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(54) **SPARSE PROJECTION FOR A VIRTUAL REALITY SYSTEM**

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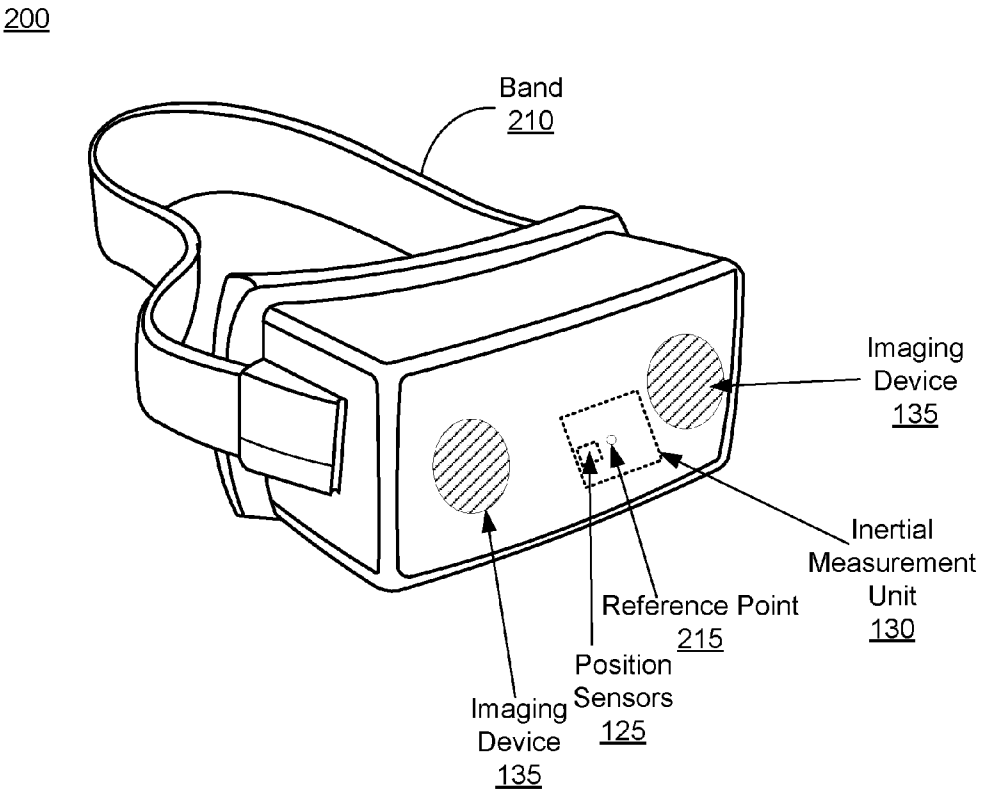
(57) **ABSTRACT**

A virtual reality (VR) includes a sparse projection system configured to generate a plurality of clusters using one or more diffractive optical elements. Each generated cluster has a unique configuration that corresponds to a unique location in a virtual mapping of a local area. The sparse projection system projects the generated clusters throughout the local area. A VR console receives a series of images of the local area from the imaging device, with at least one image includes at least one cluster. The VR console determines a location of a VR headset within the virtual mapping of the local area based at least in part on a configuration of the at least one cluster included in the series of images. Content is generated based at least in part on the determined location of the VR headset and is provided to the VR headset for presentation.



