**Title:** SINGLE OPTICAL PATH ANAMORPHIC STEREOSCOPIC IMAGER

**Abstract:** A stereoscopic imaging apparatus is provided for creating anamorphic stereoscopic image pairs on a single image sensor from light obtained along a single optical path through a single optical axis front lens assembly and through two apertures on opposite sides of the optical axis of the front lens assembly. An anamorphic element changes the aspect ratio of the stereo image pair in order to fit both images on the same sensor, one aligned above the other, compressed in the vertical by substantially 50%. A pair of sampling lenses positioned proximate, overlapping and abaxial with the corresponding apertures facilitates the direction of the images in the stereo image pair to their respective positions on the sensor. A rear lens assembly is provided for physically forming the stereo image pair on the sensor. The apparatus can be incorporated in different optical systems, including cameras, video cameras, endoscopes and microscopes.
SINGLE OPTICAL PATH ANAMORPHIC STEREOSCOPIC IMAGER

FIELD OF THE INVENTION

This invention relates, in general, to stereoscopic imaging. More specifically, this invention relates to changing the aspect ratio of stereoscopic image pairs of a scene generated along different portions of a single optical path.

BACKGROUND OF THE INVENTION

The phenomenon of stereoscopic vision, or stereopsis, is directly associated with the ability of humans and animals with binocular vision to perceive depth in a scene. It is the perceptual effect produced by the human brain simultaneously processing two sets of slightly differing two-dimensional optical data. The phenomenon, as experienced by an unaided human observer, is based on the feel that the retinal images formed by the two eyes of the observer differ slightly. A point object in a scene observed by the human observer is imaged in a slightly different position in the left retinal image as compared with the image of the same scene on the right retina.

Initially stereoscopic imagery was created using images taken by two separate cameras. Work, particularly in the video-imaging field, has led to systems in which two complete imaging systems are incorporated permanently into single stereoscopic viewers. Such viewers typically have dual optical axes and twin objective optical subsystems providing two optical paths. They typically have one optical axis for the right eye view and one for the left eye view in order to produce two complete images, one for the right eye perspective and that for he left eye perspective, side by side on two imaging sensors.

In the case where each of the images has a typical 4:3 (horizontal : vertical) landscape aspect ratio it requires two imaging sensors of that aspect ratio for optimal use of expensive
sensor real estate. Projecting the two images side by side onto a single 4:3 aspect ratio imaging sensor would waste a sizeable portion of the expensive sensor. In order to employ a single sensor efficiently in such an arrangement, a specialized double horizontal width imaging sensor could be developed with aspect ratio 8:3. Even large aspect ratio sensors, such as 16:9 will not allow two images of commercially acceptable aspect ratio to be captured side by side without reduction of the image size and consequent wastage of sensor surface in the vertical direction.

In some implementations, stereoscopic systems have a single optical path near the sensing end of the arrangement. Such viewers are most often arranged to allow the two images to be captured alternately in time on the same sensor. This approach uses synchronized time division arrangements that allow only one of the two views to be imaged at a time on the imager. The read-out and display equipment is arranged to alternately display one or the other of the left and right images at a rate that allows the human viewer of the display to observe an apparently continuous display of both images, one for the left eye and one for the right. Such systems have the additional burden of on board modulators and the electronics to drive such modulators, be these of the mechanical chopping, light valve or "liquid crystal" type. For a particular image this arrangement also halves the light available to the sensors, with negative consequences for the signal to noise performance of the electro-optic circuitry. In the ease of polarization or other filtering techniques there are additional transmission losses.

Yet other single optical path stereoscopic systems employ specialized sensors that have two sets of sensing elements within the same sensor area, one set sensing light of one characteristic and a second set sensing light of a second characteristic. The characteristic can typically be polarization or color. The images for the two eyes are then differentiated by suitable filters on the basis of polarization or color. The non-standard sensors employed in such apparatus remain a problem in the commercial arena.

SUMMARY OF THE INVENTION

In a first aspect of the invention there is provided a stereoscopic imaging apparatus for forming on a single image sensor from light obtained along a single optical path through a front lens assembly having a single optical axis an anamorphic stereoscopic image pair comprising a first image and a second image of differing perspective from the first image, the apparatus comprising: first and second apertures disposed proximate an aperture plane of the front lens
assembly, on opposite sides of an optical axis of the front lens assembly, and separated by an inter-aperture separation; at least one anamorphic element disposed in the single optical path; a first sampling lens located between the aperture plane and the sensor and proximate and overlapping with the first aperture; a second sampling lens located between the aperture plane and the sensor and proximate and overlapping with the second aperture; and a rear lens assembly disposed between the sampling lenses and the sensor for forming on the sensor the first and second images from light received through the first and second sampling lenses. The sampling lenses can be disposed to direct light received through the two apertures to form through the rear lens assembly the first and second images at different substantially non-overlapping locations on the image sensor. The at least one anamorphic element can be the two sampling lenses. In other embodiments, the at least one anamorphic element can be a single anamorphic element disposed on the optical axis. The first and second sampling lenses can be disposed abaxially with respectively the first and second apertures to form through the rear lens assembly the first and second images aligned vertically above each other and substantially non-overlapping on the image sensor. In other embodiments the first and second sampling lenses are disposed abaxially with respectively the first and second apertures to form through the rear lens assembly the first and second images aligned horizontally next to each other and substantially non-overlapping on the image sensor.

The stereoscopic imaging apparatus may be fitted to an endoscope, in which case the front lens assembly is an endoscope front lens assembly. The stereoscopic imaging apparatus may be fitted to a microscope, in which case the front lens assembly is a microscope objective lens assembly. The first and second apertures can be variable apertures, including but not limited to irises, to allow changing the depth of field of the apparatus. The inter-aperture separation between the apertures can be adjustable to adjust the stereopsis of the apparatus. The sampling lenses can be configured to move in cooperation with the apertures when the inter-aperture separation is adjusted.

