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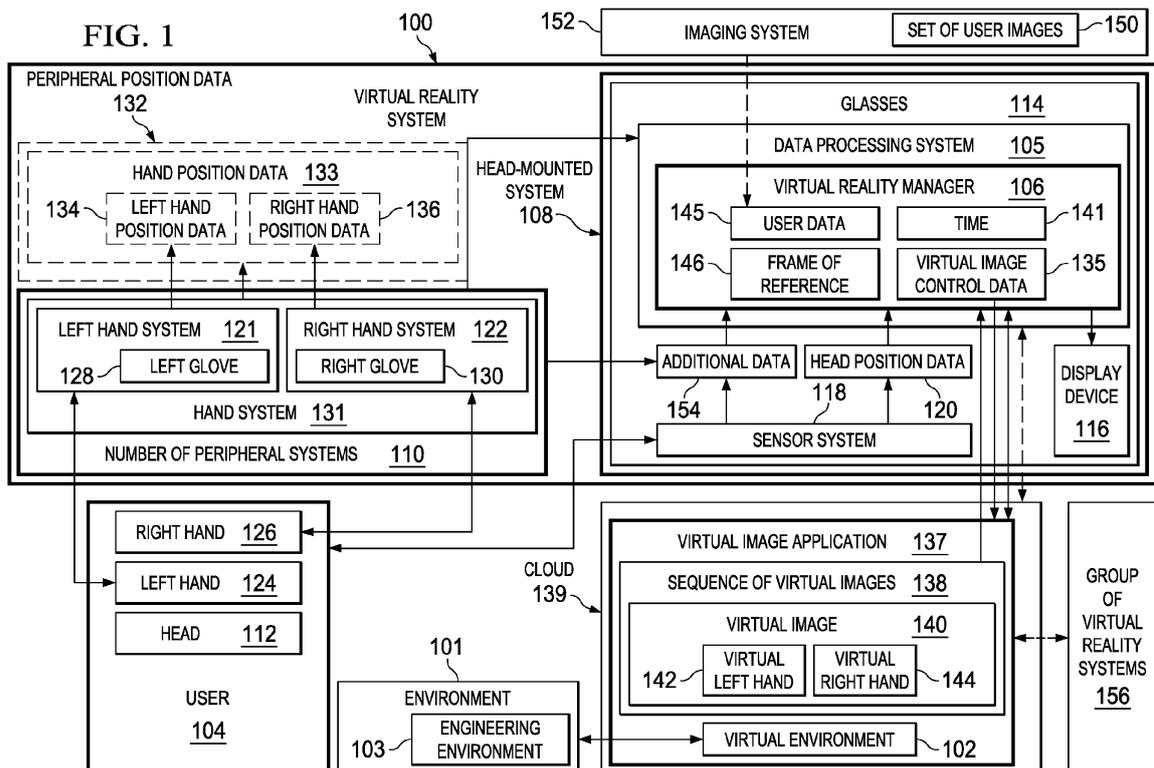
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(54) **System and method for virtual engineering**

(57) A method and system for generating a virtual image (140) of a virtual environment (102) is provided. A virtual reality manager (106) receives hand position data (133) for at least one hand of a user (104) from a hand system (131). The virtual reality manager (106) receives head position data (120) for a head (112) of the user (104) from a head-mounted system (108). The virtual reality manager (106) identifies image-based posi-

tion data (328) and a current frame of reference (330) for a current time (314) using a target image corresponding to the current time (314). The virtual reality manager (106) generates virtual image control data (135) for the current time (314) using the hand position data (133), the head position data (120), the image-based position data (328), and the current frame of reference (330). The virtual image control data (135) is configured for use by a virtual image application (137).



Description

BACKGROUND

[0001] The present disclosure relates generally to virtual reality and, in particular, to user interaction with a virtual environment. Still more particularly, the present disclosure relates to a method and system for increasing a level of eye-hand coordination when a user interacts with a virtual environment.

[0002] Virtual reality (VR) is a technology that may be used to simulate a real environment or an imaginary environment in the form of a virtual environment. A virtual environment is a computer-simulated environment that can simulate physical presence in a real environment or an imaginary environment. Typically, a virtual environment is visually presented to a user as a two-dimensional environment or a three-dimensional environment. In some cases, sensory information, such as sound, may be presented to the user in addition to the visual presentation of the virtual environment.

[0003] Different types of virtual reality systems may provide different levels of immersion for a user. As used herein, the level of "immersion" provided by a virtual reality system is the extent to which a user feels present in the virtual environment created by the virtual reality system. A user may be fully immersed in a virtual environment when the user experiences both perceptive immersion and cognitive immersion.

[0004] A user may experience perceptive immersion when the user has a sense of being physically present in the virtual environment. For example, the user may feel that his or her hands are present in the virtual environment. A user may experience cognitive immersion when the user has a sense that what is happening in the virtual environment is actually happening. In other words, the mind of the user may be immersed in the virtual environment.

[0005] Further, when a user is cognitively immersed in a virtual environment, the actions of the user may have effects on the virtual environment, and events in the virtual environment may affect the senses of the user. When the user is cognitively immersed in the virtual environment, the user may accept the effects on the virtual environment and the effects on the senses of the user as actually occurring.

[0006] Some currently available virtual reality systems may be unable to provide a desired level of immersion. For example, some currently available virtual reality systems may be unable to simulate human mobility within a virtual environment with a desired level of accuracy. In particular, these virtual reality systems may be unable to simulate rotation of human skeletal components about hinged joints with a desired level of accuracy without increasing the size and/or weight of the virtual reality systems more than desired.

[0007] For example, a gyroscope may be capable of measuring the rotation of a human skeletal component

about a hinged joint. However, the configuration for the gyroscope needed to measure this type of rotation may be larger and/or heavier than desired. Further, this configuration for the gyroscope may exert undesired forces on the human body part to which the gyroscope is attached. For example, a gyroscope attached to a hand may exert undesired forces on the hand when measuring movement of the hand. These undesired forces may cause the hand to move in an undesired manner.

[0008] Some currently available virtual reality systems may use displacement estimation techniques to track the movement of, for example, the fingers of a user. However, these displacement estimation techniques may track the movement of the fingers of the user with a less than desired accuracy.

[0009] In this manner, some of the currently available virtual reality systems may be unable to simulate the movement of the human body and/or parts of the human body with a desired level of accuracy. Consequently, these currently available virtual reality systems may be unable to provide a user with the level of eye-hand coordination needed to allow the user to feel a desired level of immersion within the virtual environment.

[0010] Without the level of eye-hand coordination needed for providing the desired level of immersion within the virtual environment, a user may be unable to perform certain tasks within the virtual environment as quickly and/or efficiently as desired. Therefore, it would be desirable to have a system and method that takes into account at least some of the issues discussed above, as well as other possible issues.

SUMMARY

[0011] In one illustrative embodiment, a method for generating a virtual image of a virtual environment is provided. A virtual reality manager receives hand position data for at least one hand of a user from a hand system. The virtual reality manager receives head position data for the head of the user from a head-mounted system. The virtual reality manager identifies image-based position data and a current frame of reference for a current time using a target image corresponding to the current time. The virtual reality manager generates virtual image control data for the current time using the hand position data, the head position data, the image-based position data, and the current frame of reference. The virtual image control data is configured for use by a virtual image application.

[0012] In another illustrative embodiment, a virtual reality system comprises a head-mounted system and a virtual reality manager. The head-mounted system is configured to be worn relative to the head of a user. The virtual reality manager is associated with the head-mounted system. The virtual reality manager is configured to receive hand position data for at least one hand of the user from a hand system. The virtual reality manager is configured to receive head position data for the

head of the user from a sensor system in the head-mounted system. The virtual reality manager is configured to identify image-based position data and a current frame of reference for a current time using a target image corresponding to the current time. The virtual reality manager is configured to generate virtual image control data for the current time using the hand position data, the head position data, the image-based position data, and the current frame of reference. The virtual image control data is configured for use by a virtual image application.

[0013] In yet another illustrative embodiment, a computer comprises a bus, a non-transitory storage device connected to the bus, and a processor unit connected to the bus. The non-transitory storage device includes program code. The processor unit is configured to execute the program code to receive hand position data for at least one hand of a user from a hand system, receive head position data for the head of the user from a head-mounted system, identify image-based position data and a current frame of reference for a current time using a target image corresponding to the current time, and generate virtual image control data for the current time using the hand position data, the head position data, the image-based position data, and the current frame of reference. The virtual image control data is configured for use by a virtual image application.

[0014] The features and functions can be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments in which further details can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The novel features believed characteristic of the illustrative embodiments are set forth in the appended claims. The illustrative embodiments, however, as well as a preferred mode of use, further objectives, and features thereof will best be understood by reference to the following detailed description of an illustrative embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:

Figure 1 is an illustration of a virtual reality system in the form of a block diagram in accordance with an illustrative embodiment;

Figure 2 is an illustration of a hand system in the form of a block diagram in accordance with an illustrative embodiment;

Figure 3 is an illustration of a head-mounted system in the form of a block diagram in accordance with an illustrative embodiment;

Figure 4 is an illustration of a data coordinator in the form of a block diagram in accordance with an illustrative embodiment;

Figure 5 is an illustration of modes of operation for a virtual reality system in the form of a block diagram in accordance with an illustrative embodiment;

Figure 6 is an illustration of a user using a virtual reality system in accordance with an illustrative embodiment;

Figure 7 is an illustration of a process for interacting with a virtual engineering environment in the form of a flowchart in accordance with an illustrative embodiment;

Figure 8 is an illustration of a process for interacting with a virtual engineering environment in the form of a flowchart in accordance with an illustrative embodiment; and

Figure 9 is an illustration of a data processing system in accordance with an illustrative embodiment.

DETAILED DESCRIPTION

[0016] The different illustrative embodiments recognize and take into account different considerations. For example, the different illustrative embodiments recognize and take into account that a virtual environment may be useful for performing different types of engineering tasks.

[0017] These engineering tasks may include, for example, without limitation, designing a vehicle, managing data for a product design, testing a structure for use in an aircraft, testing the operation of a configuration for an antenna system, inspecting a system, performing maintenance on a structure, controlling operations of a vehicle, controlling manufacturing equipment in a manufacturing facility, controlling a structure in outer space, and other suitable types of engineering tasks. Other types of engineering tasks may include, for example, without limitation, interacting with a computer program, operating an electromechanical device located in an inaccessible environment, operating a mobile platform under extreme weather conditions and/or temperature conditions, and still other suitable types of engineering tasks.

[0018] As one illustrative example, a virtual environment that simulates a testing environment having selected testing conditions may be used for testing the operation of a particular configuration for a component for a vehicle under those selected conditions. In this illustrative example, a model of the particular configuration for the component is introduced into the virtual environment.

[0019] Testing the operation of the particular configuration for the component using the model in the virtual environment may be less expensive, less time-consuming, and/or more efficient than testing the real component in a real testing environment. Further, this type of virtual testing of the component may require fewer resources and/or personnel as compared to physical testing of the component.

[0020] However, the different illustrative embodiments recognize and take into account that a user may be unable to use the virtual environment created by a virtual reality system to perform certain types of engineering tasks if the virtual reality system does not provide a desired level of eye-hand coordination. As used herein,

"eye-hand coordination" is the coordinated control of eye movement and hand movement. Eye-hand coordination is the use of visual input to guide movement of the hands and the use of proprioception of the hands to guide movement of the eyes.

[0021] Certain types of engineering tasks may require a higher level of eye-hand coordination than other types of engineering tasks. As one illustrative example, operating a virtual aircraft comprising different types of controls, switches, buttons, and user interfaces may require a higher level of eye-hand coordination than pushing a door open in a virtual environment.

[0022] The different illustrative embodiments recognize and take into account that providing a desired level of eye-hand coordination may require identifying the positions of the hands of the user and the head of the user with respect to a frame of reference for the virtual environment with a desired level of accuracy. Additionally, the different illustrative embodiments recognize and take into account that providing the desired level of eye-hand coordination may require simulating the movement of the hands and fingers of the user within the virtual environment with a desired level of accuracy in substantially real-time. As used herein, "in substantially real-time" means without time delays perceivable to the user.

[0023] Thus, the different illustrative embodiments provide a method and system for increasing a level of eye-hand coordination for a user when the user interacts with a virtual environment. In particular, the different illustrative embodiments provide a virtual reality system configured to coordinate hand position data and head position data for the user and synchronize this data with respect to time to provide the user with a desired level of eye-hand coordination within a virtual environment.

[0024] With reference now to **Figure 1**, an illustration of a virtual reality system in the form of a block diagram is depicted in accordance with an illustrative embodiment. In these illustrative examples, virtual reality system **100** is configured to visually present virtual environment **102** to user **104**. Further, user **104** may interact with virtual environment **102** using virtual reality system **100**.

[0025] In these illustrative examples, virtual environment **102** is a simulation of environment **101**. Environment **101** may be a real environment or an imaginary environment. For example, environment **101** may be a physical environment or an abstract environment.