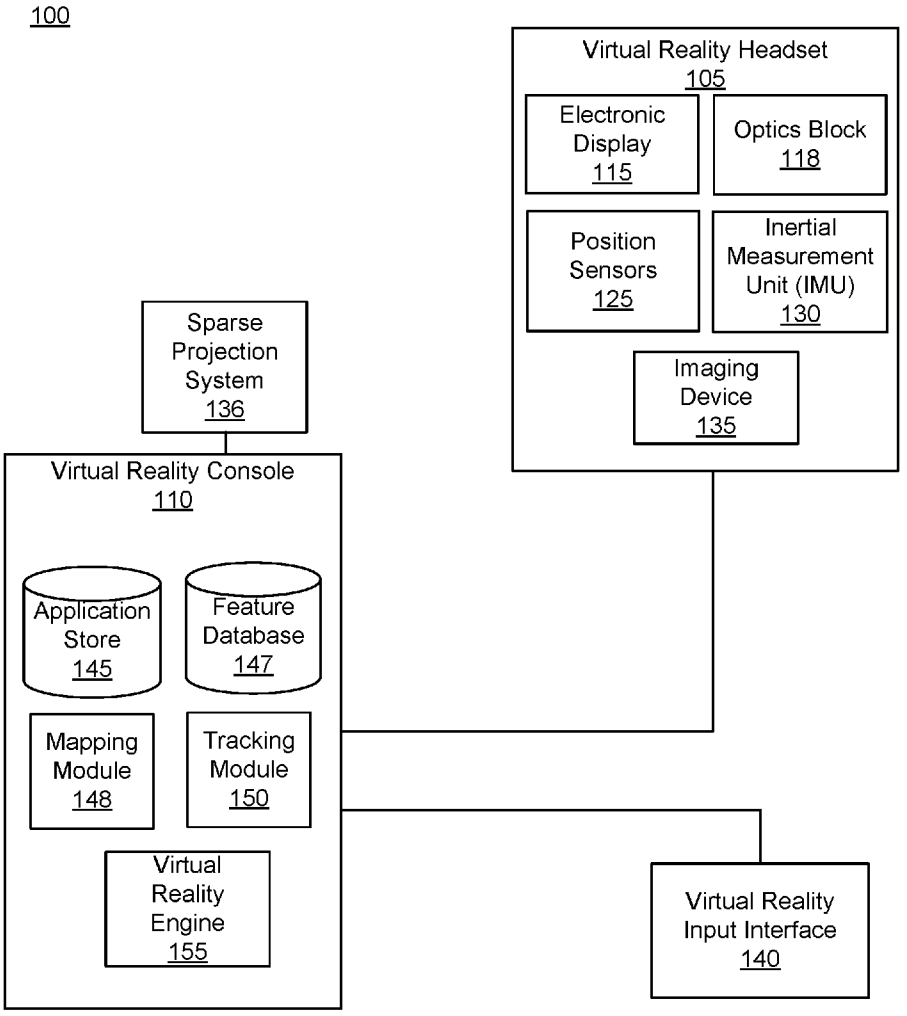

100
Virtual Reality Headset
105
Electronic Display
115
Optics Block
118
Position Sensors
125
Inertial Measurement Unit (IMU)
130
Imaging Device
135
Sparse Projection System
136
Virtual Reality Console
110
Application Store
145
Feature Database
147
Mapping Module
148
Tracking Module
150
Virtual Reality Engine
155
Virtual Reality Input Interface
140