In another aspect of the invention there is provided a stereoscopic imaging apparatus for forming an anamorphic stereoscopic image pair comprising a first image and a second image of differing perspective from the first image, the apparatus comprising: a front lens assembly comprising at least an objective lens having a field of view and a single optical axis, the front lens assembly configured to direct light from the field of view along a single optical path
generally about the optical axis; a single imaging sensor disposed along the optical axis behind the front lens assembly; first and second apertures disposed proximate an aperture plane of the front lens assembly, on opposite sides of an optical axis of the front lens assembly, and separated by an inter-aperture separation; at least one anamorphic element disposed in the single imaging path; a first sampling lens located between the aperture plane and the sensor and proximate and overlapping with the first aperture; a second sampling lens located between the aperture plane and the sensor and proximate and overlapping with the second aperture; and a rear lens assembly disposed between the sampling lenses and the sensor for forming on the sensor the first and second images from light received through the first and second sampling lenses. The front lens assembly and the rear lens assembly can form a double Gauss lens.

The single anamorphic element can be disposed on the optical axis in front of the front lens assembly, within the front lens assembly, between the front lens assembly and the sampling lenses, between the sampling lenses and the rear lens assembly, within the rear lens assembly or between the rear lens assembly and the image sensor.

The imaging sensor can be oriented in a landscape orientation with its long axis in the horizontal dimension or it can be oriented in a landscape orientation with its long axis in the horizontal dimension.

In a further aspect of the invention there is presented a method for forming on a single imaging sensor an anamorphic stereoscopic image pair comprising a first and a second image, the method comprising: gathering light from objects within a field of view of a front lens assembly; directing the gathered light along a single optical path generally about an optical axis of the front lens assembly; anamorphically magnifying the image content of the light by means of at least one anamorphic lens; sampling light from a first portion of the single optical path through a first aperture and sampling light from a second portion of the single optical path through a second aperture, the first and second apertures disposed on opposite sides of the optical axis proximate an aperture plane of the front lens assembly; and forming on the single imaging sensor disposed along the optical axis the first and second images from respectively the light sampled through the first aperture and the light sampled through a rear lens assembly. The forming first and second images can be by processing respectively the light sampled through the first aperture and the light sampled through the second aperture through a second lens disposed between the apertures and the sensor. The method can further comprise routing the light from the
first and second apertures via respectively first and second sampling lenses to form respectively the first and second images at predetermined positions relative to each other, the first and second sampling lenses being disposed proximate, overlapping and abaxial with respectively the first aperture and second aperture.

The routing can comprise displacing the centers of the two sampling lenses abaxially in respectively opposite directions from their respective proximate apertures. The anamorphically magnifying can be relatively compressing the image content of the gathered light by substantially 50% in a vertical dimension and the displacing can be aligning the first and second images vertically above each other on the sensor. The anamorphically magnifying can be relatively compressing the image content of the gathered light by substantially 50% in a horizontal dimension and the displacing can be aligning the first and second images horizontally next to each other on the sensor.

The method further comprises extracting from the single imaging sensor data describing the first and second images and digitally restoring the aspect ratio of the two images to values that pertained to an image content of the light from the objects within the field of view before the anamorphically magnifying.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features, and advantages of the invention are apparent from the following detailed description taken in conjunction with the accompanying drawing in which:

FIG. 1 shows a single optical path anamorphic stereoscopic imager;
FIG. 2 is a flow diagram of a method for creating a stereoscopic image; and
FIG. 3 shows a single optical path anamorphic stereoscopic endoscope

DETAILED DESCRIPTION OF AN ILLUSTRATIVE EMBODIMENT

Imaging sensors have been proposed in the prior art that retain the industry standard landscape aspect ratios of, for example, 4:3 and 16:9, but these proposals require special modifications to be implemented on the sensors themselves, usually in the form of special lenticular arrays or other complex means. This points away from the use of mass produced industry standard imaging sensors. The mass production of commercial Si-imaging sensors is not
geared towards the fabrication of non-standard devices. Low unit costs are based on large volume manufacture of devices of standard sizes with good yield due to smoothly running standard production. It is not just lowered ran length and associated proportionally higher set-up costs that increase the prices of non-standard devices, but also the lowered yield inherent in non-routine production.

The need therefore remains for a stereoscopic viewer that can overcome the limitations described here whilst employing single industry standard imaging sensors and simple, compact and robust optical designs that lend themselves to volume manufacture.

In accordance with a first aspect of the present invention there is provided a single optical path stereoscopic imaging apparatus for simultaneously obtaining a pair of stereoscopic images of a scene on a single imaging sensor. According to a first embodiment, shown schematically and generally at 100 in Figure 1, a stereoscopic imaging apparatus comprises a lens 102 generally oriented with its axis along an optical axis 103 and an imaging sensor 132 located in “landscape” orientation at an image plane given by lines 138 and 114 and configured for receiving images from the lens 102. The lens 102 comprises front lens assembly 124 and rear lens assembly 126. The front lens assembly 124 is operable to direct light captured within a field of view of the lens 124 to an aperture plane 104 of the lens 124. The aperture plane 104 can be a physical aperture plane of the lens 102 or can be a conjugate of the physical aperture plane. The term "aperture plane" is used to describe both the physical aperture plane and any of its conjugates. Front lens assembly 124 comprises, by way of example, lenses 118, 120 and 122. Rear lens assembly 126 can similarly comprise a plurality of lenses. For the sake of clarity, rear lens assembly 126 is schematically shown as a single lens.

