(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
07 June 2018 (07.06.2018)

WIPO | PCT

(10) International Publication Number
WO 2018/100240 A1

(51) International Patent Classification:
G02B 27/01 (2006.01)

(21) International Application Number:
PCT/FI2017/050828

(22) International Filing Date:
27 November 2017 (27.11.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
15/366,424 01 December 2016 (01.12.2016) US
15/650,796 14 July 2017 (14.07.2017) US

(71) Applicant: VARJO TECHNOLOGIES OY [FI/FI]; Aleksanterinkatu 21 H, 00100 Helsinki (FI).

(72) Inventors: SAHLSTEN, Oiva; Tuhkelotie 18, 24280 Salo (FI). OLLILA, Mikko; Vastakatu 16, 33710 Tampere (FI).

(74) Agent: MOOSEDOG OY; Rykmentintie 2B, 20810 Turku (FI).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,

(54) Title: DISPLAY APPARATUS IMAGE RENDERERS AND OPTICAL COMBINERS

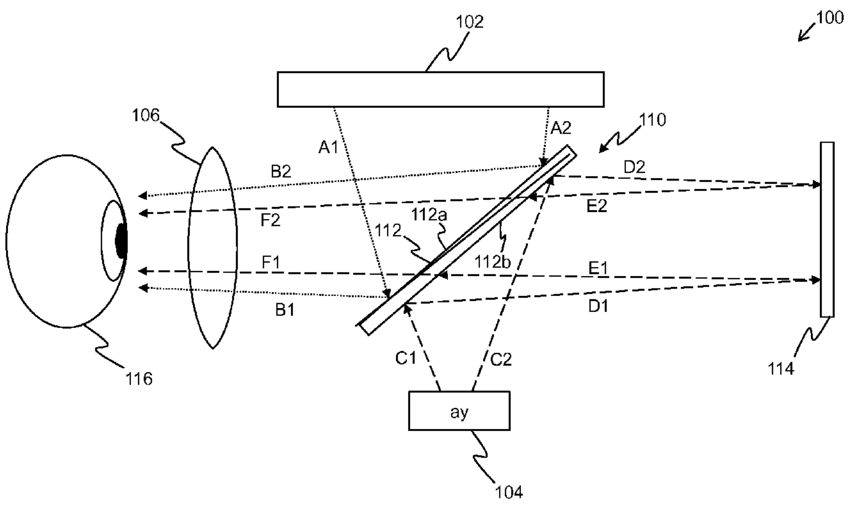

FIG. 1

(57) Abstract: Disclosed is a display apparatus and method of displaying, via the display apparatus. The display apparatus comprises context image renderer for rendering context image; focus image renderer for rendering focus image; exit optical element; and optical combiner for optically combining projection of the rendered context image with projection of the rendered focus image to create visual scene. The optical combiner comprises first semi-transparent reflective element; and a second semi-transparent reflective element. The context image renderer is arranged in a manner that projection of rendered context image is incident upon first semi- transparent reflective element and reflected towards exit optical element therefrom. The focus image renderer is arranged in a manner that projection of rendered focus image is incident upon first semi-transparent reflective element and reflected towards second semi-transparent reflective element, and then reflected towards first semi-transparent reflective element, from where projection thereof is allowed to pass through towards exit optical element.

WO 2018/100240 A1

[Continued on next page]

MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

DISPLAY APPARATUS IMAGE RENDERERS AND OPTICAL COMBINERS

TECHNICAL FIELD

The present disclosure relates generally to virtual and augmented reality; and more specifically, to display apparatuses comprising context and focus image renderers, exit optical elements and optical combiners. Furthermore, the present disclosure also relates to methods of displaying via the aforementioned display apparatuses.

BACKGROUND

In recent times, there have been rapid advancements in development and the use of technologies such as virtual reality, augmented reality, and so forth, for presenting a simulated environment to a user. Specifically, such technologies provide the user with a feeling of complete involvement (namely, immersion) within the simulated environment by employing contemporary techniques such as stereoscopy. Therefore, such simulated environments provide the user with an enhanced perception of reality around him/her. Moreover, such simulated environments relate to fully virtual environments (namely, virtual reality) as well as real world environments including virtual objects therein (namely, augmented reality).

Typically, the user may use a specialized device, for example, such as a virtual reality device or an augmented reality device, for experiencing such simulated environments. Generally, the virtual and augmented reality devices are binocular devices having separate display optics for each eye of the user. Furthermore, such specialized devices include optical elements therein to render and project constituent images that are employed for presenting the simulated environment to the user. Examples of the virtual reality devices include, head mounted virtual reality devices, virtual reality glasses, and so forth. Furthermore, examples of the augmented reality devices include augmented reality headsets, augmented reality glasses, and so forth.

However, conventional virtual and augmented reality devices have certain limitations. Firstly, such devices are susceptible to introduction of significant chromatic aberrations and optical distortions whilst projecting the constituent images towards the eyes of the user. Such chromatic aberrations and optical distortions severely diminish quality of the user s experience of the simulated environment. Secondly, the optical elements may be arranged in a complex manner within the conventional virtual and augmented reality devices, thereby often introducing obstructions within paths of projection of the constituent images. Thirdly due to the aforesaid complex arrangement of optical elements, in conventional virtual and augmented reality devices, multiple optical elements have to be adjusted to change size of the projection of images. Furthermore, changing position (namely, location) of the projection of images, in a single or multiple planes, is substantially difficult in such complex arrangements.

Therefore, in light of the foregoing discussion, there exists a need to overcome the aforementioned drawbacks associated with conventional virtual and augmented reality devices.

SUMMARY

The present disclosure seeks to provide a display apparatus. The present disclosure also seeks to provide a method of displaying, via such a display apparatus. The present disclosure seeks to provide a solution to the existing problem of chromatic aberrations and optical distortions in images displayed by conventional virtual and augmented reality devices. An aim of the present disclosure is to provide a solution that overcomes

at least partially the problems encountered in the prior art, and provides a robust, reliable and efficient display apparatus.

In one aspect, an embodiment of the present disclosure provides a display apparatus comprising:

- at least one context image renderer for rendering a context image;
- at least one focus image renderer for rendering a focus image;
- an exit optical element; and
- at least one optical combiner for optically combining a projection of the rendered context image with a projection of the rendered focus image to create a visual scene, an angular width of the projection of the rendered context image being greater than an angular width of the projection of the rendered focus image, the at least one optical combiner comprising:
- a first semi-transparent reflective element having a first side and a second side, the first side facing the exit optical element; and
- a second semi-transparent reflective element facing the second side of the first semi-transparent reflective element,

wherein the at least one context image renderer is arranged in a manner that the projection of the rendered context image emanating therefrom is incident upon the first side of the first semi-transparent reflective element and reflected towards the exit optical element therefrom, and wherein the at least one focus image renderer is arranged in a manner that the projection of the rendered focus image emanating therefrom is incident upon the second side of the first semi-transparent reflective element and reflected towards the second semi-transparent reflective element therefrom, and is then reflected from the second semi-transparent reflective element towards the first semi-transparent reflective element, from where the projection of the rendered focus image is allowed to pass through towards the exit optical element.

In another aspect, an embodiment of the present disclosure provides a method of displaying, via a display apparatus comprising at least one context image renderer, at least one focus image renderer, an exit optical element and at least one optical combiner, the at least one optical combiner comprising a first semi-transparent reflective element and a second semi-transparent reflective element, the first semi-transparent reflective element having a first side facing the exit optical element and a second side facing the second semi-transparent reflective element, the method comprising:

- rendering a context image at the at least one context image renderer;
- rendering a focus image at the at least one focus image renderer; and
- using the at least one optical combiner to optically combine a projection of the rendered context image with a projection of the rendered focus image to create a visual scene, an angular width of the projection of the rendered context image being greater than an angular width of the projection of the rendered focus image,

wherein the at least one context image renderer is arranged in a manner that the projection of the rendered context image emanating therefrom is incident upon the first side of the first semi-transparent reflective element and reflected towards the exit optical element therefrom, and

wherein the at least one focus image renderer is arranged in a manner that the projection of the rendered focus image emanating therefrom is incident upon the second side of the first semi-transparent reflective element and reflected towards the second semi-transparent reflective element therefrom, and is then reflected from the second semi-transparent reflective element towards the first semi-transparent reflective element, from where the projection of the rendered focus image is allowed to pass through towards the exit optical element.

Embodiments of the present disclosure substantially eliminate or at least partially address the aforementioned problems in the prior art, and enables elimination of chromatic aberrations and optical distortions in images displayed by display apparatuses.

Additional aspects, advantages, features and objects of the present disclosure would be made apparent from the drawings and the detailed description of the illustrative embodiments construed in conjunction with the appended claims that follow.

It will be appreciated that features of the present disclosure are susceptible to being combined in various combinations without departing from the scope of the present disclosure as defined by the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The summary above, as well as the following detailed description of illustrative embodiments, is better understood when read in conjunction with the appended drawings. For the purpose of illustrating the present disclosure, exemplary constructions of the disclosure are shown in the drawings. However, the present disclosure is not limited to specific methods and instrumentalities disclosed herein. Moreover, those in the art will understand that the drawings are not to scale. Wherever possible, like elements have been indicated by identical numbers.

Embodiments of the present disclosure will now be described, by way of example only, with reference to the following diagrams wherein:

FIGs.1-5 are exemplary implementations of a display apparatus, in accordance with various embodiments of the present disclosure;

FIG. 6 illustrates an exemplary representation of a context image and a focus image to be rendered and projected via the display apparatus, in accordance with an embodiment of the present disclosure; and

FIG. 7 illustrates steps of a method of displaying via the display apparatus, in accordance with an embodiment of the present disclosure.

In the accompanying drawings, an underlined number is employed to represent an item over which the underlined number is positioned or an item to which the underlined number is adjacent. A non-underlined number relates to an item identified by a line linking the non-underlined number to the item. When a number is non-underlined and accompanied by an associated arrow, the non-underlined number is used to identify a general item at which the arrow is pointing.

DETAILED DESCRIPTION OF EMBODIMENTS

The following detailed description illustrates embodiments of the present disclosure and ways in which they can be implemented. Although some modes of carrying out the present disclosure have been disclosed, those skilled in the art would recognize that other embodiments for carrying out or practising the present disclosure are also possible.

In one aspect, an embodiment of the present disclosure provides a display apparatus comprising:

- at least one context image renderer for rendering a context image;
- at least one focus image renderer for rendering a focus image;
- an exit optical element; and
- at least one optical combiner for optically combining a projection of the rendered context image with a projection of the rendered focus image to create a visual scene, an angular width of the projection of the

rendered context image being greater than an angular width of the projection of the rendered focus image, the at least one optical combiner comprising:

- a first semi-transparent reflective element having a first side and a second side, the first side facing the exit optical element; and
- a second semi-transparent reflective element facing the second side of the first semi-transparent reflective element,

wherein the at least one context image renderer is arranged in a manner that the projection of the rendered context image emanating therefrom is incident upon the first side of the first semi-transparent reflective element and reflected towards the exit optical element therefrom, and

wherein the at least one focus image renderer is arranged in a manner that the projection of the rendered focus image emanating therefrom is incident upon the second side of the first semi-transparent reflective element and reflected towards the second semi-transparent reflective element therefrom, and is then reflected from the second semi-transparent reflective element towards the first semi-transparent reflective element, from where the projection of the rendered focus image is allowed to pass through towards the exit optical element.

