

(12) **United States Patent**
Hartley et al.

(10) **Patent No.:** US 6,667,826 B1
(45) **Date of Patent:** Dec. 23, 2003

- (54) **CHROMATIC MODULATOR FOR HIGH RESOLUTION CCD OR APS DEVICES**
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- (21) **Appl. No.:** 10/087,683
- (22) **Filed:** Mar. 1, 2002
- (51) **Int. Cl.⁷** G02F 1/23; G09G 5/00; H04N 5/335; H04N 9/04; H04N 9/083
- (52) **U.S. Cl.** 359/278; 345/207; 348/273; 348/277
- (58) **Field of Search** 359/245, 254, 359/278, 259, 282, 308; 345/204, 207, 30, 32, 55, 84, 85; 348/273, 277

(57) **ABSTRACT**

A system for providing high-resolution color separation in electronic imaging. Comb drives controllably oscillate a red-green-blue (RGB) color strip filter system (or otherwise) over an electronic imaging system such as a charge-coupled device (CCD) or active pixel sensor (APS). The color filter is modulated over the imaging array at a rate three or more times the frame rate of the imaging array. In so doing, the underlying active imaging elements are then able to detect separate color-separated images, which are then combined to provide a color-accurate frame which is then recorded as the representation of the recorded image. High pixel resolution is maintained. Registration is obtained between the color strip filter and the underlying imaging array through the use of electrostatic comb drives in conjunction with a spring suspension system.

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18 Claims, 5 Drawing Sheets

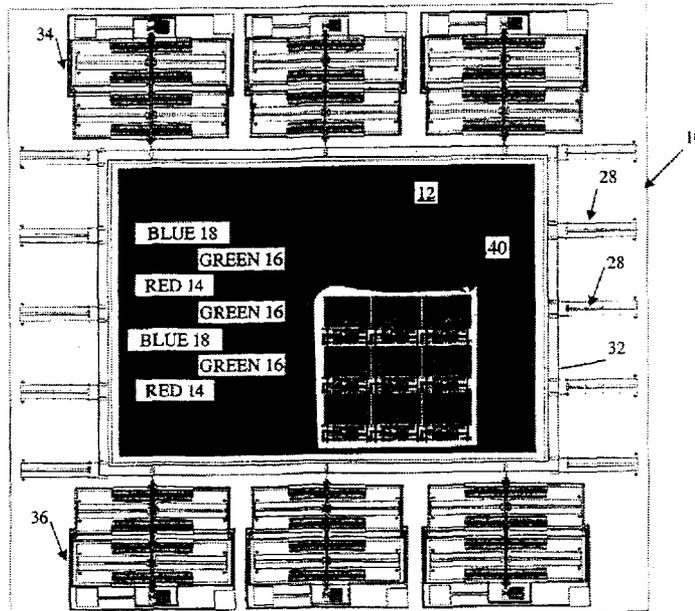
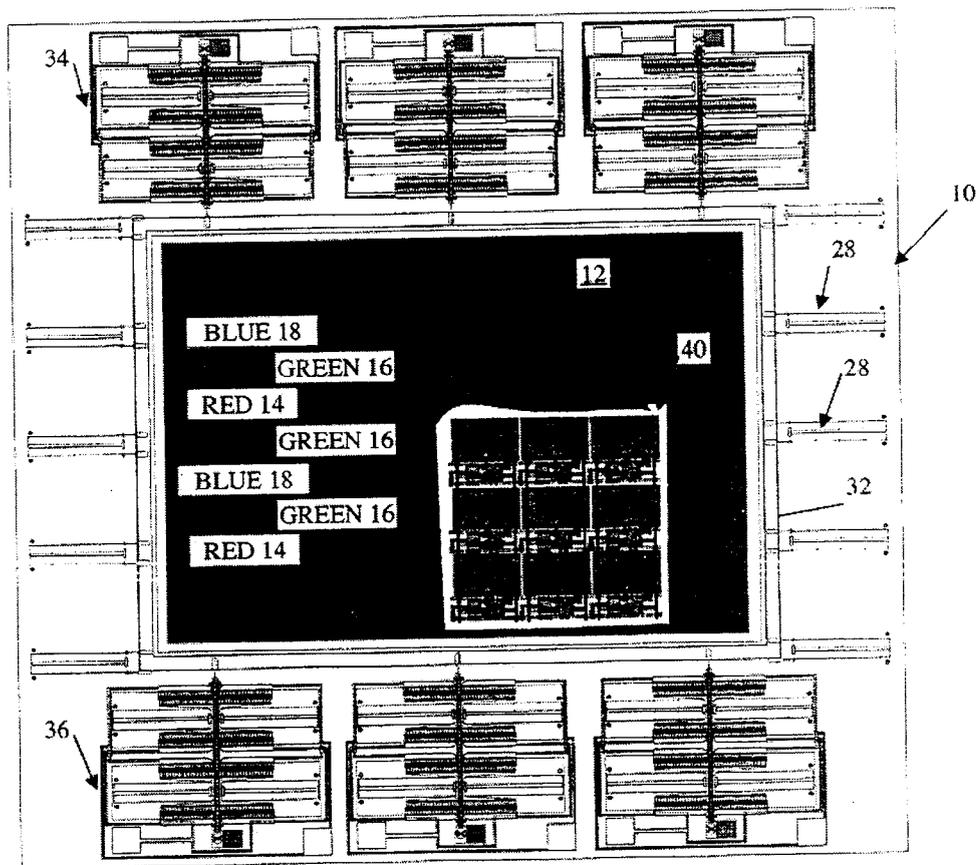


