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Compact augmented reality / virtual reality display

Abstract

Implementations of an augmented reality (AR)-capable display device for displaying light generated by a display onto a predefined field of view are disclosed herein. Within one implementation, the display device comprises a mount assembly configured to removably attach with a mobile computing device associated with the display, to thereby arrange the display with a predefined position. The display device further comprises an optical arrangement having a predefined arrangement relative to the predefined position and defining the field of view. The optical arrangement comprises a first mirror element configured to reflect a first portion of first incident light that is based on the light generated by the display, and a second mirror element disposed within the field of view and configured to reflect, onto the field of view, a second portion of second incident light that is based on the first portion.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a divisional of co-pending U.S. patent application Ser. No. 15/366,884 filed Dec. 1, 2016, which claims benefit of U.S. provisional patent application Ser. No. 62/290,292 filed Feb. 2, 2016. Each of the aforementioned related patent applications is herein incorporated by reference in its entirety.

BACKGROUND
Field of the Disclosure
(1) The present disclosure generally relates to computer-based entertainment, and more specifically to optical arrangements suitable for augmented reality (AR) and/or virtual reality (VR) display devices.
Description of the Related Art
(2) Computer graphics technology has significantly progressed since the first video games were developed. Relatively inexpensive 3D graphics engines now provide nearly photo-realistic interactive game play on hand-held video game, home video game, and personal computer hardware platforms costing only a few hundred dollars. These video game systems typically include a hand-held controller, game controller, or, in the case of a hand-held video game platform, an integrated controller. A user interacts with the controller to send commands or other instructions to the video game system to control a video game or other simulation. For example, the controller may include a joystick and buttons operated by the user.
(3) While video games allow the user to interact directly with the video game system, such interactions primarily influence the graphical depiction shown on the video game device (or on a connected display), and rarely influence any other objects outside of the virtual world. That is, a user may specify an input to the video game system, indicating that the user's avatar should perform a jump action, and in response the video game system could display the user's avatar jumping. However, such interactions are typically limited to the virtual world, and any interactions outside the virtual world are limited (e.g., a hand-held gaming device could vibrate when certain actions occur).
(4) Additionally, many hand-held gaming devices include some form of visual sensing device which may be used to capture an image or a series of images of a physical, real-world scene. The captured images can then be displayed, for instance, on a display of the hand-held gaming device. Certain devices may be configured to insert virtual objects into the captured images before the

images are displayed. Additionally, other devices or applications may enable users to draw or paint particular within a captured image of a physical scene. However, as such alterations apply only to a single image of the physical scene, subsequent captured images of the physical scene from different perspectives may not incorporate the user's alterations.

SUMMARY

(5) One embodiment described herein is an augmented reality (AR)-capable display device for displaying light generated by a display onto a predefined field of view. The display device comprises an optical arrangement having a predefined arrangement relative to a predefined position of the display and defining the field of view. The optical arrangement comprises a beam splitter element disposed within the field of view and configured to transmit a first portion of first incident light that is based on the light generated by the display, and a first mirror element configured to reflect, toward the beam splitter element, a second portion of second incident light that is based on the first portion. The beam splitter element is further configured to reflect, onto the field of view, a third portion of third incident light that is based on the second portion.

(6) Another embodiment described herein is an augmented reality (AR)-capable display device for displaying light generated by a display onto a predefined field of view. The display device comprises an optical arrangement having a predefined arrangement relative to a predefined position of the display and defining the field of view. The optical arrangement comprises a first mirror element configured to reflect a first portion of first incident light that is based on the light generated by the display, and a second mirror element disposed within the field of view and configured to reflect, onto the field of view, a second portion of second incident light that is based on the first portion.

(7) Another embodiment described herein is an augmented reality (AR)-capable display device for displaying light generated by a display onto a predefined field of view. The display device comprises an optically transmissive display disposed within the field of view and a first lens element disposed within the field of view on a first side of the optically transmissive display, the first lens element having a positive optical power. The display device further comprises a second lens element disposed within the field of view on a second side of the optically transmissive display opposite the first side, the second lens element having a negative optical power equal in magnitude to the positive optical power.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) So that the manner in which the above recited aspects are attained and can be understood in detail, a more particular description of embodiments of the disclosure, briefly summarized above, may be had by reference to the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of the disclosure and are therefore not to be considered limiting of its scope, for the disclosure may admit to other equally effective embodiments.

(2) FIG. **1** illustrates an exemplary interactive environment, according to one embodiment.

(3) FIG. **2** is a diagram illustrating an AR/VR headset configured to interact with a mobile computing device, according to embodiments described herein.

(4) FIG. **3** is a diagram illustrating attachment of a mobile computing device with a mount assembly, according to embodiments described herein.

(5) FIGS. **4-11** illustrate exemplary implementations of a compact AR/VR display device, according to various embodiments.

DETAILED DESCRIPTION

(6) Various implementations for a compact AR/VR display device are disclosed herein. It is

generally beneficial to design a compact AR/VR display device to have a relatively small size and weight, which allows for use by younger users or other users with reduced strength, and which is generally less fatiguing during use. A compact implementation tends to reduce manufacturing costs through reduced material and process requirements, and may also be more aesthetically pleasing for users, when compared with a large or bulky display device.

(7) Implementations of a compact AR/VR display device may use dedicated hardware and/or may use a smartphone or other mobile computing device. For example, implementations able to adapt the viewer's smartphone can provide a reduced manufacturing cost of the compact AR/VR display device, as no separate computing hardware or display hardware need be included. Using the viewer's own smartphone may also provide increased convenience to the viewer, and may provide a relatively large display for viewing.

(8) Within the compact AR/VR display device, the positioning of the mobile computing device and/or an optical arrangement can also be advantageously selected to reduce a moment on the viewer (e.g., corresponding to strain on the neck or upper body). For example, in a head-worn compact AR/VR display device, positioning a smartphone closer to the viewer's head provides a smaller moment.

(9) FIG. **1** illustrates an exemplary interactive environment, according to one embodiment. Within a system **100**, a computing device **105** communicates with one or more storytelling devices **150**, one or more sensor devices **160**, one or more display devices **170**, and one or more audio output devices **180**. As will be discussed in greater detail below, the computing device **105** may provide an augmented reality (AR) and/or virtual reality (VR) display functionality for a user in the interactive environment. The computing device **105** may be embodied in any suitable form. In some embodiments, the computing device **105** is a body-worn computing device, e.g., integrated into an assembly worn on the head, arm, etc. of a user. In some embodiments, the computing device **105** comprises a mobile computing device, such as a smartphone, tablet, etc. The mobile computing device may be configured to physically and removably attach with a body-worn assembly.