In another aspect, an embodiment of the present disclosure provides a method of displaying, via a display apparatus comprising at least one context image renderer, at least one focus image renderer, an exit optical element and at least one optical combiner, the at least one optical combiner comprising a first semi-transparent reflective element and a second semi-transparent reflective element, the first semi-transparent reflective element having a first side facing the exit optical element and a second side facing the second semi-transparent reflective element, the method comprising:

- rendering a context image at the at least one context image renderer;

- rendering a focus image at the at least one focus image renderer; and
- using the at least one optical combiner to optically combine a projection of the rendered context image with a projection of the rendered focus image to create a visual scene, an angular width of the projection of the rendered context image being greater than an angular width of the projection of the rendered focus image,

wherein the at least one context image renderer is arranged in a manner that the projection of the rendered context image emanating therefrom is incident upon the first side of the first semi-transparent reflective element and reflected towards the exit optical element therefrom, and wherein the at least one focus image renderer is arranged in a manner that the projection of the rendered focus image emanating therefrom is incident upon the second side of the first semi-transparent reflective element and reflected towards the second semi-transparent reflective element therefrom, and is then reflected from the second semi-transparent reflective element towards the first semi-transparent reflective element, from where the projection of the rendered focus image is allowed to pass through towards the exit optical element.

The present disclosure provides the aforementioned display apparatus and the aforementioned method of displaying, via such a display apparatus. The display apparatus described herein allows for elimination of chromatic aberrations and optical distortions in images displayed by the display apparatus. Furthermore, the display apparatus facilitates a change in size of images projected therein, by way of minimal adjustment of optical elements employed within the display apparatus. Additionally, an arrangement of optical elements within the display apparatus provides minimal obstruction in paths of the images projected therein. Moreover, position of the images projected within the display apparatus may be changed relatively easily in single or multiple planes.

Context and Focus Image:

Optionally, the term *context image* relates to a wide image of the visual scene to be rendered and projected via the display apparatus. Optionally, the term *focus image* relates to another image depicting a part (namely, a portion) of the visual scene to be rendered and projected via the display apparatus. Therefore, it is to be understood that the focus image is dimensionally smaller than the context image. Furthermore, the context and focus images collectively constitute the visual scene upon optical combination of the projections thereof.

Throughout the present disclosure, the term *angular width* refers to an angular width of a given projection as seen from the user s eyes, when the display apparatus is worn by the user. It will be appreciated that the angular width of the projection of the rendered context image is greater than the angular width of the projection of the rendered focus image since the rendered focus image is typically projected on and around the fovea of the user s eyes, whereas the rendered context image is projected upon the retina of the user s eyes. Furthermore, the angular widths of the projections of the rendered context and focus images allow for coping with saccades and microsaccades associated with movement of the user s eyes.

In some implementations, the angular width of the projection of the rendered context image may be, for example, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210 or 220 degrees, whereas the angular width of the projection of the rendered focus image may be, for example, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55 or 60 degrees.

In other implementations, the angular width of the projection of the rendered context image is greater than 220 degrees.

It will be appreciated that the context and focus images described herein, are employed to present the visual scene of a simulated environment (for example, such as a virtual reality environment, an augmented reality environment, and so forth) to a user of the display apparatus, when the display apparatus is worn by the user. In such an instance, the display apparatus is operable to act as a device (for example, such as a virtual reality headset, a pair of virtual reality glasses, an augmented reality headset, a pair of augmented reality glasses and the like) for presenting the simulated environment to the user.

In an embodiment, the visual scene is a setting (for example, such as a coffee shop environment, a haunted house, a forest scene, and so forth) within a simulated environment to be presented to the user.

Furthermore, the aforementioned arrangement facilitates proper optical combination of the projections of the rendered context and focus images. If such a combination is less than optimal (or improper), the visual scene so created may appear distorted.

Context and Focus Image Renderer:

Throughout the present disclosure, the term *context image renderer* relates to equipment configured to facilitate rendering of the context image. Similarly, the term *focus image renderer* relates to equipment configured to facilitate rendering of the focus image.

Optionally, the at least one context image renderer and/or the at least one focus image renderer are implemented by way of at least one projector and a projection screen associated therewith. Optionally, a single projection screen may be shared between separate projectors employed to implement the at least one context image renderer and the at least one focus image renderer. Optionally, the at least one projector is selected from the group consisting of: a Liquid Crystal Display (LCD)-

based projector, a Light Emitting Diode (LED)-based projector, an Organic LED (OLED)-based projector, a Liquid Crystal on Silicon (LCoS)-based projector, a Digital Light Processing (DLP)-based projector, and a laser projector.

Optionally, the at least one context image renderer and/or the at least one focus image renderer is implemented by way of at least one display. Optionally, in this regard, the at least one context image renderer is implemented by way of at least one context display configured to emit the projection of the rendered context image therefrom, and the at least one focus image renderer is implemented by way of at least one focus display configured to emit the projection of the rendered focus image therefrom. In such a case, the term *context display* used herein relates to a display (or screen) configured to facilitate rendering of the context image thereon. Similarly, the term *focus display* used herein relates to a display (or screen) configured to facilitate rendering of the focus image thereon. Optionally, the at least one context display and/or the at least one focus display are selected from the group consisting of: a Liquid Crystal Display (LCD), a Light Emitting Diode (LED)-based display, an Organic LED (OLED)-based display, a micro OLED-based display, and a Liquid Crystal on Silicon (LCoS)-based display.

Furthermore, optionally, dimensions of the at least one context display are larger as compared to dimensions of the at least one focus display. Specifically, the at least one focus display may be much smaller in size than the at least one context display. Therefore, it will be appreciated that the at least one focus display may be moved easily as compared to the at least one context display.

Optical Combiner:

In one embodiment, the term *at least one optical combiner* relates to equipment (for example, such as optical elements) for optically combining the projection of the rendered context image with the projection of the rendered focus image to create the visual scene. It will be appreciated that the at least one optical combiner includes optical and/or mechanical elements (for example, such as, beam splitters, semi-transparent mirrors, prisms, waveguides, polarizers, actuators, active optical elements, and the like) in order to implement the aforesaid optical combination operation.

Furthermore, the first semi-transparent reflective element has the first side and the second side, the first side facing the exit optical element. Optionally, the second side of the first semi-transparent reflective element is facing the at least one focus image renderer. In an example, the first side and the second side are obliquely facing the exit optical element and the at least one focus image renderer, respectively.

Optionally, the first and second sides of the first semi-transparent reflective element are opposite to each other.

Optionally, the first side of the first semi-transparent reflective element is substantially reflective.

Moreover, optionally, the second side of the first semi-transparent reflective element is substantially transmissive, reflective or combination thereof.

Optionally, the first semi-transparent reflective element is implemented by way of at least one of: a semi-transparent mirror, a semi-transparent film, a beam splitter, a prism, a polarizer, a lens, an optical waveguide, an off-axis parabolic mirror. In an example, the semi-transparent mirror for implementing the first semi-transparent reflective element may be a pellicle mirror.

As an example, the first semi-transparent reflective element could be implemented by way of a semi-transparent mirror, wherein the first and second sides of the semi-transparent mirror are opposite to each other. Optionally, in such an example, the first side of the semi-transparent mirror may be substantially reflective whereas the second side of the semi-transparent mirror may be substantially transmissive, reflective or both.

As another example, the first semi-transparent reflective element could be implemented by way of an off-axis parabolic mirror, wherein the first and second sides of the off-axis parabolic mirror are opposite to each other.

Optionally, the first semi-transparent reflective element is static. In such an instance, a position of the first semi-transparent reflective element within the display apparatus is fixed. It will be appreciated that the aforesaid static arrangement (namely, placement) of the first semi-transparent reflective element allows for simplification of optical paths of the projection of the rendered context image and the projection of the rendered focus image. Beneficially, such a static first semi-transparent reflective element allows for reduction in geometric and chromatic aberrations within the display apparatus. Consequently, optical distortion of the focus and context images is substantially minimized.

As mentioned previously, the at least one optical combiner comprises the second semi-transparent reflective element facing the second side of the first semi-transparent reflective element. In an example, the second side of the first semi-transparent reflective element is obliquely facing the second semi-transparent reflective element.

Optionally, the second semi-transparent reflective element is implemented by way of at least one of: a semi-transparent mirror, a semi-transparent film, a fully reflective mirror, a beam splitter, a prism, a polarizer, a lens, an optical waveguide. In an example, the second semi-transparent reflective element is implemented by way of the fully reflective mirror. In such an instance, the fully reflective mirror may be semi-transparent.

In an embodiment, the second semi-transparent reflective element is curved in shape. It will be appreciated that the curve shape of the second semi-transparent reflective element can be in any suitable direction and shape, for example such as an outside-in hemisphere, an inside-out hemisphere, a parabolic shape, and so forth. Beneficially, the curved shape of the second semi-transparent reflective element allows for a potential increase in field of view of the display apparatus and allows for a reduction in size of the display apparatus. It will be appreciated that the curved shape of the second semi-transparent reflective element also allows for a reduction in geometric and chromatic aberrations occurring within the display apparatus.

In another embodiment, the second semi-transparent reflective element is flat (namely, planar) in shape. In yet another embodiment, the second semi-transparent reflective element is freeform in shape. Optionally, in this regard, the freeform shape is implemented as a combination of flat and curved surfaces including protrusions and depressions on a surface of the second semi-transparent reflective element.

As mentioned previously, in the display apparatus, the at least one context image renderer is arranged in a manner that the projection of the rendered context image emanating therefrom is incident upon the first side of the first semi-transparent reflective element and reflected towards the exit optical element therefrom. It will be appreciated that optical properties (namely, reflection characteristics) of the first semi-transparent reflective element allow for controlling the optical path of the projection of the rendered context image, in the aforesaid manner. Furthermore, the aforesaid arrangement of the at least one context image renderer, the first semi-transparent reflective element and the exit optical element with respect to each other enables the aforesaid control of the optical path of the projection of the rendered context image.

In an exemplary implementation, the projection of the rendered context image is incident upon the first side of the first semi-transparent reflective element. The first side of the first semi-transparent reflective element is substantially reflective and allows the projection of the rendered context image to reflect therefrom. Furthermore, the projection of the rendered context image reflects from the first semi-transparent reflective element, and is directed towards the exit optical element.

Furthermore, in the display apparatus, the at least one focus image renderer is arranged in a manner that the projection of the rendered focus image emanating therefrom is incident upon the second side of the first semi-transparent reflective element and reflected towards the second semi-transparent reflective element therefrom, and is then reflected from the second semi-transparent reflective element towards the first semi-transparent reflective element, from where the projection of the rendered focus image is allowed to pass through towards the exit optical element. It will be appreciated that optical properties (namely, reflection and/or transmission characteristics) of the first semi-transparent reflective element and the second semi-transparent reflective element, allow for controlling the optical path of the projection of the rendered focus image, in the aforesaid manner. Furthermore, the aforesaid arrangement of the at least one focus image renderer, the first semi-transparent reflective element, the second semi-transparent reflective element and the exit optical element with respect to each other enables the aforesaid control of the optical path of the projection of the rendered focus image.

In an exemplary implementation, the projection of the rendered focus image is incident upon the second side of the first semi-transparent reflective element. The second side of the first semi-transparent reflective element is substantially reflective and allows the projection of the rendered focus image to reflect from the first semi-transparent reflective element. Furthermore, the reflected projection of the rendered focus image is directed towards the second semi-transparent reflective element. The reflected projection of the rendered focus image is incident upon the second semi-transparent reflective element, and is further reflected therefrom. Consequently, upon the aforementioned reflection from the second semi-transparent reflective element, the projection of the rendered focus image is directed towards the second side of the first semi-transparent reflective element. Optionally, the second side of the first semi-transparent reflective element is substantially transmissive, and allows the projection of the rendered focus image to pass therethrough towards the exit optical element.

