixels containing red 118, green 120 and blue 122 data columns is shown. The overall colour balance of the combined image is set as a standard white. The equivalent photopic luminance 124 of the three channels against position 126 is shown below. The graph shows that the luminance perceived from the green pixels is greater than the luminance of the red and blue pixels due to the human photopic efficacy function. At high resolutions, the human visual system cannot resolve the separate luminance levels of the RGB pixels and so this luminance
difference is not perceived and the image appears uniform. However, if the pixel resolution falls as is the case with the half horizontal resolution stereo image, then the difference between the luminance of the red and blue pixels and the luminance of the green pixel may become apparent. The brighter green pixel columns may thus be seen as interspersed by dimmer red and blue columns, causing stripes to appear in the stereo image. Such a stripe appearance would be visible irrespective of the pixel shape on the display. Thus, removing the gap between the pixels would not be expected to have any significant impact on image stripes in the stereoscopic mode of the display.

Accordingly, the embodiments of the present invention use one of the following pixel configurations. In all the configurations, the pixels are arranged in rows and columns extending perpendicular to one another. The columns of pixels extend in parallel with, and are aligned with, the geometric axis of the birefringent microlens 1072 so that light from successive columns of pixels are directed to one of the viewing windows imaged by the birefringent microlens 1072.

A first pixel configuration is shown in Fig. 11a. The pixel pattern is shown with the relative orientation of a two-view lenticular screen for illustrative purposes. The pixel pattern comprises columns of alternating rows of red pixels 128 and green pixels 130 and columns of alternating rows of blue pixels 132 and green pixels 134. The red pixels 128 and blue pixels 132 are arranged in separate pixel columns so that they are interlaced along the rows. The area of the green pixels 130 and 132 is substantially half of the total area of the red pixels 128 and blue pixels 132. The colour filter transmission profiles are nominally the same as the base RGB stripe panel if the green pixels are of half the size of the R and B pixels to maintain the colour balance of the display.

In the 2D mode of operation, the pixel pattern of Fig. 11a will be seen, while in the 3D mode of operation, the pixel pattern of Fig. 11b, will be seen by the right eye of the observer at the correct viewing position. Each lens of the lens array serves to direct light from a green pixel to each of the viewing windows. This means that an observer in the window plane will see a green pixel under each of the lenses of the
lens array from each window. Thus in the 3D mode of operation, the spatial
frequency of the display luminance is higher than that of the prior art display
systems. The proportion of green light directed to each of the viewing windows is
half of the light from the other colour pixels for each lens, so that the overall colour
balance across several lenses is preserved. This allows the use of thicker glass or
shorter viewing distance which is particularly advantageous as will be described
below. Thus, the observer will see the colour sub-pixels formed at the aperture of the
parallax optic, which in the example shown is a lenticular screen. The red pixels 129,
blue pixels 133 and green pixels 131 have a small gap 135 in a horizontal direction
and a gap 137 in the vertical direction defined by the gap 139 of the base panel in the
vertical direction.

The panel can be compared to an RGB stripe panel with a colour sub-pixel
pitch of 80µm (colour pixel pitch of 240µm). Such a 2D panel does not show image
stripiness for a viewing distance of 400mm. In a two view autostereoscopic 3D
mode, the RGB panel has a lens pitch of substantially 160µm and a 3D luminance
pitch of substantially 480µm. For a nominal window size of 65mm at a nominal
viewing distance of 400mm, and a refractive index of glass substrate of 1.5, this
requires a separation of the lens from the pixel plane of less than 750µm. Given
typical thickness of waveplates and parallax optic substrates is 200µm, then a 550µm
thick counter substrate is required. Such a display will show distinct image stripes at
the apertures of the lenses or other parallax optic.

It is desirable that the two view 3D luminance pitch should be of order
240µm. In an RGB stripe panel, the pixel pitch is therefore required to be 40µm. This
gives a total glass thickness between pixel plane and lens of 375µm. A white pixel is
formed from the combination of red, green and blue pixel columns. A counter
substrate thickness requirement of 175µm is also required. This substrate is required
to have colour filters, black mask and other processing steps applied, and will thus be
difficult to handle in a standard manufacturing process, reducing display yield and
increasing display cost.