(10) Computing device **105** comprises, without limitation, a processor **110** and memory **115**. The processor **110** generally retrieves and executes programming instructions stored in the memory **115**. Processor **110** is included to be representative of a single central processing unit (CPU), multiple CPUs, a single CPU having multiple processing cores, graphics processing units (GPUs) having multiple execution paths, and the like. The memory **115** is generally included to be representative of a random access memory, but may further include non-volatile storage of any suitable type(s).

(11) Memory **115** generally includes program code for performing various functions related to generating and maintaining the storytelling environment. The program code is generally described as various functional “modules” within memory **115**, although alternate implementations may have different functions and/or combinations of functions. Within memory **115**, a storytelling module **120** is generally configured to generate a story using a selected predetermined story template (e.g., stored in memory **115**), and based on a number of identified storytelling devices **150** that are available for participating in the storytelling experience. The storytelling devices **150** can be identified using a registration process performed by any suitable methods of communication. One non-limiting example includes a controller device (which may be a storytelling device **150** or the computing device **105**) emitting a first signal such as an infrared (IR) signal, and other storytelling devices **150** transmitting a response signal such as a radio frequency (RF) signal in response to receiving the first signal.

(12) The sensor devices **160** may be of any suitable type(s) and configured to sense information regarding the storytelling environment. Some non-limiting examples of sensor devices **160** include visual sensors **165**, pressure sensors, acceleration sensors, and temperature sensors. The visual sensors **165** can include cameras configured to sense visible light and/or infrared light. In some embodiments, the sensor devices **160** may be included with (or within) the computing device **105**. For example, where the computing device **105** is a smartphone or tablet device, the sensor devices

160 may include camera(s), inertial motion units (IMUs), etc. that included within the smartphone/tablet device. In some embodiments, the sensor devices **160** comprise sensors that are external to the computing device **105**, e.g., a visual sensor **165** included with a head-worn device.
(13) The memory **115** further includes an image processing module **125** configured to perform processing of visual information captured by visual sensors **165**. The image processing module **125** may include any number of image processing functions, such as an object detection and tracking sub-module **130** configured to detect physical objects within the interactive environment (e.g., based on edge detection information, color information, and/or other suitable features) and to track the relative location of detected objects over time (e.g., as a user and/or the objects move throughout the interactive environment). The image processing module **125** further includes a depth estimation sub-module **135** configured to dynamically estimate a distance of the detected objects from the user.
(14) The system **100** includes one or more display devices **170**, and one or more audio output devices **180**. The display devices **170** may include visual displays of any suitable type. The display devices **170** may include any type of dynamic display capable of displaying a visual interface to a user, and may include any type of light emitting diode (LED), organic LED (OLED), cathode ray tube (CRT), liquid crystal display (LCD), plasma, electroluminescence (EL), or other display technology. In some embodiments, the display devices **170** are included within the computing device **105** (e.g., a main display screen of the smartphone, tablet device, etc.). In other embodiments, the display devices **170** are separate from the computing device **105** but are configured to superimpose virtual imagery onto physical objects in the user's field of view. For example, the display devices **170** may be integrated into a body-worn device such as a headset, and the display devices **170** may be configured as an eyepiece or lens worn in front of the user's eye. In another example, the display devices **170** may be integrated into other devices that are carried or handled by the user, or having any other suitable user interaction during the storytelling experience. For example, while participating in the storytelling experience, the user can carry a toy blaster that includes an optical sight for aiming, and the display devices **170** may be integrated in the optical sight.
(15) The audio output devices **180** may include conventional audio speakers having any suitable form factor (e.g., standalone, integrated in a stereo, headphones, etc.), as well as devices using alternative methods of producing sound perceptible by a user, such as bone conduction transducers in a body-worn device. In some embodiments, the audio output devices **180** are included within the computing device **105** (e.g., speakers of the smartphone, tablet device, etc.). In other embodiments, the audio output devices **180** are separate from the computing device **105**.
(16) In some embodiments, the computing device **105** is configured to operate in an augmented reality (AR) mode, generally configured to superimpose virtual images such as characters, objects, and/or dynamic visual effects into the user's natural field of view of the environment using a display device **170**. The field of view of the user is generally determined using sensor devices **160** such as the visual sensors **165**. In some embodiments, the computing device **105** is configured to operate in a virtual reality (VR) mode, generally replacing the user's natural field of view of the environment with virtual imagery using display device **170**.
(17) For example, the display device **170** could superimpose a virtual character to appear seated on a physical chair detected within the environment. The display of the virtual character on the display device **170** is dynamically adjusted based on the user's field of view (orientation), the determined depth of the chair from the user, and so forth.
(18) In some embodiments, the computing device **105** is configured to dynamically select one of the AR mode and VR mode based on the sensed characteristics of the environment and/or based on the story generated by the storytelling module. The selection of the AR or VR modes is represented as AR/VR display mode **140** and included in memory **115**. For example, the visual sensors **165** may detect that the environment is extremely bright (e.g., when the user is in direct sunlight),

which may be difficult for a user to view overlaid information using the display device **170**. In another example, a virtual setting of the story generated by the storytelling module **120** specifies a night-time setting. In these examples, the VR mode may be enabled in order to substantially isolate the user's field of view from the surrounding physical environment and thereby reduce the amount of light received from the environment. In both cases, dynamic selection of the AR/VR display mode **140** can improve the immersive nature of the storytelling environment, whether through ensuring the user is able to suitably view the overlaid information or through providing a more realistic setting consistent with the virtual setting of the story.

(19) Switching between AR and VR modes may be accomplished through any suitable techniques. In some embodiments, a user-worn headset includes a light-blocking assembly comprising cross polarizers that are disposed in front of each of the user's eyes. When one or both of the cross polarizers are rotated, the light from the physical environment that is transmitted to the user's eyes can be selectively reduced, and can substantially isolate the user's field of view from the physical environment (e.g., a VR mode). Rotating the cross polarizers may be performed manually (e.g., the user turns a knob linked with the cross polarizers), or electronically (e.g., a motor receives control signals from computing device **105** based on the AR/VR display mode **140** and rotates the cross polarizers. In other embodiments, the light-blocking assembly includes a partially or fully transparent “see-through” display, such as an OLED or side-lit or naturally lit LCD. The display receives control signals from computing device **105** based on the AR/VR display mode **140** and can selectively darken the display to substantially isolate the user's field of view from the physical environment.