[0026] In one illustrative example, environment **101** takes the form of engineering environment **103**. Engineering environment **103** may be selected from one of, for example, without limitation, a design environment, a manufacturing environment, a computer environment, a testing environment, a data management environment, an inspection environment, an operations environment, or some other suitable type of engineering environment.

[0027] When virtual environment **102** is a simulation of engineering environment **103**, user **104** may use virtual reality system **100** to interact with virtual environment **102** to perform one or more engineering tasks. For ex-

ample, user **104** may use virtual reality system **100** to design an object, such as an aircraft or a part for an aircraft, within virtual environment **102**.

[0028] In another illustrative example, user **104** may use virtual reality system **100** to perform tasks related to air traffic control. For example, virtual environment **102** may be a simulation of a region of airspace. User **104** may use virtual reality system **100** to control operation of and/or exchange information with an aircraft in this region of airspace using a model of the aircraft in virtual environment **102**.

[0029] Further, in yet another illustrative example, virtual environment **102** may be a simulation of a user interface for a computer program. User **104** may use virtual reality system **100** to interact with the virtual user interface to interact with the computer program. For example, the computer program may be a database management program. User **104** may use virtual reality system **100** to interact with a virtual user interface for this data management application.

[0030] As depicted, virtual reality system **100** comprises virtual reality manager **106**, head-mounted system **108**, and number of peripheral systems **110**. In these illustrative examples, virtual reality manager **106** may be implemented using hardware, software, or a combination of the two. For example, virtual reality manager **106** may be implemented in data processing system **105**.

[0031] In these illustrative examples, data processing system **105** is associated with head-mounted system **108**. When one component is "associated" with another component, this association is a physical association in these examples.

[0032] For example, a first component, such as data processing system **105**, may be considered to be associated with a second component, such as head-mounted system **108**, by being secured to the second component, bonded to the second component, mounted to the second component, welded to the second component, fastened to the second component, electrically connected to the second component, and/or connected to the second component in some other suitable manner. The first component also may be connected to the second component using a third component. The first component may also be considered to be associated with the second component by being formed as part of and/or as an extension of the second component.

[0033] In these illustrative examples, data processing system **105** is considered part of head-mounted system **108**. Of course, in other illustrative examples, virtual reality manager **106** may be implemented in a processor unit separate from head-mounted system **108** but configured to communicate with head-mounted system **108** wirelessly.

[0034] Head-mounted system **108** is configured to be worn relative to head **112** of user **104**. For example, head-mounted system **108** may be worn over and/or on head **112** of user **104**. Head-mounted system **108** may take a number of different forms. For example, head-mounted

system **108** may take the form of a helmet, a visor, a hat, glasses, goggles, or some other suitable type of device configured to be worn over and/or on head **112** of user **104**. In one illustrative example, head-mounted system **108** takes the form of glasses **114**.

[0035] Any number of different components may be associated with head-mounted system **108**. For example, display device **116** and sensor system **118** may be associated with head-mounted system **108**. When head-mounted system **108** takes the form of glasses **114**, display device **116** and sensor system **118** may be attached to, part of, and/or otherwise associated with glasses **114**.

[0036] Virtual reality manager **106** is configured to visually present virtual environment **102** to user **104** on display device **116**. In one illustrative example, display device **116** may be the lenses in glasses **114**. Virtual reality manager **106** may visually present virtual environment **102** on these lenses such that virtual environment **102** is visually presented in front of the eyes of user **104** when user **104** is wearing glasses **114**. In this manner, user **104** may feel present in virtual environment **102**.

[0037] Of course, in other illustrative examples, display device **116** may take some other form. For example, display device **116** may comprise one or two contact lenses configured to be worn by user **104**.

[0038] Sensor system **118** may include one or more sensors. The sensors in sensor system **118** may include, for example, without limitation, any number of microelectromechanical sensors (MEMS), nanoelectromechanical sensors (NEMS), motion sensors, angle sensors, velocity sensors, acceleration sensors, position sensors, cameras, video cameras, image sensors, and/or other suitable types of sensors. Head-mounted system **108** is configured to generate head position data **120** using sensor system **118**.

[0039] In these illustrative examples, each peripheral system in number of peripheral systems **110** in virtual reality system **100** may be configured to generate and send data to virtual reality manager **106**. As used herein, a "peripheral system", such as one of number of peripheral systems **110**, is a system that is configured to communicate with head-mounted system **108** but that is not considered part of head-mounted system **108**. Further, as used herein, a "number of" items means one or more items. For example, number of peripheral systems **110** may be one or more peripheral systems.

[0040] In these illustrative examples, each peripheral system in number of peripheral systems **110** may be configured to generate data about a particular body part of user **104**. For example, a peripheral system in number of peripheral systems **110** may be configured to generate data about a hand, a foot, an arm, a leg, a torso, a finger, a toe, or another body part of user **104**.

[0041] In one illustrative example, number of peripheral systems **110** includes hand system **131**. Hand system **131** is configured to generate hand position data **133**. Hand position data **133** may form at least a portion of peripheral position data **132** generated by number of

peripheral systems **110**. As used herein, "at least a portion" means some or all. Peripheral position data **132** may include data about the position of any number of body parts for user **104** over time.

[0042] Hand position data **133** may include data about at least one of left hand **124** and right hand **126** of user **104**. For example, hand system **131** may comprise at least one of left hand system **121** and right hand system **122**. Left hand system **121** may generate data about left hand **124** of user **104**, while right hand system **122** may generate data about right hand **126** of user **104**.

[0043] In these illustrative examples, left hand system **121** may take the form of left glove **128** configured for use with left hand **124** of user **104**, while right hand system **122** may take the form of right glove **130** configured for use with right hand **126** of user **104**. Left glove **128** and right glove **130** may be gloves configured to generate data about the position of left hand **124** and right hand **126**, respectively, over time.

[0044] In particular, left glove **128** generates left hand position data **134** for left hand **124**, while right glove **130** generates right hand position data **136** for right hand **126** when user **104** is wearing left glove **128** and right glove **130**, respectively. Left hand position data **134** and right hand position data **136** may include data about the position of left hand **124** and right hand **126**, respectively, over time, as well as data about the positions of the wrists and fingers corresponding to these hands over time.

[0045] Virtual reality manager **106** is configured to receive peripheral position data **132** from number of peripheral systems **110** and head position data **120** from sensor system **118** in head-mounted system **108**. In particular, virtual reality manager **106** receives hand position data **133** and head position data **120** in substantially real-time. In other words, virtual reality manager **106** receives the position data as the position data is being generated without perceivable delays.

[0046] In these illustrative examples, virtual reality manager **106** may use hand position data **133** and head position data **120** to generate virtual image control data **135**. Virtual image control data **135** may be data configured for use by virtual image application **137** to control a virtual image of virtual environment **102**.

[0047] For example, virtual image application **137** is computer software configured to create virtual images of virtual environment **102**. As used herein, a "virtual image" of a virtual environment, such as virtual environment **102**, is an image of at least a portion of the virtual environment. In some cases, virtual image application **137** may be configured to create virtual environment **102**. In other cases, virtual image application **137** may be configured to use virtual environment **102** created by another application.

[0048] Virtual reality manager **106** may be configured to communicate with virtual image application **137** using, for example, without limitation, cloud **139**. Cloud **139** may be a network comprised of applications, computer programs, devices, servers, client computers, and/or other computing components connected to each other. Virtual

reality manager **106** may be configured to access cloud **139** and, thereby, virtual image application **137**, using, for example, without limitation, the Internet.

[0049] In these illustrative examples, virtual image application **137** is configured to generate sequence of virtual images **138** of virtual environment **102**. As used herein, a "sequence of images", such as sequence of virtual images **138**, is one or more images ordered with respect to time. In this manner, each virtual image in sequence of virtual images **138** corresponds to a particular time. In some illustrative examples, sequence of virtual images **138** may also be referred to as a sequence of virtual frames.

[0050] Virtual image application **137** generates each virtual image in sequence of virtual images **138** using virtual image control data **135** generated by virtual reality manager **106**. For example, virtual image application **137** may use virtual image control data **135** to update a previously generated virtual image of virtual environment **102**. This updated virtual image may be sent back to virtual reality manager **106**. Virtual reality manager **106** may then display this updated virtual image on display device **116**.

[0051] In this manner, virtual reality manager **106** may display the virtual images in sequence of virtual images **138** generated by virtual image application **137** on display device **116** as the virtual images are received from virtual image application **137**. Virtual reality manager **106** displays sequence of virtual images **138** on display device **116** to visually present virtual environment **102** to user **104** on display device **116**.

[0052] Virtual image **140** is an example of a virtual image in sequence of virtual images **138**. Virtual image **140** may be a two-dimensional image or a three-dimensional image, depending on the implementation. Virtual image **140** corresponds to time **141**. Virtual image **140** is generated using the portion of hand position data **133** and the portion of head position data **120** generated within time **141**. Time **141** may be, for example, an instant in time or a period of time.

[0053] In particular, the portion of hand position data **133** and the portion of head position data **120** generated within time **141** is used to form virtual image control data **135** corresponding to time **141**. Virtual image control data **135** corresponding to time **141** may be used by virtual image application **137** to form virtual image **140**.

[0054] Further, virtual reality manager **106** may use head position data **120** and/or other data generated by sensor system **118** to identify frame of reference **146** for virtual image **140**. Frame of reference **146** is a coordinate system for virtual image **140** with respect to virtual environment **102**. In particular, frame of reference **146** is the portion of virtual environment **102** captured within virtual image **140**. Frame of reference **146** is identified based on the position of head **112** of user **104**. In other words, frame of reference **146** is identified based on the direction in which head **112** of user **104** is pointing.

[0055] In these illustrative examples, virtual reality

manager **106** is configured to generate virtual image control data **135** using frame of reference **146** and by coordinating hand position data **133** and head position data **120**. Virtual reality manager **106** may coordinate hand position data **133** and head position data **120** by synchronizing hand position data **133** and head position data **120** with respect to time. This type of synchronization may increase a level of eye-hand coordination provided to user **104**.

[0056] For example, synchronization of hand position data **133** and head position data **120** with respect to time **141** may result in virtual image control data **135** that has a desired level of accuracy. When virtual image control data **135** has the desired level of accuracy, sequence of virtual images **138** of virtual environment **102** generated by virtual image application **137** may represent a substantially real-time simulation of the movement and presence of user **104** within virtual environment **102**.

[0057] Further, virtual reality manager **106** may be configured to display sequence of virtual images **138** in substantially real-time. By allowing the movement of user **104** and the presence of user **104** within virtual environment **102** to be simulated in virtual environment **102** in substantially real-time, virtual reality manager **106** may allow user **104** to perform one or more tasks within virtual environment **102** with a desired level of accuracy, speed, and efficiency.

[0058] In these illustrative examples, virtual image **140** includes at least one of virtual left hand **142** and virtual right hand **144**. Virtual left hand **142** may be an image that represents left hand **124** of user **104** in virtual image **140**. Virtual right hand **144** may be an image that represents right hand **126** of user **104** in virtual image **140**. Virtual image application **137** may determine the positions for virtual left hand **142** and virtual right hand **144** within virtual image **140** using virtual image control data **135**.

[0059] Additionally, in these illustrative examples, virtual image control data **135** may also be generated using user data **145**. User data **145** may include data about user **104**. In particular, user data **145** may include data about the geometry of one or more body parts of user **104**.

[0060] For example, user data **145** may include data about at least one of left hand **124**, right hand **126**, and head **112** of user **104**. Data about a hand of user **104**, such as left hand **124** or right hand **126**, may include, for example, without limitation, measurements of the dimensions of the hand, measurements of the wrist corresponding to the hand, measurements of the fingers on the hand, measurements of a range of motion for one or more of the fingers on the hand, measurements of a distance between the fingers on the hand at rest and/or in motion, and/or other suitable types of data.

[0061] User data **145** may be identified using set of user images **150** generated by imaging system **152**. As used herein, a "set of" items means one or more items. For example, set of user images **150** means one or more user images.

[0062] Imaging system 152 is not part of virtual reality system 100 in these illustrative examples. In one illustrative example, imaging system 152 may be a three-dimensional laser scanning system. In this illustrative example, set of user images 150 is a set of three-dimensional laser scans of user 104 that captures the geometry of left hand 124 and right hand 126 of user 104. Further, this set of three-dimensional laser scans may also capture the geometry of the wrists and fingers of user 104.

[0063] In one illustrative example, virtual reality manager 106 may be configured to receive set of user images 150 and identify user data 145 using set of user images 150. In another illustrative example, user data 145 may be uploaded directly into virtual reality manager 106. In yet another illustrative example, user data 145 may be set of user images 150.

[0064] When virtual image 140 is displayed on display device 116 to user 104, user 104 sees virtual left hand 142 and virtual right hand 144. In particular, user 104 sees virtual left hand 142 and virtual right hand 144 in virtual image 140 in positions that correspond to the real positions of left hand 124 and right hand 126, respectively. In this manner, user 104 may feel present in virtual environment 102.