Fig. 1



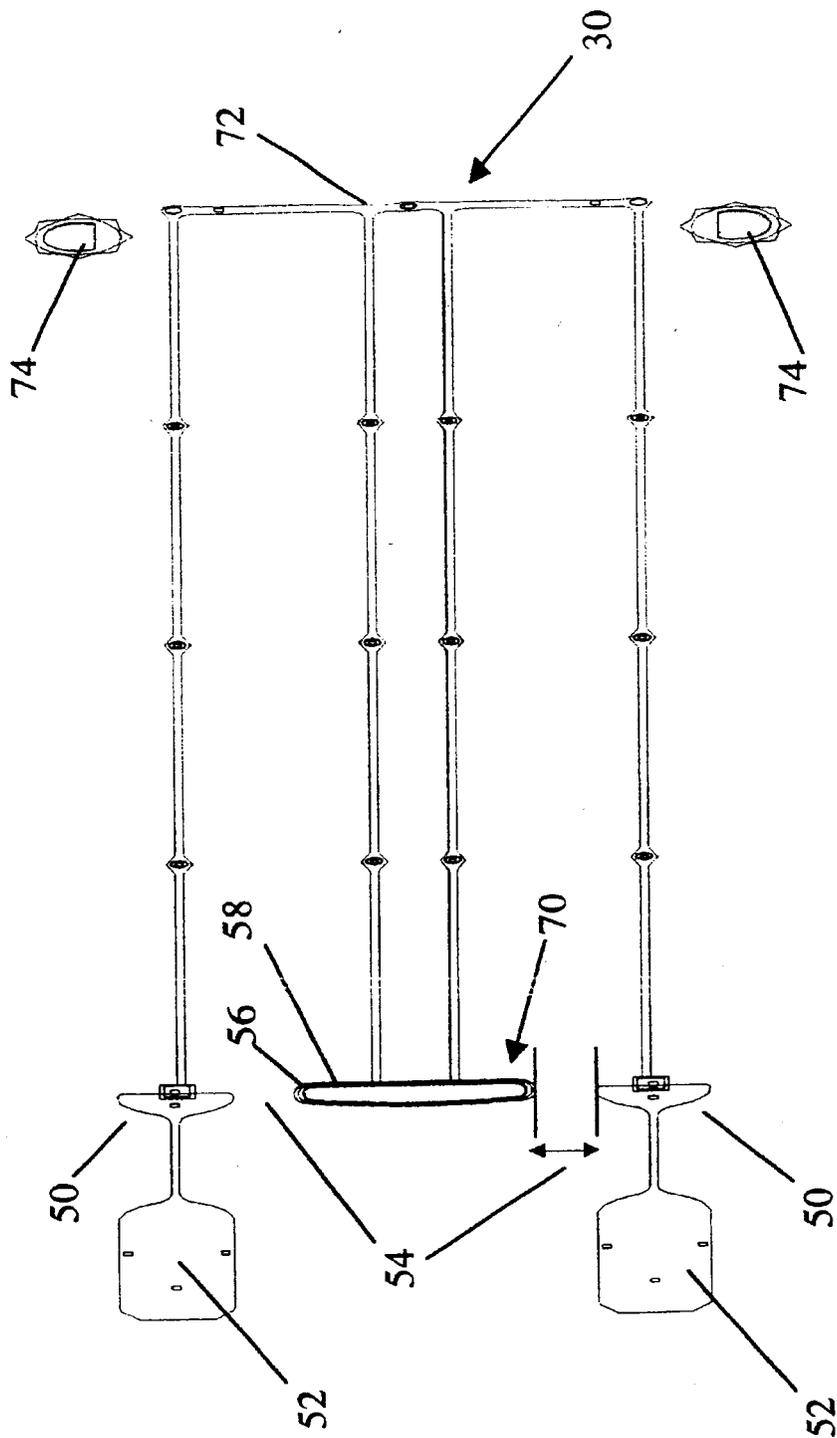