(20) The display devices **170** are generally used within system **100** to provide a compact AR/VR display that may be carried or worn by the user during the storytelling experience. As discussed above, the display devices **170** may include devices that are separate from the display device of a mobile computing device (e.g., a smartphone or tablet device). Implementations of the compact AR/VR display that use a smartphone or other mobile computing device offer several advantages. For example, implementations able to adapt the user's smartphone provide a reduced manufacturing cost of the compact AR/VR display, as no separate computing hardware or display hardware need be included. A camera included in the smartphone may be used as visual sensor **165** to dynamically provide information regarding the physical environment and the user's field of view. Using a smartphone may also provide increased convenience to the user, and may provide a relatively large display for viewing.

(21) A number of considerations influence the design of a compact AR/VR display that uses a mobile computing device. Generally, the compact AR/VR display includes an optical arrangement that is configured to transmit some or all of the display of the mobile computing device to the user's eyes. Depending on the currently selected mode (AR or VR), the optical arrangement is further configured to transmit some or all of the light from the physical environment to the user's eyes. It may be beneficial to design a compact AR/VR display to have a relatively small size and weight. Smaller and lighter body-worn implementations allow for use by younger users or other users with reduced size and/or strength, and are generally less fatiguing during storytelling experience. The positioning of the mobile computing device and/or the optical arrangement can also be selected to reduce a moment on the user. For example, in a head-worn compact AR/VR display, including a smartphone in a position closer to the user's head provides a smaller moment (e.g., corresponding to strain on the neck or upper body) than an implementation in which the smartphone is positioned further from the user's head. A compact (small-sized) implementation also reduces manufacturing costs through reduced material and process requirements. A compact implementation may also be more aesthetically pleasing for users, when compared with a large or bulky implementation.

(22) Using a mobile computing device in conjunction with an optical arrangement can provide the user a reasonably good field of view, which enhances the immersive nature of the interactive environment. Generally, the size of the user's field of view is proportional to size of the elements

included in the optical arrangement for a particular distance from the user's eyes.
(23) FIG. **2** is a diagram **200** illustrating an AR/VR headset configured to interact with a mobile computing device, according to embodiments described herein. As shown, the diagram **200** depicts a mobile computing device **210** and an AR/VR-capable display device in the form of an AR/VR headset **220**. The AR/VR headset **220** generally includes a mount assembly **225** (or “mobile device adapter”), a headstrap **235**, and a mirrored lens **240**. The mount assembly **225** defines an opening **230** into which the mobile computing device **210** is received. Generally, insertion of the mobile computing device **210** into the opening **230** provides a removable attachment of the mobile computing device **210** with the mount assembly **225** and further arranges the display **215** (representing an example of the display device **170** of FIG. **1**) with a predefined position. In the predefined position, the display **215** has a suitable orientation relative to optical components (not shown) included in the AR/VR headset **220**. The mount assembly **225** may include any suitable means for removably attaching the mobile computing device **210**. The mount assembly **225** is further configured to hold or retain the mobile computing device **210** with a desired position and orientation relative to a wearer of the AR/VR headset **220**.
(24) The light generated by the display **215** of the mobile computing device **210** (e.g., based on display signals) is redirected through the optical components of the AR/VR headset **220** so that the light can be seen by a wearer of the AR/VR headset **220**. For example, the generated light could pass through a beam-splitter and reflect off the mirrored lens **240** and into the wearer's eyes. Thus, virtual objects that are displayed using the display **215** appear as if present within the physical environment of the viewer. Advantageously, by leveraging the hardware resources of the mobile computing device **210**, the AR/VR headset **220** can be produced and sold at reduced costs, relative to other AR devices containing dedicated computer processors, display devices, and so forth.
(25) FIG. **3** is a diagram **300** illustrating attachment of a mobile computing device with a mount assembly, according to embodiments described herein. More specifically, diagram **300** depicts an exemplary sequence for inserting the mobile computing device **210** into the mount assembly **225**. The mount assembly **225** may be formed of one or more elements of any material having suitable strength for retaining the mobile computing device **210**. In some embodiments, the mount assembly **225** is formed of a plastic material, which advantageously provides a lighter display device.
(26) The mobile computing device **210** is inserted through an opening **230** formed in the mount assembly **225**. The intermediate position **310** represents possible positioning of the mobile computing device **210** before reaching a predefined final position **315**. At the predefined final position **315** of the mobile computing device **210**, the display **215** of the mobile computing device **210** has a predefined position **320** relative to the optical arrangement **335**.
(27) A lower surface **325** of the mount assembly **225** is generally optically transmissive of light **330** generated by the display **215**. In some embodiments, the lower surface **325** is formed of an optically transmissive material, such as a plastic or glass, through which light **330** from the display **215** is transmitted. In other embodiments, the lower surface **325** defines an opening through which light **330** from the display **215** is transmitted. For example, the lower surface **325** may support the mobile computing device **210** around a periphery of the mobile computing device **210**.
(28) Although not explicitly shown, the mount assembly **225** may include further elements for removably attaching the mobile computing device **210** with the mount assembly **225**. For example, a press fit may be formed between the mobile computing device **210** and mount assembly **225** using adjustable corner piece(s), a sliding tray with guide plug, toggle pin(s), a stepped slot, a replaceable tray, etc. For example, the mobile computing device **210** may be inserted into a replaceable tray or other suitable carrier member, which is then inserted to the mount assembly **225** to thereby arrange the display **215** with the predefined position **320**. In this way, different carrier members may be used to accommodate different types of mobile computing devices **210** for a particular mount assembly **225**.
(29) The removable attachment of the mobile computing device **210** with the mount assembly **225**

may have any suitable orientation within an associated display device. The elements of the optical arrangement **335** collectively define a field of view relative to a predefined optical reference point, and the display device is generally designed such that the eye(s) of the viewer is aligned with the optical reference point. To support an AR capability of the display device, the mobile computing device **210** and mount assembly **225** are generally disposed outside of the field of view to allow a viewer to observe the physical environment through the optical arrangement **335**. For example, for a head-worn display device in which a line of sight of the viewer corresponds to the field of view of the optical arrangement **335**, the mobile computing device **210** and mount assembly **225** may be positioned above, below, or to a side of the viewer's line of sight.