In another exemplary implementation, the first semi-transparent reflective element is implemented by way of the off-axis parabolic mirror. In such an instance, the projection of the rendered focus image is incident upon the second side of the off-axis parabolic mirror, wherein the off-axis parabolic mirror is configured to collimate the projection of the rendered focus image incident thereupon whilst reflecting the projection of the rendered focus image towards the second semi-transparent reflective element. Therefore, the collimated projection of the rendered focus image is incident upon the second semi-transparent reflective element and is reflected substantially parallely to the incident collimated projection, from the second semi-transparent reflective element. Thereafter, upon the aforesaid reflection from the second semi-transparent reflective element, the projection of the rendered focus image is directed towards the off-axis parabolic mirror, from where the projection of the rendered focus image is allowed to pass through towards the exit optical element. It will be appreciated that use of an active optical element such as the aforesaid off-axis parabolic mirror allows for the focus image to appear at optical infinity (namely, at an infinite distance from the user s eyes). Beneficially, in such an instance, the focus image appears to be static with respect to the visual scene incident upon the user s eyes, even upon movement of the user s eyes.

Throughout the present disclosure, the term *exit optical element* relates to an optical device configured to direct the projection of the rendered context image and the projection of the rendered focus image, towards the eyes of the user of the display apparatus, when the display apparatus is worn by the user.

Optionally, the exit optical element receives the projection of the rendered context image and the projection of the rendered focus image, from the first semi-transparent reflective element, and modifies an optical path and/or optical characteristics of at least one of the projection of the rendered context image and the projection of the rendered focus image, prior to directing the aforesaid projections onto the eyes of the user. In one example, the exit optical element may magnify a size (or angular dimensions) of the projection of the rendered focus image. In such a case, use of a magnifying optical element allows for use of dimensionally small components within the display apparatus.

Furthermore, optionally, the exit optical element is implemented by way of at least one of: a convex lens, a plano-convex lens, a Liquid Crystal (LC) lens, a liquid lens, a Fresnel lens, aspherical lens, achromatic lens.

Optionally, the exit optical element has a curved surface facing the first semi-transparent reflective element. In such an instance, the curved surface may be convex (namely, bulging towards the first semi-transparent reflective element) or concave (namely, bulging inwards, away from the first semi-transparent reflective element).

Optionally, the at least one optical combiner further comprises at least one first actuator for moving the second semi-transparent reflective element, the display apparatus further comprising a processor coupled to the at least one first actuator, the processor being configured to control the at least one first actuator to adjust a tilt of the second semi-transparent reflective element to change a location of the projection of the rendered focus image incident upon the exit optical element. Optionally, the processor is configured to control the at least one first actuator by generating an actuation signal (for example, such as an electric current, hydraulic pressure, mechanical power, and so forth). It will be appreciated that by employing the at least one first actuator, the location of the projection of the rendered focus image can be changed (namely, adjusted) without moving the at least one focus image renderer. Beneficially, the at least one first actuator adjusts the tilt of the second semi-transparent reflective element, to adjust the location of the projection of the rendered focus image along a single plane (namely, either horizontally or vertically) or along multiple planes (namely, both horizontally and vertically).

Optionally, such movement of the second semi-transparent reflective element further comprises at least one of: displacement of the second semi-transparent reflective element, rotation of the second semi-transparent reflective element.

Optionally, the processor could be implemented by way of hardware, software, firmware or a combination thereof, suitable for controlling the operation of the display apparatus. Optionally, the processor is configured to control the operation of the display apparatus to present (namely, to project) the visual scene onto the eyes of the user. Furthermore, the processor may or may not be external to the device.

Optionally, the at least one optical combiner further comprises at least one second actuator for moving the at least one focus image renderer, the processor being coupled to the at least one second actuator, the processor being configured to control the at least one second actuator to adjust a tilt of the at least one focus image renderer to change the location of the projection of the rendered focus image incident upon the exit optical element. Optionally, the processor is configured to control the at least one second actuator by generating an actuation signal (for example, such as an electric current, hydraulic pressure, mechanical power, and so forth). It will be appreciated that by employing the at least one second actuator, the location of the projection of the rendered focus image can be changed (namely, adjusted) by moving the at least one focus image renderer. Beneficially, the at least one second actuator adjusts the tilt of the at least one focus image renderer, to adjust the location of the projection of the rendered focus image along a single plane (namely, either horizontally or vertically) or along multiple planes (namely, both horizontally and vertically).

Optionally, the at least one focus image renderer is tilted by the at least one second actuator about a first axis, whereas the second semi-transparent reflective element is tilted by the at least one first actuator about a second axis. Alternatively, only the second semi-transparent reflective element is tilted by the at least one second actuator, namely about the first and second axes.

Optionally, such movement of the at least one focus image renderer further comprises at least one of: displacement of the at least one focus image renderer, rotation of the at least one focus image renderer.

Optionally, at least one of the first side and/or the second side of the first semi-transparent reflective element has polarizing properties. Optionally, in this regard, the first side and/or the second side of the first semi-transparent reflective element is configured to allow only light waves of a predefined polarization orientation to pass therethrough, whilst blocking (namely, via reflecting, absorbing, or a combination thereof) light waves of other polarization orientations.

More optionally, the polarizing properties of the first side and/or the second side of the first semi-transparent reflective element comprise at least the predefined polarization orientation associated with the first side and/or the second side of the first semi-transparent reflective element.

Optionally, the polarizing properties of the first side and/or the second side of the first semi-transparent reflective element are adjustable. Optionally, the polarization properties of the first side of the first semi-transparent reflective element are manually adjustable. Alternatively, optionally, the processor is configured to perform (namely, implement) the aforesaid adjustment.

Furthermore, optionally, the first side and/or the second side of the first semi-transparent reflective element are implemented by way of at least one of: thin film polarizer, Polaroid® polarizing filter, absorptive crystal polarizer, birefringent polarizer. As an example, the first side and/or the second side of the first semi-transparent reflective element may be implemented by way of a thin film polarizer including a substrate (for example, such as glass, plate, mirror, prism, waveguide, and the like) whereon a thin film of a specialized optical coating is applied. In such a case, the specialized optical coating (for example, such as a dielectric material) may be configured to implement the desired polarization effect. As another example, the first side and/or the second side of the first semi-transparent reflective element may be implemented as a birefringent polarizer (for example, such as a Liquid Crystal variable retarder).

Optionally, the display apparatus further comprises a polarization retarder or retardation layer positioned between the first semi-transparent reflective element and the second semi-transparent reflective element. The polarization retarder or retardation layer is employed in an instance when the first side of the first semi-transparent reflective element optionally has polarizing properties. In such a case, a combination of properties of the polarization retarder or retardation layer and the polarizing properties of the first side of the first semi-transparent reflective element, allow for achieving a desired polarization effect within the display apparatus.

Therefore, throughout the present disclosure, the term *polarization retarder or retardation layer* relates to an optical element configured to alter a polarization orientation of light waves incident thereupon.

Optionally, optical retardance of the polarization retarder or retardation layer is one of: /2 (namely, 90 degrees), or (namely, 180 degrees).

In an exemplary implementation, the display apparatus may comprise a quarter wave retardation layer positioned between the first semi-transparent reflective element and the second semi-transparent reflective element. In such an example, the first side of the first semi-transparent reflective element may be configured to allow only s-polarized light waves to pass therethrough, whilst blocking the light waves of other polarization orientations. Therefore, in such an example, p-polarized light waves within the projection of the rendered context image emanating from the at least one context image renderer may reflect from the first side of the first semi-transparent reflective element, towards the exit optical element. Furthermore, in such an example, p-polarized light waves within the projection of the rendered focus image emanating from the at least one focus image renderer may reflect from the second side of the first semi-transparent reflective element, towards the quarter wave retardation layer. Such s-polarized light waves are incident on the quarter wave retardation layer that is configured to alter polarization orientation of the s-polarized light waves into p-polarization. Therefore, p-polarization light waves of the projection of the rendered focus image are incident upon the second semi-transparent reflective element, and are reflected therefrom, towards the second side of the first semi-transparent reflective element. Consequently, when p-polarized light waves of the projection of the rendered focus image are incident upon the first side of the first semi-transparent reflective element, the projection of the rendered focus image passes through the first side towards the exit optical element.

Optionally, the display apparatus further comprises a gaze-tracking unit comprising at least one photo sensor for sensing reflections of light from a user s eye when the display apparatus is worn by the user, wherein the at least one photo sensor is positioned behind the second semi-transparent reflective element. In such an instance, the second semi-transparent reflective element is substantially transparent so as to allow the aforesaid reflections of light to be received by the at least one photo sensor. Notably, the at least one photo sensor is well-aligned with the user s eye, without coming in the optical path of the projection of the focus image. The at least one photo sensor is configured to capture an image depicting positions and/or arrangement of the reflections of light from the user s eye. Furthermore, such an image is processed (for example, such as by the processor of the display apparatus or a separate processor of the gaze-tracking unit) to detect a gaze direction of the user.

Throughout the present disclosure, the term *gaze-tracking unit* relates to specialized equipment for detecting and/or following a direction of gaze of the user of the display apparatus, when the user of the display apparatus views the visual scene. It will be appreciated that an accurate detection of the gaze direction enables the display apparatus to closely implement gaze contingency thereon. Furthermore, the gaze-tracking unit may or may not be placed in contact with the eyes of the user, when the display apparatus is in use.

It is to be understood that the gaze-tracking unit may also be referred to as an *eye-tracker system* , a *means for detecting a gaze direction* , or a *gaze-tracking system* .

Optionally, the processor is coupled to the gaze-tracking unit, wherein the processor is configured to receive the detected gaze direction of the user from the gaze-tracking unit. Optionally, the processor is configured to receive an input image, and use the detected gaze direction to determine a region of visual accuracy of the input image. Throughout the present disclosure, the term *input image* used herein relates to the image of the visual scene to be displayed via the display apparatus. Specifically, the input image depicts the simulated environment to be displayed to the eyes of the user. In an embodiment, the input image is received from an imaging sensor coupled to the display apparatus. In such a case, the imaging sensor (for example, such as an imaging sensor of a pass-through digital camera) may capture an image of a real-world environment as the input image to be projected onto the eyes. In another embodiment, the input image is received from a memory unit coupled in communication with the processor. Furthermore, optionally, the memory unit is configured to store the input image in a suitable format, for example, such as, Motion Picture Experts Group (MPEG), Joint Photographic Experts Group (JPEG), Tagged Image File Format (TIFF), Portable Network Graphics (PNG), Graphics Interchange Format (GIF), Bitmap file format (BMP) and the like. Optionally, the input image is a computer generated image.

Optionally, the processor is configured to use the detected gaze direction to determine a region of visual accuracy of the input image. Throughout the present disclosure, the term *region of visual accuracy* relates to a region of the input image whereat the detected gaze direction of the user is directed (namely, focused) when the user of the head-mounted display apparatus views the input image. Notably, the region of visual accuracy is a region of interest (or a fixation point) within the input image, and is projected onto the fovea of the user s eyes. Therefore, it is to be understood that the region of visual accuracy relates to a region resolved to a much greater detail as compared to other regions of the input image, when the input image is viewed by a human visual system. One such region of visual accuracy has been illustrated in conjunction with FIG. 6, as elucidated in detail below.

Furthermore, optionally, the processor is configured to process the input image to generate the context image and the focus image, based upon the region of visual accuracy of the input image, the context image having a first resolution and the focus image having a second resolution. Optionally, in this regard, the second resolution is higher than the first resolution. Optionally, the focus image substantially corresponds to the region of visual accuracy of the input image. The context image corresponds to a low-resolution representation of the input image. Therefore, the context image includes the region of visual accuracy of the input image along with remaining region of the input image. The focus image corresponds to a high-resolution representation of the region of visual accuracy of the input image. Such resolution of the focus and context images allow for emulating visual characteristics of the human visual system when the input image is viewed by the user of the head-mounted display apparatus. Furthermore, a size of the context image is larger than a size of the focus image, since the focus image corresponds to only a portion of the input image whereat the detected gaze direction of the eyes may be focused (namely, at the region of visual accuracy of the input image).