FIG. 1

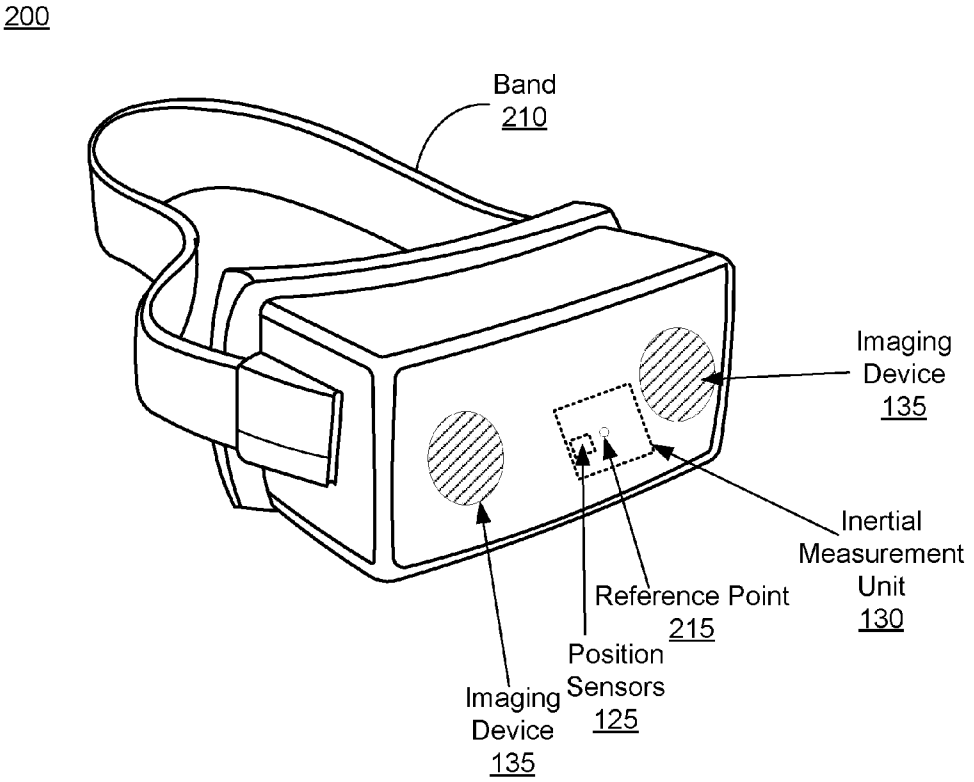

200
Band
210
Imaging
Device
135
Inertial
Measurement
Unit
130
Reference Point
215
Position
Sensors
125
Imaging
Device
135