(30) FIG. **4** illustrates an exemplary implementation of a compact AR/VR display device **400**, according to one embodiment. The display device **400** illustrates a smartphone (i.e., one example of a mobile computing device **210**) and an optical arrangement **405** that is configured to reflect at least a portion of the display **215** of the smartphone to an eye **415** of a viewer. The elements of the optical arrangement **405** collectively define a field of view **410** relative to a predefined optical reference point. The display device **400** is generally designed such that the eye **415** of the viewer is aligned with the optical reference point.

(31) Although not shown, the optical arrangement **405** may include a mask that is configured to block light from some of the display area of display **215** and/or from other portions of the smartphone to prevent these portions from being seen by the viewer. For example, a mask may be provided to prevent the smartphone edges from being visible within the field of view **410**, which tends to distract the viewer from the immersive nature of the interactive environment.

(32) As shown, the smartphone is arranged with its display **215** facing in an upward direction. In some embodiments, the smartphone is removably attached with the optical arrangement **405** in the display device **400**, which may be body-worn or carried by the viewer. The removable attachment of the smartphone allows its display **215** to maintain a desired orientation with the elements of the optical arrangement **405** despite movement of the viewer during usage. Note that the structural elements attaching portions of the optical arrangement **405**, the smartphone, and/or the viewer are not depicted for simplicity. For example, the display device **400** may include a flexible headstrap allowing comfortable wear by the viewer on his or her head. The light **330** (or “imagery”) generated by the display **215** is transmitted in the upward direction towards a first mirror element **425**. In some embodiments, the first mirror element **425** has a positive optical power and the imagery from the display **215** is typically focused between about 1 meter and optical infinity.

(33) Based on the light **330**, a first incident light **430** is incident on a beam splitter element **420**. The beam splitter element **420** is disposed within the field of view **410** and configured to transmit a first portion **435** of the first incident light **430**. In some embodiments, the beam splitter element **420** reflects 50% of first incident light **430** and transmits 50% of first incident light **430**. Alternative implementations of the beam splitter element **420** may have differing percentage ratios. A second incident light **440** based on the transmitted first potion **435** (e.g., 50% of the first incident light **430**) is incident upon the first mirror element **425**, and a second portion **445** of the second incident light **440** is reflected off the first mirror element **425** toward the beam splitter element **420**. Generally, the first mirror element **425** is 100% front surface coated to reflect substantially all of the second incident light **440**. Alternative implementations of the first mirror element may have different reflectivity. A third incident light **450** based on the second portion **445** is incident upon the beam splitter element **420**, and the beam splitter element **420** reflects a third portion **455** of the third incident light **450** onto the field of view **410**. In some embodiments, the beam splitter element **420** reflects 50% of the third incident light **450** to the eye **415** of the viewer. Therefore, in one embodiment, approximately 25% (50% reflected of the 50% transmitted through the beam splitter) of the light power generated by the display **215** is transmitted to the eye of the viewer.

(34) As shown, a camera **460** of the smartphone is included on an opposite surface from the display **215**. The display device **400** further includes a second mirror element **470** configured to reorient a

sensing axis **465** of the camera **460**. In some embodiments, the camera **460** senses in the forward direction along sensing axis **475**, which corresponds to an axis **412** of the field of view **410**. In this orientation, the camera **460** is able to acquire visual information for the environment for performing optical detection and tracking, depth estimation, and so forth. The second mirror element **470** is illustrated as a single 90° fold mirror for simplicity; however, the mirroring arrangement for the camera **460** can be more complex including multiple mirrors and/or different mirror curvatures. In another implementation, the camera **460** of the smartphone may be included on the same surface as the display **215**.

(35) The display device **400** further includes a light-blocking assembly **480** disposed within the field of view **410**. In some embodiments, the light-blocking assembly **480** comprises cross polarizers. When one or both of the cross polarizers are rotated, the amount of light from the physical environment that is transmitted to the viewer's eyes (e.g., through the beam splitter element **420**) can be controlled to substantially isolate the field of view **410** from the physical environment (e.g., corresponding to a selected VR mode). Rotating the cross polarizers may be performed manually (e.g., the viewer turns a knob linked with the cross polarizers) or electronically. For example, a motor linked with the cross polarizers receives control signals from an associated computing device (such as the mobile computing device **210**) and rotates the cross polarizers based on a selected AR or VR display mode. In other embodiments, the light-blocking assembly **480** includes a partially or fully transmissive “see-through” display, such as an OLED or a side-lit or naturally lit LCD. In this case, the partially or fully transmissive display receives control signals from the associated computing device and selectively darkens the display based on the selected AR or VR display mode.

(36) Note that although the optical arrangements of FIGS. **4-11** are shown relative to a single eye **415** of the viewer, implementations of the display device **400**, **500**, etc. can include independent optics for each eye of the viewer. Further, in some embodiments, implementations of the display device **400**, **500**, etc. may include some independent optics (e.g., one per eye) and some shared optics (e.g., one for both eyes). In one example, a single beam splitter element **420** may be shared by two independent lens systems (i.e., two independent positive optical power mirrors) corresponding to the viewer's two eyes. Note additionally that alternative implementations of display device **400**, **500**, etc. may include one or more separate display devices (i.e., not included in the smartphone) and or one or more separate cameras (or other visual sensors). Further, the features described with respect to a particular implementation may be beneficially applied to other implementations without requiring an explicit recitation.

(37) FIG. **5** illustrates an exemplary implementation of a compact AR/VR display device **500**, according to one embodiment. Within optical arrangement **505**, the first mirror element includes a flat mirror **510** instead of a curved, positive optical power mirror (as shown in FIG. **4**). The optical arrangement **505** further comprises a lens element **515** disposed between the beam splitter element **420** and flat mirror **510**. In some embodiments, the lens element **515** provides a positive optical power.

(38) The imagery generated by the display **215** (represented by light **330**) is incident on the beam splitter element **420**, and a portion is transmitted through the beam splitter element **420** and through the lens element **515**, reflected by the flat mirror **510** through the lens element **515**, and a portion reflected by the beam splitter element **420** onto the field of view **410**. The transmission of the imagery though the lens element **515** twice causes the optical power of the imagery to be doubled.