[0065] In some illustrative examples, number of peripheral systems 110 and/or sensor system 118 in head-mounted system 108 may generate additional data 154 in addition to position data. Additional data 154 may be used to generate virtual image control data 135. For example, additional data 154 may be used to generate data that may be used by virtual image application 137 to control one or more interactive controls in virtual environment 102.

[0066] In one illustrative example, additional data 154 may include pressure data for the fingers on left hand 124 and right hand 126. In other illustrative examples, additional data 154 may include image data. Of course, in still other illustrative examples, additional data 154 may include other types of sensor data.

[0067] In some illustrative examples, virtual reality manager 106 may also be configured to communicate with group of virtual reality systems 156 using cloud 139. Each virtual reality system in group of virtual reality systems 156 may comprise a virtual reality manager that may be implemented in a manner similar to virtual reality manager 106. Cloud 139 may allow different virtual reality managers to interact with virtual image application 137 at the same time. In some cases, cloud 139 may allow different users to interact with each other within virtual environment 102.

[0068] With reference now to Figure 2, an illustration of a left hand system in the form of a block diagram is depicted in accordance with an illustrative embodiment. In Figure 2, an example of one implementation for left hand system 121 from Figure 1 is depicted. The configuration depicted for left hand system 121 may also be used to implement right hand system 122 in Figure 1.

[0069] As depicted, left hand system 121 takes the

form of left glove 128. Left glove 128 is configured to substantially conform to left hand 124 of user 104 in Figure 1. As one illustrative example, left glove 128 may be fabricated based on a set of user images, such as, for example, set of user images 150 in Figure 1, and/or user data, such as user data 145 in Figure 1. Set of user images 150 may be used to fabricate a glove that substantially conforms to left hand 124 of user 104. For example, left glove 128 may be fabricated using a material configured to substantially conform to left hand 124 of user 104. Further, left glove 128 may be fabricated having dimensions that substantially match the geometry of left hand 124.

[0070] In this illustrative example, left glove 128 comprises sensor system 202, data manager 204, and communications unit 206. Sensor system 202 comprises a number of sensors selected from a group comprising microelectromechanical sensors, nanoelectromechanical sensors, motion sensors, angle sensors, position sensors, velocity sensors, acceleration sensors, cameras, video cameras, image sensors, pressure sensors, tactile sensors, and/or other suitable types of sensors.

[0071] Sensor system 202 may be integrated into the material used to fabricate left glove 128 in some illustrative examples. For example, one or more sensors in sensor system 202 may be integrated into the material used to fabricate left glove 128 in a manner such that these sensors may not be visible to user 104. The position of each sensor in sensor system 202 with respect to left glove 128 may be determined using, for example, without limitation, set of user images 150 and/or user data 145 in Figure 1.

[0072] As depicted, sensor system 202 is configured to generate raw hand position data 210 for left hand 124 of user 104. Raw hand position data 210 may comprise, for example, without limitation, a set of dynamic system state variables (DSSV).

[0073] In some illustrative examples, sensor system 202 may be calibrated using set of user images 150 and/or user data 145. As one illustrative example, these images may be used to impose constraints on raw hand position data 210 generated by sensor system 202.

[0074] Data manager 204 may comprise hardware, software, or a combination of the two. For example, data manager 204 may be implemented within data processing system 205. In some illustrative examples, data processing system 205 may be implemented within sensor system 202. In other illustrative examples, data processing system 205 may be implemented within left glove 128 separate from sensor system 202.

[0075] In still other illustrative examples, data processing system 205 may be associated with left glove 128 in some other suitable manner. For example, without limitation, data processing system 205 may be a wristwatch-type device associated with left glove 128.

[0076] Data manager 204 is configured to modify raw hand position data 210 to form left hand position data 134. Data manager 204 may modify raw hand position

data 210 using set of filters 212. Set of filters 212 may include, for example, without limitation, any number of motion smoothing filters, jitter filters, Kalman filters, and/or other suitable types of filters. Further, data manager 204 may also modify raw hand position data 210 based on constraints identified for the movement of left hand 124 of user 104 based on set of user images 150 in Figure 1.

[0077] In this manner, left hand position data 134 may compensate for undesired movement of one or more sensors in sensor system 202 while raw hand position data 210 is being generated. This undesired movement may include, for example, shaking, vibrations, jitter, and/or other suitable types of undesired movement.

[0078] In some cases, left hand position data 134 may also compensate for imprecise gestures and undesired movement of left hand 124 of user 104. For example, left hand position data 134 may compensate for undesired spikes in the motion of left hand 124 in response to an undesired jerking type of motion of left hand 124. In these illustrative examples, modifying raw hand position data 210 to form left hand position data 134 may be referred to as stabilizing raw hand position data 210.

[0079] Data manager 204 sends left hand position data 134 to virtual reality manager 106 in Figure 1 using communications unit 206. Communications unit 206 is used to form one or more wireless communications links between left glove 128 and other peripheral systems and/or head-mounted system 108. As one illustrative example, communications unit 206 forms wireless communications link 214 with head-mounted system 108. Communications unit 206 may transmit left hand position data 134 to head-mounted system 108 in Figure 1 over wireless communications link 214 using, for example, without limitation, radio frequency (RF) signals.

[0080] In some illustrative examples, data manager 204 may also be used to calibrate sensor system 202. In other illustrative examples, data manager 204 may be configured to modify raw hand position data 210 to electronically compensate for mounting issues with sensor system 202.

[0081] Turning now to Figure 3, an illustration of a head-mounted system in the form of a block diagram is depicted in accordance with an illustrative embodiment. In Figure 3, an example of one implementation for head mounted-system 108 from Figure 1 is depicted.

[0082] In this illustrative example, head-mounted system 108 takes the form of glasses 114. As depicted, virtual reality manager 106, display device 116, sensor system 118, data manager 302, and communications unit 300 are associated with glasses 114. In particular, virtual reality manager 106, display device 116, sensor system 118, data manager 302, and communications unit 300 are part of glasses 114 in this example.

[0083] Communications unit 300 is configured to form any number of wireless communications links to allow communications between head-mounted system 108 and a number of other systems, such as, for example,

number of peripheral systems 110 in Figure 1. For example, head-mounted system 108 may receive peripheral position data 132 from number of peripheral systems 110 in Figure 1 using communications unit 300.

[0084] In particular, virtual reality manager 106 receives left hand position data 134 from left hand system 121 in Figure 1 and right hand position data 136 from right hand system 122 in Figure 1 using communications unit 300. For example, communications unit 300 may receive left hand position data 134 from left glove 128 using wireless communications link 214 established between communications unit 300 and communications unit 206 of left glove 128 in Figure 2.

[0085] As depicted, sensor system 118 is configured to generate raw head position data 304. Raw head position data 304 may comprise, for example, without limitation, a set of dynamic system state variables (DSSV). In some illustrative examples, sensor system 118 may be calibrated using set of user images 150 in Figure 1.

[0086] In these illustrative examples, data manager 302 may be implemented using hardware, software, or a combination of the two. In one illustrative example, data manager 302 may be implemented within data processing system 305. In some cases, data processing system 305 may be associated with data processing system 105 in Figure 1. In other cases, data processing system 305 may be associated with sensor system 118. In some illustrative examples, data manager 302 may be implemented within data processing system 105 in Figure 1 instead of data processing system 305.

[0087] Data manager 302 is configured to modify raw head position data 304 to form head position data 120 in Figure 1. Data manager 302 may modify raw head position data 304 using set of filters 308. Set of filters 308 may include, for example, without limitation, any number of motion smoothing filters, jitter filters, Kalman filters, and/or other suitable types of filters. Further, data manager 302 may also modify raw head position data 304 based on constraints identified for the movement of head 112 of user 104 using set of user images 150 in Figure 1.

[0088] In this manner, head position data 120 may be used to compensate for undesired movement of one or more sensors in sensor system 118 while raw head position data 304 is being generated. This undesired movement may include, for example, shaking, vibrations, jitter, and/or other suitable types of undesired movement.

[0089] Further, in some cases, head position data 120 may also be used to compensate for undesired movement of head 112 of user 104. For example, head position data 120 may compensate for undesired spikes in the motion of head 112 in response to an undesired jerking type of motion of head 112. In these illustrative examples, modifying raw head position data 304 to form head position data 120 may be referred to as stabilizing raw head position data 304. Data manager 302 sends head position data 120 to virtual reality manager 106.

[0090] In some illustrative examples, data manager 302 may also be used to calibrate sensor system 118.

In other illustrative examples, data manager **302** may be configured to modify raw head position data **304** to electronically compensate for mounting issues with sensor system **118**.

[0091] Additionally, sensor system **118** includes imaging system **322** in this illustrative example. Imaging system **322** comprises one or more cameras configured to point in a substantially same direction in which head **112** of user **104** is pointed. Imaging system **322** is configured to have a field of view that is wide enough and deep enough to capture a number of visual targets on number of peripheral systems **110**. These visual targets may include, for example, visual markers, labels, buttons, contours, shapes, and/or other suitable types of visual targets.

[0092] As one illustrative example, a number of visual markers may be present on each of left glove **128** and right glove **130** in **Figure 1**. Imaging system **322** is configured to have a field of view wide enough and deep enough to capture these visual markers in a target image generated by imaging system **322**.

[0093] In this illustrative example, target image **324** is an example of one of sequence of target images **320**. Target image **324** is generated by imaging system **322** at current time **314**. Image processor **326** in virtual reality manager **106** is configured to generate image-based position data **328** using target image **324**. Image-based position data **328** identifies the positions of left glove **128** and right glove **130** within target image **324** at current time **314**. These positions are identified using the visual targets on left glove **128** and right glove **130**.

[0094] Further, image processor **326** is also configured to use target image **324** to identify current frame of reference **330** for current virtual image **310**. Current frame of reference **330** may be, for example, the portion of virtual environment **102** that corresponds to target image **324**. For example, a first target image that captures an area to the left of an area captured in a second target image corresponds to a portion of virtual environment **102** that is to the left of the portion of virtual environment **102** corresponding to the second target image.

[0095] Image processor **326** is configured to send current frame of reference **330** and image-based position data **328** to data coordinator **336**. Data coordinator **336** uses current frame of reference **330**, image-based position data **328**, head position data **120**, left hand position data **134**, and right hand position data **136** to generate virtual image control data **135** for current time **314**. In particular, data coordinator **336** uses head position data **120**, left hand position data **134**, and right hand position data **136** generated at current time **314** to form virtual image control data **135** for current time **314**.

[0096] Virtual image control data **135** may include, for example, a position for left glove **128** and right glove **130** in **Figure 1** with respect to current frame of reference **330** that may be used to control, for example, a position of a virtual left hand and a virtual right hand within a virtual image of virtual environment **102**. In the illustrative ex-

amples, data coordinator **336** sends virtual image control data **135** to virtual image application **137** for processing.

[0097] Virtual image application **137** may include image generator **338**. Image generator **338** uses virtual image control data **135** to form current virtual image **310** of virtual environment **102** for current time **314**. Current virtual image **310** is based on current frame of reference **330**. Current virtual image **310** may be the virtual image being formed for display on display device **116**. In other words, current virtual image **310** has not yet been displayed on display device **116** in this example.

[0098] In this example, current virtual image **310** may be an updated version of previous virtual image **312** currently being displayed on display device **116**. Previous virtual image **312** may have been generated by virtual image application **137** for previous time **332**. Current frame of reference **330** used for forming current virtual image **310** may be the same as or different from previous frame of reference **334** used for generating previous virtual image **312**.

[0099] As depicted, current virtual image **310** includes current virtual left hand **316** and current virtual right hand **318**. The positions for current virtual left hand **316** and current virtual right hand **318** may be based on the positions identified for left glove **128** and right glove **130** in virtual image control data **135**.

[0100] Once current virtual image **310** has been generated by image generator **338**, virtual image application **137** sends current virtual image **310** to data coordinator **336**. Data coordinator **336** sends current virtual image **310** to display device **116** such that current virtual image **310** may be displayed on display device **116** in the place of previous virtual image **312**.

[0101] In this manner, virtual reality manager **106** and virtual image application **137** may communicate with each other to form sequence of virtual images **138** in **Figure 1** for a plurality of times spanning a particular period of time. The virtual images in sequence of virtual images **138** may be displayed on display device **116** as the images are generated in substantially real-time such that the different positions for the virtual left hand and virtual right hand in the virtual images over the particular period of time simulate movement of left hand **124** and right hand **126**, respectively, of user **104** in **Figure 1**.

[0102] In some illustrative examples, head-mounted system **108** may also include microphone **340** and/or speaker system **342**. User **104** may use microphone **340** to generate audio data for use by virtual reality manager **106**. Further, virtual reality manager **106** may be configured to generate sounds using speaker system **342**. These sounds may allow user **104** to be further immersed in virtual environment **102**. Speaker system **342** may take the form of, for example, headphones **344**.

[0103] With reference now to **Figure 4**, an illustration of a data coordinator in the form of a block diagram is depicted in accordance with an illustrative embodiment. In **Figure 4**, an example of one implementation for data coordinator **336** from **Figure 3** is depicted.