Optionally, the first and second resolutions are to be understood in terms of angular resolution. In other words, pixels per degree indicative of the second resolution are higher than pixels per degree indicative of the first resolution. As an example, the fovea of the eye of the user corresponds to 2 degrees of visual field and receives the projection of the focus image of angular cross section width equal to 114 pixels indicative of 57 pixels per degree. Therefore, an angular pixel size corresponding to the focus image would equal 2/114 or 0.017. Furthermore, in such an example, the retina of the eye corresponds to 180 degrees of visual field and receives the projection of the context image of angular cross section width equal to 2700 pixels indicative of 15 pixels per degree. Therefore, an angular pixel size corresponding to the context image would equal 180/2700 or 0.067. As calculated, the angular pixel size corresponding to the context image is clearly much larger than the angular pixel size corresponding to the focus image. However, a perceived angular resolution indicated by a total number of pixels may be greater for the context image as compared to the focus image since the focus image corresponds to only a part of the context image, wherein the part corresponds to the region of visual accuracy of the input image.

Moreover, optionally, the region of visual accuracy of the input image is represented within both the rendered context image of low resolution and the rendered focus image of high resolution. Moreover, the rendered focus image having a high resolution may include more information pertaining to the region of visual accuracy of the input image, as compared to the rendered context image having a low resolution. Optionally, the processor is configured to mask the region of the context image that substantially corresponds to the region of visual accuracy of the input image. It will be appreciated that such masking enables in avoiding optical distortion of the region of visual accuracy of the input image, when the projection of the rendered focus image is combined with the projection of the rendered context image. As an example, pixels of the context image corresponding to the region of visual accuracy of the input image may be dimmed (namely, darkened) for masking.

Furthermore, optionally, the processor is configured to mask the region of the context image corresponding to the region of visual accuracy of the input image in a manner that transitional area seams (or edges) between the region of visual accuracy of the input image and the remaining region of the input image are reduced, for example minimized.

In such an instance, the masking could be performed as a gradual gradation in order to reduce (for example, to minimize) transitional area seams between the superimposed context and focus images so that the displayed image appears continuous. For example, the processor may significantly dim pixels of the context image corresponding to the region of visual accuracy of the input image, and gradually reduce an amount of dimming of the pixels with an increase in distance thereof from the region of visual accuracy of the input image. Furthermore, the masking could be performed using linear transparency mask blend of inverse values between the context image and the focus image at the transition area, stealth (or camouflage) patterns containing shapes naturally difficult for detection by the eyes of the user, and so forth.

Optionally, the processor is configured to control the at least one optical combiner for optically combining the projection of the rendered context image with the projection of the rendered focus image in a manner that the projection of the rendered focus image substantially overlaps the projection of the masked region of the rendered context image. It will be appreciated that the context image and the focus image are rendered substantially simultaneously in order to avoid time lag during combination of projections thereof.

Optionally, the processor is configured to implement image processing functions for at least one of: the at least one context image renderer, the at least one focus image renderer. In such an instance, the image processing functions are implemented prior to rendering the context image and the focus image via the at least one context image renderer and the at least one focus image renderer, respectively. It will be appreciated that the implementation of such image processing functions allows for optimizing quality of the rendered context and focus images. Furthermore, the image processing functions are selected by taking into account properties of at least one of: the at least one context image renderer, the at least one focus image renderer, the input image to be displayed via the head-mounted display apparatus.

Optionally, the image processing functions for the at least one context image renderer comprise at least one function for optimizing perceived context image quality, the at least one function selected from the group comprising low pass filtering, colour processing, gamma correction, and edge processing to minimize perceived distortion on a boundary of combined projections of the rendered context and focus images.

Furthermore, optionally, the image processing functions for the at least one focus image renderer comprise at least one function for optimizing perceived focus image quality, the at least one function selected from the group comprising image cropping, image sharpening, colour processing, gamma correction, and edge processing to reduce, for example to minimize, perceived distortion on the boundary of combined projections of the rendered context and focus images.

Optionally, the second semi-transparent reflective element is arranged to allow a projection of a real-world image to pass through towards the first semi-transparent reflective element, whereat the projection of the real-world image is optically combined with the projection of the rendered context image and the projection of the rendered focus image to create the visual scene. Optionally, in this regard, the focus image and the context image depict at least one virtual object to be overlaid on the projection of the real-world image so as to create the visual scene. In such an instance, the second semi-transparent reflective element is substantially transparent (namely, has substantial transmissive properties) to allow the projection of the real-world image to pass therethrough. It will be appreciated that in such a case, the visual scene created by the aforesaid optical combination presents the simulated environment (for example, such as the augmented reality environment) to the user of the display apparatus.

Furthermore, optionally, examples of the at least one virtual object include, but are not limited to, a virtual navigation tool (for example, such as a virtual map, virtual direction signage, and so forth), a virtual gadget (for example, such as a virtual calculator, a virtual computer, and so forth), a virtual message (for example, such as a virtual instant message, a virtual chat conversation, a virtual to-do note), a virtual entity (for example, such as a virtual person, a virtual animal, and so forth), and a virtual media (for example, such as a virtual video, a virtual interactive advertisement, a virtual news, virtual data, and so forth).

Optionally, the display apparatus further comprises at least one optical filter for adjusting light transmittance of the projection of the real-world image passing through the at least one optical filter, wherein the at least one optical filter is positioned behind the second semi-transparent reflective element. Optionally, the at least one optical filter is associated with at least two optical properties such that selection of one property among two properties allows the projection of the real-world image to pass therethrough and selection of another property blocks passage of the projection of the real-world image therethrough. Optionally, the at least one optical filter is mechanically switchable. Alternatively, optionally, the at least one optical filter is electrically switchable.

Optionally, the at least one optical filter is semi-transparent in nature. Alternatively, optionally, the at least one optical filter is opaque in nature. Optionally, the at least one optical filter is configured to move to either allow or block blocks the passage of the projection of the real-world image therethrough. In such an instance, the at least one optical filter is operatively coupled to an actuator for movement thereof, and coupled to the processor for receiving instructions for such movement.

Optionally, the at least one optical filter is implemented by way of at least one of: a Liquid Crystal shutter, an electrochromic filter.

As an example, the at least one optical filter is implemented by way of a Liquid Crystal shutter. Optionally, the Liquid Crystal shutter comprises at least one liquid crystal film arranged between two layers of a substrate, wherein the two layers of the substrate are electrically coupled to the processor via a plurality of electrical connectors. Examples of the substrate include, but are not limited to, a transparent glass substrate, a semi-transparent glass substrate, a transparent plastic substrate, and a semi-transparent plastic substrate. In such an example, the processor may generate at least one excitation signal to adjust the light transmittance of the projection of the real-world image passing through the Liquid Crystal shutter. Optionally, a voltage and/or frequency of the at least one excitation signal allows for the Liquid Crystal shutter to transmit and/or reflect light of at least one wavelength. Optionally, in this regard, the aforesaid transmissive and/or reflective properties of the Liquid Crystal shutter may change upon change in the at least one excitation signal. For example, a Liquid Crystal shutter OF1 may only transmit light of 500 nanometre wavelength when an excitation signal S1 is applied thereto, but the Liquid Crystal shutter OF1 may become fully transmissive to light of all wavelengths if the excitation signal S1 is removed. Furthermore, optionally, properties of the at least one liquid crystal film also allow for controlling transmission and/or reflection of light through the at least one optical filter. Examples of such properties include, but are not limited to, composition/material of the at least one liquid crystal film, crystal alignment within the at least one liquid crystal film, and thickness of the at least one liquid crystal film. For example, a 1 volt excitation signal may be applied to a 5 micrometer thick liquid crystal film of a liquid crystal shutter, to transmit light of wavelengths between 390 nanometre and 700 nanometre, whilst reflecting light of all other wavelengths. Optionally, the voltage and/or frequency of the excitation signal allows for the Liquid Crystal shutter to transmit and/or reflect light of at least one polarization orientation. For example, a 2 volt excitation signal may be applied to a first liquid crystal film of a liquid crystal shutter LCS1 to allow only light of a first polarization orientation to pass therethrough whilst a 3 volt excitation signal may be applied to a second liquid crystal film of the liquid crystal shutter LCS1 to allow only light of a second polarization orientation to pass therethrough. It will be appreciated that different liquid crystal films may be employed to control transmission and/or reflection of light of different wavelengths and/or polarization orientations by providing different excitation signals to the different liquid crystal films. Alternatively, a single liquid crystal film may be employed to control transmission and/or reflection of light of different wavelengths and/or polarization orientations by providing different excitation signals to the single liquid crystal film.

As another example, the at least one optical filter is implemented by way of an electrochromic filter. Optionally, the electrochromic filter comprises at least one film of electrochromic material arranged between two layers of a substrate, wherein the two layers of the substrate are electrically coupled to the processor via a plurality of electrical connectors. Examples of the substrate include, but are not limited to, a transparent glass substrate, a semi-transparent glass substrate, a transparent plastic substrate, and a semi-transparent plastic substrate. In such an example, the processor may generate at least one excitation signal to adjust the light transmittance of the projection of the real-world image passing through the electrochromic filter. Optionally, a voltage and/or frequency of the at least one excitation signal allows for the electrochromic filter to transmit and/or reflect light of at least one wavelength. For example, a 2 volt excitation signal may be applied to a first film of electrochromic material of an electrochromic filter EF1 to allow only light of 390 nanometre to 700 nanometre (namely, visible spectrum) to pass therethrough whilst a 3 volt excitation signal may be applied to a second film of electrochromic material of the electrochromic filter EF1 to allow only light of 800 nanometre to 900 nanometre to pass therethrough.

Optionally, the display apparatus further comprises at least one focusing lens that is positioned on the optical path between the first semi-transparent reflective element and the at least one focus image renderer, and at least one third actuator for moving the at least one focusing lens with respect to the at least one focus image renderer. In such an instance, the processor is configured to control the at least one third actuator to adjust a focus of the projection of the rendered focus image. Furthermore, optionally, the at least one focusing lens utilizes specialized properties thereof to adjust a focus of the projection of the rendered focus image by changing the optical path thereof. Beneficially, the focus of the projection of the rendered focus image can be adjusted to accommodate for diopter tuning, astigmatism correction, and so forth. Optionally, the processor is configured to control the at least one third actuator by generating an actuation signal (for example, such as an electric current, hydraulic pressure, and so forth).

Optionally, the processor is configured to control at least one active optical characteristic of the at least one focusing lens by applying a control signal to the at least one focusing lens. Some examples of the at least one active optical characteristic include, but are not limited to, focal length and optical power. Furthermore, the control signal can be an electrical signal, hydraulic pressure, and so forth.

Optionally, the at least one focusing lens is a Liquid Crystal lens (LC lens).

Optionally, the at least one focusing lens is positioned on an optical path between the second semi-transparent reflective element and the first semi-transparent reflective element.

Optionally, the physical size (or dimensions) of the at least one context image renderer and the at least one focus image renderer may not limit operation of the display apparatus described hereinabove. Optionally, physically small sized context image renderer and focus image renderer may be used along with a lens (for example, such as an enlarging lens, a collimating lens, and so forth) in the optical paths of the projections of the rendered context and/or focus images to ensure desired size and/or desired optical path of the projections thereof. As an example, a lens (for example, such as a convex lens) may be positioned on the optical path of the projection of the rendered focus image, between the at least one focus image renderer and the first semi-transparent reflective element. As another example, a collimating lens may be positioned on the optical path of the projection of the rendered focus image, between the focus image renderer and the first semi-transparent reflective element, to allow for collimating the projection of the rendered focus image.