(39) The optical arrangement **505** of display device **500** generally provides a reduced weight and cost. Normally, an optical power through a lens element is increased by shortening the radius of curvature of the lens, which tends to increase size, weight, and cost of the lens. As disclosed, providing two passes through the same lens element **515** provides an increased optical power without additional size, weight, and cost. Further, one non-limiting example of the lens element **515** is a Fresnel lens, which is a relatively lightweight lens compared with certain other lens

implementations. Moreover, a flat mirror **510** is generally less expensive than a curved mirror.
(40) In one alternate embodiment, the optical arrangement **505** may further include a refractive power. In this embodiment, certain optical elements included within group **520** are replaced by optical elements of group **520′**. More specifically, group **520′** includes a curved mirror **525** instead of the flat mirror **510**, and further includes a layer **530** between the lens element **515** and the curved mirror **525**. The layer **530** comprises a plastic or glass material, and has a thickness that may be selected such that the lens element **515** provides a refractive power in addition to the optical power provided by the curved mirror **525**. In another embodiment, instead of two separate pieces, the curved mirror **525** may be fused (or otherwise integrally formed) with the lens element **515** to form a single refractive lens. For example, a top surface of the single refractive lens has a reflective coating, and a thickness of the plastic or glass is thicker near the center of the single refractive lens to form a positive optical power meniscus lens. One non-limiting example of a suitable single refractive lens is a Mangin mirror. The single refractive lens may be used to shorten focal length and to correct optical aberrations (such as spherical aberration) and thereby provide a higher quality image.
(41) FIG. **6** illustrates an exemplary implementation of a compact AR/VR display device **600**, according to one embodiment. Display device **600** generally provides greater recovery of the light **330** generated by the display **215**, when compared with display device **400** shown in FIG. **4**.
(42) Within display device **600**, the display **215** is a polarized display generating imagery that is linearly polarized (whether in s-polarization or p-polarization), and the beam splitter element comprises a polarizing beam splitter **610** having a polarization axis aligned with the linearly polarized light **330**. Based on the linearly polarized light **330**, a first incident light **430** is incident on the polarizing beam splitter **610**. Because the linearly polarized light **330** from the display **215** and the polarization axis of the polarizing beam splitter **610** are aligned, the first portion **435** transmitted by the polarizing beam splitter **610** comprises a majority of the linearly polarized light **330**.
(43) The first portion **435** passes through a quarter-wave plate element **615** (or “quarter-wave retarder”), which transforms the linear polarization of the first portion **435** into a circular polarization. The circularly polarized light is incident on the first mirror element as second incident light **440**, and a second portion **445** of the second incident light **440** is reflected off the first mirror element **425**. The reflected light passes through the quarter-wave plate element **615**, which transforms the circularly polarized light into linearly polarized light with a net 90°-rotated polarization from the polarization axis of the polarizing beam splitter **610**. A third incident light **450** is incident on the polarizing beam splitter **610**, and a third portion **455** is reflected onto the field of view **410** by the polarizing beam splitter **610**. The third portion **455** comprises a majority of the linearly polarized third incident light **450**. In this way, losses are reduced at each incidence of the light on the polarizing beam splitter **610** (transmission and subsequent reflection). In some embodiments, the amount of the linearly polarized light **330** that reaches the viewer's eye **415** can be further increased by substituting a polarized reflector for the first mirror element **425**, such that a majority of the circularly-polarized second incident light **440** that is incident on the polarized reflector is reflected back (as second portion **445**) through the quarter-wave plate element **615**.
(44) FIG. **7** illustrates an exemplary implementation of a compact AR/VR display device **700**, according to one embodiment. As shown in display device **700**, the display **215** is downward facing. Light **330** produced by the display **215** is transmitted in a downward direction, and first incident light **720** based on the light **330** is incident on a first mirror element **710** disposed within the field of view **410**. Within display device **700**, the first mirror element **710** comprises a beam splitter element. A first portion **725** of the first incident light **720** is reflected by the beam splitter element toward a second mirror element **715**. The second mirror element **715** generally comprises a positive optical power see-through mirror having any suitable reflectance.
(45) Second incident light **730** is incident on the second mirror element **715**, and a second portion

735 is reflected toward the first mirror element **710**. The reflected light of the second portion **735** may have a focus between about 1 meter and optical infinity. Third incident light **740** is incident on the first mirror element **710** and a third portion **745** is transmitted through the first mirror element **710** to the viewer's eye **415**.

(46) The implementation of display device **700** provides several benefits. The first mirror element **710** of the optical arrangement **705** has an orientation away from the viewer's eye **415**, which generally allows a more comfortable wear or use of the display device **700**. The design of display device **700** also allows the focal length of the second mirror element **715** to be significantly shorter, which reduces the overall size and weight of the optical arrangement **705**. In some cases, display device **700** may be scaled to about half the size of display devices **400**, **500**, **600** discussed above. For example, the height of the optical arrangement **705** (as viewed, top to bottom) may be on the order of two inches. Although not shown, the optical arrangement **705** may be small enough that only a portion of the display **215** is displayed to the viewer (e.g., a portion of the display **215** extends away from the viewer and forward of the second mirror element **715**.

(47) FIG. **8** illustrates an exemplary implementation of a compact AR/VR display device **800**, according to one embodiment. Within display device **800**, the display **215** comprises a polarized display generating imagery that is linearly polarized (whether in s-polarization or p-polarization), and the first mirror element of optical arrangement **805** comprises a polarized beam splitter element **810** having a polarization axis aligned with the linearly polarized light **330**. The optical arrangement **805** further comprises a quarter-wave plate element **815** having a vertical orientation (as shown) and disposed between the polarized beam splitter element **810** and the second mirror element **715**.

(48) Within the field of view **410**, the polarized beam splitter element **810** with the series combination of the quarter-wave plate element **815** and second mirror element **715** are arranged such that most of the first incident light **720** having a first polarization is reflected by the polarized beam splitter element **810** (as second portion **725**), and most of the third incident light **740** having a second polarization (e.g., a 90°-rotated polarization from the polarization axis of the beam splitter element **810**) is transmitted by the polarized beam splitter element **810** (as third portion **745**). In this way, losses are reduced at each incidence of the light on the polarizing beam splitter element **810**.

(49) Generally, although the second mirror element **715** has a positive optical power, the second mirror element **715** does not distort or refocus the imagery as the thickness of the second mirror element **715** is consistent. In other words, the second mirror element **715** has a reflective optical power but does not have a refractive optical power. In one alternate embodiment, the second mirror element **715** is polarized in order to further increase the amount of light reflected (i.e., the second portion **735**) toward the polarizing beam splitter element **810** and ultimately transmitted to the viewer.