[0104] In this illustrative example, data coordinator **336** is configured to receive input **402** for use in forming current virtual image **310** for current time **314**. In response to receiving input **402**, data coordinator **336** generates output **404**. Input **402** may include, for example, without limitation, user data **145**, image-based position data **328**, hand position data **133**, head position data **120**, current frame of reference **330**, and/or other suitable data. Image-based position data **328**, hand position data **133**, head position data **120**, and current frame of reference **330** may be data corresponding to current time **314**. Output **404** may be current virtual image **310**.

[0105] As illustrated in this figure, data coordinator **336** includes constraint identifier **406**, data modulator **408**, feedback controller **410**, virtual image analyzer **411**, control data generator **412**, and image visualizer **414**. In this illustrative example, constraint identifier **406** identifies set of constraints **416** for forming virtual image control data **135** based on, for example, without limitation, user data **145**. Set of constraints **416** may include, for example, constraints on the positions and/or movement of left hand **124**, right hand **126**, and/or head **112** of user **104** in **Figure 1**. Constraint identifier **406** sends set of constraints **416** to feedback controller **410**.

[0106] As depicted, data modulator **408** includes hand data modulator **418** and head data modulator **420**. Hand data modulator **418** is configured to use both image-based position data **328** and hand position data **133** to form modified hand position data **422**. Modified hand position data **422** may be formed by applying weights to image-based position data **328** and hand position data **133**. These weights may be based on, for example, a speed of movement of left hand **124** and/or right hand **126** of user **104**.

[0107] In this illustrative example, image-based position data **328** may provide a more accurate position for a hand of user **104** than hand position data **133** generated using a sensor system on a glove for the hand over time. In particular, image-based position data **328** may provide more accurate data than hand position data **133** when the hand is moving slowly. Hand position data **133** may provide more accurate data than image-based position data **328** when the hand is moving quickly.

[0108] Consequently, when a hand of user **104** is moving quickly enough, hand data modulator **418** applies weights to the corresponding hand position data in hand position data **133** that are higher than the weights applied to image-based position data **328**. On the other hand, when a hand of user **104** is moving slowly enough, hand data modulator **418** applies weights to the corresponding hand position data in hand position data **133** that are lower than the weights applied to image-based position data **328**. The speed at which the weights are applied may vary, depending on the particular implementation.

[0109] Further, head data modulator **420** is configured to use both head position data **120** and current frame of reference **330** to form modified head position data **424**. Head data modulator **420** may combine head position

data **120** and current frame of reference **330** and weight these two types of data to form modified head position data **424**. Current frame of reference **330** may be weighted higher than head position data **120** when head **112** of user **104** is moving slowly. Head position data **120** may be weighted higher than current frame of reference **330** when head **112** of user **104** is moving quickly.

[0110] Data modulator **408** sends modified hand position data **422** and modified head position data **424** to feedback controller **410**. Further, data modulator **408** sends modified hand position data **422** and modified head position data **424** to control data generator **412**. Control data generator **412** is configured to use modified hand position data **422** and modified head position data **424** to form virtual image control data **135**.

[0111] For example, control data generator **412** may use set of filters **425** to form virtual image control data **135**. Set of filters **425** may be configured to smooth out modified hand position data **422** and modified head position data **424**, remove undesired discontinuities in modified hand position data **422** and modified head position data **424**, and synchronize modified hand position data **422** and modified head position data **424** with respect to time. Control data generator **412** sends virtual image control data **135** to virtual image application **137**.

[0112] Image generator **338** in virtual image application **137** is configured to generate current virtual image **310** using virtual image control data **135**. In particular, image generator **338** updates previous virtual image **312** to form current virtual image **310** of virtual environment **102** in **Figure 1**. Image generator **338** sends current virtual image **310** to virtual image analyzer **411** and image visualizer **414**.

[0113] In this illustrative example, virtual image analyzer **411** is configured to analyze current virtual image **310** to generate actual data **427** based on current virtual image **310**. For example, virtual image analyzer **411** may decompose current virtual image **310** to generate actual data **427** that identifies the actual position for head **112** of user **104**, the actual position for left hand **124** of user **104**, and/or the actual position for right hand **126** of user **104** in **Figure 1** based on current virtual image **310**. Virtual image analyzer **411** sends actual data **427** to feedback controller **410**.

[0114] Feedback controller **410** is configured to use actual data **427**, set of constraints **416**, modified hand position data **422**, and modified head position data **424** to form finger position error **426**, relative hand position error **428**, and head position error **430**. Finger position error **426** may be the difference between the positions of the fingers of user **104** identified in modified hand position data **422** and the positions of the fingers of user **104** simulated in current virtual image **310**.

[0115] Further, relative hand position error **428** may be the difference between the positions of the hands of user **104** identified in modified hand position data **422** and the positions of the virtual hands in current virtual image **310** with respect to the position of head **112** of user **104** and/or

current frame of reference **330**. Head position error **430** may be the difference between the position of head **112** of user **104** identified in modified head position data **424** and the position of head **112** of user **104** indicated based on current virtual image **310**.

[0116] In some illustrative examples, feedback controller **410** may send finger position error **426**, relative hand position error **428**, and head position error **430** to control data generator **412** to adjust virtual image control data **135**. Of course, in some illustrative examples, the process of sending virtual image control data **135** to image generator **338** and feedback controller **410** using current virtual image **310** to adjust virtual image control data **135** may be repeated until virtual image control data **135** has a desired level of accuracy. In other words, this process may loop until finger position error **426**, relative hand position error **428**, and head position error **430** are within selected tolerances.

[0117] Virtual image control data **135** that has been adjusted to have the desired level of accuracy may then be used by image visualizer **414** to adjust current virtual image **310**. Image visualizer **414** may then output current virtual image **310** that has been adjusted.

[0118] In this manner, virtual image control data **135** generated over time with the desired level of accuracy may be used to generate sequence of virtual images **138** in **Figure 1**. When virtual image control data **135** is generated with the desired level of accuracy, sequence of virtual images **138** may provide user **104** with a desired level of eye-hand coordination. In other words, the positions of the virtual left hands and the virtual right hands in these virtual images may have a desired level of accuracy. Further, movement of head **112**, left hand **124**, and/or right hand **126** of user **104** may be simulated within sequence of virtual images **138** with a desired level of accuracy.

[0119] With reference now to **Figure 5**, an illustration of modes of operation for a virtual reality system is depicted in accordance with an illustrative embodiment. In this illustration example, modes **500** may be modes of operations for virtual reality system **100** in **Figure 1**. As depicted, modes **500** may include at least one of learning and calibration mode **502**, static mode **504**, dynamic mode **506**, and transparent mode **508**. Of course, in other illustrative examples, modes **500** may include one or more other modes in addition to or in place of these modes.

[0120] In learning and calibration mode **502**, user **104** in **Figure 1** may perform an actual task while using at least one of hand system **131** and head-mounted system **108** in **Figure 1**. This actual task may be, for example, a non-virtual task that is performed in reality and not in virtual reality. This non-virtual task may be, for example, without limitation, typing on a keyboard, playing a piano, playing a guitar, using different types of equipment, performing a medical procedure, performing a physical task, or some other suitable type of non-virtual task.

[0121] In learning and calibration mode **502**, virtual re-

ality manager **106** uses at least one of hand position data **133** generated by hand system **131** and head position data **120** to calibrate virtual reality system **100** in **Figure 1**. For example, virtual reality manager **106** may use the data collected while user **104** is performing the non-virtual task to correct for inconsistencies in the data generated when user **104** performs a corresponding virtual task using virtual reality system **100**.

[0122] In static mode **504**, user **104** may use virtual reality system **100** to perform a virtual task in which only the hands of user **104** may be used. For example, user **104** may use left hand **124** and/or right hand **126** in **Figure 1** to perform the virtual task. In static mode **504**, all of the virtual images in sequence of virtual images **138** displayed to user **104** may remain stationary despite any movement of head **112** of user **104** in **Figure 1**.

[0123] For example, frame of reference **146** in **Figure 1** for all of the virtual images in sequence of virtual images **138** may remain fixed and pointed towards the virtual device being controlled by hand system **131**. The positions of virtual left hand **142**, virtual right hand **144**, and/or other virtual components may change between the different virtual images in sequence of virtual images **138** in **Figure 1**, while frame of reference **146** remains stationary. In one illustrative example, virtual reality manager **106** may be configured to filter out any head position data **120** generated by sensor system **118** in head-mounted system **108** in **Figure 1**, while user **104** performs the virtual task.

[0124] In dynamic mode **506**, both hand position data **133** and head position data **120** are used by virtual reality manager **106** to control sequence of virtual images **138** displayed to user **104**. Frame of reference **146** for each image in sequence of virtual images **138** may change based on the movement of head **112** of user **104**.

[0125] In transparent mode **508**, no virtual images are displayed on display device **116** in **Figure 1**. Instead, user **104** may be allowed to see through glasses **114** in **Figure 1**. In other words, in transparent mode **508**, the lenses of glasses **114** may be made transparent.

[0126] The illustrations of virtual reality system **100** in **Figure 1**, left hand system **121** in **Figure 2**, head-mounted system **108** in **Figure 3**, data coordinator **336** in **Figure 4**, and modes **500** in **Figure 5** are not meant to imply physical or architectural limitations to the manner in which an illustrative embodiment may be implemented. Other components in addition to or in place of the ones illustrated may be used. Some components may be unnecessary. Also, the blocks are presented to illustrate some functional components. One or more of these blocks may be combined, divided, or combined and divided into different blocks when implemented in an illustrative embodiment.

[0127] In some illustrative examples, virtual image application **137** may be implemented within virtual reality system **100** in **Figure 1**. For example, virtual image application **137** may be implemented within data processing system **105**. In other illustrative examples, data manager

204 may be implemented separately from sensor system 202 in Figure 2.

[0128] In some cases, other modes may be included in modes 500 of operation for virtual reality system 100 in addition to and/or in place of the ones described in Figure 5. In one illustrative example, learning and calibration mode 502 may be separated into a learning mode and a calibration mode.

[0129] With reference now to Figure 6, an illustration of a user using a virtual reality system is depicted in accordance with an illustrative embodiment. In this illustrative example, user 600 is wearing virtual reality system 601. User 600 is an example of user 104 in Figure 1. Further, virtual reality system 601 is an example of one implementation for virtual reality system 100 in Figure 1.

[0130] As depicted, virtual reality system 601 includes head-mounted system 602, left glove 604, and right glove 606. Head-mounted system 602 is an example of one implementation for head-mounted system 108 in Figures 1 and 3. As depicted, head-mounted system 602 includes glasses 608. Glasses 608 are an example of one implementation for glasses 114 in Figures 1 and 3. Further, left glove 604 and right glove 606 are examples of implementations for left glove 128 and right glove 130, respectively, in Figure 1.

[0131] In this illustrative example, a virtual reality manager, such as virtual reality manager 106 in Figure 1, may visually present virtual image 610 on glasses 608 in front of the eyes of user 600. Virtual image 610 may be an example of one implementation for virtual image 140 in Figure 1. Further, virtual image 610 is an image of a virtual environment. The virtual reality manager is configured to use data generated by left glove 604, right glove 606, and head-mounted system 602 in response to movement of user 600 to allow user 600 to control and interact with this virtual environment.

[0132] With reference now to Figure 7, an illustration of a process for interacting with a virtual engineering environment in the form of a flowchart is depicted in accordance with an illustrative embodiment. The process illustrated in Figure 7 may be implemented using virtual reality system 100 in Figure 1. In particular, this process may be implemented using virtual reality manager 106 in communication with virtual image application 137 in Figures 1 and 3.

[0133] The process may begin by receiving hand position data for at least one hand of a user from a hand system (operation 700). Hand position data may include position data for a left hand and/or a right hand of a user. The hand system may comprise a left glove for the left hand of the user and/or a right glove for the right hand of the user. The hand system may be, for example, hand system 131 in Figure 1.

[0134] The process may then receive head position data for the head of the user from a head-mounted system (operation 702). The head-mounted system may be, for example, head-mounted system 108 in Figures 1 and 3. In one illustrative example, the head-mounted system

may take the form of glasses 114 in Figures 1 and 3.

[0135] Thereafter, the process identifies image-based position data and a current frame of reference for a current time using a target image for the current time (operation 704). Operation 704 may be performed using, for example, image processor 326 in Figure 3. The target image may be, for example, target image 324 generated using imaging system 322 in sensor system 118 associated with head-mounted system 108 in Figure 3. Target image 324 allows a position for left glove 128 and right glove 130 in target image 324 to be identified.

[0136] The process then coordinates the hand position data and the head position data with the image-based position data and the current frame of reference to form virtual image control data (operation 706). Operation 706 may be performed using, for example, data coordinator 336 in Figures 3 and 4. Then, the process generates a current virtual image of a virtual environment using the virtual image control data (operation 708), with the process terminating thereafter.