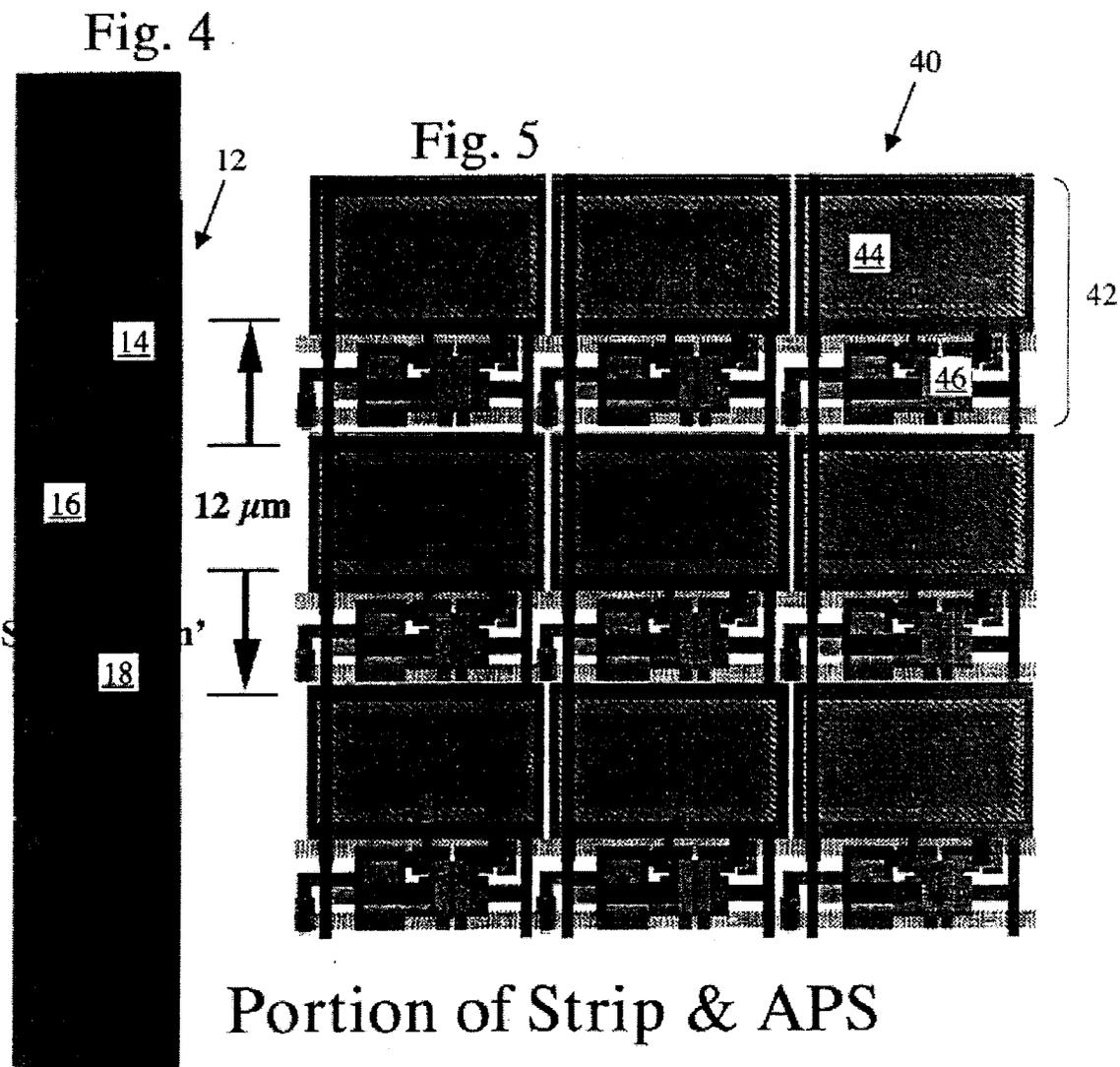