The present disclosure also relates to the method as described above. Various embodiments and variants disclosed above apply mutatis mutandis to the method. More specifically, the method may further comprise controlling at least one first actuator of the at least one optical combiner to adjust a tilt of the second semi-transparent reflective element, so as to change a location of the projection of the rendered focus image incident upon the exit optical element. According to another embodiment, the method comprises controlling at least one second actuator of the at least one optical combiner to adjust a tilt of the at least one focus image renderer, so as to change the location of the projection of the rendered focus image incident upon the exit optical element.

In yet another embodiment, the display apparatus further comprises a gaze-tracking unit comprising at least one photo sensor positioned behind the second semi-transparent reflective element, and the method further comprises using the at least one photo sensor to sense reflections of light from a user s eye when the display apparatus is worn by the user. The method may also comprise arranging for the second semi-transparent reflective element to allow a projection of a real-world image to pass through towards the first semi-transparent reflective element, whereat the projection of the real-world image is optically combined with the projection of the rendered context image and the projection of the rendered focus image to create the visual scene. In this embodiment the display apparatus can further comprise at least one optical filter positioned behind the second semi-transparent reflective element, and the method further comprises using the at least one optical filter to adjust light transmittance of the projection of the real-world image passing through the at least one optical filter.

DETAILED DESCRIPTION OF THE DRAWINGS

Referring to FIGs. 1-5, illustrated are exemplary implementations of a display apparatus, in accordance with various embodiments of the present disclosure. It is to be understood by a person skilled in the art that the FIGs 1-5 include simplified arrangements for implementation of the display apparatus for the sake of clarity, which should not unduly limit the scope of the claims herein. The person skilled in the art will recognize many variations, alternatives, and modifications of embodiments of the present disclosure.

Referring to FIG. 1, illustrated is an exemplary implementation of a display apparatus **100**, in accordance with an embodiment of the present disclosure. The display apparatus **100** includes at least one context image renderer, such as a context image renderer **102**, for rendering a context image; at least one focus image renderer, such as a focus image renderer **104**, for rendering a focus image; an exit optical element **106**, and at least one optical combiner **110** for optically combining a projection of the rendered context image with a projection of the rendered focus image to create a visual scene. The at least one optical combiner **110** includes a first semi-transparent reflective element **112** and a second semi-transparent reflective element **114**. The first semi-transparent reflective element **112** includes a first side **112a** and a second side **112b**, and the first side **112a** faces the exit optical element **106**. The second semi-transparent reflective element **114** faces the second side **112b** of the first semi-transparent reflective element **112**.

The at least one context image renderer **102** is arranged in a manner that the projection of the rendered context image emanating therefrom, depicted by rays **A1**, **A2**, is incident upon the first side **112a** of the first semi-transparent reflective element **112** and reflected towards the exit optical element **106** therefrom, depicted by rays **B1**, **B2**. The at least one focus image renderer **104** is arranged in a manner that the projection of the rendered focus image emanating therefrom, depicted by rays **C1**, **C2**, is incident upon the second side **112b** of the first semi-transparent reflective element **112** and reflected towards the second semi-transparent reflective element **114** therefrom, depicted by rays **D1**, **D2**, and is then reflected from the second semi-transparent reflective element **114** towards the first semi-transparent reflective element **112**, depicted by rays **E1**, **E2**, from where the projection of the rendered focus image is allowed to pass through towards the exit optical element **106**, depicted by rays **F1**, **F2**. The rays **B1**, **B2** (associated with the projection of the rendered context image) reflected from the first side **112a** of the first semi-transparent reflective element **112** and the rays **F1**, **F2** (associated with the projection of the rendered focus image) passing through the first semi-transparent reflective element **112** create the visual scene for an eye **116**.

Referring to FIG. 2, illustrated is an exemplary implementation of a display apparatus **200**, in accordance with another embodiment of the present disclosure. The display apparatus **200** includes at least one context image renderer, such as a context image renderer **202**, for rendering a context image; at least one focus image renderer, such as a focus image renderer **204**, for rendering a focus image; an exit optical element **206**, and at least one optical combiner **210** for optically combining a projection of the rendered context image with a projection of the rendered focus image to create a visual scene. The at least one optical combiner **210** includes a first semi-transparent reflective element **212** and a second semi-transparent reflective element **214**. The first semi-transparent reflective element **212** includes a first side **212a** and a second side **212b**, and the first side **212a** faces the exit optical element **206**. The second semi-transparent reflective element **214** faces the second side **212b** of the first semi-transparent reflective element **212**. The at least one optical combiner **210** further includes at least one first actuator, such as a first actuator **220**, for moving the second semi-transparent reflective element **214**. The display apparatus **200** further includes a processor **230** coupled to the at least one first actuator **220**. The processor **230** is configured to control the at least one first actuator **220** to adjust a tilt, depicted by an arrow **X1**, of the second semi-transparent reflective element **214** to change a location of the projection of the rendered focus image incident upon the exit optical element **206**.

The at least one optical combiner **210** further includes at least one second actuator, such as a second actuator **240**, for moving the at least one focus image renderer **204**. The processor **230** is coupled to the at least one second actuator **240** and the processor **230** is configured to control the at least one second actuator **240** to adjust a tilt, depicted by an arrow **Y1**, of the at least one focus image renderer **204** to change the location of the projection of the rendered focus image incident upon the exit optical element **206**. The display apparatus **200** further includes a polarization retarder **250** (or retardation layer) positioned between the first semi-transparent reflective element **212** and the second semi-transparent reflective element **214**. The display apparatus **200** further includes a lens **260** positioned between the at least one focus image renderer **204** and the second side **212b** of the first semi-transparent reflective element **212**.

The at least one context image renderer **202** is arranged in a manner that the projection of the rendered context image emanating therefrom, depicted by rays **A3**, **A4**, is incident upon the first side **212a** of the first semi-transparent reflective element **212** and reflected towards the exit optical element **206** therefrom, depicted by rays **B3**, **B4**. The at least one focus image renderer **204** is arranged in a manner that the projection of the rendered focus image emanating therefrom passes through the lens **260**, depicted by rays **C3**, **C4**, is incident upon the second side **212b** of the first semi-transparent reflective element **212** and reflected towards the polarization retarder **250**, depicted by rays **D3**, **D4**. The rays **D3**, **D4** thereafter passes through the polarization retarder **250** and incident on the second semi-transparent reflective element **214**, depicted by rays **E3**, **E4**, and is then reflected from the second semi-transparent reflective element **214** towards the first semi-transparent reflective element **212**, depicted by rays **F3**, **F4**, from where the projection of the rendered focus image is allowed to pass through towards the exit optical element **206**, depicted by rays **G1**, **G2**. The rays **B3**, **B4** (associated with the projection of the rendered context image) reflected from the first side **212a** of the first semi-transparent reflective element **212** and the rays **G1**, **G2** (associated with the projection of the rendered focus image) passing through the first semi-transparent reflective element **212** create the visual scene for an eye **216**.

Referring to FIG. 3, illustrated is an exemplary implementation of a display apparatus **300**, in accordance with another embodiment of the present disclosure. The display apparatus **300** includes at least one context image renderer, such as a context image renderer **302**, for rendering a context image; at least one focus image renderer, such as a focus image renderer **304**, for rendering a focus image; an exit optical element **306**, and at least one optical combiner **310** for optically combining a projection of the rendered context image with a projection of the rendered focus image to create a visual scene. The at least one optical combiner **310** includes a first semi-transparent reflective element **312** and a second semi-transparent reflective element **314**. The first semi-transparent reflective element **312** includes a first side **312a** and a second side **312b**, and the first side **312a** faces the exit optical element **306**. The second semi-transparent reflective element **314** faces the second side **312b** of the first semi-transparent reflective element **312**. The at least one optical combiner **310** further includes at least one first actuator, such as a first actuator **320**, for moving the second semi-transparent reflective element **314**. It will be appreciated that the display apparatus **300** optionally includes a processor (not shown), such as the processor **230** shown in FIG. 2, coupled to the at least one first actuator **320**. The processor is configured to control the at least one first actuator **320** to adjust a tilt, depicted by an arrow **X2**, of the second semi-transparent reflective element **314** to change a location of the projection of the rendered focus image incident upon the exit optical element **306**. The display apparatus **300** further includes a lens **360** positioned between the at least one focus image renderer **304** and the second side **312b** of the first semi-transparent reflective element **312**. The display apparatus **300** further includes a gaze-tracking unit **370** having at least one photo sensor **372** for sensing reflections of light from a user s eye **316** when the display apparatus **300** is worn by the user (not shown). The at least one photo sensor **372** is positioned behind the second semi-transparent reflective element **314**. Furthermore, it will be appreciated that the gaze-tracking unit **370** optionally operatively coupled to the processor.

The at least one context image renderer **302** is arranged in a manner that the projection of the rendered context image emanating therefrom, depicted by rays **A5**, **A6**, is incident upon the first side **312a** of the first semi-transparent reflective element **312** and reflected towards the exit optical element **306** therefrom, depicted by rays **B5**, **B6**. The at least one focus image renderer **304** is arranged in a manner that the projection of the rendered focus image emanating therefrom passes through the lens **360**, depicted by rays **C5**, **C6**, is incident upon the second side **312b** of the first semi-transparent reflective element **312** and reflected towards the second semi-transparent reflective element **314**, depicted by rays **D5**, **D6**, and is then reflected from the second semi-transparent reflective element **314** towards the first semi-transparent reflective element **312**, depicted by rays **E5**, **E6**, from where the projection of the rendered focus image is allowed to pass through towards the exit optical element **306**, depicted by rays **F5**, **F6**. The rays **B3**, **B4** (associated with the projection of the rendered context image) reflected from the first side **312a** of the first semi-transparent reflective element **312**, and the rays **F5**, **F6** (associated with the projection of the rendered focus image) passing through the first semi-transparent reflective element **312** create the visual scene for the eye **316**.

Referring to FIG. 4, illustrated is an exemplary implementation of a display apparatus **400**, in accordance with another embodiment of the present disclosure. The display apparatus **400** is substantially structurally and functionally similar to the display apparatus **300** explained herein above in conjunction with FIG. 3. For example, the display apparatus **400** also includes at least one context image renderer, such as a context image renderer **402**, at least one focus image renderer, such as a focus image renderer **404**, an exit optical element **406**, at least one optical combiner **410** having a first semi-transparent reflective element **412** and a second semi-transparent reflective element **414**, at least one first actuator, such as a first actuator **420**, a lens **460**, and a gaze-tracking unit **470** having at least one photo sensor **472**. However, the second semi-transparent reflective element **414** is curved in shape, as compared to the second semi-transparent reflective element **314** (shown in FIG. 3) which is flat (namely, planar) in shape. Furthermore, it will be appreciated that the display apparatus **400** optionally includes a processor (not shown), such as the processor **230** shown in FIG. 2, coupled to the at least one first actuator **420**. The processor is configured to control the at least one first actuator **420** to adjust a tilt, depicted by an arrow **X3**, of the second semi-transparent reflective element **414** to change a location of the projection of the rendered focus image incident upon the exit optical element **406**. The at least one optical combiner **410** accordingly optically combines a projection of the rendered context image with a projection of the rendered focus image to create a visual scene for an eye **416**.