An aperture plate 108 is disposed proximate aperture plane 104. The aperture plate 108 comprises a first aperture 128 and a second aperture 130 disposed either side of the optical axis 103 and separated in a horizontal plane by an inter-aperture distance. The term "inter-aperture separation" is used in the present specification to describe the center-to-center distance between the two apertures 128 and 130. The term "horizontal" is used in this specification to denote an orientation in a plane containing the optical axis 103 and the line between the centers of apertures 128 and 130. The term "vertical" is used to describe a direction perpendicular to the plane containing the optical axis 103 and the line between the centers of apertures 128 and 130. In Fig.1 the vertical is given by line 138.
The lens 102 comprises a first sampling lens 142 disposed proximate and overlapping with the first aperture 128 and located between the aperture plane 104 and the sensor 132. The lens 102 comprises a second sampling lens 144 disposed proximate and overlapping with the second aperture 130 and located between the aperture plane 104 and the sensor 132 in substantially the same plane as first sampling lens 142 perpendicular to the optical axis 103. First sampling lens 142 operates on light captured with a first perspective from within the field of view of the lens 102 by the front lens assembly 124. Second sampling lens 144 operates on light captured with a second perspective from within the field of view of the lens 102 by the front lens assembly 124. The first sampling lens 142 therefore samples light from a first portion of an optical path generally about the optical axis 103, while the second sampling lens 144 samples light from a second portion of the same optical path. Light from the first sampling lens 142 is imaged onto the imaging sensor 132 by the rear lens assembly 126 to form a first image 134 having a first perspective of an object 116 disposed within the field of view of the lens 102. Light from the second sampling lens 144 is imaged onto the imaging sensor 132 by the rear lens assembly 126 to form a second image 136 having a second perspective of the object 116.

In one embodiment an anamorphic element 110, such as a lens, is disposed between the front lens assembly 124 and the aperture plane 104. This ensures that any images produced on sensor 132 from light transiting through apertures 128 and 130 are anamorphic images of the object 116. In a more general implementation, the anamorphic element 110 can be disposed in front of front lens assembly 124 or inside front lens assembly 124.

In one embodiment the anamorphic element 110 has a magnification of substantial[.]’ 50% in the horizontal as compared with the vertical. This ensures that any images formed from light transiting through apertures 128 and 130 are compressed by substantially 50% in the horizontal dimension.

In another embodiment the anamorphic element 110 has a magnification of substantially 50% in the vertical as compared with the horizontal. This ensures that any images formed from light transiting through apertures 128 and 130 are compressed by substantially 50% in the vertical dimension.

While the above descriptions are based on an anamorphic element 110 in the form of a lens, other refractive, diffractive or reflective optical elements can be employed to provide suitable anamorphic deformation of the first and second images 134 and 136.
The matter of directing the images 134 and 136 to be non-overlapping on sensor 132 is addressed by disposing the sampling lenses 142 and 144 to be abaxial with apertures 128 and 130 respectively. In Figure 1 the embodiment employing an anamorphic element 110 with substantially 50% vertical compression is shown. The degree of abaxial displacement of the sampling lenses 142 and 144 is exaggerated in Figure 1 for the sake of clarity. The term "abaxial" is used in the present specification to describe a mutual orientation wherein the axes through the centers of the first aperture 128 and the first sampling lens 142 are parallel, but not coinciding. The term "abaxial displacement" is used to describe the perpendicular distance between the axis through the center of the first aperture 128 and the axis through the center first the sampling lens 142. The direction and size of the abaxial displacement of the second sampling lens 144 from the optical axis of the second aperture 130 is substantially opposite and equal to the direction and size of the abaxial displacement of the first sampling lens 142 from the optical axis of the first aperture 130.

For the "vertical compression" embodiment shown in Figure 1 the axes of sampling lenses 142 and 144 are displaced not just along the horizontal in order to specifically cause images 134 and b to be aligned in the horizontal, but also they are also displaced vertically in opposite directions in order cause images 134 and 136 to be substantially non-overlapping. The result is a stereoscopic image pair that is aligned in the vertical and that can be arranged to be non-overlapping, but substantially abutting along their facing horizontal perimeters. This arrangement makes optimal use of the sensor pixel distribution, in a more general case, the two images 134 and 136 are not constrained to abut each other.

For the case where anamorphic element 110 is chosen to have substantially 50% relative horizontal magnification, the axes of sampling lenses 142 and 144 are displaced from those of apertures 128 and 130 respectively only in the horizontal dimension, and the images 134 and 136 thereby shifted horizontally on the sensor 132 to ensure that they are substantially non-overlapping and abutting along their facing vertical perimeters, thereby to make maximal use of the sensor element distribution on sensor 132. In a more general case, the two images 134 and 136 are not constrained to abut each other. If, for some or other reason, the images 134 and 136 are not perfectly aligned, the vertical displacements of sampling lenses 142 and 144 can be adjusted by a small amount to realign the images. The use of abaxially disposed sampling lenses
avoids the use of expensive custom-made image sensors and provides control over the placement of images 134 and 136.

To the extent that the first image 134 and the second image 136 represent different perspectives of the object 116, they may be employed to derive three-dimensional (3D) information about the object 116. More particularly, a controller 115 may extract image data representing the two images 134 and 136 from imaging sensor via image data output connection 117. Controller 115 can be configured to process the images digitally to restore the original aspect ratio as per the optical image information content of the light from the field of view of front end lens assembly 124 before entering the anamorphic lens. Hereby the stereoscopic image pair is supplied in appropriate format to a three-dimensional display or viewing system (not shown), imaging sensor 132 can be a single array imaging sensor, including but not limited to a Charge Coupled Device (CCD).