FIG. 2

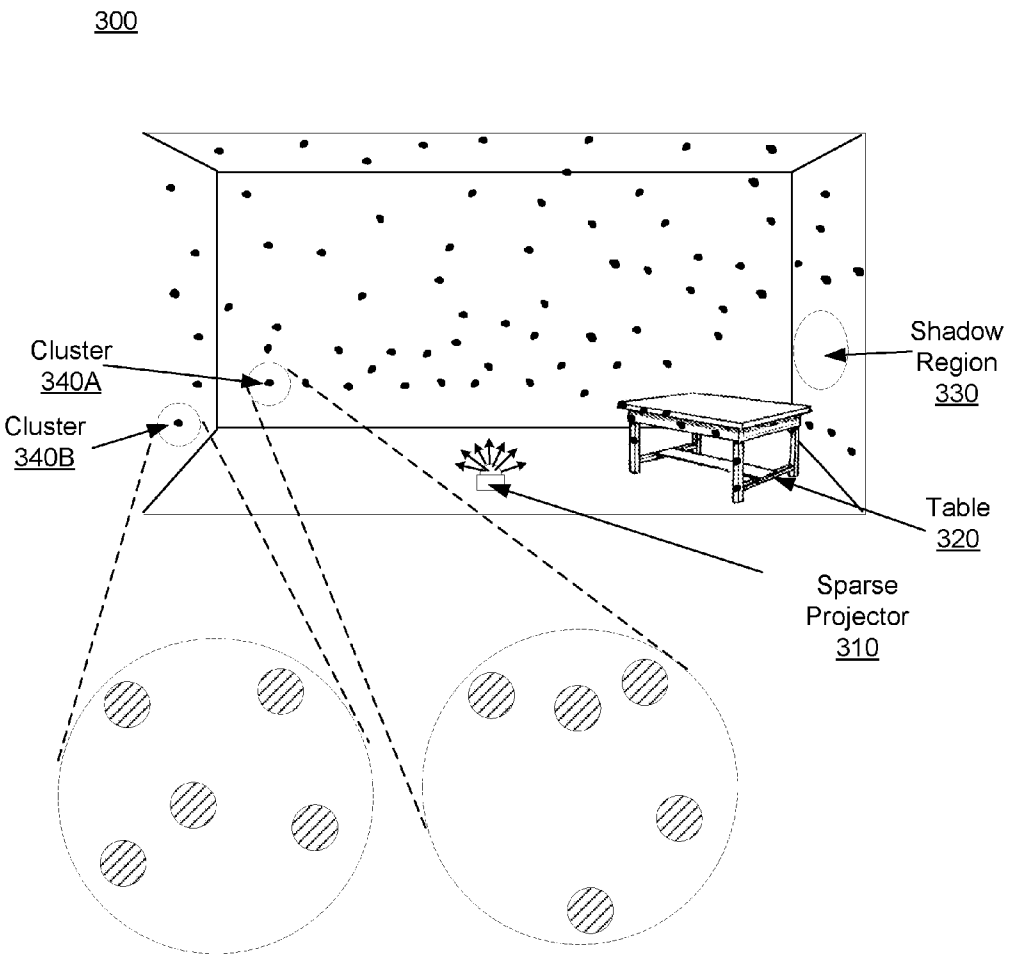

300
Cluster
340A
Cluster
340B
Shadow
Region
330
Table
320
Sparse
Projector
310

FIG. 3

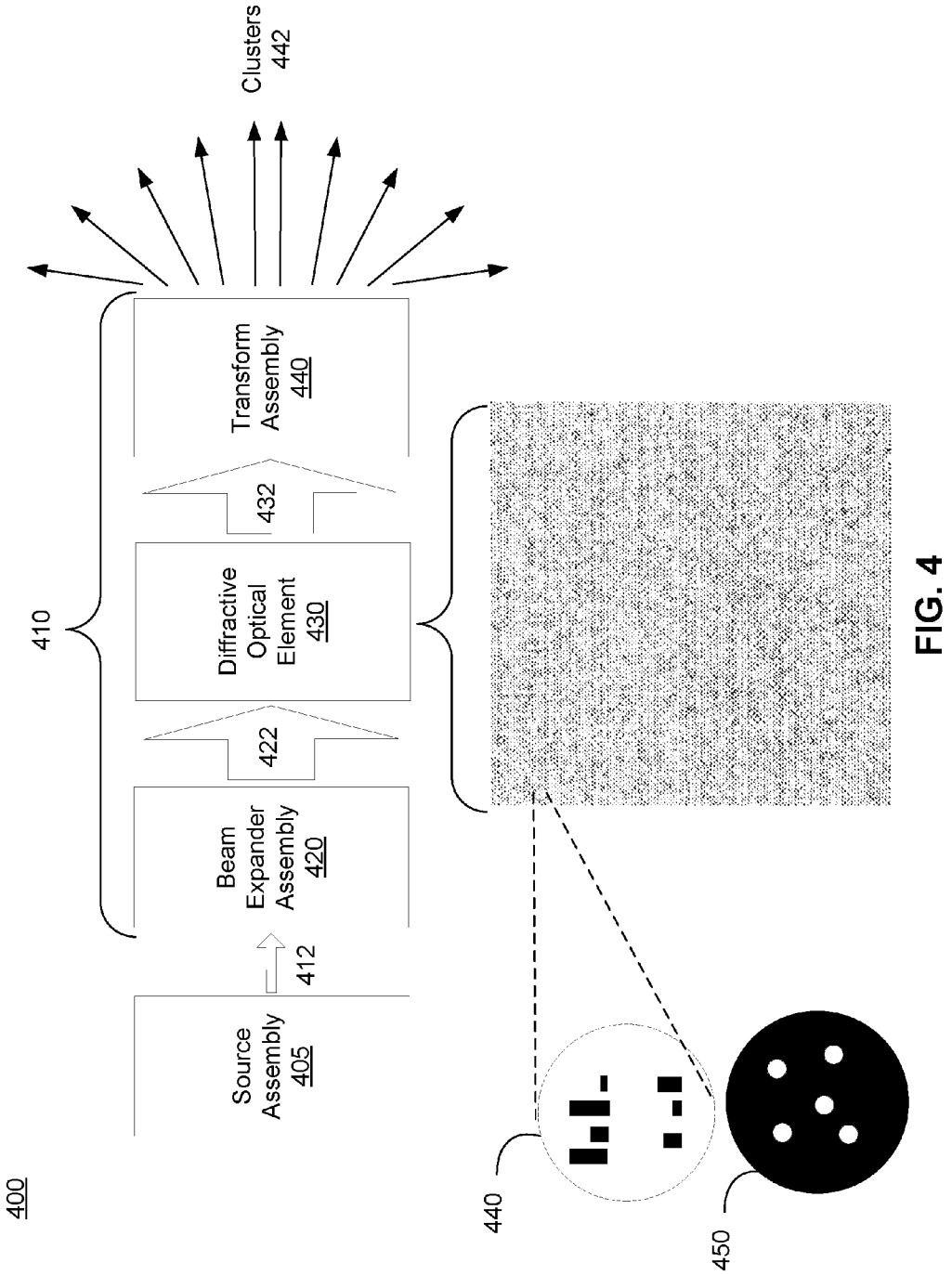

400
Source Assembly 405
412
Beam Expander Assembly 420
422
Diffractive Optical Element 430
432
Transform Assembly 440
410
Clusters 442
440
450