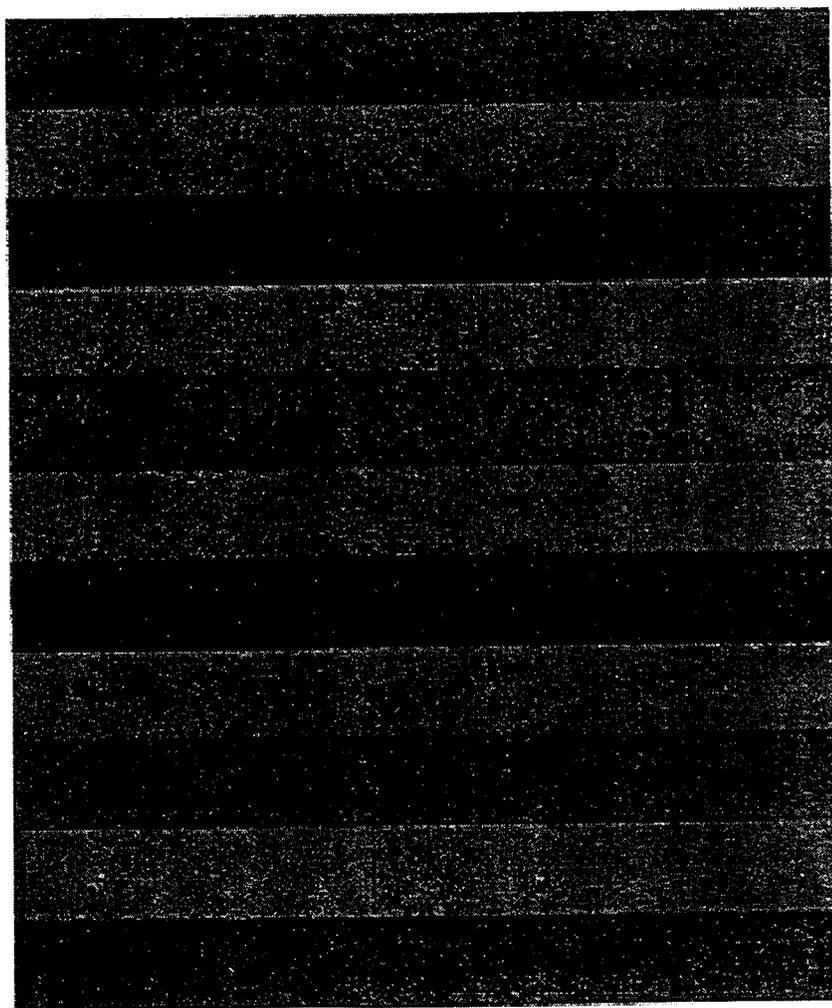