In the embodiments of this invention, the pixel column pitch is increased
which has unexpected advantages for the manufacturability and cost of autostereoscopic displays. In the configuration of Fig. 11a, the column pitch in order to achieve a spatial luminance pitch of 240µm in a two view display is 60µm. The spatial luminance pitch is defined as the pitch of the red pixels in this configuration. This requires a total glass thickness of 560µm and a counter substrate thickness of 360µm. Thus the total glass thickness is 50% greater than the prior art system, but due to the waveplate and polariser thicknesses, the counter substrate thickness for the spatial light modulator has increased from 175µm. This is a factor of more than two increase in counter substrate thickness. Such a substrate is significantly easier to handle in manufacturing process which increases display yield and reduces cost. This increase in manufacturability arises because each lens serves to direct green light to each of the viewing windows.

This advantage applies to all of the autostereoscopic display embodiments of the present invention.

If the luminance pitch can be relaxed to the pitch of the green pixels, then the column width would be 120µm and the glass thickness can be relaxed further to 1125µm. Such a configuration may provide some residual luminance variation in red and blue channels, and so residual luminance artefacts at the lens aperture.

The increase in pixel size means that the alignment tolerances of the lens elements with respect to the display are similarly relaxed, as the lens needs to be aligned to a certain proportion of pixel size so that the window is aligned to a certain proportion of a window size. As each lens serves to direct green light to each of the viewing windows, the pixel size can be increased, and thus the lens alignment tolerance can be relaxed. Due to the finite size of electrodes, transistors and storage capacitors, the aperture ratio of the panel is increased. Thus the panel is of higher brightness. The gaps between the pixels may be reduced in proportion to the pixel width and thus the gaps between the windows in the window plane may be equivalently reduced.

The vertical luminance frequency is the same as the RGB stripe panel. The total number of addressable sub-pixels in a colour pixel has increased from three to
four, with a doubling in the number of row drivers. Advantageously, the row and source drivers could be rotated, so that the number of source drivers is increased by a factor of two and the number of row drivers reduced.

In Fig. 11a, the horizontal resolution of the red and blue pixels 128,132 is half of the horizontal resolution of the green pixels 130,134. However, there is a clumping effect created by the need to have alternating red and blue pixels in the 3D mode of operation. Although there is additional spatial resolution in the red and blue channels, the changing effect will result in the 2D (optical element switched off) and 3D (optical element switched on) modes being similar in appearance. The main difference will be the increase in luminance frequency from the extra green pixels. This effect can be used to reduce system cost by allowing the use of an unswitched parallax optical element with high spatial frequency and similar image appearance in 2D and 3D modes. Such a display advantageously is lower cost, easier to manufacture, thinner and lighter.

Thus these embodiments allows the production of a display which has higher spatial luminance frequency in both 2D and 3D modes of operation when combined with a spatial multiplexing parallax optical element such as a lenticular screen or parallax barrier. This is advantageously achieved without changing the colour balance of the panel or substantial degradation in brightness. The number of additional addressed pixels is increased by only one third compared to the standard RGB panel in order to achieve an effective doubling of spatial resolution in both modes.

In an alternative configuration, the total number of pixels on the panel can be maintained, and the pitch of the pixel columns can be increased to compensate. To continue the example, this would require a column pitch of 160μm. The luminance frequency remains greater in both 2D and 3D modes than that of the base RGB stripe panel. Advantageously, the viewing distance or glass thickness of the counter substrate can be further relaxed.

In this invention the pixel apertures are different sizes for green and other colour sub-pixels and therefore the pixel capacitance would be different also. This
can be compensated for altering the TFT drive signals. Generally a storage capacitor is associated with each pixel and would typically be a multiple of the pixel capacitance of 2 to 10. If the storage capacitances are the same for both sizes of pixel then it may not be necessary to alter the TFT drive signals.

Fig. 12a shows an alternative pixel arrangement in which the red and blue pixels alternate on a single column, and alternate in rows to form a chequerboard pattern. The red pixels and blue pixels are interlaced vertically along each pixel column. The green pixels are arranged as rows alternating the red and blue pixels and have substantially half the area of the red and blue pixels. In this case, the stereo image shown in Fig. 12b comprises alternating rows of red and blue pixels rather than the alternating columns of Fig. 11b. This configuration may be advantageous because the pixel structure in the 2D full resolution mode does not require double columns of red and blue pixels. However, the height of the colour pixel is substantially increased which may lead to diagonal stripes in the image. Thus in this embodiment, each lens of the lens array directs green light to each of the viewing windows. This produces the advantages of substantial increase in counter substrate thickness, aperture ratio, display brightness, 3D image cross talk and viewing freedom, as described previously.