(50) FIG. **9** illustrates an exemplary implementation of a compact AR/VR display device **900**, according to one embodiment. In display device **900**, the beam splitter element comprises a dichroic beam splitter **910** (or “dichroic mirror”) exhibiting different transmission and/or reflection properties for different wavelengths of incident light. Furthermore, the particular spectral bandpass of the dichroic beam splitter **910** can vary based on the incidence angle of the light. In one embodiment, the light **330** generated by the display **215** includes substantially red, green, and blue (RGB) wavelengths, which is shown in chart **925** as red wavelength **930**R, green wavelength **930**G, and blue wavelength **930**B. In this case, the dichroic beam splitter **910** comprises a triple-band dichroic mirror configured to reflect only the RGB wavelengths while transmitting substantially all other wavelengths. Other embodiments may use a dichroic beam splitter **910** using alternative color models. In some embodiments, the dichroic beam splitter **910** includes a dichroic surface (e.g., a dichroic coating) configured to reflect light at one set of wavelengths while transmitting light at other wavelengths. In one embodiment, a second mirror element **920** (e.g., a positive optical power

see-through mirror) also includes a dichroic surface.

(51) In one embodiment, first incident light **930** based on the light **330** is incident on the dichroic beam splitter **910** at a 45° angle, which provides a first type of reflectance of the light (as first portion **950**). For example, the light at specific RGB wavelengths may be mostly reflected at the 45° incidence angle with the dichroic beam splitter **910**, while light at other wavelengths passes through the dichroic beam splitter **910** as a transmitted portion **935**. At a normal (i.e., 90°) incidence with the dichroic beam splitter **910**, the light at the RGB wavelengths may be mostly transmitted through the dichroic beam splitter **910** instead of being reflected. Chart **955** illustrates these reflectance and transmittance properties of the dichroic beam splitter **910** for red wavelength **960**R, green wavelength **960**G, and blue wavelength **960**B.

(52) The second mirror element **920** reflects some or substantially all (e.g., depending on whether the second mirror element **920** includes the dichroic surface) of the light at the RGB wavelengths. Including a dichroic surface in the second mirror element **920** can generally provide an increased percentage of the light **330** that is passed to the eye **415** through the optical arrangement **905**. In some embodiments, the dichroic surface has spectral reflectance properties that match both the emission spectrum of the display **215** and the reflection spectrum of the dichroic beam splitter **910** at a 45° incidence angle. In some embodiments, the spectral reflectance properties of the dichroic surface also match the transmission spectrum of the dichroic beam splitter **910** at a normal incidence.

(53) A second incident light **975** is incident on the second mirror element **920**, and a second portion **980** of the second incident light **975** is reflected toward the dichroic beam splitter **910**. In some embodiments, a third incident light **985** based on the second portion **980** is incident on the dichroic beam splitter **910** at a 90° angle, and the light at RGB wavelengths is mostly transmitted through the dichroic beam splitter **910** as third portion **990**.

(54) Optical arrangement **905** may include additional optical element(s) to suitably orient the second incident light **975** on the second mirror element **920** such that the third incident light **985** is incident on the dichroic beam splitter **910** at substantially 90° (or alternative incidence angle that allows the RGB wavelengths to be mostly transmitted). As shown, optical arrangement **905** comprises a third mirror element **915** having a predefined arrangement relative to the dichroic beam splitter **910** and second mirror element **920**. The third mirror element **915** is configured to reflect a fourth portion **970** of fourth incident light **965**, where the fourth incident light **965** is based on the first portion **950** reflected by the dichroic beam splitter **910**. In some embodiments, the third mirror element **915** comprises a flat mirror, and in some cases may include a dichroic surface configured to reflect only RGB wavelengths of the fourth incident light **965**. The second incident light **975** incident on the second mirror element **920** is based on the fourth portion **970**. Although the implementation of optical arrangement **905** may be relatively complex compared with other display devices **400**, **500**, etc., the use of dichroic surfaces in display device **900** generally allows better energy preservation of the light **330** generated by the display **215**.

(55) In some embodiments, the dichroic beam splitter **910** has a slight difference in the wavelengths of reflected light and the wavelengths of transmitted light. Chart **940** illustrates a first set of RGB wavelengths **945**R**1**, **945**G**1**, and **945**B**1** corresponding to reflectance of the dichroic beam splitter **910**, and a second set of RGB wavelengths **945**R**2**, **945**G**2**, and **945**B**2** corresponding to a transmittance of the dichroic beam splitter **910**. Such a difference can reduce color tinging effects for background light that transmits through the second mirror element **920**, as the difference generally causes the viewer to visually integrate the two sets of colors and thereby reduce the perceived tinting effects.

(56) FIG. **10** illustrates an exemplary implementation of a compact AR/VR display device **1000**, according to one embodiment. As discussed above, display device **400** (FIG. **4**) transmits to the eye of the viewer approximately 25% of the light power produced by the display. In display device **700** (FIG. **7**), which includes a positive optical power see-through mirror within the field of view, the

displayed light passes through the beam splitter twice and reflects from the positive optical power see-through mirror once, which corresponds to about one-eighth (i.e., 12.5%) of the display light power being transmitted to the eye of the viewer. As a result, the imagery generated by the display and light transmitted from the physical background may appear relatively dim to the viewer.

(57) To increase the brightness of the displayed imagery and the background light for the viewer, optical arrangement **1005** includes a first mirror element **1010** that is nearly 100% front surface mirrored instead of a beam splitter element. The optical arrangement **1005** also defines a field of view **410** with a different positioning relative to the eye **415** of the viewer. In this case, the field of view **410** extends through a separation **1040** between the display **215** and the first mirror element **1010**. In one embodiment, the separation **1040** between the first mirror element **1010** and the display **215** is on the order of one-half inch to one inch.

(58) Using the first mirror element **1010**, approximately half (i.e., 50%) of the power of light **330** generated by the display **215** is transmitted to the viewer's eye **415**, corresponding to a four-times (i.e., 4×) increase in brightness when compared with display device **700**, while having substantially the same cost and weight. First incident light **1020** based on the light **330** is incident on the first mirror element **1010**, and a first portion **1025** representing substantially all (i.e., 100%) of the light power is reflected toward the second mirror element **1015**. The second mirror element **1015** generally comprises a positive optical power see-through mirror. Second incident light **1030** based on the first portion **1025** is incident on the second mirror element **1015**, which reflects a second portion **1035** onto the field of view **410**. In some embodiments, the second portion **1035** represents half (i.e., 50%) of the light power generated by the display **215**.