Returning to the substantially 50% vertical compression implementation; when the imaging data is extracted from the sensor 132 for further processing and display, one portion of the vertical axis data from the sensor 132 is associated with the image 136 and another portion of the vertical axis data from the sensor 132 is associated with the image 134. On the basis of this differentiation the two images 136 and 134 can be separately extracted from the sensor 132.

The degree of stereopsis achievable with a three-dimensional imager is fundamentally dependent on the angular difference between the two perspectives used to create the images used to render the three-dimensional view. In the description herein the specific use of sampling lenses 142 and 144 provides the benefit of a large perspective difference as a result of the use of the front lens assembly 124 that is large in comparison with the anamorphic sampling lenses 142 and 144, whilst still producing an overall lens system, given by lens 102, that has a short focal length. This allows the lens 102 to be employed with small low cost imaging sensors. The inter-aperture distance between apertures 128 and 130 is greater than that achievable in three-dimensional imagers employing such small imaging sensors in conjunction with prior art imaging lens arrangements. The result is greater stereopsis than that achievable with prior art lenses applied to comparable imaging sensors. This is particularly relevant in camera applications where adequate stereopsis is often difficult to attain.

In some embodiments of the invention apertures 128 and 130 can be variable apertures, including but not limited to irises, to provide the facility of varying the depth of field of lens 102,
In some embodiments apertures 128 and 130 can be fixed apertures. In other embodiments the first and second apertures 128 and 130 can be configured to allow changing the stereopsis of the imager by changing the inter-aperture separation. First sampling lens 142 can be configured to move in cooperation with first aperture 128 and second sampling lens 144 can be configured to move in cooperation with second aperture 130. The cooperative motion ensures that images 134 and 136 remain mutually positioned as before.

In one embodiment the combined structure of front lens assembly 124 and rear lens assembly 126 form a double-Gauss lens. Double-Gauss optical designs are known in the art for their superlative performance in respect of keeping optical aberration in the system very low. The use of double Gauss lenses is well established in the field of wide-aperture lenses on standard 35mm cameras. The focal lengths of the first sampling lens 142 and the second sampling lens 144 can be less than half the focal length of the combination of the front lens assembly 124 and the rear lens assembly 126 in the absence of the first sampling lens 142 and the second sampling lens 144. With this choice of focal lengths, the focal length of the combination of the front lens assembly 124, the rear lens assembly 126 and one of the first sampling lens 142 and second sampling lens 144 can be less than the focal length of the combination of the front lens assembly 124 and the rear lens assembly 126 in the absence of the first sampling lens 142 and the second sampling lens 144.

Sampling lenses 142 and 144 can each have a positive power. By way of example, tens 102 without the sampling lenses 142 and 144 can have a focal length of 126 mm. Sampling lenses 142 and 144 can each have a focal length of 44 mm. Based on these choices, the combined lens 102 will have a resulting focal length of 60 mm. The arrangement allows a 60mm lens to employ a larger inter-aperture distance that is appropriate to a much larger 126 mm lens with an associated larger entrance pupil. The consequence is a much larger stereopsis attainable with the 60 mm lens arrangement than what might be expected from a typical 60 mm lens with its wider angle and its naturally larger field of view. It combines the benefits of the 126 mm lens with those of a 60mm lens as regards three-dimensional imaging applications.

In a further embodiment of the present invention the combined structure of front lens assembly 124 and rear lens assembly 126 can allow the lens 102 to be a zoom lens for changing the sizes of images 134 and 136 on imaging sensor 132. In other embodiments of the invention yet further lens combinations are possible for the front lens assembly 124 and rear lens assembly
Because of the single optical path arrangement, the apparatus allows for the lens 102 to function as one or both of a zoom and a macro lens. This is a major benefit compared with several systems described in the prior art. The single optical path arrangement also makes the apparatus compact and the absence of mirrors in some embodiments makes it robust and durable. The single optical path arrangement also makes the invention compatible with commercial and consumer camera and video equipment.

It is to be noted that the stereoscopic imaging apparatus 100 of the present invention, as shown in Figure 1 does not create a real image of the object 100 between either the first or the second sampling lens 142 or 144 and rear lens assembly 126. This reduces the complexity of the sampling lens arrangement as compared with a system that forms an image after the sampling lenses and then relays it. The stereoscopic imaging apparatus 100 samples light from the first and second portions of the optical path simultaneously and, unlike many prior art single channel stereoscopic imaging devices, can simultaneously create the first and second images 134 and 136 on imaging sensor 132. The stereoscopic imaging apparatus 100 also holds the benefit of not requiring any polarization of the light from the object in order to operate. This implies that light levels are more than doubled in comparison with polarization based systems. The double Gauss arrangement of lens 102 provides a high-speed lens system with excellent aberration performance over a large area of imaging sensor 132.

The invention allows the use of industry standard imaging sensors since the vertical compression ensures that both the image 134 and the image 136 can fit on an imaging sensor that would, in the absence of the invention, have been used for one of the two images. The invention is not prescriptive in respect of the format of the sensor and is applicable to all imaging sensor aspect ratio and size formats.

In a practical application of the invention the imaging sensor 132 can be the sensor in a "black box" of a standard commercial digital SLR (D-SLR) camera, such as but not limited to a Nikon D50, produced by the Nikon Corporation of Japan. This particular commercial D-SLR camera comprises a sensor that has 3008 pixels resolution in the horizontal direction and 2000 pixels in the vertical direction. With lens 102 as per the foregoing embodiments fitted to the D50 D-SLR camera, the arrangement can capture a stereoscopic image pair arranged one above the other along the vertical dimension. Ideally the images substantially abut each other and do not overlap to a degree that is objectionable to the user, the compression along the vertical dimension...
being substantially 50%. Each of the two images is of size 3008x1000 and the vertical dimension of each of the two images is substantially half of its natural dimension. It is a simple matter to resample each of the two images to 3008x2000 after downloading the image from the camera. Many graphics software tools exist to allow the user to do such resampling, even though the real resolution in the vertical dimension for each of the images remains half of what the camera is inherently capable of. The sacrifice of resolution along the vertical dimension is more than compensated for by the benefit of an apparatus that inherently captures stereoscopic images of any scene in an easy to use format.