Referring to FIG. 5, illustrated is an exemplary implementation of a display apparatus **500**, in accordance with another embodiment of the present disclosure. The display apparatus **500** is substantially structurally and functionally similar to the display apparatus **300** explained herein above in conjunction with FIG. 3. For example, the display apparatus **500** also includes at least one context image renderer, such as a context image renderer **502**, at least one focus image renderer, such as a focus image renderer **504**, an exit optical element **506**, at least one optical combiner **510** having a first semi-transparent reflective element **512** and a second semi-transparent reflective element **514**, at least one first actuator, such as a first actuator **520**, and a lens **560**. However, the display apparatus **500** further includes at least one optical filter, such as an optical filter **580**, instead of the gaze-tracking unit **370** shown in FIG. 3, positioned behind the second semi-transparent reflective element **514**. Furthermore, the second semi-transparent reflective element **514** is arranged to allow a projection of a real-world image **590**, depicted by a ray **H**, to pass through towards the first semi-transparent reflective element **512**, whereat the projection of the real-world image **590** is optically combined with the projection of the rendered context image and the projection of the rendered focus image to create a visual scene for an eye **516**. The at least one optical filter **580** allows adjusting light transmittance of the projection of the real-world image **590** passing therethrough. Furthermore, it will be appreciated that the display apparatus **500** optionally includes a processor (not shown) coupled to the at least one first actuator **520**. The processor is configured to control the at least one first actuator **520** to adjust a tilt, depicted by an arrow **X4**, of the second semi-transparent reflective element **514** to change a location of the projection of the rendered focus image incident upon the exit optical element **506**.

Referring to FIG. 6, illustrated is an exemplary representation of a context image **602** and a focus image **604** to be rendered and projected via a display apparatus (for example, such as the display apparatus **100** of FIG. 1), in accordance with an embodiment of the present disclosure. The context image **602** is rendered by at least one context image renderer whereas the focus image **604** is rendered by at least one focus image renderer. As shown, an angular dimension (namely, an angular width) of the context image **602** is larger as compared to an angular dimension of the focus image **604**. Optionally, the context image **602** and the focus image **604** are generated by processing an input image. The context image **602** corresponds to a low-resolution representation of the input image. Furthermore, the focus image **604** substantially corresponds to a region of visual accuracy **606** of the input image whereat a gaze direction of a user of the display apparatus is focused. Optionally, a processor of the display apparatus is configured to mask a region of the context image **602** that substantially corresponds to the region of visual accuracy **606** of the input image.

It will be appreciated that the context image **602** and/or the focus image **604** are not limited to only rectangular shapes, and can have any suitable shape, for example, such as a substantially oval shape, a substantially round shape and so on.

Referring to FIG. 7, illustrated are steps of a method **700** of displaying via a display apparatus (such as the display apparatus **100** of FIG.1), in accordance with an embodiment of the present disclosure. At step **702**, a context image is rendered at the at least one context image renderer. At step **704**, a focus image is rendered at the at least one focus image renderer. At step **706**, the at least one optical combiner is used to optically combine a projection of the rendered context image with a projection of the rendered focus image to create a visual scene. An angular width of the projection of the rendered context image is greater than an angular width of the projection of the rendered focus image. The at least one context image renderer is arranged in a manner that the projection of the rendered context image emanating therefrom is incident upon the first side of the first semi-transparent reflective element and reflected towards the exit optical element therefrom. The at least one focus image renderer is arranged in a manner that the projection of the rendered focus image emanating therefrom is incident upon the second side of the first semi-transparent reflective element and reflected towards the second semi-transparent reflective element therefrom, and is then reflected from the second semi-transparent reflective element towards the first semi-transparent reflective element, from where the projection of the rendered focus image is allowed to pass through towards the exit optical element.

The steps **702** to **706** are only illustrative and other alternatives can also be provided where one or more steps are added, one or more steps are removed, or one or more steps are provided in a different sequence without departing from the scope of the claims herein.

Modifications to embodiments of the present disclosure described in the foregoing are possible without departing from the scope of the present disclosure as defined by the accompanying claims. Expressions such as including , comprising , incorporating , have , is used to describe and claim the present disclosure are intended to be construed in a non-exclusive manner, namely allowing for items, components or elements not explicitly described also to be present. Reference to the singular is also to be construed to relate to the plural.

CLAIMS

1. A display apparatus comprising:

- at least one context image renderer for rendering a context image;
- at least one focus image renderer for rendering a focus image;
- an exit optical element; and
- at least one optical combiner for optically combining a projection of the rendered context image with a projection of the rendered focus image to create a visual scene, an angular width of the projection of the rendered context image being greater than an angular width of the projection of the rendered focus image, the at least one optical combiner comprising:
- a first semi-transparent reflective element having a first side and a second side, the first side facing the exit optical element; and
- a second semi-transparent reflective element facing the second side of the first semi-transparent reflective element,

wherein the at least one context image renderer is arranged in a manner that the projection of the rendered context image emanating therefrom is incident upon the first side of the first semi-transparent reflective element and reflected towards the exit optical element therefrom, and wherein the at least one focus image renderer is arranged in a manner that the projection of the rendered focus image emanating therefrom is incident upon the second side of the first semi-transparent reflective element and reflected towards the second semi-transparent reflective element therefrom, and is then reflected from the second semi-transparent reflective element towards the first semi-transparent reflective element, from where the projection of the rendered focus image is allowed to pass through towards the exit optical element.

2. The display apparatus of claim 1, wherein the first semi-transparent reflective element is static.

3. The display apparatus of claim 1 or 2, wherein the at least one optical combiner further comprises at least one first actuator for moving the second semi-transparent reflective element, the display apparatus further comprising a processor coupled to the at least one first actuator, the processor being configured to control the at least one first actuator to adjust a tilt of the second semi-transparent reflective element to change a location of the projection of the rendered focus image incident upon the exit optical element.

4. The display apparatus of claim 3, wherein the at least one optical combiner further comprises at least one second actuator for moving the at least one focus image renderer, the processor being coupled to the at least one second actuator, the processor being configured to control the at least one second actuator to adjust a tilt of the at least one focus image renderer to change the location of the projection of the rendered focus image incident upon the exit optical element.

5. The display apparatus of any of claims 1 to 4, wherein at least one of the first side and/or the second side of the first semi-transparent reflective element has polarizing properties.

6. The display apparatus of claim 5, further comprising a polarization retarder or retardation layer positioned between the first semi-transparent reflective element and the second semi-transparent reflective element.

7. The display apparatus of any of claims 1 to 6, further comprising a gaze-tracking unit comprising at least one photo sensor for sensing reflections of light from a user s eye when the display apparatus is worn by the user, wherein the at least one photo sensor is positioned behind the second semi-transparent reflective element.

8. The display apparatus of any of claims 1 to 7, wherein the second semi-transparent reflective element is curved in shape.

9. The display apparatus of any of claims 1 to 8, wherein the second semi-transparent reflective element is arranged to allow a projection of a real-world image to pass through towards the first semi-transparent reflective element, whereat the projection of the real-world image is optically combined with the projection of the rendered context image and the projection of the rendered focus image to create the visual scene.

10. The display apparatus of claim 9, further comprising at least one optical filter for adjusting light transmittance of the projection of the real-world image passing through the at least one optical filter, wherein the at least one optical filter is positioned behind the second semi-transparent reflective element.

11. A method of displaying, via a display apparatus comprising at least one context image renderer, at least one focus image renderer, an exit optical element and at least one optical combiner, the at least one optical combiner comprising a first semi-transparent reflective element and a second semi-transparent reflective element, the first semi-transparent reflective element having a first side facing the exit optical element and a second side facing the second semi-transparent reflective element, the method comprising:

- rendering a context image at the at least one context image renderer;
- rendering a focus image at the at least one focus image renderer; and
- using the at least one optical combiner to optically combine a projection of the rendered context image with a projection of the rendered focus image to create a visual scene, an angular width of the projection of the rendered context image being greater than an angular width of the projection of the rendered focus image,

wherein the at least one context image renderer is arranged in a manner that the projection of the rendered context image emanating therefrom is incident upon the first side of the first semi-transparent reflective element and reflected towards the exit optical element therefrom, and wherein the at least one focus image renderer is arranged in a manner that the projection of the rendered focus image emanating therefrom is incident upon the second side of the first semi-transparent reflective element and reflected towards the second semi-transparent reflective element therefrom, and is then reflected from the second semi-transparent reflective element towards the first semi-transparent reflective element, from where the projection of the rendered focus image is allowed to pass through towards the exit optical element.

12. The method of claim 11, further comprising controlling at least one first actuator of the at least one optical combiner to adjust a tilt of the second semi-transparent reflective element, so as to change a location of the projection of the rendered focus image incident upon the exit optical element.

13. The method of claim 12, further comprising controlling at least one second actuator of the at least one optical combiner to adjust a tilt of the at least one focus image renderer, so as to change the location of the projection of the rendered focus image incident upon the exit optical element.

14. The method of claim 11, 12 or 13, wherein the display apparatus further comprises a gaze-tracking unit comprising at least one photo sensor positioned behind the second semi-transparent reflective element, and wherein the method further comprises using the at least one photo sensor to sense reflections of light from a user s eye when the display apparatus is worn by the user.

15. The method of any of claims 11 to 14, further comprising arranging for the second semi-transparent reflective element to allow a projection of a real-world image to pass through towards the first semi-transparent reflective element, whereat the projection of the real-world image is optically combined with the projection of the rendered context image and the projection of the rendered focus image to create the visual scene.

16. The method of claim 15, wherein the display apparatus further comprises at least one optical filter positioned behind the second semi-transparent reflective element, and the method further comprises using the at least one optical filter to adjust light transmittance of the projection of the real-world image passing through the at least one optical filter.

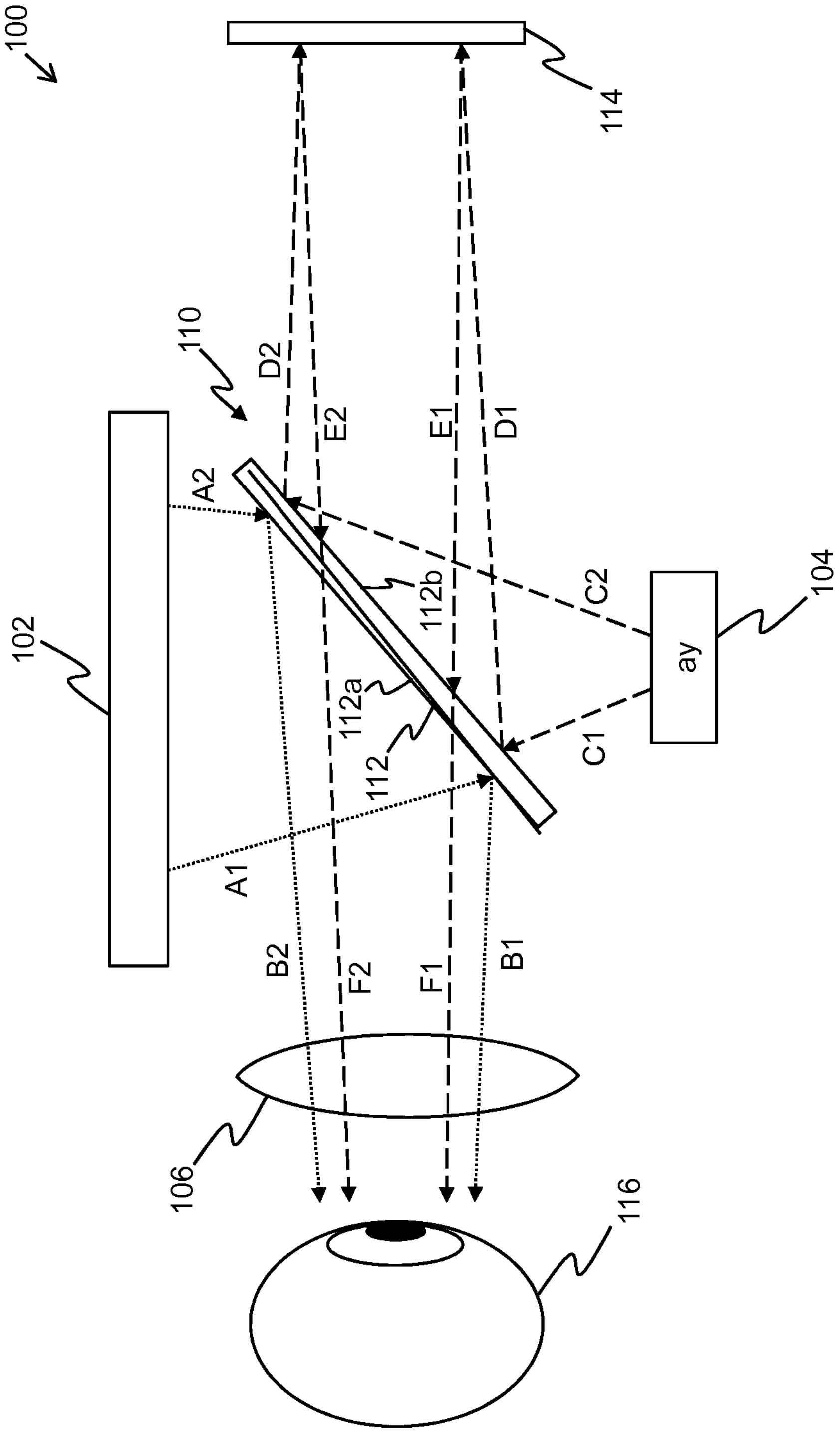
100
114
110
D2
E2
E1
D1
A2
102
112b
C2
104
ay
112a
112
C1
A1
B2
F2
F1
B1
106
116