Fig. 13a shows an alternative pixel configuration in which the pixels are staggered in the vertical direction in adjacent pixel columns. This allows the staggering of pixels in the 2D and 3D mode, but has the disadvantage that there is some vertical disparity generated between left and right eye views, which may cause some visual stress. In the 2D mode, the colour pixels are arranged as diagonal stripes. The visual resolution limit is reduced at these orientations, and thus the pixel rows will be less visible to an observer. However, such patterns may display vertical and horizontal lines less well which may be important for some applications. Also, the vertical resolution of the panel is reduced which may lead to horizontal or diagonal stripes in the image. Thus in this embodiment, each lens of the lens array directs green light to each of the viewing windows. This produces the advantages of substantial increase in counter substrate thickness, aperture ratio, display brightness,
3D image cross talk and viewing freedom, as described previously.

Fig. 14 shows an alternative configuration of pixels. In this case, the 3D colour pixels are made up of adjacent blocks 141, 143 of pixels, each comprising a set of red, green and blue pixels. In the 2D mode, the colour pixel 145 may comprise adjacent colour sub-pixels. Fig. 15 shows the appearance of the right eye image of Fig. 14. Thus in this embodiment, each lens of the lens array directs green light to each of the viewing windows. This produces the advantages of substantial increase in counter substrate thickness, aperture ratio, display brightness, 3D image cross talk and viewing freedom, as described previously.

In addressing colour filter patterns of the present embodiments, it is often desirable that the number of rows of pixels is reduced as far as possible to optimise the driving conditions of the display, particularly for TFT displays. In the case of half green pixels, the green pixels will generally be added as rows and so the driving of the display may become non-optimal. However, the number of red and blue columns may be reduced and thus it may be desirable to drive the panel with source drivers on the rows and gate drivers on the columns of the pixels.

Fig. 16 shows an alternative alignment of the lens 100 which is similar to Fig. 11 except that each lens has a pair of columns of colour sub-pixels of the same colour. In this way, each eye will see the same colour data at each lens, which can reduce the stereo aliasing artefact at the lens.

Fig. 17a shows the lens and pixel appearance and Fig. 17b show the image appearance in 3D for an alternative configuration in which the red and green colour sub-pixels are arranged as rows of pixels. Such a configuration would have reduced red and blue resolution in the vertical direction, but would avoid the loss of colour resolution in the horizontal direction, as shown for example in Fig. 16.

Fig. 18a shows the use of prior art overlapping pixel shapes in combination with the pixel configurations of this invention to increase luminance resolution. Fig. 18b shows the appearance of the 3D image. Horizontal bands 147 of lower intensity are produced.

The embodiments shown in Fig. 19 uses additional white pixels 149.
interlaced with the red and blue pixels in order to increase the luminance frequency and the brightness of the display. In this case, there is a green pixel for each red 128, blue 132 or white 149 pixel. The use of a white pixel 149 allows the maximum display brightness to be increased, while placing some limits on the profile of the colour gamut of the display and requiring an increased resolution of the panel for a certain colour pixel luminance frequency. It can be seen that in this case, there is no clumping of red and blue pixels. However, there is an increase in luminance because of the green component in the white pixel, and so some stripiness may be introduced in to the 3D image.

This effect can be advantageously reduced by using the configuration of Fig. 20 in which a magenta pixel 150, which is a green absorbing pixel, is interlaced with the red and blue pixels. Of particular advantage for this embodiment is that it is possible to produce a uniform pixel pattern, with increased luminance offered by the magenta pixel, while maintaining spatial frequency in the red and blue channels. In the example given previously, the 3D luminance pitch is required to be 240μm. As the magenta column contains red and blue data, then the pixel pitch may be set from a red and magenta pixel pair pitch or a blue and magenta pixel pair pitch as 60μm, giving a substrate thickness of 560μm.

In one mode of operation, the data content of the magenta pixel can be interpolated from the data content of the adjacent red and blue pixels so that the overall change in luminance is minimized. In this manner, the display can show reduced visibility of stripiness. In an embodiment of the present invention, it is desirable to switch this mode of operation on in 3D mode setting. Alternatively, the data can be set to optimise the brightness of the displayed image, or to maximize the colour gamut of the display. It may be desirable to switch the minimized stripe artefact mode of operation on in 3D mode setting, and use maximum brightness or maximum gamut mode in the 2D mode of operation. This is illustrated in Fig. 21. The source data 200 comprising red 202, green 204 and blue 206 data signals is read in to a multiplexer 208. A control signal 209 from a 2D/3D mode select input 210 together with a control signal 211 from a colour gamut select 212 is fed in to the
multiplexer 208 and are used to determine the optimum setting for the red, green,
blue and magenta outputs 214-220 for input into the display unit 222.