Fig. 3



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Fig. 6



BLUE 18

GREEN 16

RED 14

CHROMATIC MODULATOR FOR HIGH RESOLUTION CCD OR APS DEVICES

STATEMENT AS TO RIGHTS TO INVENTIONS MADE UNDER FEDERALLY-SPONSORED RESEARCH AND DEVELOPMENT

The invention described herein was made in the performance of work under a NASA contract, and is subject to the provisions of Public Law 96-517 (35 USC 202) in which the contractor has elected not to retain title.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to image generation and more particularly to a color filter system for CCD or APS devices using Red-Green-Blue (RGB) color separation in order to provide color images.

2. Description of the Related Art

Traditionally, the Red-Green-Blue (RGB) separation of color in electronic imaging is done in a variety of ways. In one system, electronic imaging is performed by the use of fixed filters over three separate imagers. Problems sometimes arise with this configuration, as there may be some mis-registration between each of these three separate imagers. In fact, when multiple imagers are used, a high degree of registration between the separate imagers is required.

Another way to perform RGB color separation is to use time multiplexed filters imposed over a single imager. In this system, separate filters provide a series of time exposures to single imagers. The resulting separate images are combined to provide a resulting color image. Lastly, another method by which to achieve RGB color separation is with the use of three colored (or four pixel blocks for symmetry) arrays of pixel sized filters covering a single imager.

Each of these prior ways of achieving RGB color separation has its drawbacks. With the separate imagers, the optics is complicated and, as mentioned previously, high registration requirements are imposed upon the system in order to ensure clarity of the ultimate image. With the other systems, filter wheels are expensive and any camera using such a system is bulky and more unwieldy than if the filter wheels were absent. Using a fixed pixilated color filter generally reduces the resolution of the ultimate image by reducing its pixel density. Additionally, color aliasing is inadvertently introduced which produces disturbing or distracting images in patterned scenes or scenes where high contrast lines are in motion across the field of view.

Consequently, it can be seen that the art still demands, and looks for, an RGB color separation system that overcomes the drawbacks of the prior art.

SUMMARY OF THE INVENTION

The present invention realizes an efficient, lightweight, and robust means by which RGB encoding of image data without loss of pixel resolution is achieved.

The present invention provides a system for providing high-resolution color separation in electronic imaging. A Red-Green-Blue (RGB) color strip filter system (or otherwise) is used over an electronic imaging system such as a charge-coupled device (CCD) or active pixel sensor (APS). The color filter is generally modulated over the imaging array at a rate four times the frame rate of the imaging array. In so doing, the underlying imaging elements are then able to detect four separate color-separated images

which are then combined to provide a color-accurate frame which is then recorded as the representation of the recorded image. High pixel resolution is maintained. Registration is obtained between the color strip filter and the underlying imaging array through the use of electrostatic comb drives in conjunction with a spring suspension system. The spring suspension system aligns the color strip filter (which is held by a frame) over the imaging array in the first and neutral position. The frame with the color strip filter is then snapped to an up position, and then to a down position before returning to the neutral position. In this way, a cycle is presented over the imaging array so that each individual color filter is presented to an underlying image sensor element one time for each frame of the entire imaging array. In-situ encoding of the filter rows is made by overlays or otherwise that may only be necessary on a few of the rows in order to preserve the image and reduce the pixel losses due to such overlays.

A micro-machined (MEMS—Micro Electro Mechanical Systems) modulator of an RGB strip filter provides the results currently lacking in the art. None of the above-mentioned shortcomings are present in the chromatic modulator of the present invention. Such drawbacks are avoided, as the various color strips used are generally the width of and register with the active pixel area. They also generally match the width of the intermediate dead space. The color strips are moved back and forth over the optical imaging area a distance that equals the width of the filters and at a rate that generally matches the number of filters, namely four times the frame rate of the imager. In so doing, chroma modulation is achieved for all pixels of an imaging array whether a charge-coupled device (CCD) or active pixel sensor (APS). The chromatic modulator of the present invention may be used in camera recorders, or camcorders, digital cameras, APS color filters, and the like. Generally, optical recording equipment implementing the present invention might be brought to market relatively quickly.

OBJECTS OF THE INVENTION

It is an object of the present invention to provide better color imaging for optical recorders such as cameras.

It is yet another object of the present invention to provide better RGB color separation and electronic imaging.

It is yet another object of the present invention to provide better color imaging in a manner that maintains image resolution.

It is yet another object of the present invention to provide a filter exposure density greater than two.

It is yet another object of the present invention to provide high-resolution color imaging in a commercially-achievable manner.

These and other objects and advantages of the present invention will be apparent from a review of the following specification and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plan view of a framework for holding the RGB strip filter of the present invention. Shown in cutaway view is the underlying image array beneath the RGB strip filter. FIG. 1 is not to scale.

FIG. 2 is an enlarged view of a single comb drive array used in the framework shown in FIG. 1.

FIG. 3 is a top plan view of a spring used in the framework in FIG. 1 and the comb drive of FIG. 2 with buffer stops and spring stops used to control the excursions

embodiment, the last two pixel columns of a selected strip color filter are made opaque with metal coatings. One implementation of such a system would be where red filter strips 14 have a metal coating overlay over the second to last (penultimate) pixel column, while the blue filter strips 16 have a metal coating overlay at the last pixel column. For the green strip filters 18, there can be either no metal coating overlays or metal coating overlays for both of the pixel columns. By detecting the presence of the overlays, identification of the particular color filter (composed of same-color strips) can be made immediately. One exception to this is when a totally black image is present that provides no contrast between the overlays covering part of the image array and those that are not covered by such overlays.