FIG. 4

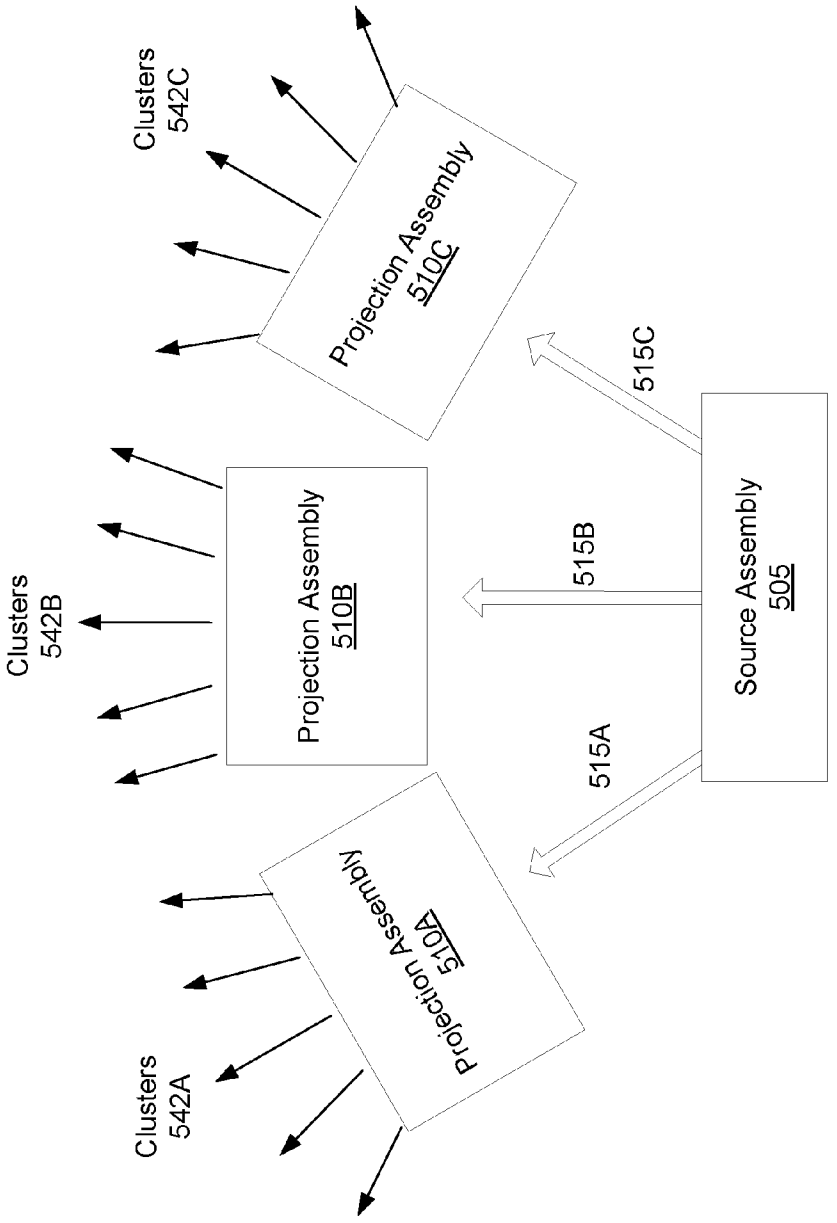

Clusters
542C
Projection Assembly
510C
515C
Source Assembly
505
515B
Clusters
542B
Projection Assembly
510B
515A
Clusters
542A
Projection Assembly
510A

FIG. 5

SPARSE PROJECTION FOR A VIRTUAL REALITY SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 62/128,433, filed Mar. 4, 2015, the disclosure of which is hereby incorporated by reference in its entirety.

BACKGROUND

[0002] The present disclosure generally relates to virtual reality systems, and more specifically relates to projection systems for virtual reality systems.

[0003] Virtual reality (VR) systems include components for determining position and movement of a VR headset worn by a user. Conventional VR systems determine position and movement of a VR headset through active devices (e.g., light emitting diodes) that emit light used by the VR system to track the location of the VR headset. However, using active components to track position and movement VR headsets increases the complexity of design and manufacture of VR headsets.

SUMMARY

[0004] A virtual reality (VR) system includes a VR headset including an imaging device, a sparse projection system, and a VR console. The sparse projection system generates a plurality of clusters using one or more diffractive optical elements and projects the clusters throughout a local area including the sparse projection system. Each cluster has a unique location configuration that corresponds to a unique location in a virtual mapping of the local area including the sparse projection system. The VR headset includes an imaging device configured to capture a series of images of portions of the local area, with one or more of the images including at least one cluster. Additionally, the VR headset includes an electronic display configured to output content based at least in part on the virtual mapping of the local area. The VR console receives the series of images from the imaging device of the VR headset and determines a location of the VR headset within the virtual mapping of the local area based at least in part on a location configuration of the at least one cluster in the series of images. For example, based at least in part on the determined location of the VR headset within the virtual mapping of the local area, the VR console generates content that is provided to the VR headset for presentation by the electronic display.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. **1** is a block diagram of a system environment including a virtual reality system, in accordance with an embodiment.