(59) In one embodiment, optical arrangement **1005** includes two of the second mirror element **1015** (i.e., two positive optical power see-through mirrors) corresponding to the viewer's two eyes. In another embodiment, optical arrangement **1005** includes a single second mirror element **1015** such that both of the viewers' eyes look at the same second mirror element **1015**, which may be a less expensive implementation. Generally, implementations having a single second mirror element **1015** are suitable for providing a bi-ocular display device (i.e., providing the same image to both eyes) with the full resolution of the full raster of the display **215**, instead of splitting the display between the eyes of the viewer with the possible loss of display resolution.

(60) FIG. **11** illustrates an exemplary implementation of a compact AR/VR display device **1100**, according to one embodiment. In display device **1100**, an optically transmissive display **1110** is disposed within the field of view **410** between a first lens element **1105** and a second lens element **1115**. In other words, the first lens element **1105** is disposed on a first side of the optically transmissive display **1110** and the second lens element **1115** is disposed on a second side of the optically transmissive display **1110**. In some embodiments, the first lens element **1105** has a positive optical power, and the second lens element **1115** has a negative optical power that is equal in magnitude to the positive optical power. The first lens element **1105** and the second lens element **1115** may be disposed as close as possible to the optically transmissive display **1110**.

(61) The optically transmissive display **1110** is selectively transmissive of light from the physical environment. For example, each pixel of the optically transmissive display **1110** includes a clear (i.e., transmissive) portion and a reflective (or emitting) portion that permits a partial visibility through the array of pixels. Some non-limiting examples of optically transmissive display **1110** include an edge-lit LCD, a naturally-lit LCD, and transparent OLED display. In some embodiments, the optically transmissive display **1110** is a display separate from a mobile computing device (such as a smartphone). However, the processing capabilities of a smartphone may be used to drive the separate optically transmissive display **1110**.

(62) In some embodiments, the first lens element **1105** has a positive optical power for viewing the optically transmissive display **1110**. The first lens element **1105** creates an image of the optically transmissive display **1110** with a focus of about 1 meter and optical infinity. However, viewing the optically transmissive display **1110** through the first lens element **1105** causes light from the

physical environment to be defocused (e.g., blurs the background). Within display device **1100**, the effects of the first lens element **1105** are compensated by including the second lens element **1115** having a negative optical power that is equal in magnitude to the positive optical power. The net effect of the first lens element **1105** and the second lens element **1115** is a clear view of the optically transmissive display **1110** and of the background with no optical power. In other words, the negative optical power of the second lens element **1115** corrects the light coming from the physical environment such that the environment appears undistorted to the viewer.
(63) Advantageously, display device **1100** provides a very compact implementation. For example, the height of the optical arrangement of display device **1100** (as viewed, top to bottom) may be on the order of one-half inch to one inch. Display device **1100** may further provide a wider field of view for the viewer, as the display device **1100** can generally use shorter focal length lenses for the first lens element **1105** and the second lens element **1115**. Further, display device **1100** does not require a beam splitter element to optically combine the virtual imagery **1125** provided by the optically transmissive display **1110** with the physical imagery **1120** from the environment. As a result, the display device **1100** can be arranged closer to the viewer's eye, and the implementation is generally smaller, lighter, and less expensive than implementations including a beam splitter element.
(64) In the preceding, reference is made to embodiments of the disclosure. However, the disclosure is not limited to specific described embodiments. Instead, any combination of the preceding features and elements, whether related to different embodiments or not, is contemplated to implement and practice the disclosure. Furthermore, although embodiments of the disclosure may achieve advantages over other possible solutions and/or over the prior art, whether or not a particular advantage is achieved by a given embodiment is not limiting of the disclosure. Thus, the preceding aspects, features, embodiments, and advantages are merely illustrative and are not considered elements or limitations of the appended claims except where explicitly recited in a claim(s). Likewise, reference to “the disclosure” shall not be construed as a generalization of any inventive subject matter disclosed herein and shall not be considered to be an element or limitation of the appended claims except where explicitly recited in a claim(s).
(65) Aspects of the present disclosure may be embodied as a system, method, or computer program product. Accordingly, aspects of the present disclosure may take the form of an entirely hardware embodiment, an entirely software embodiment (including firmware, resident software, micro-code, etc.) or an embodiment combining software and hardware aspects that may all generally be referred to herein as a “circuit,” “module,” or “system.” Furthermore, aspects of the present disclosure may take the form of a computer program product embodied in one or more computer readable medium(s) having computer readable program code embodied thereon.
(66) Any combination of one or more computer readable medium(s) may be utilized. The computer readable medium may be a computer readable signal medium or a computer readable storage medium. A computer readable storage medium may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. More specific examples (a non-exhaustive list) of the computer readable storage medium would include the following: an electrical connection having one or more wires, a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an optical fiber, a portable compact disc read-only memory (CD-ROM), an optical storage device, a magnetic storage device, or any suitable combination of the foregoing. In the context of this document, a computer readable storage medium may be any tangible medium that can contain, or store a program for use by or in connection with an instruction execution system, apparatus, or device.
(67) A computer readable signal medium may include a propagated data signal with computer readable program code embodied therein, for example, in baseband or as part of a carrier wave.

Such a propagated signal may take any of a variety of forms, including, but not limited to, electro-magnetic, optical, or any suitable combination thereof. A computer readable signal medium may be any computer readable medium that is not a computer readable storage medium and that can communicate, propagate, or transport a program for use by or in connection with an instruction execution system, apparatus, or device.

(68) Program code embodied on a computer readable medium may be transmitted using any appropriate medium, including but not limited to wireless, wireline, optical fiber cable, RF, etc., or any suitable combination of the foregoing.

(69) Computer program code for carrying out operations for aspects of the present disclosure may be written in any combination of one or more programming languages, including an object oriented programming language such as Java, Smalltalk, C++ or the like and conventional procedural programming languages, such as the “C” programming language or similar programming languages. The program code may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider).

(70) Aspects of the present disclosure are described above with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems) and computer program products according to embodiments of the disclosure. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

(71) These computer program instructions may also be stored in a computer readable medium that can direct a computer, other programmable data processing apparatus, or other devices to function in a particular manner, such that the instructions stored in the computer readable medium produce an article of manufacture including instructions which implement the function/act specified in the flowchart and/or block diagram block or blocks.