While there may be some pixel loss with respect to the overlay system set forth above, the pixel losses for this encoding are minor and are virtually zero if only a few rows are encoded rather than whole columns in the strip array. As all rows of the imaging array 40 are generally subject to the same color from the filter 12 at one time, providing a sensing area in just one row supplies the needed color information for all rows.

Depending upon the frame rate for the capture of images by the image array 40, the frame 32 with its RGB strip filter 12 may modulate at approximately 96-120 "snaps" per second. This corresponds, respectively, to 24-30 frames per second. Generally, this frame rate is sufficient for human beings, as it prevents the eye from seeing erratic or jerky motion in the recorded image.

While the present invention is readily adaptable to current standards of video gathering transmission at known frame rates, other significant advantages in the video signal gathering art are delivered by the present invention. For example, motion picture film is often presented at 24 frames per second (24 fps), while PAL/SECAM video signal uses a frame rate of 25 frames per second (25 fps). NTSC video uses a frame rate of 30 frames per second (30 fps). The present invention easily allows the gathering of video information for any one of these three video protocols. Depending upon the number of filtered images needed to produce a single color image, the comb drives 34, 36 would generally run at a "snap rate," or rate of changing the filter for each pixel row, three-to-four times that of the desired and ultimate frame rate, or presentation rate. However, the rate at which the chromatic modulator of the present invention gathers filtered images for a single color image is not necessarily limited to those known in the public or entertainment media. For example, in machine vision systems, frequency rates from 1,000 to 4,000 cycles per second (1kHz-4kHz) may be desired and obtained by the present invention.

The electrostatic comb drive system of the present invention can operate at a very high frequency. Generally, this is due to the strong and rapidly changeable nature of electrostatic charge as well as the low mass, or inertia, of the system. Consequently, driving the comb drives 34, 36 with an alternating signal at a kilohertz or megahertz (1,000 or 1,000,000 cycles per second) is not beyond the realm of the present invention. Additionally, as the distance is traveled by the comb drive and other elements of the present invention decreases with increased miniaturization, frequency regimes in the tens to the thousands of megahertz (one gigahertz) may be possible and easily realized in the future.

As the ultimate presentation frame rate of the present invention is generally one-third to one-fourth of the snap rate, presentation rates on the order of one-fourth of a gigahertz or 250 megahertz may be possible.

At such high frequency rates for the comb drive 34, 36 and the RGB filter strip 12, the underlying imaging array 40 must be able to gather the incoming light at a rate sufficient to deliver an adequate image. If the source of light is extremely bright (as would occur from a nuclear blast), the imaging array 40 may not need to be extremely sensitive. However, in gathering starlight from distant galaxies, the imaging array 40 would advantageously be as sensitive as possible in order to gather as much incoming light as possible.

Additionally, the imaging array need not be dedicated to the visible regime of the electromagnetic spectrum. "Images" in the x-ray, gamma ray, infra-red, or even microwave regimes could be captured by adapting the present invention. The color filter 12 then becomes a frequency transmitter/filter for selected light-frequency ranges. The imaging array 40 then becomes one sensitive to the frequency regimes of interest.

With such high frame rates and dynamic response, the nature of combustion, the sequence of events in an explosion, the flight mechanics of hummingbirds, and other rapidly-occurring events could foreseeably be recorded by a camera implementing the present invention. Other high-speed or changeable speed applications will occur to those of ordinary skill in the art as the need arises.

Note should be taken that the RGB filter strip 12 is not necessarily limited to the embodiment described herein. The RGB filter strip 12 may be changed according to the applications involved. Additionally, should liquid crystal display or other technology provide, each of the filter strips may be changeable in its color according to the desires of the person taking the images. However, under such circumstances, it may be that a colored liquid crystal display may operate on its own to provide the necessary frame rates with each of the filters changing as if they were snapped back and forth by the comb drives 34, 36. However, the rate of a color change in a filter may not sufficiently exceed or match that of the comb drives with their snapping action. In such a case, an additional level of adjustability is provided by having the comb drive-driven chromatic modulator of the present invention coupled with color adjustable filter strips.