In this way, the appearance of a 3D image in the embodiments of this
invention may be improved by removal of stripe structure in the final image. Such an
improvement may be obtained without the need for substantial increases in the panel
resolution as is required in the prior art. The configurations given further do not
change the panel colour balance and do not significantly reduce the aperture ratio of
the individual pixels. Further, in the 3D mode of operation, a short viewing distance
may be maintained while using standard thickness glass substrates.

Such pixel configurations are particularly suitable for switchable 2D-3D
displays where the improvement of appearance will be obtained in both 2D and 3D
modes compared to the standard configurations.

Many compression schemes use different resolutions for chrominance and
luminance functions. The different resolutions of the red and blue channels can be
synchronized with the chrominance output of compression algorithms.

The increased spatial resolution may also be used to increase the number of
views presented by the display, as illustrated in Fig. 22. In Fig. 22a, the parallax
element 100 covers three adjacent columns of pixels 224, 226, 228. Each column has
an associated green pixel aperture 230, 232, 234 as described elsewhere in the
invention. Fig. 22b shows the appearance of the first view from the display. In this
case, the image from three adjacent lenses of the lens array 100 is shown. Each
column has a green pixel, and thus the spatial luminance of the three view display is
increased.

In this way, the spatial luminance frequency in a multi-view display (i.e. a
display with more than 2 views) can be advantageously increased. Similarly, the
stripiness of such an image is advantageously reduced. This is of particular
advantage in multi-view displays because the resolution loss of each individual
image increases with increasing number of views. In this way, the spatial luminance
resolution can be maintained while increasing the number of views and thus the
viewing freedom of an observer when viewing the display.
The present invention can be applied to other types of multi-view displays, including (but not limited to) increased numbers of pixel columns in which the lens array geometric axis is parallel to the pixel columns, or to displays in which the lens array geometric axis is inclined to the pixel columns.
Claims

1. An autostereoscopic display apparatus comprising:
   a spatial light modulator comprising an array of colour pixels arranged in
   rows and columns; and
   a spatially multiplexing parallax element capable of directing light from
   successive columns of pixels towards successive ones of two or more viewing
   windows,
   wherein green pixels are arranged in every column of the array of colour
   pixels, the green pixels having an area which is of the order of half the area of all the
   other pixels combined.

2. A display apparatus according to claim 1, wherein the other pixels consist of
   interlaced red and blue pixels.

3. A display apparatus according to claim 2, wherein the red and blue pixels are
   interlaced along the rows of the array of pixels.

4. A display apparatus according to claim 2, wherein the red and blue pixels are
   interlaced along the columns of the array of pixels.

5. A display apparatus according to claim 1, wherein the other pixels consist of
   interlaced red, blue and white pixels.

6. A display apparatus according to claim 5, wherein the red, blue and white
   pixels are interlaced along the rows of the array of pixels.

7. A display apparatus according to claim 1, wherein the other pixels consist of
   interlaced red, blue and magenta pixels.
8. A display apparatus according to claim 7, wherein the red, blue and magenta pixels are interlaced along the rows of the array of pixels.

9. A display apparatus according to claim 7 or 8, wherein the display apparatus further comprises a multiplexer circuit arranged to generate data for supply to the green, red, blue and magenta pixels from input data consisting of data for green, red and blue pixels.

10. A display apparatus according to any one of the preceding claims, wherein the display apparatus is switchable between a first mode in which the spatially multiplexing parallax element is effective to direct light from successive columns of pixels towards an alternate one of two viewing windows and a second mode in which the spatially multiplexing parallax element has no effect.

11. A display apparatus according to any one of the preceding claims, wherein the spatially multiplexing parallax element has a structure which is uniform in a direction parallel to the columns of the array of pixels and which repeats in a direction parallel to the rows of the array of pixels.

12. A display apparatus according to any one of the preceding claims, wherein the spatially multiplexing parallax element is a lenticular array.

13. A display apparatus according to claim 12, wherein the lenticular array has a structure which repeats at a pitch of substantially twice the pitch of the columns of the array of pixels.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04N13/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
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C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Date of the actual completion of the international search
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Date of mailing of the international search report
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European Patent Office, P.B. 5816 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040, Tx 31 651 epc nl<br>Fax: (+31-70) 340-3016

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