[0137] With reference now to Figure 8, an illustration of a process for interacting with a virtual engineering environment in the form of a flowchart is depicted in accordance with an illustrative embodiment. The process illustrated in Figure 8 may be implemented using virtual reality system 100 in Figure 1. Further, this process is a more-detailed process of the process described in Figure 7.

[0138] The process begins by receiving left hand position data and right hand position data from a left glove and a right glove, respectively (operation 800). The left hand position data identifies positions for a left hand of a user over time. The right hand position data identifies positions for a right hand of the user over time.

[0139] Further, the process receives head position data from a sensor system in a head-mounted system (operation 802). The head position data identifies positions for the head of the user over time.

[0140] The process then receives a sequence of target images from an imaging system in the sensor system of the head-mounted system (operation 804). Thereafter, the process identifies image-based position data and a current frame of reference for a current time using a target image in the sequence of target images corresponding to the current time (operation 806).

[0141] Next, the process synchronizes the left hand position data, the right hand position data, and the head position data with respect to time (operation 808). The process then coordinates the synchronized left hand position data, right hand position data, and head position data with the image-based position data and the current frame of reference to form virtual image control data (operation 810).

[0142] The process sends the virtual image control data to a virtual image application using a cloud (operation 812). The virtual image application is configured to use the virtual image control data to generate a current virtual image of a virtual environment for the current time. Next,

the process receives the current virtual image generated by the virtual image application (operation **814**).

[0143] The process displays the current virtual image on a display device associated with the head-mounted system (operation **816**), with the process returning to operation **800**. In operation **800**, the current virtual image replaces a previously-generated virtual image displayed on the display device. The user sees the current virtual image and may feel present in the virtual environment.

[0144] When the process returns to operation **800** after performing operation **816** and repeats operations **802**, **804**, and **806**, the current time used in operation **806** is a time after the current time for the current virtual image in operation **816**. In other words, the process described in **Figure 8** may be repeated to form a next virtual image. In this manner, a sequence of virtual images ordered with respect to time may be generated and displayed on the display device.

[0145] The flowcharts and block diagrams in the different depicted embodiments illustrate the architecture, functionality, and operation of some possible implementations of apparatuses and methods in an illustrative embodiment. In this regard, each block in the flowcharts or block diagrams may represent a module, segment, function, and/or a portion of an operation or step. For example, one or more of the blocks may be implemented as program code, in hardware, or a combination of the program code and hardware. When implemented in hardware, the hardware may, for example, take the form of integrated circuits that are manufactured or configured to perform one or more operations in the flowcharts or block diagrams.

[0146] In some alternative implementations of an illustrative embodiment, the function or functions noted in the blocks may occur out of the order noted in the figures. For example, in some cases, two blocks shown in succession may be executed substantially concurrently, or the blocks may sometimes be performed in the reverse order, depending upon the functionality involved. Also, other blocks may be added in addition to the illustrated blocks in a flowchart or block diagram.

[0147] Turning now to **Figure 9**, an illustration of a data processing system is depicted in accordance with an illustrative embodiment. In this illustrative example, data processing system **900** may be used to implement data processing system **105** in **Figure 1**. In this illustrative example, data processing system **900** includes communications framework **902**, which provides communications between processor unit **904**, memory **906**, persistent storage **908**, communications unit **910**, input/output (I/O) unit **912**, and display **914**.

[0148] Processor unit **904** serves to execute instructions for software that may be loaded into memory **906**. Processor unit **904** may be a number of processors, a multi-processor core, or some other type of processor, depending on the particular implementation. A number, as used herein with reference to an item, means one or more items. Further, processor unit **904** may be imple-

mented using a number of heterogeneous processor systems in which a main processor is present with secondary processors on a single chip. As another illustrative example, processor unit **904** may be a symmetric multi-processor system containing multiple processors of the same type.

[0149] Memory **906** and persistent storage **908** are examples of storage devices **916**. A storage device is any piece of hardware that is capable of storing information, such as, for example, without limitation, data, program code in functional form, and/or other suitable information either on a temporary basis and/or a permanent basis. Storage devices **916** also may be referred to as computer readable storage devices in these examples. Memory **906**, in these examples, may be, for example, a random access memory or any other suitable volatile or non-volatile storage device. Persistent storage **908** may take various forms, depending on the particular implementation.

[0150] For example, persistent storage **908** may contain one or more components or devices. For example, persistent storage **908** may be a hard drive, a flash memory, a rewritable optical disk, a rewritable magnetic tape, or some combination of the above. The media used by persistent storage **908** also may be removable. For example, a removable hard drive may be used for persistent storage **908**.

[0151] Communications unit **910**, in these examples, provides for communications with other data processing systems or devices. In these examples, communications unit **910** is a network interface card. Communications unit **910** may provide communications through the use of either or both physical and wireless communications links.

[0152] Input/output unit **912** allows for input and output of data with other devices that may be connected to data processing system **900**. For example, input/output unit **912** may provide a connection for user input through a keyboard, a mouse, and/or some other suitable input device. Further, input/output unit **912** may send output to a printer. Display **914** provides a mechanism to display information to a user.

[0153] Instructions for the operating system, applications, and/or programs may be located in storage devices **916**, which are in communication with processor unit **904** through communications framework **902**. In these illustrative examples, the instructions are in a functional form on persistent storage **908**. These instructions may be loaded into memory **906** for execution by processor unit **904**. The processes of the different embodiments may be performed by processor unit **904** using computer-implemented instructions, which may be located in a memory, such as memory **906**.

[0154] These instructions are referred to as program code, computer usable program code, or computer readable program code that may be read and executed by a processor in processor unit **904**. The program code in the different embodiments may be embodied on different

physical or computer readable storage media, such as memory **906** or persistent storage **908**.

[0155] Program code **918** is located in a functional form on computer readable media **920** that is selectively removable and may be loaded onto or transferred to data processing system **900** for execution by processor unit **904**. Program code **918** and computer readable media **920** form computer program product **922** in these examples. In one example, computer readable media **920** may be computer readable storage media **924** or computer readable signal media **926**.

[0156] Computer readable storage media **924** may include, for example, an optical or magnetic disk that is inserted or placed into a drive or other device that is part of persistent storage **908** for transfer onto a storage device, such as a hard drive, that is part of persistent storage **908**. Computer readable storage media **924** also may take the form of a persistent storage, such as a hard drive, a thumb drive, or a flash memory, that is connected to data processing system **900**. In some instances, computer readable storage media **924** may not be removable from data processing system **900**.

[0157] In these examples, computer readable storage media **924** is a physical or tangible storage device used to store program code **918** rather than a medium that propagates or transmits program code **918**. Computer readable storage media **924** is also referred to as a computer readable tangible storage device or a computer readable physical storage device. In other words, computer readable storage media **924** is a media that can be touched by a person.

[0158] Alternatively, program code **918** may be transferred to data processing system **900** using computer readable signal media **926**. Computer readable signal media **926** may be, for example, a propagated data signal containing program code **918**. For example, computer readable signal media **926** may be an electromagnetic signal, an optical signal, and/or any other suitable type of signal. These signals may be transmitted over communications links, such as wireless communications links, optical fiber cable, coaxial cable, a wire, and/or any other suitable type of communications link. In other words, the communications link and/or the connection may be physical or wireless in the illustrative examples.

[0159] In some illustrative embodiments, program code **918** may be downloaded over a network to persistent storage **908** from another device or data processing system through computer readable signal media **926** for use within data processing system **900**. For instance, program code stored in a computer readable storage medium in a server data processing system may be downloaded over a network from the server to data processing system **900**. The data processing system providing program code **918** may be a server computer, a client computer, or some other device capable of storing and transmitting program code **918**.

[0160] The different components illustrated for data processing system **900** are not meant to provide archi-

tectural limitations to the manner in which different embodiments may be implemented. The different illustrative embodiments may be implemented in a data processing system including components in addition to or in place of those illustrated for data processing system **900**. Other components shown in **Figure 9** can be varied from the illustrative examples shown. The different embodiments may be implemented using any hardware device or system capable of running program code. As one example, the data processing system may include organic components integrated with inorganic components and/or may be comprised entirely of organic components excluding a human being. For example, a storage device may be comprised of an organic semiconductor.

[0161] In another illustrative example, processor unit **904** may take the form of a hardware unit that has circuits that are manufactured or configured for a particular use. This type of hardware may perform operations without needing program code to be loaded into a memory from a storage device to be configured to perform the operations.

[0162] For example, when processor unit **904** takes the form of a hardware unit, processor unit **904** may be a circuit system, an application specific integrated circuit (ASIC), a programmable logic device, or some other suitable type of hardware configured to perform a number of operations. With a programmable logic device, the device is configured to perform the number of operations. The device may be reconfigured at a later time or may be permanently configured to perform the number of operations. Examples of programmable logic devices include, for example, a programmable logic array, a field programmable logic array, a field programmable gate array, and other suitable hardware devices. With this type of implementation, program code **918** may be omitted, because the processes for the different embodiments are implemented in a hardware unit.

[0163] In still another illustrative example, processor unit **904** may be implemented using a combination of processors found in computers and hardware units. Processor unit **904** may have a number of hardware units and a number of processors that are configured to run program code **918**. With this depicted example, some of the processes may be implemented in the number of hardware units, while other processes may be implemented in the number of processors.

[0164] In another example, a bus system may be used to implement communications framework **902** and may be comprised of one or more buses, such as a system bus or an input/output bus. Of course, the bus system may be implemented using any suitable type of architecture that provides for a transfer of data between different components or devices attached to the bus system.

[0165] Additionally, a communications unit may include a number of devices that transmit data, receive data, or transmit and receive data. A communications unit may be, for example, a modem or a network adapter, two network adapters, or some combination thereof. Fur-

ther, a memory may be, for example, memory 906 or a cache, such as found in an interface and memory controller hub that may be present in communications framework 902.

[0166] Thus, the different illustrative embodiments provide a method and apparatus for generating virtual images of a virtual environment. In one illustrative embodiment, a method for generating a virtual image of a virtual environment is provided. A virtual reality manager receives hand position data for at least one hand of a user from a hand system. The virtual reality manager receives head position data for the head of the user from a head-mounted system. The virtual reality manager identifies image-based position data and a current frame of reference for a current time using a target image corresponding to the current time. The virtual reality manager generates virtual image control data for the current time using the hand position data, the head position data, the image-based position data, and the current frame of reference. The virtual image control data is configured for use by a virtual image application.

[0167] The different illustrative embodiments provide a method and system for allowing a user to interact with a virtual environment. In particular, virtual reality system 100 in Figure 1 allows a user, such as user 104 in Figure 1, to interact with a virtual image application, such as virtual image application 137 in Figure 1. The user may interact with the virtual image application in a manner that affects the virtual environment managed using the virtual image application.

[0168] Virtual reality system 100 may be used to perform virtual engineering. For example, a user may use virtual reality system 100 to interact with a virtual engineering environment. Virtual reality system 100 is configured to provide a desired level of eye-hand coordination such that the user may experience a desired level of immersion within the virtual engineering environment.

[0169] In the figures and the text, in one aspect, a method is disclosed for generating a virtual image 140 of a virtual environment 102, the method includes: receiving, at a virtual reality manager 106, hand position data for at least one hand of a user 104 from a hand system 131; receiving, at the virtual reality manager 106, head position data 120 for a head 112 of the user 104 from a head-mounted system 108; identifying, by the virtual reality manager 106, image-based position data 328 and a current frame of reference 330 for a current time 314 using a target image corresponding to the current time 314; and generating, by the virtual reality manager 106, virtual image control data for the current time 314 using the hand position data 133, the head position data 120, the image-based position data 328, and the current frame of reference 330, wherein the virtual image control data 135 is configured for use by a virtual image application 137.

[0170] In one variant, the method further includes: sending, by the virtual reality manager 106, the virtual image control data 135 to the virtual image application 137; and generating, by the virtual image application 137,

a current virtual image 310 of the virtual environment 102 for the current time 314 using the virtual image control data 135 for the current time 314.

In another variant, the method includes wherein the step of generating the current virtual image 310 of the virtual environment 102 for the current time 314 using the virtual image control data 135 for the current time 314 includes: positioning a virtual left hand 142 and a virtual right hand 144 in the current virtual image 130 based on the virtual image control data 135, wherein the virtual left hand 142 is an image representing a left hand 124 of the user 104 and the virtual right hand 144 is an image representing a right hand 126 of the user 104.

[0171] In yet another variant, the method further includes: displaying, by the virtual reality manager 106, the current virtual image 310 of the virtual environment 102 to the user 104 on a display device 116 associated with the head-mounted system 108, wherein the current virtual image 310 replaces a previous virtual image 312 displayed on the display device 116. In one example, the method includes wherein the step of generating the virtual image control data 135 for the current time 314 using the hand position data 133, the head position data 120, the image-based position data 328, and the current frame of reference 330 includes: synchronizing, by the virtual reality manager 106, the hand position data 133 and the head position data 120 with respect to time. In still another variant, the method further includes: generating left hand position data 134 using a left glove 128 configured to substantially conform to a left hand 124 of the user 104; and generating right hand position data 136 using a right glove 130 configured to substantially conform to a right hand 126 of the user 104, wherein the left hand position data 134 and the right hand position data 136 form the hand position data 133.