FIG. 1

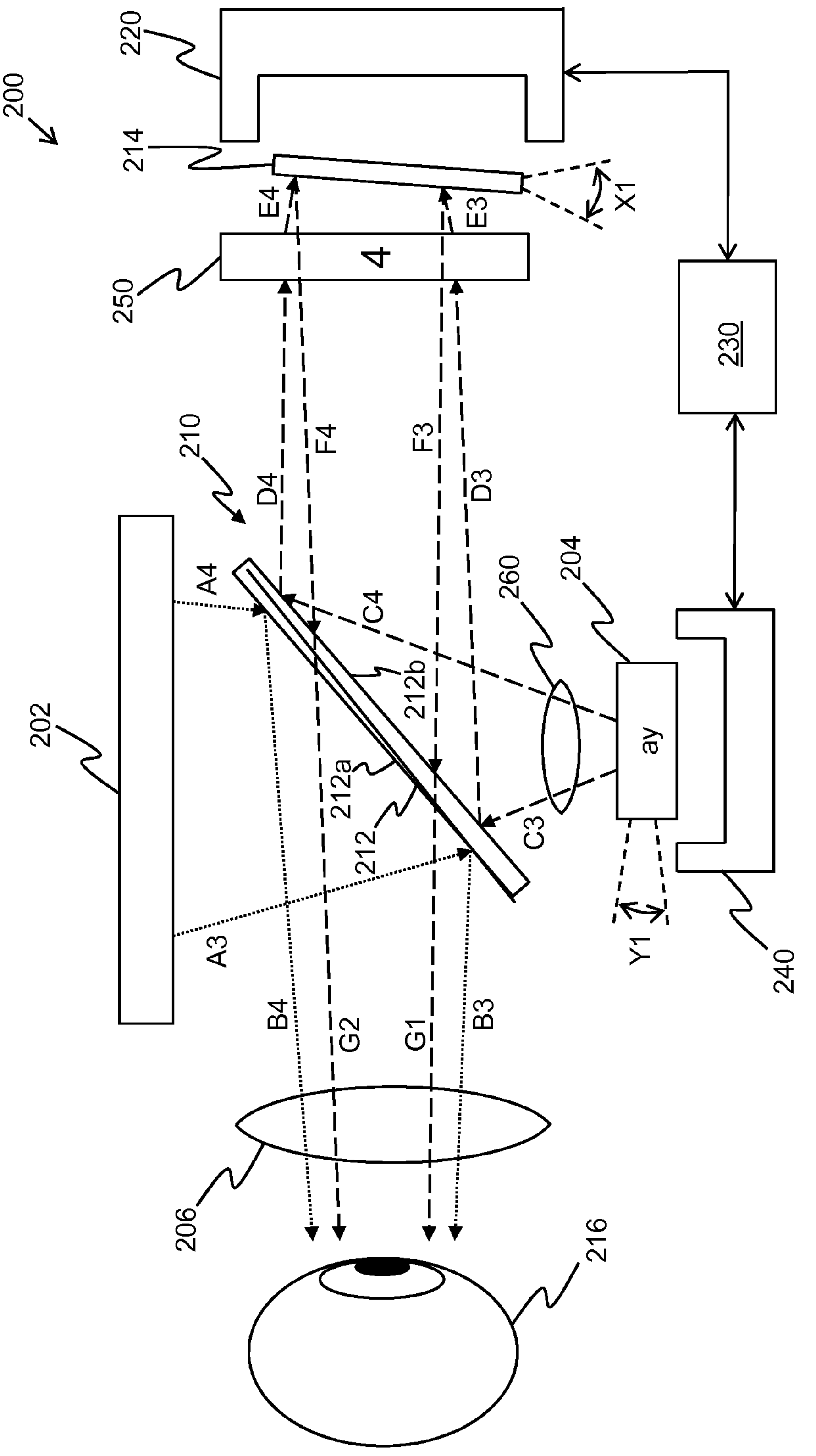
200
220
214
250
4
E4
E3
X1
230
210
D4
F4
F3
D3
A4
C4
212b
260
204
ay
202
212a
212
C3
A3
B4
G2
G1
B3
Y1
240
206
216

FIG. 2

3/6

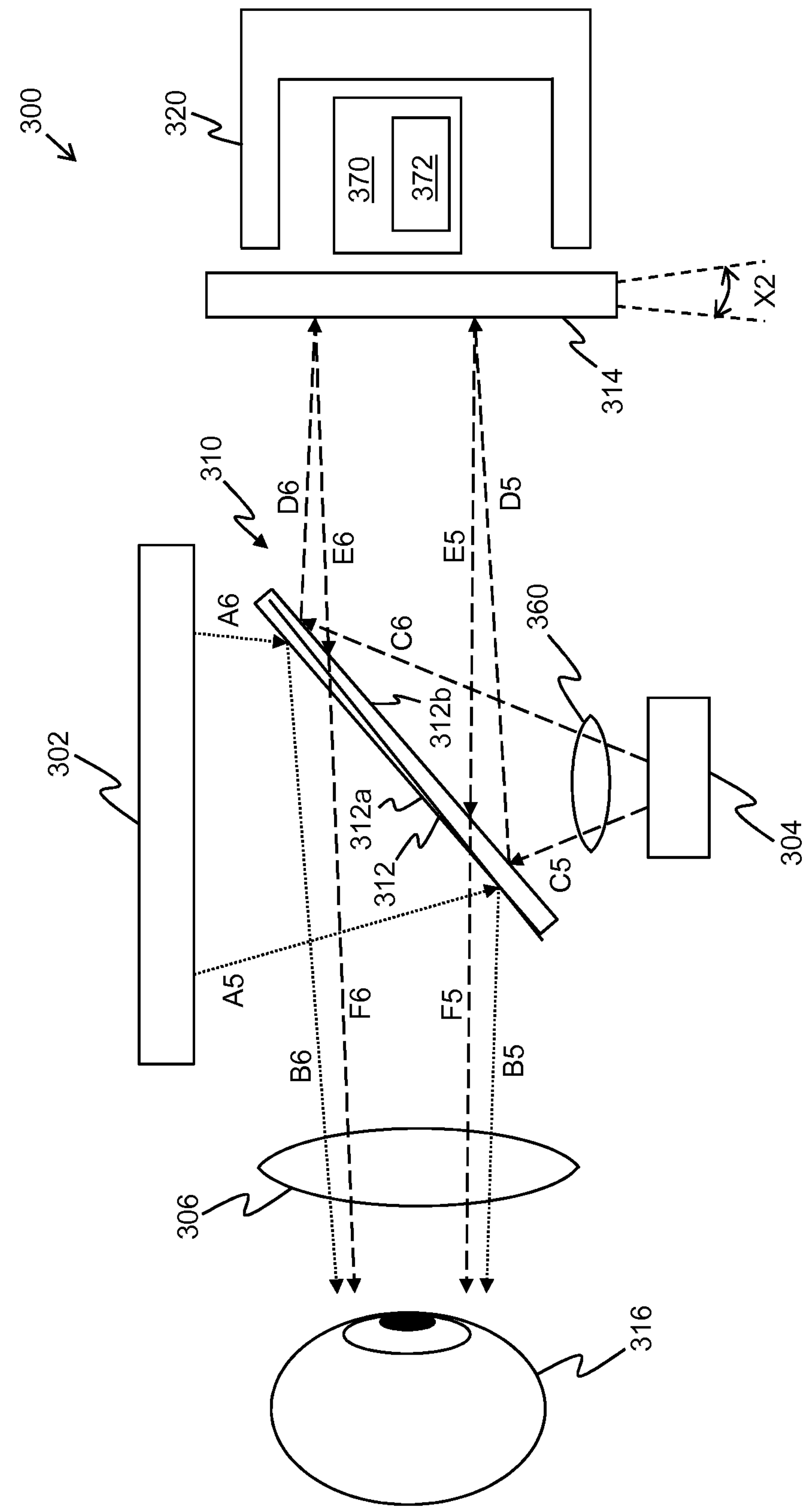
300
320
370
372
X2
314
310
D6
E6
E5
D5
302
A6
C6
360
312b
312a
312
C5
304
A5
F6
F5
B6
B5
306
316