Figure 2 is a flow chart of a method for forming on the imaging sensor 132 of Figure 1 a stereoscopic image pair, the image pair comprising the first image 134 and the second image 136 providing two different perspectives of the object 116 within the field of view of a first lens, being the front lens assembly 124 of Figure 1, disposed along the optical axis 103.

The method comprises gathering [200] through the front lens assembly 124 light from a scene in the field of view of front lens assembly 124; directing [210] the gathered light along a single optical path generally about the optical axis 103 to the aperture plane 104; anamorphically magnifying [220] the image content of the light by means of at least one anamorphic lens, being either anamorphic element 110 or first and second sampling lenses 142 and 144; sampling [230] light from a first portion of the single optical path through first aperture 128 disposed proximate the aperture plane 104 and on a first side of the optical axis 103; simultaneously sampling [235] light from a second portion of the single optical path through the second aperture 130 disposed proximate the aperture plane 104 and on an opposite side of the optical axis 103 from the first aperture 128; and forming on the imaging sensor 132 disposed along the optical axis 103 first and second images 134 and 136 from respectively the light sampled from the first portion of the single imaging path and the light sampled from the second portion of the imaging path. Forming [240] the first image 134 by processing the light sampled from the first portion of the single optical path through a second lens, being the rear lens assembly 126 of Figure 1, disposed on the optical axis 103; and the forming [245] the second image 136 by processing the light sampled by second sampling lens 144 from the second portion of the single optical path through the second lens, being the rear lens assembly 126.

The method further comprises routing [250] the light from the first aperture 128 and routing [255] the light from the second aperture 130 via respectively sampling lenses 142 and
144 to form images 134 and 136 respectively at predetermined positions relative to each other, the sampling lenses 142 and 144 being disposed proximate, overlapping and abaxial with respectively the first aperture 128 and the second aperture 130.

The method can further comprise at least one of varying a depth of field for the first image 134 by varying [260] the size of the first aperture 128 in the aperture plate 108; and varying a depth of field for the second image 136 by varying [265] the size of the second aperture 130 in the aperture plate 108.

The method can further comprise changing the perspective difference between the two images 134 and 136 by changing [270] the inter-aperture separation between first aperture 128 and second aperture 130 in the aperture plate 108.

The method can further comprise extracting [280] the data describing first and second images 1.34 and 1.36 from imaging sensor 132 using controller 115 via image data output connection 117 and digitally restoring the original aspect ratios of images 1.34 and 1.36 using, for example, controller 115. The two images 1.34 and 1.36, with their aspect ratio restored, thereby constitute a stereo image pair that may be viewed with suitable stereo viewing equipment.

Stereoscopic optical subsystem 150, comprising anamorphic element 110, aperture plate 108 with apertures 128 and 1.30, sampling lenses 142 and 144, and rear lens assembly 126 can be applied to many different optical apparatus to generate stereoscopic images. The apparatus described in Figure 1 in particular is configured to serve, among other applications, as a camera or video camera as described above. In a further embodiment, the front lens assembly 124 shown in Figure 1 can be a microscope lens system. All elements remain as in Figure 1 and retain the same numbering. Stereoscopic optical subsystem 1.50 remains the same as in the embodiment described in Figure 1. The microscope lens system can be any of a wide variety of monoscopic microscope systems. By way of non-limiting example, lenses 118 and 1.20 together can be the objective lens system of the microscope lens system, while lens 122 can be the ocular lens of the microscope lens system. In operation, light gathered from within the field of view of the microscope objective lens system (comprised of lens 1.18 and lens 120) is imaged in front of lens 122. Lens system 122 can be chosen to manipulate the image-bearing light to suit the input requirements of different further optical subsystems. Stereoscopic optical subsystem 150 is one such further optical subsystem. The application of stereoscopic optical subsystem 150 to a
microscope can be as part of the inherent design of the microscope, or can be a post-
manufacturing addition by the user and can be carried out in the field.

In yet a further embodiment, shown schematically and not to scale in Figure 3, the front
lens assembly 124 of Figure 1 is replaced by a single optical channel endoscopic lens system
1.60. All other elements remain as in Figure 1 and retain the same numbering. Endoscopic lens
system 160 can be any of a wide variety of single channel endoscopic systems. By way of non-
limiting example, endoscopic lens system 160 can comprise, as shown specifically in Figure 3,
an objective lens system 162; a relay lens system 164; and, optionally, an exit lens system 166.
In operation, light gathered from within the field of view of the endoscopic objective lens system
162 is imaged by objective lens system 162 and the image thus formed is relayed by relay lens
system 1.64 along the length of the endoscope lens system 160. Optional exit lens system 166 can
be chosen to manipulate the image-bearing light to suit the input requirements of different further
optical subsystems. Stereoscopic optical subsystem 150 is one such further optical subsystem. In
this arrangement exit lens system 166 can be the ocular lens of an endoscope that comprises
endoscope lens system 160. The application of stereoscopic optical subsystem 150 to an
endoscope can be as part of the inherent design of the endoscope, or can be a post-manufacturing
addition by the user and can be carried out in the field.