[0172] In one instance, the method includes wherein the step of generating the virtual image control data 135 for the current time 314 includes: identifying modified hand position data 422 using left hand position data 134 in the hand position data 133, right hand position data 136 in the right hand position data, and the image-based position data 328; identifying modified head position data 120 using the head position data 120 and the current frame of reference 330; and generating the virtual image control data 135 using the modified hand position data 422, the modified head position data 120, and a set of constraints 416. In another instance, the method includes wherein the step of generating the virtual image control data 135 for the current time 314 further includes identifying the set of constraints 416 using user data 145, wherein the user data 145 is based on a set of user images 150.

[0173] In yet another instance, the method includes wherein the step of generating the virtual image control data 135 using the modified hand position data 422, the modified head position data 120, and the set of constraints 416 includes: identifying a finger position error 426, a relative hand position error 428, and a head po-

sition error 430 using a feedback controller 410, the modified hand position data, the modified head position data 422, and the set of constraints 416; and generating the virtual image control data 135 with a desired level of accuracy using the feedback controller 410, the finger position error 426, the relative hand position error 428, and the head position error 430. In one example, the method includes wherein the virtual environment 102 is a simulation of an engineering environment selected from one of a design environment, a manufacturing environment, a computer environment, a testing environment, a data management environment, an inspection environment, and an operations environment.

[0174] In one aspect, a virtual reality system is disclosed including: a head-mounted system 108 configured to be worn relative to a head 112 of a user 104; and a virtual reality manager 106 associated with the head-mounted system 108, wherein the virtual reality manager 106 is configured to: receive hand position data 133 for at least one hand of the user 104 from a hand system 131; receive head position data 120 for the head 112 of the user 104 from a sensor system 118 in the head-mounted system 108; identify image-based position data 328 and a current frame of reference 330 for a current time 314 using a target image corresponding to the current time 314; and generate virtual image control data 135 for the current time 314 using the hand position data 133, the head position data 133, the image-based position data 328, and the current frame of reference 330, wherein the virtual image control data 135 is configured for use by a virtual image application 137.

[0175] In one variant, the virtual reality system includes wherein the virtual reality manager 106 is configured to send the virtual image control data 135 to the virtual image application 137 and receive a current virtual image 310 of a virtual environment 102 for the current time 314 from the virtual image application 137. In another variant, the virtual reality system further includes: a display device 116 associated with the head-mounted system 108, wherein the virtual reality manager 106 is further configured to display the current virtual image 310 of the virtual environment 102 to the user 104 on the display device 116. In yet another variant, the virtual reality system includes wherein the current virtual image 310 includes a virtual left hand 142 and a virtual right hand 144 in which the virtual left hand 142 is an image representing a left hand 124 of the user 104 and the virtual right hand 14 is an image representing a right hand 126 of the user 104.

[0176] In still another variant, the virtual reality system includes wherein the virtual reality manager 106 comprises: a data coordinator 336 configured to synchronize the hand position data 133 and the head position data 120 with respect to time, wherein the data coordinator 336 includes: a hand data modulator 418 configured to identify modified hand position data 422 using left hand position data 134 in the hand position data 133, right hand position data 136 in the hand position data 133, and the image-based position data 328; a head data mod-

ulator 420 configured to identify modified head position data 120 using the head position data 120 and the current frame of reference 330; a control data generator 412 configured to generate the virtual image control data 135 using the modified hand position data 422, the modified head position data 120, and a set of constraints 416; and a constraint identifier 406 configured to identify the set of constraints 416 using user data 145, wherein the user data 145 is based on a set of user images 150.

[0177] In one instance, the virtual reality system includes wherein the data coordinator 336 further includes: a feedback controller 410 configured to identify a finger position error 426, a relative hand position error 428, and a head position error 430 using the modified hand position data 422, the modified head position data 120, and the set of constraints 416, wherein the control data generator 412 is configured to use the finger position error 428, the relative hand position error 430, and the head position error 430 to generate the virtual image control data 135. In still another instance, the virtual reality system includes wherein the virtual reality system further includes: the hand system 131, wherein the hand system 131 includes: a left glove 128 configured to generate left hand position data 134, wherein the left glove 128 is configured to substantially conform to a left hand 124 of the user 104; and a right glove 130 configured to generate right hand position data 136, wherein the right glove 130 is configured to substantially conform to a right hand 126 of the user 104.

[0178] In yet another instance, the virtual reality system includes wherein the virtual image control data 135 is used to control a virtual image 140 of a virtual environment 102 in which the virtual environment 102 is a simulation of an engineering environment 103 selected from one of a design environment, a manufacturing environment, a computer environment, a testing environment, a data management environment, an inspection environment, and an operations environment.

[0179] In one aspect, a computer is disclosed including: a bus; a non-transitory storage device connected to the bus, wherein the non-transitory storage device includes program code; and a processor unit 904 connected to the bus, wherein the processor unit 904 is configured to execute the program code to: receive hand position data 133 for at least one hand of a user 104 from a hand system 131; receive head position data 120 for a head 112 of the user 104 from a head-mounted system 108;

identify image-based position data 328 and a current frame of reference 330 for a current time 134 using a target image corresponding to the current time 134; and generate virtual image control data 135 for the current time 314 using the hand position data 133, the head position data 120, the image-based position data 328, and the current frame of reference 330, wherein the virtual image control data 135 is configured for use by a virtual image application 137.

[0180] In one variant, the computer includes wherein

the processor unit 904 is further configured to execute the program code to display a current virtual image 310 for the current time 314, received from the virtual image application 137, on a display device 116 associated with the head-mounted system 108.

[0181] The description of the different illustrative embodiments has been presented for purposes of illustration and description and is not intended to be exhaustive or limited to the embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different illustrative embodiments may provide different features as compared to other illustrative embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

Claims

1. A method for generating a virtual image (140) of a virtual environment (102), the method comprising:

receiving, at a virtual reality manager (106), hand position data for at least one hand of a user (104) from a hand system (131);
 receiving, at the virtual reality manager (106), head position data (120) for a head (112) of the user (104) from a head-mounted system (108);
 identifying, by the virtual reality manager (106), image-based position data (328) and a current frame of reference (330) for a current time (314) using a target image corresponding to the current time (314); and
 generating, by the virtual reality manager (106), virtual image control data for the current time (314) using the hand position data (133), the head position data (120), the image-based position data (328), and the current frame of reference (330), wherein the virtual image control data (135) is configured for use by a virtual image application (137).

2. The method of claim 1 further comprising:

sending, by the virtual reality manager (106), the virtual image control data (135) to the virtual image application (137); and
 generating, by the virtual image application (137), a current virtual image (310) of the virtual environment (102) for the current time (314) using the virtual image control data (135) for the current time (314); wherein the step of generating the current virtual image (310) of the virtual environment (102) for the current time (314) us-

ing the virtual image control data (135) for the current time (314) includes: positioning a virtual left hand (142) and a virtual right hand (144) in the current virtual image (130) based on the virtual image control data (135), wherein the virtual left hand (142) is an image representing a left hand (124) of the user (104) and the virtual right hand (144) is an image representing a right hand (126) of the user (104).

3. The method of any of claims 1 or 2 further comprising:

displaying, by the virtual reality manager (106), the current virtual image (310) of the virtual environment (102) to the user (104) on a display device (116) associated with the head-mounted system (108), wherein the current virtual image (310) replaces a previous virtual image (312) displayed on the display device (116); and
 generating left hand position data (134) using a left glove (128) configured to substantially conform to a left hand (124) of the user (104); and
 generating right hand position data (136) using a right glove (130) configured to substantially conform to a right hand (126) of the user (104), wherein the left hand position data (134) and the right hand position data (136) form the hand position data (133) wherein the step of generating the virtual image control data (135) for the current time (314) using the hand position data (133), the head position data (120), the image-based position data (328), and the current frame of reference (330) comprises:
 synchronizing, by the virtual reality manager (106), the hand position data (133) and the head position data (120) with respect to time.

4. The method of any of claims 1 or 2, wherein the step of generating the virtual image control data (135) for the current time (314) comprises:

identifying modified hand position data (422) using left hand position data (134) in the hand position data (133), right hand position data (136) in the right hand position data, and the image-based position data (328);
 identifying modified head position data (120) using the head position data (120) and the current frame of reference (330);
 generating the virtual image control data (135) using the modified hand position data (422), the modified head position data (120), and a set of constraints (416); and
 identifying the set of constraints (416) using user data (145), wherein the user data (145) is based on a set of user images (150).

5. The method of claim 4, wherein the step of generating the virtual image control data (135) using the modified hand position data (422), the modified head position data (120), and the set of constraints (416) comprises:

identifying a finger position error (426), a relative hand position error (428), and a head position error (430) using a feedback controller (410), the modified hand position data, the modified head position data (422), and the set of constraints (416); and
 generating the virtual image control data (135) with a desired level of accuracy using the feedback controller (410), the finger position error (426), the relative hand position error (428), and the head position error (430); wherein the virtual environment (102) is a simulation of an engineering environment selected from one of a design environment, a manufacturing environment, a computer environment, a testing environment, a data management environment, an inspection environment, and an operations environment.

6. A virtual reality system comprising:

a head-mounted system (108) configured to be worn relative to a head (112) of a user (104); and a virtual reality manager (106) associated with the head-mounted system (108), wherein the virtual reality manager (106) is configured to:

receive hand position data (133) for at least one hand of the user (104) from a hand system (131);
 receive head position data (120) for the head (112) of the user (104) from a sensor system (118) in the head-mounted system (108);
 identify image-based position data (328) and a current frame of reference (330) for a current time (314) using a target image corresponding to the current time (314); and
 generate virtual image control data (135) for the current time (314) using the hand position data (133), the head position data (133), the image-based position data (328), and the current frame of reference (330), wherein the virtual image control data (135) is configured for use by a virtual image application (137).

7. The virtual reality system of claim 6 further comprising:

a display device (116) associated with the head-mounted system (108), wherein the virtual real-

ity manager (106) is further configured to display a current virtual image (310) of the virtual environment (102) to the user (104) on the display device (116);

wherein the virtual reality manager (106) is configured to send the virtual image control data (135) to the virtual image application (137) and receive the current virtual image (310) of the virtual environment (102) for the current time (314) from the virtual image application (137); wherein the current virtual image (310) includes a virtual left hand (142) and a virtual right hand (144) in which the virtual left hand (142) is an image representing a left hand (124) of the user (104) and the virtual right hand (144) is an image representing a right hand (126) of the user (104).

8. The virtual reality system of any of claims 6 or 7, wherein the virtual reality manager (106) comprises:

a data coordinator (336) configured to synchronize the hand position data (133) and the head position data (120) with respect to time, wherein the data coordinator (336) comprises:

a hand data modulator (418) configured to identify modified hand position data (422) using left hand position data (134) in the hand position data (133), right hand position data (136) in the hand position data (133), and the image-based position data (328);
 a head data modulator (420) configured to identify modified head position data (120) using the head position data (120) and the current frame of reference (330);
 a control data generator (412) configured to generate the virtual image control data (135) using the modified hand position data (422), the modified head position data (120), and a set of constraints (416); and
 a constraint identifier (406) configured to identify the set of constraints (416) using user data (145), wherein the user data (145) is based on a set of user images (150);

wherein the data coordinator (336) further comprises:

a feedback controller (410) configured to identify a finger position error (426), a relative hand position error (428), and a head position error (430) using the modified hand position data (422), the modified head position data (120), and the set of constraints (416), wherein the control data generator (412) is configured to use the finger position error (428), the relative hand position error (430), and the head position error (430) to

generate the virtual image control data (135).