(72) The computer program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other devices to cause a series of operational steps to be performed on the computer, other programmable apparatus or other devices to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide processes for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

(73) The flowchart and block diagrams in the Figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various embodiments of the present disclosure. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function(s). In some alternative implementations, the functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. Each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special-purpose hardware-based systems that perform the specified functions or acts, or

combinations of special purpose hardware and computer instructions.

(74) Additional examples of storytelling devices and story management and creation techniques, as well as proximity detection techniques and communication protocols, are provided in the attached appendices.

(75) While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

Claims

1. An augmented reality (AR)-capable display device for displaying light generated by a display onto a field of view, the display device comprising: an optical arrangement having a positioning relative to a predefined position of the display and defining the field of view, the optical arrangement comprising: a first mirror element configured to reflect at least some display light generated by the display as first reflected display light, wherein the first mirror element comprises a dichroic beam splitter, which splits incident light based on wavelength; a second mirror element configured to reflect at least some of the first reflected display light reflected by the first mirror element as second reflected display light, wherein the second mirror element comprises a second dichroic surface configured to reflect red, green, and blue wavelengths; and a third mirror element configured to reflect at least some of the second reflected display light reflected by the second mirror element through the first mirror element and onto the field of view.
2. The display device of claim 1, wherein the dichroic beam splitter includes a first dichroic surface, wherein the second mirror element includes the second dichroic surface, wherein the third mirror element comprises a third dichroic surface having spectral reflectance properties matching a transmission spectrum of the dichroic beam splitter at normal incidence and further matching an emission spectrum of the display and a reflection spectrum of the second mirror element at a specified incidence angle, and wherein the first, second, and third dichroic surfaces permit a higher percentage of the display light in the optical arrangement to a user relative to an optical arrangement that does not include a dichroic surface.
3. The display device of claim 1, wherein the dichroic beam splitter is configured to split incident light by exhibiting different properties for different wavelengths of incident light, the different properties being of a type selected from a transmissive type or a reflective type, wherein the dichroic beam splitter has a spectral bandpass that varies based on an angle of incidence of any light that is incident on the dichroic beam splitter, wherein the dichroic beam splitter comprises a triple-band dichroic mirror configured to reflect red, green, and blue wavelengths while transmitting substantially all other visible wavelengths, and wherein the triple-band dichroic mirror is characterized by triple bands that are selected to pass wavelengths of the display light generated by the display.
4. The display device of claim 1, wherein: the display light comprises red, green, and blue (RGB) light, and the first mirror element is configured at a specified angle relative to the display such that at least some of the display light is reflected by the first mirror element as the first reflected display light.
5. The display device of claim 1, wherein: the third mirror element is configured to reflect the at least some of the second reflected display light reflected by the second mirror element as third reflected display light, and the first mirror element is configured at a specified angle relative to the third mirror element such that at least some of the third reflected display light reflected by the third mirror element is transmitted through the first mirror element.
6. The display device of claim 1, wherein the third mirror element has spectral reflectance properties that match both: (i) an emission spectrum of the display, and (ii) a reflection spectrum of the dichroic beam splitter at a first specified incidence angle of light incident on the dichroic beam

splitter.
7. The display device of claim 6, wherein the third mirror element has spectral reflectance properties that match a transmission spectrum of the dichroic beam splitter at a second specified incidence angle of light incident on the dichroic beam splitter.
8. The display device of claim 1, wherein the dichroic beam splitter exhibits a difference in wavelengths of light reflected by the dichroic beam splitter and wavelengths of light transmitted by the dichroic beam splitter.
9. The display device of claim 1, wherein the third mirror element comprises a see-through mirror that transmits background light through the third mirror element and onto the field of view.
10. A method, comprising: reflecting, using a first mirror element of a display device, at least some display light generated by a display as first reflected display light, wherein the first mirror element comprises a dichroic beam splitter, which splits incident light based on wavelength; reflecting, using a second mirror element of the display device, at least some of the first reflected display light reflected by the first mirror element as second reflected display light, wherein the second mirror element comprises a second dichroic surface configured to reflect red, green, and blue wavelengths; and reflecting, using a third mirror element of the display device, at least some of the second reflected display light reflected by the second mirror element through the first mirror element and onto a field of view.
11. The method of claim 10, wherein the dichroic beam splitter includes a first dichroic surface, wherein the second mirror element includes the second dichroic surface, wherein the third mirror element comprises a third dichroic surface having spectral reflectance properties matching a transmission spectrum of the dichroic beam splitter at normal incidence and further matching an emission spectrum of the display and a reflection spectrum of the second mirror element at a specified incidence angle, and wherein the first, second, and third dichroic surfaces permit a higher percentage of the display light in the display device to a user relative to a display device that does not include a dichroic surface.
12. The method of claim 10, wherein the dichroic beam splitter is configured to split incident light by exhibiting different properties for different wavelengths of incident light, the different properties being of a type selected from a transmissive type or a reflective type, wherein the dichroic beam splitter has a spectral bandpass that varies based on an angle of incidence of any light that is incident on the dichroic beam splitter, wherein the dichroic beam splitter comprises a triple-band dichroic mirror configured to reflect red, green, and blue wavelengths while transmitting substantially all other visible wavelengths, and wherein the triple-band dichroic mirror is characterized by triple bands that are selected to pass wavelengths of the display light generated by the display.
13. The method of claim 10, wherein: the display light comprises red, green, and blue (RGB) light, and the first mirror element is configured at a specified angle relative to the display such that at least some of the display light is reflected by the first mirror element as the first reflected display light.
14. The method of claim 10, wherein: the third mirror element is configured to reflect the at least some of the second reflected display light reflected by the second mirror element as third reflected display light, and the first mirror element is configured at a specified angle relative to the third mirror element such that at least some of the third reflected display light reflected by the third mirror element is transmitted through the first mirror element.
15. The method of claim 10, wherein the third mirror element has spectral reflectance properties that match both: (i) an emission spectrum of the display, and (ii) a reflection spectrum of the dichroic beam splitter at a first specified incidence angle of light incident on the dichroic beam splitter.
16. The method of claim 15, wherein the third mirror element has spectral reflectance properties that match a transmission spectrum of the dichroic beam splitter at a second specified incidence

angle of light incident on the dichroic beam splitter.
17. The method of claim 10, wherein the dichroic beam splitter exhibits a difference in wavelengths of light reflected by the dichroic beam splitter and wavelengths of light transmitted by the dichroic beam splitter.
18. The method of claim 10, wherein the third mirror element comprises a see-through mirror that transmits background light through the third mirror element and onto the field of view.