In another endoscopic embodiment best described at the hand of Figure 1, front lens
assembly 1.24 of Figure 1 can be the objective lens assembly of an endoscope and be located at
the probe tip of the insertion part of an endoscope, while stereoscopic optical subsystem 150 and
sensor 132 can both be located in the insertion part proximate the front lens assembly 124. This
is popularly referred to as the "chip on a stick" implementation of endoscopes. This
implementation therefore provides a stereoscopic endoscope of simplicity suitable for
incorporation within the narrow confines of the insertion part of the endoscope. The absence of
any modulators - particularly mechanical modulators - within stereoscopic optical subsystem
150 facilitates this particular implementation.

In another embodiment, the anamorphic element 11.0 can be disposed on the optical axis
103 between the sampling lenses 142 and 144 and the rear lens assembly 126. In other
embodiments the anamorphic element 110 can be disposed inside of rear lens assembly 126 or
between lens assembly 126 and sensor 132, In yet further embodiments, anamorphic element 110
can be omitted and sampling lenses 142 and 144 can be made anamorphic for compressing images 134 and 138 by substantially 50% in the vertical dimension.

Without limiting the scope of the invention, it bears pointing out that, in all the embodiments described above, the stereoscopic imager employs a single first objective lens that directs light through at least one anamorphic lens along a single optical path generally about the optical axis 103 to a single sensor 132 without modulating the light. While the exit pupil of the front lens assembly 124 is sampled by the combinations of apertures 128 and 130 and their corresponding sampling lenses 142 and 144, no reflective, prism, or other beam-splitting components are required. The stereoscopic imager provided in this specification anamorphically alters two images with different perspectives of a field of view of an objective lens, while maintaining maximal resolution in the horizontal dimension for associated maximal stereoscopic quality. Though the images 134 and 136 as formed on imaging sensor 132 lose substantially 50% of their resolution in the vertical compression by the anamorphic lens(es), the desired stereoscopic viewing experience is based on perspective differences in the horizontal dimension, as opposed to the compressed vertical.

In other embodiments, sensor 132 can be oriented in the portrait orientation with its long axis in the vertical, and anamorphic lens(es) can be chosen to compress images 142 and 144 along the horizontal dimension to fit the sensor 132 which, in the case of a 4x3 sensor, will be in what is effectively a 3x4 orientation. This can be advantageous in applications where greater vertical resolution may be desirable and some relative loss of horizontal resolution is acceptable.

NOTES

The drawings and the associated descriptions are provided to illustrate embodiments of the invention and not to limit the scope of the invention. Reference in the specification to "one embodiment" or "an embodiment" is intended to indicate that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least an embodiment of the invention. The appearances of the phrase "in one embodiment" or "an embodiment" in various places in the specification are not necessarily all referring to the same embodiment. As used in this disclosure, except where the context requires otherwise, the term "comprise" and variations of the term, such as "comprising," "comprises" and "comprised" are not intended to exclude other additives, components, integers or steps.
Also, it is noted that the embodiments are disclosed as a process that is depicted as a flowchart, a flow diagram, a structure diagram, or a block diagram. Although a flowchart may disclose various steps of the operations as a sequential process, many of the operations can be performed in parallel or concurrently. The steps shown are not intended to be limiting nor are they intended to indicate that each step depicted is essential to the method, but instead are exemplary steps only.

In the foregoing specification, the invention has been described with reference to specific embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention. The specification and drawing are, accordingly, to be regarded in an illustrative rather than a restrictive sense. It should be appreciated that the present invention should not be construed as limited by such embodiments.

From the foregoing description it will be apparent that the present invention has a number of advantages, some of which have been described herein, and others of which are inherent in the embodiments of the invention described or claimed herein. Also, it will be understood that modifications can be made to the device, apparatus and method described herein without departing from the teachings of subject matter described herein. As such, the invention is not to be limited to the described embodiments except as required by the appended claims.

In an example embodiment, the invention may be combined with the subject matter of our provisional application no. 61/586,738, entitled SINGLE AXIS STEREOSCOPIC IMAGING APPARATUS WITH DUAL SAMPLING LENSES filed on January 13, 2012 and incorporated herein by reference.

PARTS LIST
100. Single axis stereoscopic imaging system
102. Lens
103. Optical axis
104. Aperture plane
108. Aperture plate
110. Anamorphic element
118. Lens
120. Lens
122. Lens
124. Front lens assembly
126. Rear lens assembly
128. First aperture
130. Second aperture
132. Imaging sensor
134. First image
136. Second image
138. Vertical line
142. First sampling lens
144. Second sampling lens
150. Stereoscopic optical subsystem
160. Endoscope lens system
162. Objective lens system
164. Relay lens system
165. Exit lens system
115. Controller
117. Image data output connection
[200]. Gathering light from the field of view of lens
[210]. Directing light along single optical path
[220]. Anamorphically magnifying image content of the light
[230]. Sampling light from first portion of the single optical path with first sampling lens
[235]. Sampling light from second portion of the single optical path with second sampling lens
[240]. Forming first image on imaging sensor with second lens (rear lens assembly 126)
[245]. Forming second image on imaging sensor with second lens (rear lens assembly 126)
[250]. Routing light from first aperture using first abaxial sampling lens
[255]. Routing light from second aperture using second sampling abaxial lens
[260]. Adjusting depth of field for first image by changing size of first aperture
[265]. Adjusting depth of field for second image by changing size of second aperture
[270]. Changing inter-aperture separation
[280]. Extracting data describing first and second images from sensor
[290]. Digitally restoring the original aspect ratios of first and second images
What is claimed is

1. A stereoscopic imaging apparatus for forming on a single image sensor from light obtained along a single optical path through a front lens assembly having a single optical axis an anamorphic stereoscopic image pair comprising a first image and a second image of differing perspective from the first image, the apparatus comprising:

   first and second apertures disposed proximate an aperture plane of the front lens assembly, on opposite sides of an optical axis of the front lens assembly, and separated by an inter-aperture separation;

   at least one anamorphic element disposed in the single optical path;

   a first sampling lens located between the aperture plane and the sensor and proximate and overlapping with the first aperture;

   a second sampling lens located between the aperture plane and the sensor and proximate and overlapping with the second aperture; and

   a rear lens assembly disposed between the sampling lenses and the sensor for forming on the sensor the first and second images from light received through the first and second sampling lenses.