The present invention overcomes difficulties present in the prior art. In some applications, pixel densities have been increased so that color filtering may be achieved by the pixels themselves. In such a situation, pixel clusters have individual pixels allocated to different colors in order to deliver the ultimate image. However, due to displacement requirements, this generally leads to a diminishment or reduction of ultimate video signal resolution.

As the present invention provides adjustability without constraint to any particular color ratio, provides adaptability to any pixel density, avoids the prior art problems of having a fixed filter with alignment problems or fixed color patterns on a single imager with dedicated color ratios, and as high-speed events such as the filming of a hummingbird, a fast conveyor belt, a fruit sorter, or rotating equipment are achieved by the present invention, advantages heretofore not seen in the art are provided by the present invention. Additionally, the present invention provides means by which machine imaging or robotic imaging can be achieved. Images may be gathered by the chromatic modulator of the present invention and used by robotic or machine recognition methods, software or otherwise. Also, the present invention provides for operation at arbitrarily high frame rates.

Significant attributes of this image generation and color filter system of the present invention include three APS

device performance by temporal "times four" ("×4") multiplexing with the color filter. The Nyquist frequency is increased by a factor of four, diminishing spatial aliasing. The use of a crystalline quartz birefringent blur filter increases the horizontal blur filter duty cycle such that $G=1$. No "Bayer" interpolation is required, therefore eliminating the need for chromic aliasing, spatial chromic multiplexing, vertical "blur" filtering, and defocus capabilities. Also, achromatic compensation compromises are eliminated.

Certain special applications may be achieved by the present invention including low light applications, changing of the filter strip's 12 color ratios as the system operates ("on the fly"), dynamically changing the colors of the color strip 12 as the system operates, and the like.

While the present invention has been described with regards to particular embodiments, it is recognized that additional variations of the present invention may be devised without departing from the inventive concept of the present invention.

What is claimed is:

1. A light-frequency modulator system for providing frequency regime, or color, separation in an imaging array, comprising:

an imaging array having active imaging elements arranged in a first geometrical pattern;

a light-frequency strip filter, said light-frequency strip filter having filter elements arranged in correspondence with said first geometrical pattern; and

a modulator, said modulator modulating said light-frequency strip filter between said imaging array and an image to be imaged, said modulator modulating said light-frequency strip filter according to a sequence; whereby

light transmitted to said active imaging elements is filtered by said light-frequency strip filter according to said modulator sequence to effect a light-frequency image by said imaging array.

2. A light-frequency modulator system as set forth in claim 1, wherein said imaging array is selected from the group consisting of:

charge-coupled devices (CCDs) and active pixel sensors (APSs).

3. A light-frequency modulator system as set forth in claim 1, wherein said first geometrical pattern is selected from the group consisting of:

rows, lines, and columns.

4. A light-frequency modulator system as set forth in claim 1, wherein said light-frequency strip filter further comprises:

a color strip filter, said color strip filter having filter elements arranged in correspondence with said first geometrical pattern.

5. A light-frequency modulator system as set forth in claim 4, wherein said color strip filter is a red-green-blue (RGB) strip filter.

6. A light-frequency modulator system as set forth in claim 5, wherein said filter elements of said red-green-blue (RGB) strip filter are strips of green filter adjacent strips of red filter and strips of blue filter, said strips being in width the same as a width of said active imaging elements.

7. A light-frequency modulator system as set forth in claim 1, wherein:

said modulator modulates said light-frequency strip filter to present each different type of light-frequency transmitted by said filter elements to an active imaging

element during an interval during which said imaging array constructs a frame of imaging.

8. A light-frequency modulator system as set forth in claim 7, further comprising:

said light-frequency strip filter including a red-green-blue (RGB) light-frequency strip filter.

9. A light-frequency modulator system as set forth in claim 1, wherein said modulator further comprises:

first and second comb drive elements, said first and second comb drive elements coupled to a first end of said light-frequency strip filter such that said first and second comb drives operate in opposite directions;

a spring suspension system, said spring suspension system coupled to a periphery of said light-frequency strip filter, said spring suspension system generally retaining said light-frequency strip filter in a central location subject to offset or excursion by said first and second comb drives.