9. The virtual reality system of any of claims 6-8, wherein the virtual reality system further comprises: 5

the hand system (131), wherein the hand system (131) comprises:

a left glove (128) configured to generate left hand position data (134), wherein the left glove (128) is configured to substantially conform to a left hand (124) of the user (104); and 10

a right glove (130) configured to generate right hand position data (136), wherein the right glove (130) is configured to substantially conform to a right hand (126) of the user (104); 15

wherein the virtual image control data (135) is used to control a virtual image (140) of a virtual environment (102) in which the virtual environment (102) is a simulation of an engineering environment (103) selected from one of a design environment, a manufacturing environment, a computer environment, a testing environment, a data management environment, an inspection environment, and an operations environment. 20 25 30

10. The method of any of claims 1-5 for generating the virtual image (140) of the virtual environment (102) being executable by a computer comprising:

a bus; 35
 a non-transitory storage device connected to the bus, wherein the non-transitory storage device includes a program code; and
 a processor unit (904) connected to the bus, wherein the processor unit (904) is configured to execute the program code including the steps of the method of any of the claims 1-5. 40

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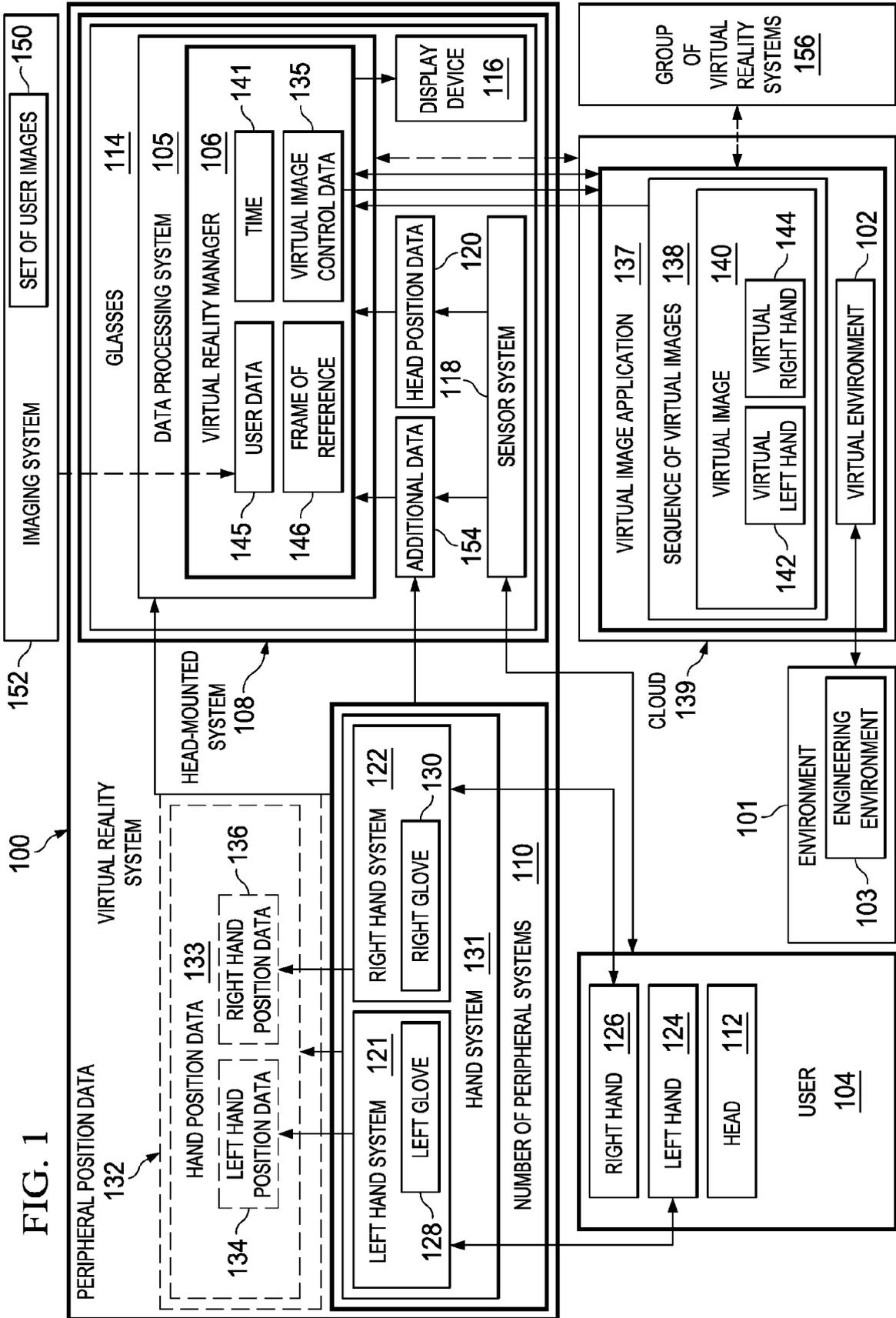
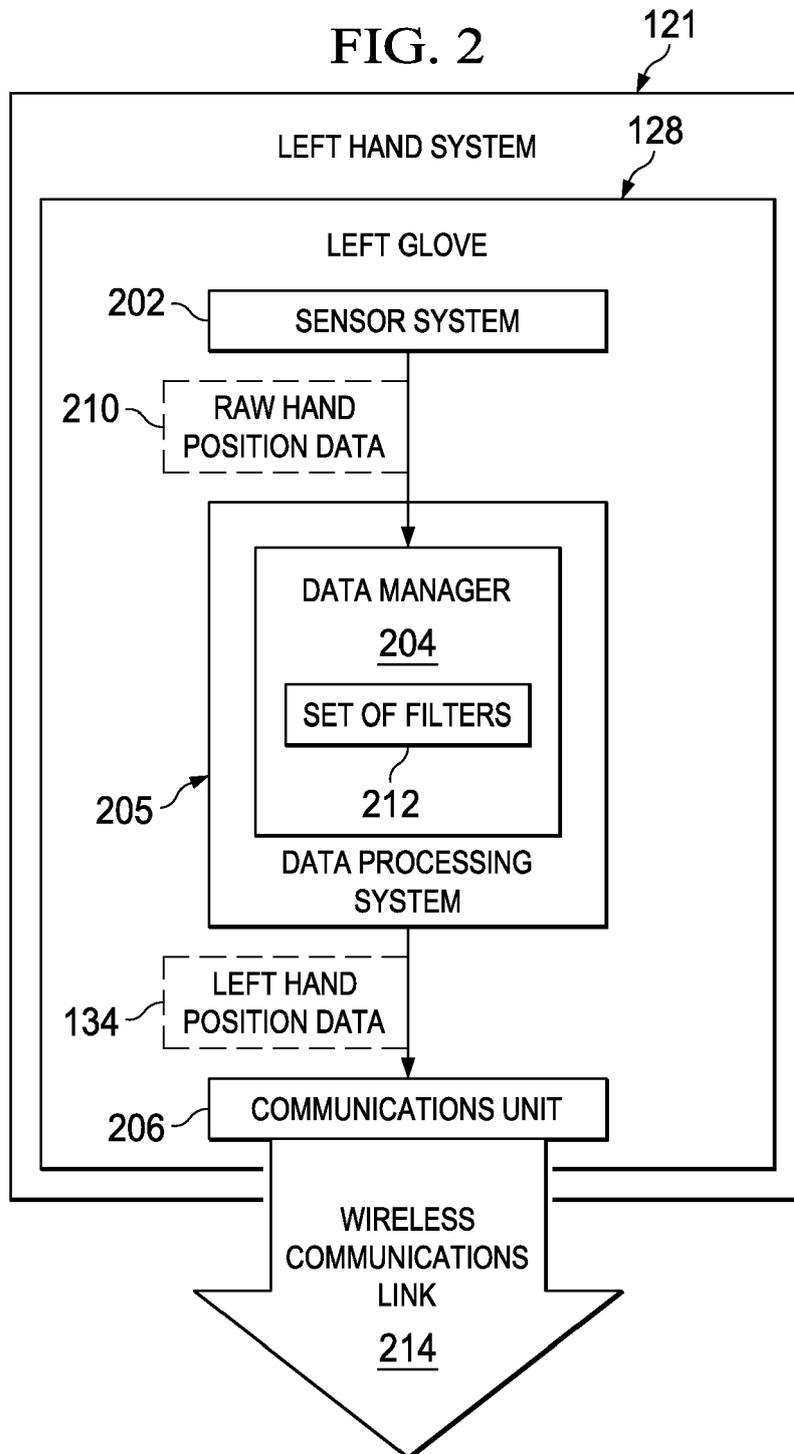


FIG. 2



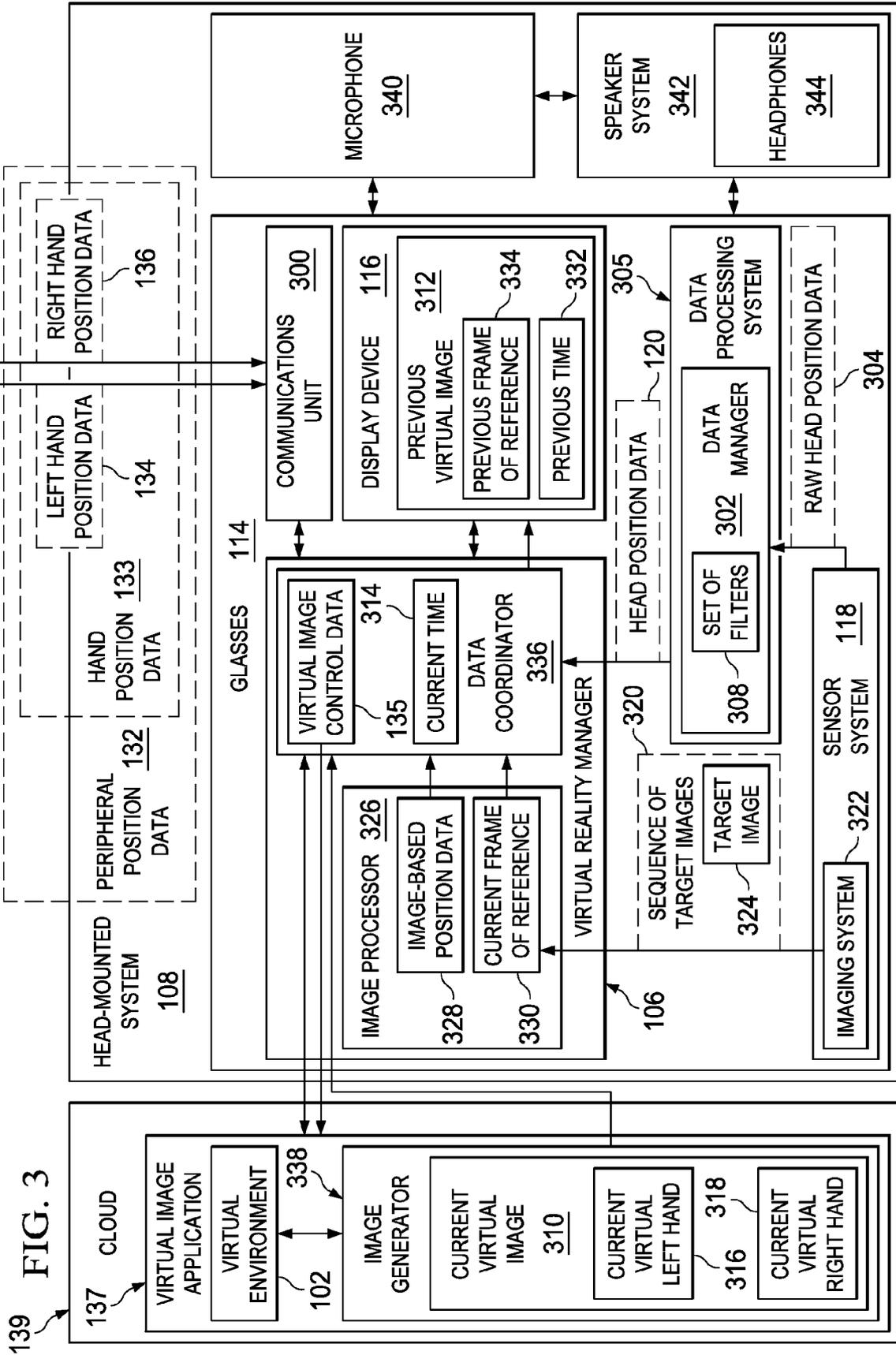
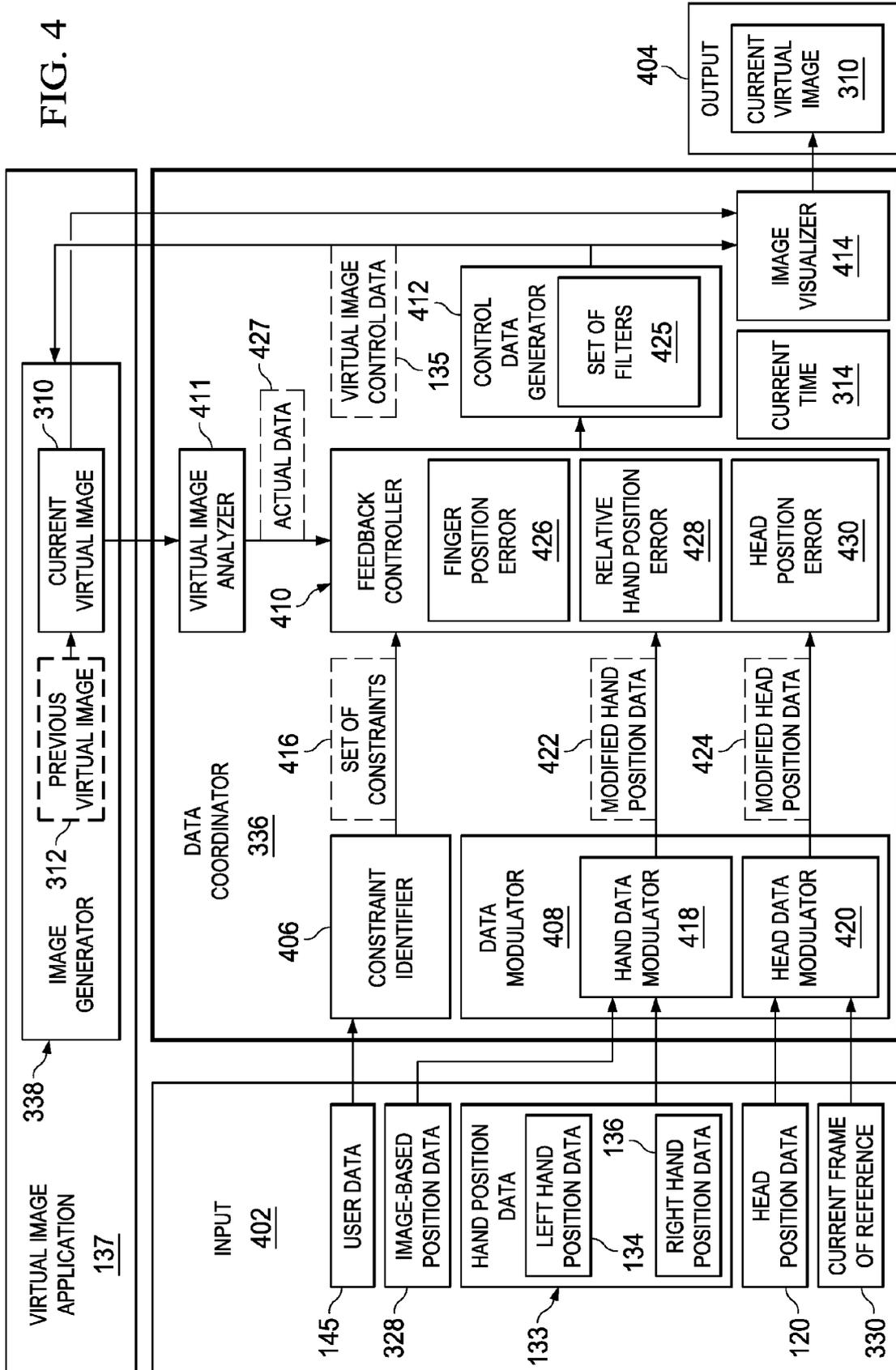