2. The apparatus of claim 1, wherein the sampling lenses are disposed to direct light received through the two apertures to form through the rear lens assembly the first and second images at different substantially non-overlapping locations on the image sensor.

3. The apparatus of claim 1, wherein the first and second sampling lenses are disposed abaxially with respectively the first and second apertures to form through the rear lens assembly the first and second images aligned vertically above each other and substantially non-overlapping on the image sensor.
4. The apparatus of claim 1, wherein the first and second sampling lenses are disposed abaxially with respectively the first and second apertures to form through the rear lens assembly the first and second images aligned horizontally next to each other and substantially non-overlapping on the image sensor.

5. The apparatus of claim 1, wherein the at least one anamorphic element is a single anamorphic lens disposed on the optical axis between the sampling lenses and the rear lens assembly.

6. The apparatus of claim 1, wherein the at least one anamorphic element is a single anamorphic lens disposed on the optical axis between the rear lens assembly and the image sensor.

7. The apparatus of claim 1, wherein the at least one anamorphic element is a single anamorphic lens disposed on the optical axis within the rear lens assembly.

8. The apparatus of claim 1, wherein the at least one anamorphic element is a single anamorphic lens disposed on the optical axis between the front lens assembly and the sampling lenses.

9. The apparatus of claim 1, wherein the first and second sampling lenses also define the at least one anamorphic element.

10. The apparatus of claim 1, wherein the front lens assembly is an endoscope front lens assembly.

11. The apparatus of claim 1, wherein the front lens assembly is a microscope objective lens assembly.

12. The apparatus of claim 1, wherein the front lens assembly is a camera lens assembly.
13. The apparatus of claim 1, wherein the first and second apertures are variable apertures.

14. The apparatus of claim 1, wherein the inter-aperture separation is adjustable.

15. The apparatus of claim 14, wherein the sampling lenses are configured to move in cooperation with the apertures when the inter-aperture separation is adjusted.

16. A stereoscopic imaging apparatus for forming an anamorphic stereoscopic image pair comprising a first image and a second image of differing perspective from the first image, the apparatus comprising:

   a front lens assembly, comprising at least an objective lens having a field of view and a single optical axis, the front lens assembly configured to direct light from the field of view along a single optical path generally about the optical axis;

   a single imaging sensor disposed along the optical axis behind the front lens assembly;

   first and second apertures disposed proximate an aperture plane of the front lens assembly, on opposite sides of an optical axis of the front lens assembly, and separated by an inter-aperture separation;

   at least one anamorphic element disposed in the single imaging path;

   a first sampling lens located between the aperture plane and the sensor and proximate and overlapping with the first aperture;

   a second sampling lens located between the aperture plane and the sensor and proximate and overlapping with the second aperture; and
a rear lens assembly disposed between the sampling lenses and the sensor for forming on the sensor the first and second images from light received through the first and second sampling lenses.

17. The stereoscopic imaging apparatus of claim 16, wherein the front lens assembly and the rear lens assembly form a double Gauss lens.

18. The apparatus of claim 16, wherein the sampling lenses are disposed to direct light received through the two apertures to form through the rear lens assembly the first and second images at different substantially non-overlapping locations on the image sensor.

19. The apparatus of claim 16, wherein the first and second sampling lenses are disposed abaxially with respectively the first and second apertures to form through the rear lens assembly the first and second images aligned vertically above each other and substantially non-overlapping on the image sensor.

20. The apparatus of claim 16, wherein the first and second sampling lenses are disposed abaxially with respectively the first and second apertures to form through the rear lens assembly the first and second images aligned horizontally next to each other and substantially non-overlapping on the image sensor.

21. The apparatus of claim 16, wherein the at least one anamorphic element is a single anamorphic lens disposed on the optical axis between the sampling lenses and the rear lens assembly.

22. The apparatus of claim 16, wherein the at least one anamorphic element is a single anamorphic lens disposed on the optical axis between the rear lens assembly and the image sensor.

23. The apparatus of claim 16, wherein the at least one anamorphic element is a single anamorphic lens disposed on the optical axis within the rear lens assembly.
24. The apparatus of claim 16, wherein the at least one anamorphic element is a single anamorphic lens disposed on the optical axis between the front lens assembly and the sampling lenses.

25. The apparatus of claim 16, wherein the at least one anamorphic element is a single anamorphic lens disposed on the optical axis in front of the front lens assembly.

26. The apparatus of claim 16, wherein the at least one anamorphic element is a single anamorphic lens disposed on the optical axis within the front lens assembly.

27. The apparatus of claim 16, wherein the first and second sampling lenses also define the at least one anamorphic element.

28. The apparatus of claim 16, wherein the front lens assembly is an endoscope front lens assembly.

29. The apparatus of claim 16, wherein the front lens assembly is a microscope objective lens assembly.

30. The apparatus of claim 16, wherein the front lens assembly is a camera lens assembly.

31. The apparatus of claim 16, wherein the first and second apertures are variable apertures.

32. The apparatus of claim 16, wherein the inter-aperture separation is adjustable.

33. The apparatus of claim 32, wherein the sampling lenses are configured to move in cooperation with the apertures when the inter-aperture separation is adjusted.