10. A chromatic modulator system for providing color separation in a visual imaging array, comprising:

a visual imaging array having active imaging elements arranged in rows having a visual element width, said visual imaging array selected from the group consisting of charge-coupled devices (CCDs) and active pixel sensors (APSs);

a red-green-blue (RGB) color strip filter, said RGB strip filter having parallel strips of red, green, and blue filter elements arranged in rows corresponding with said rows of said visual imaging array, said RGB strip filter having strips of green filter adjacent strips of red filter and strips of blue filter, said strips being in width the same as said visual element width; and

a modulator, said modulator modulating said RGB strip filter between said visual imaging array and an image to be imaged, said modulator having first and second comb drives, said first comb drive coupled to said RGB strip filter, said second comb drive coupled to said RGB strip filter so that said first and second comb drives operate in opposite directions, said modulator also having a spring suspension system, said spring suspension system coupled to a periphery of said RGB strip filter, said spring suspension system retaining said RGB strip filter in a central location subject to offset or excursion by said first and second comb drives;

said modulator modulating said RGB strip filter four times as fast as a time interval in which said visual imaging array constructs a frame of visual imaging; whereby

light transmitted to said active imaging elements is filtered by said RGB strip filter according to said modulator to effect a color image by said visual imaging array and to provide an efficient, lightweight and robust means of providing RGB encoding of imaged data with reduced loss of pixel resolution.

11. A modulated light filter system for providing light-frequency separation in an imaging array, comprising:

a light-frequency strip filter, said light-frequency strip filter having filter elements arranged in correspondence with a first geometrical pattern present in the imaging array; and

a modulator, said modulator modulating said strip filter between the imaging array and an image to be imaged; whereby

light transmitted to the imaging array is filtered by said light-frequency strip filter according to a sequence

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effected by said modulator to effect an image by the imaging array.

12. A modulated light filter system as set forth in claim 11, wherein said first geometrical pattern is selected from the group consisting of:

rows, lines, and columns.

13. A modulated light filter system as set forth in claim 11, wherein said light-frequency strip filter is a red-green-blue (RGB) strip filter.

14. A modulated light filter system as set forth in claim 13, wherein said red-green-blue (RGB) strip filter having strips of green filter adjacent strips of red filter and strips of blue filter, said strips being in width the same as active imaging elements of the imaging array.

15. A modulated light filter system as set forth in claim 11, wherein said modulator further comprises:

first and second comb drives coupled to said light-frequency strip filter so that said first and second comb drives operate in opposite directions;

a spring suspension system, said spring suspension system coupled to a periphery of said light-frequency strip filter, said spring suspension system retaining said light-frequency strip filter in a central location subject to offset or excursion by said first and second comb drives.

16. A modulated light filter system as set forth in claim 11, further comprising:

said modulator modulating said light-frequency strip filter to present each different type of light frequency filtered by said filter elements to an imaging element during an interval in which the visual imaging array constructs a frame of visual imaging.

17. A modulated light filter system as set forth in claim 16, further comprising:

said light-frequency strip filter comprising a red-green-blue (RGB) color strip filter.

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18. A modulated chromatic filter system for providing color separation in a visual imaging array, comprising:

a red-green-blue (RGB) color strip filter, said RGB strip filter having parallel strips of red, green, and blue filter elements arranged in rows corresponding with rows of the visual imaging array, said RGB strip filter having strips of green filter adjacent strips of red filter and strips of blue filter, said strips being in width approximately the same as said rows of the visual imaging array; and

a modulator, said modulator modulating said RGB strip filter between the visual imaging array and an image to be imaged, said modulator having first and second comb drives, said first comb drive coupled to said RGB strip filter, said second comb drive coupled to said RGB strip filter so that said first and second comb drives operate in opposite directions, said modulator also having a spring suspension system, said spring suspension system coupled to a periphery of said RGB strip filter, said spring suspension system retaining said RGB strip filter in a central location subject to offset or excursion by said first and second comb drives;

said modulator modulating said RGB strip filter three or more times as fast as a time interval in which the visual imaging array constructs a frame of visual imaging; whereby

light transmitted to the visual imaging array is filtered by said RGB strip filter according to a sequence effected by said modulator to effect a color image by the visual imaging array and to provide an efficient, lightweight and robust means of providing RGB encoding of imaged data with reduced loss of pixel resolution.

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