FIG. 4



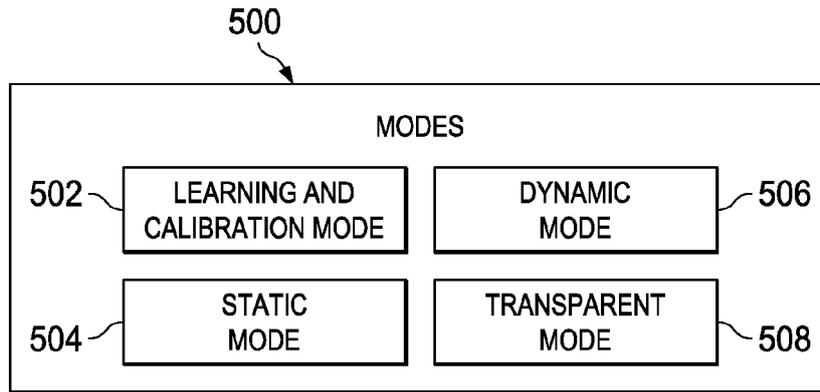


FIG. 5

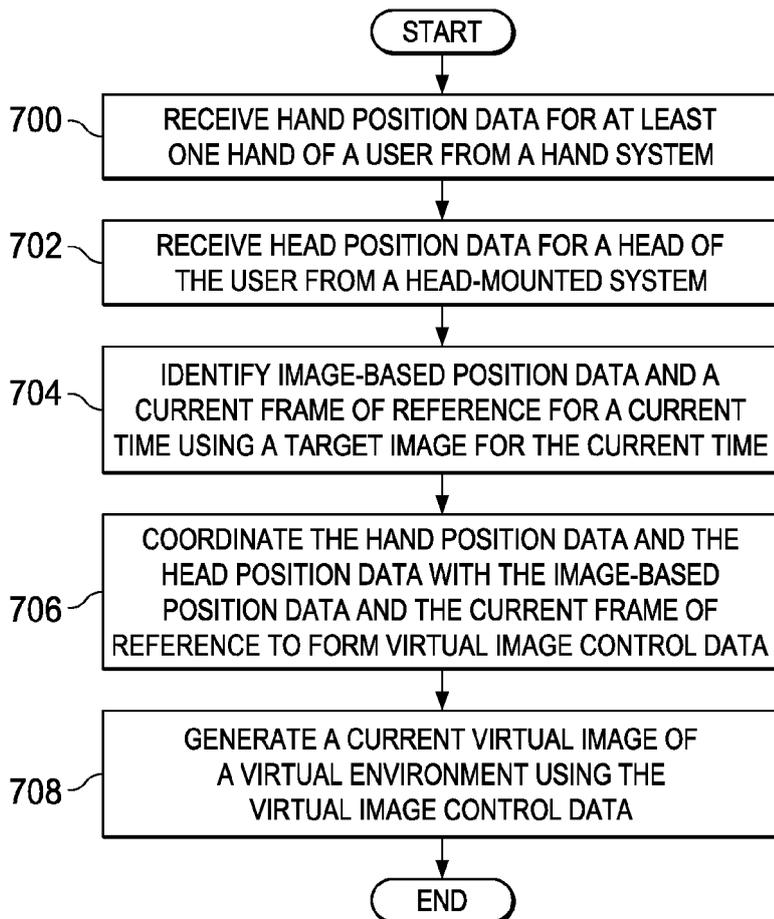
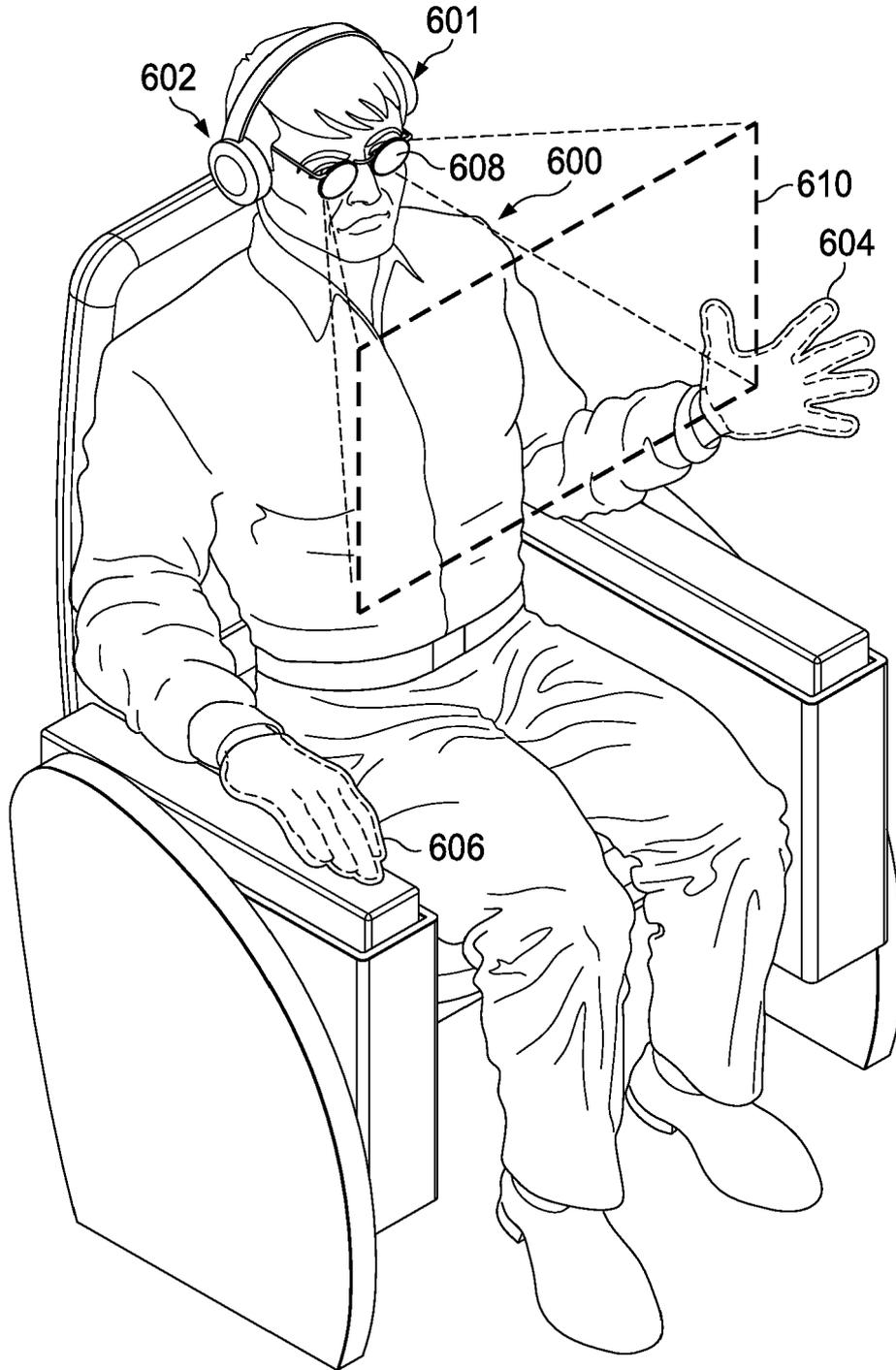


FIG. 7

FIG. 6



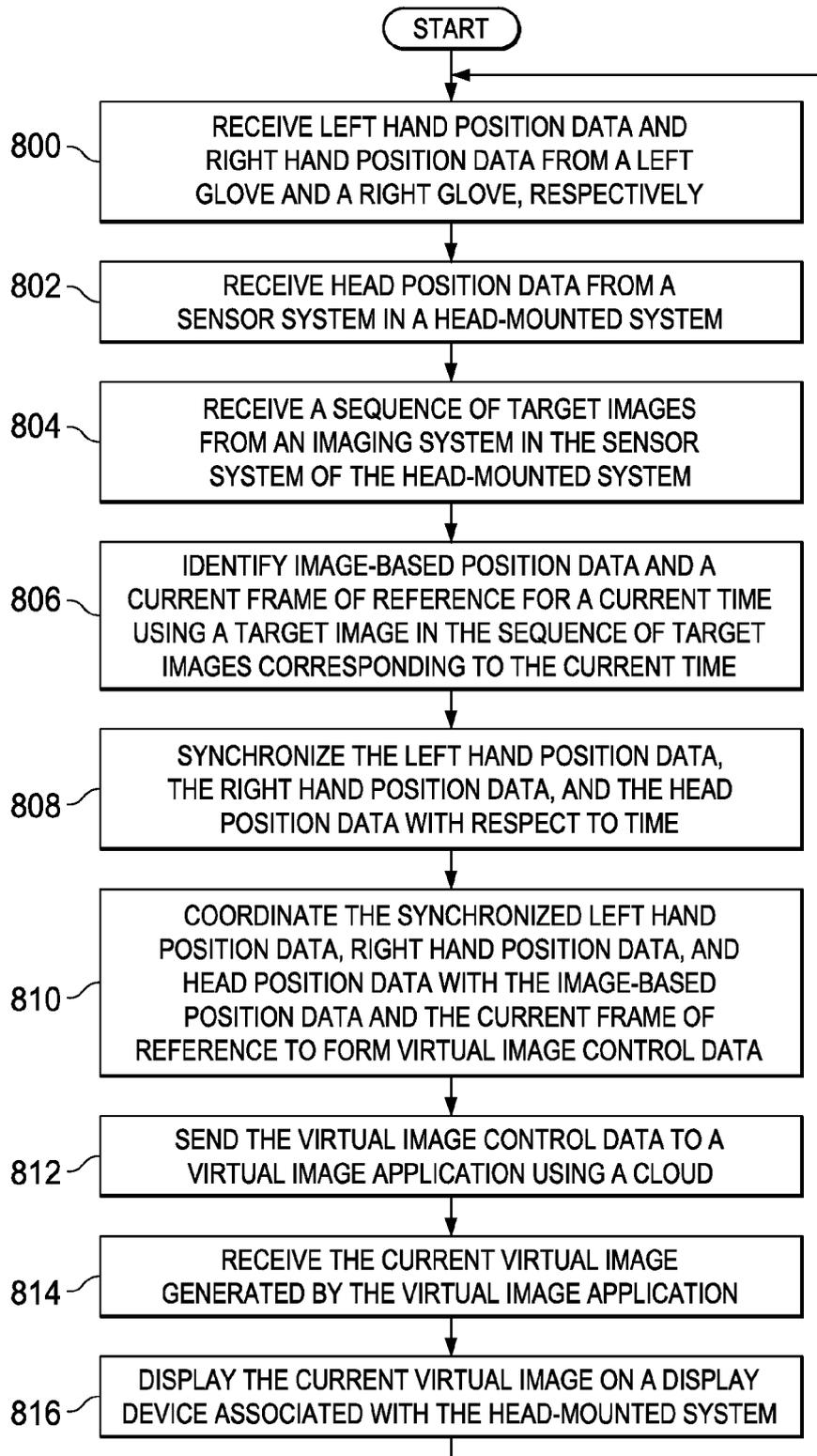


FIG. 8

FIG. 9