FIG. 3

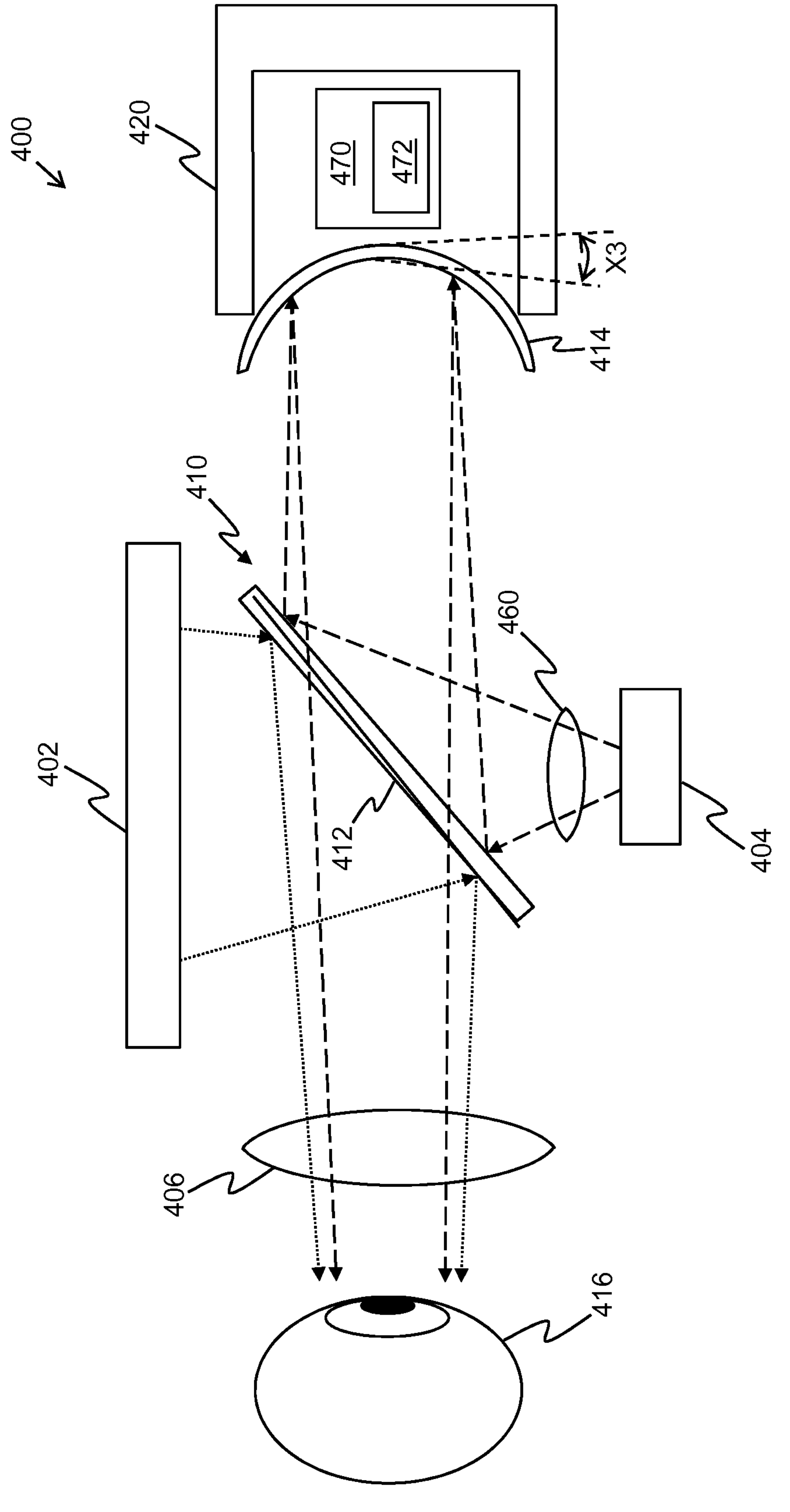

FIG. 4

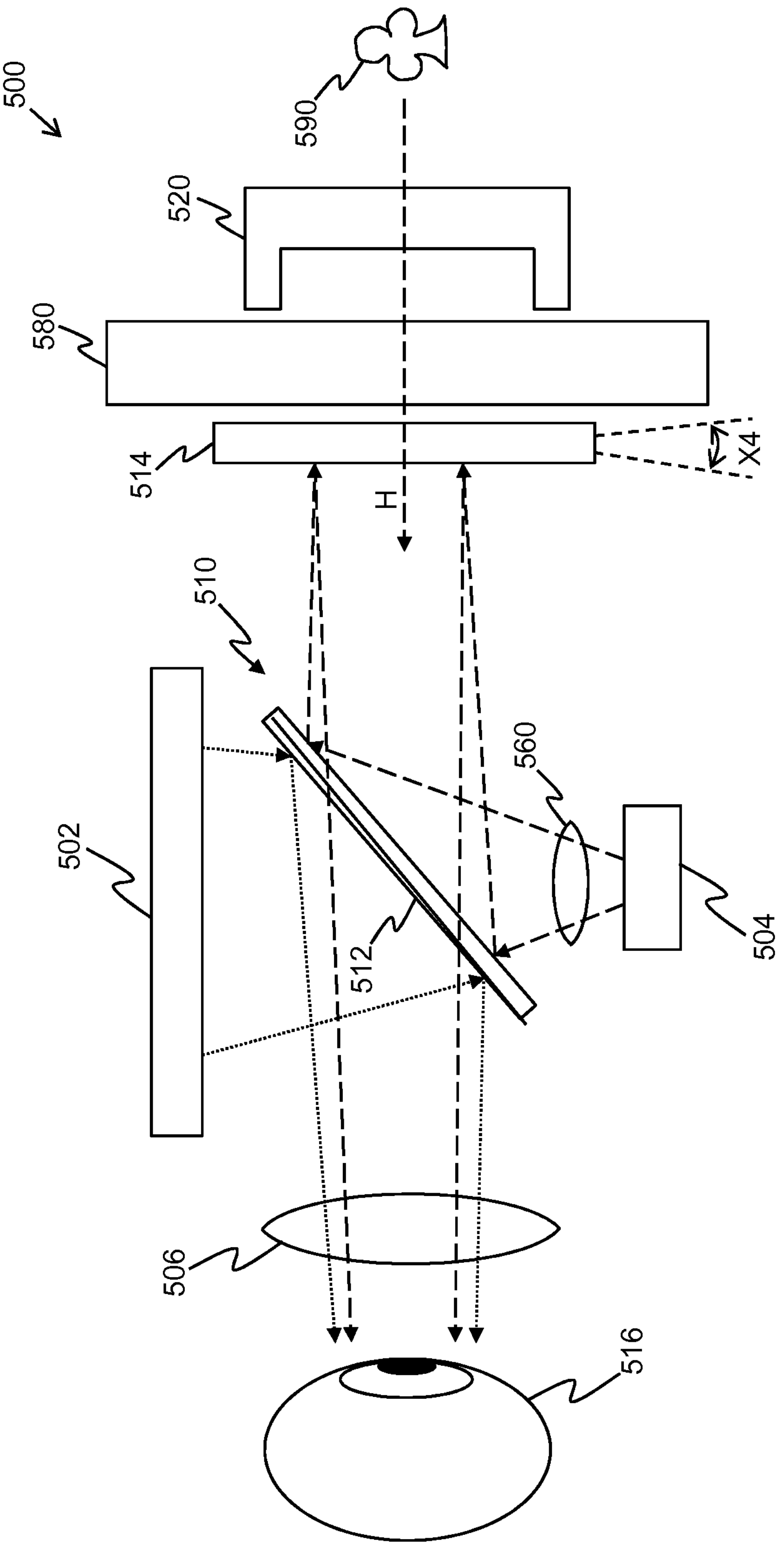

FIG. 5

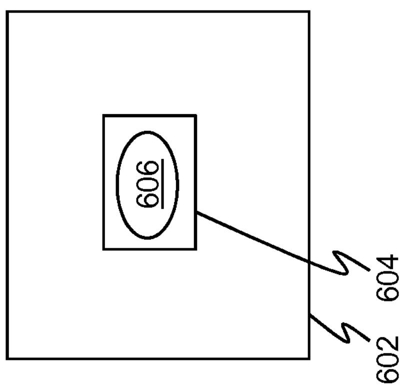
606
604
602

FIG. 6

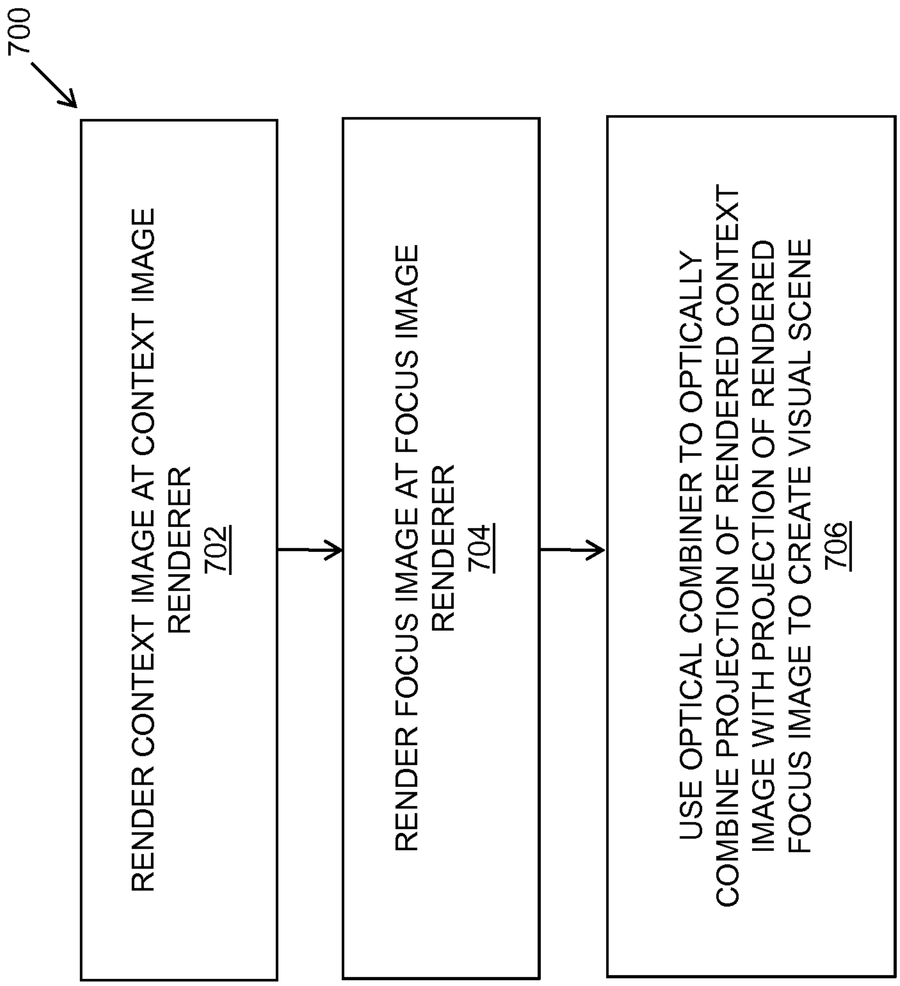
700
RENDER CONTEXT IMAGE AT CONTEXT IMAGE RENDERER
702
RENDER FOCUS IMAGE AT FOCUS IMAGE RENDERER
704
USE OPTICAL COMBINER TO OPTICALLY COMBINE PROJECTION OF RENDERED CONTEXT IMAGE WITH PROJECTION OF RENDERED FOCUS IMAGE TO CREATE VISUAL SCENE
706

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2017/050828

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B27/01
ADD.

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)
G02B

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 practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 5 808 589 A (FERGASON JAMES L [US]) 15 September 1998 (1998-09-15) abstract column 7, line 27 - line 40 column 14, line 37 - column 15, line 64 figures 1, 7, 10 -----	1,2,5,6, 8,11 7,9,10, 14-16
Y A	US 4 028 725 A (LEWIS EDGAR B) 7 June 1977 (1977-06-07) abstract column 3, line 32 - column 5, line 59 figures 1-3 -----	7,14 3,4,12, 13

-/--

[X] 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	Date of mailing of the international search report
27 February 2018	21/03/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Schenke, Cordt

2

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	WO 95/21395 A1 (VIRTUAL I O INC [US]; RALLISON DENNIS RICHARD [US]; AMADON C GREGORY [) 10 August 1995 (1995-08-10) abstract page 9, line 27 - page 10, line 35 page 17, line 13 - line 16 page 18, line 6 - line 11 figures 8, 9 -----	9,10,15, 16 3,4,12, 13

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/FI2017/050828

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 5808589	A	15-09-1998	AU	4593896	A	29-03-1996
			US	5808589	A	15-09-1998
			WO	9608736	A2	21-03-1996
US 4028725	A	07-06-1977	NONE			
WO 9521395	A1	10-08-1995	AU	1330295	A	21-08-1995
			AU	2156295	A	21-08-1995
			EP	0763216	A2	19-03-1997
			JP	H09508478	A	26-08-1997
			JP	H09508711	A	02-09-1997
			WO	9521395	A1	10-08-1995
			WO	9521396	A2	10-08-1995