34. The apparatus of claim 16, wherein the imaging sensor is oriented in a landscape orientation with its long axis in the horizontal dimension.
35. The apparatus of claim 16, wherein the imaging sensor is oriented in a portrait orientation with its long axis in the vertical dimension.

36. A method for forming on a single imaging sensor an anamorphic stereoscopic image pair comprising a first and a second image, the method comprising

- gathering light from objects within a field of view;
- directing the gathered light along a single optical path generally about the optical axis;
- anamorphically magnifying the image content of the light;
- sampling light from a first portion of the single optical path through a first aperture and sampling light from a second portion of the single optical path through a second aperture, the first and second apertures disposed on opposite sides of the optical axis proximate an aperture plane; and
- forming on the single imaging sensor disposed along the optical axis the first and second images from respectively the light sampled through the first aperture and the light sampled through the second aperture.

37. The method of claim 36, wherein the forming of the first and second images is performed by processing respectively the light sampled through the first aperture and the light sampled through the second aperture through a second lens disposed between the apertures and the sensor.

38. The method of claim 37, further comprising routing the light from the first and second apertures via respectively first and second sampling lenses to form respectively the first and second images at predetermined positions relative to each other, the first and second
sampling lenses being disposed proximate, overlapping and abaxial with respectively the first aperture and second aperture.

39. The method of claim 38, wherein the routing comprises displacing the centers of the two sampling lenses abaxially in respectively opposite directions from their respective proximate apertures.

40. The method of claim 39, wherein:

   the anamorphically magnifying is relatively compressing the image content of the gathered light by substantially 50% in a vertical dimension compared with a horizontal dimension; and

   the displacing includes aligning the first and second images vertically above each other on the sensor.

41. The method of claim 39, wherein:

   the anamorphically magnifying includes relatively compressing the image content of the gathered light by substantially 50% in a horizontal dimension as compared with a vertical dimension; and

   the displacing includes aligning the first and second images horizontally next to each other on the sensor.

42. The method of claim 38, wherein the anamorphically magnifying is performed by the first and second sampling lenses.

43. The method of claim 36, wherein the anamorphically magnifying is performed by a single anamorphic element disposed on the optical axis between the front lens assembly and the aperture plane of the front lens assembly.
44. The apparatus of claim 36, wherein the anamorphically magnifying is performed by a single anamorphic element disposed on the optical axis in front of the front lens assembly.

45. The apparatus of claim 36, wherein the anamorphically magnifying is performed by a single anamorphic element disposed on the optical axis within the front lens assembly.

46. The method of claim 36, wherein the anamorphically magnifying is performed by a single anamorphic element disposed on the optical axis and between the sampling lenses and the rear lens assembly.

47. The apparatus of claim 36, wherein the anamorphically magnifying is performed by a single anamorphic element disposed on the optical axis between the rear lens assembly and the image sensor.

48. The apparatus of claim 36, wherein the anamorphically magnifying is performed by a single anamorphic element disposed on the optical axis within the rear lens assembly.

49. The method of claim 36, further comprising varying a depth of field for at least one of the first image and the second image by varying the size of the corresponding aperture through which its light is sampled.

50. The method of claim 36, further comprising changing the perspective difference between the first and second images by changing an inter-aperture separation between the first aperture and the second aperture.

51. The method of claim 50, further comprising moving a position of first and second sampling lenses in cooperation with respectively the first and second apertures during the changing of an inter-aperture separation.
52. The method of claim 36, further comprising extracting from the single imaging sensor data describing the first and second images.

53. The method of claim 52, further comprising digitally restoring the aspect ratio of the first and second images to values that pertained to an image content of the light from the objects within the field of view before the anamorphically magnifying.
Gathering light from field of view of lens

Directing light along single optical path about optical axis

Anamorphically magnifying image content of light

230
Sampling light from first portion of the single optical path

250
Routing light from first aperture using first abaxial sampling lens

240
Forming first image on sensor using light from first portion of single optical path using second lens

235
Sampling light from second portion of the single optical path

255
Routing light from second aperture using second abaxial sampling lens

245
Forming second image on sensor using light from second portion of single optical path using second lens

280
Extracting data describing first and second images from sensor

290
Digitally restoring the original aspect ratios of first and second images

FIG. 2
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
   IPC: G02B 27/22 (2006.01), G02B 13/08 (2006.01), H04N 5/335 (2011.01)
   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: G02B 27/22 (2006.01), G02B 13/08 (2006.01), H04N 5/335 (2011.01) (In combination with keywords)

   Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
   Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
   Total Patent (keywords stereoscopic, anamorphic, single sensor)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
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<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
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<tr>
<td>Y</td>
<td>US7372642B2, Rohaly et al. 13 May 2008 (13-05-2008) (See figures 6, 8, 9a, 9b, column 10, lines 13-46)</td>
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<tr>
<td>A</td>
<td>US200815014A1, Shafer et al. 26 June 2008 (26-06-2008) (See whole document)</td>
<td>1-53</td>
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[ ] Further documents are listed in the continuation of Box C. [X] See patent family annex.

“*” Special categories of cited documents:
“A” document defining the general state of the art which is not considered to be of particular relevance
“E” earlier application or patent but published on or after the international filing date
“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
“O” document referring to an oral disclosure, use, exhibition or other means
“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
“&” document member of the same patent family

Date of the actual completion of the international search
12 April 2013 (12-04-2013)

Date of mailing of the international search report
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Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
Place du Portage I, C114 - 1st Floor, Box PCT
50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 001-819-953-2476

Authorized officer
David E. Green (819) 994-8213

Form PCT/ISA/210 (second sheet) (July 2009)
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**Information on patent family members**

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