[0006] FIG. **2** is a wire diagram of a virtual reality headset, in accordance with an embodiment.

[0007] FIG. **3** is an example of a local area being illuminated by a sparse projection system, in accordance with an embodiment.

[0008] FIG. **4** is a sparse projector including a projection assembly, in accordance with an embodiment.

[0009] FIG. **5** is a block diagram of a sparse projector including multiple projection assemblies, in accordance with an embodiment.

[0010] The figures depict embodiments of the present disclosure for purposes of illustration only. One skilled in the art will readily recognize from the following description that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles, or benefits touted, of the disclosure described herein.

DETAILED DESCRIPTION

System Overview

[0011] FIG. **1** is a block diagram of a virtual reality (VR) system environment **100** in which a VR console **110** operates. The system environment **100** shown by FIG. **1** comprises a VR headset **105** that includes an imaging device **135**, a sparse projection system **136**, and a VR input interface **140** that are each coupled to the VR console **110**. While FIG. **1** shows an example system environment **100** including one VR headset **105**, one sparse projection system **136**, and one VR input interface **140**, in other embodiments any number of these components may be included in the system environment **100**. For example, there may be multiple sparse projection systems **136** projecting a plurality of clusters in a local area including the sparse projection system **136**, which the VR headset **105** and/or the VR input interface **140** use to orient themselves within a virtual mapping of the local area. In the preceding example, each VR headset **105**, VR input interface **140**, sparse projection system **136**, and imaging device **135** communicates with the VR console **110**. In alternative configurations, different and/or additional components may be included in the system environment **100**.

[0012] The sparse projection system **136** includes one or more sparse projectors that generate and project a plurality of clusters throughout a local area that includes the sparse projection system **136**. In some embodiments, the sparse projection system **136** includes one or more light sources that emit coherent light at specific bands (e.g., a range of wavelengths of light). Example bands of light emitted by one or more light sources in the sparse projection system **136** include a visible band (~380 nm to 750 nm), an infrared (IR) band (~750 nm to 1 mm), an ultraviolet band (10 nm to 380 nm), another portion of the electromagnetic spectrum, or some combination thereof. For example, a light source in the sparse projection system **136** is a laser producing light in the IR band. To generate the plurality of clusters, one or more diffractive optical elements are illuminated by the one or more light sources in the sparse projection system **136**. The generated plurality of clusters are then projected into the local area by the sparse projection system **136**. Sparse projection systems **136** are further described below in conjunction with FIGS. **4** and **5**.

[0013] A cluster is a unique pattern or configuration of illuminated regions that corresponds to a unique location in a virtual mapping of the local area including the sparse projection systems **136**. Hence, different clusters are associated with different locations in the virtual mapping of the local area, which is a real world environment onto which the sparse projection system **136** projects the clusters. For example, a local area is an interior of a room enclosing a sparse projection system **136** that projects clusters onto one or more surfaces within the room. Each cluster includes various illuminated regions that have a unique location configuration, which describes a spatial configuration of a cluster and a reflectance type of the cluster. The spatial configuration of a

cluster describes a number and an arrangement of illuminated regions within the cluster, while the reflectance type specifies a band of light (e.g., a range of wavelengths of light) used to generate the cluster. No two clusters have the same unique location configuration. For example, each cluster has a different spatial configuration, but have a common reflectance type. Alternatively, multiple clusters may have the same spatial configuration but have different reflectance types.

[0014] The VR headset **105** is a head-mounted display that presents content to a user. Examples of content presented by the VR headset **105** includes one or more images, video, audio, or some combination thereof. In some embodiments, audio is presented via an external device (e.g., speakers and/or headphones) that receives audio information from the VR headset **105**, the VR console **110**, or both, and presents audio data based on the audio information. An embodiment of the VR headset **105** is further described below in conjunction with FIG. **2**. The VR headset **105** may comprise one or more rigid bodies, which may be rigidly or non-rigidly coupled to each other together. A rigid coupling between rigid bodies causes the coupled rigid bodies to act as a single rigid entity. In contrast, a non-rigid coupling between rigid bodies allows the rigid bodies to move relative to each other. In some embodiments, the VR headset **105** may also act as an augmented reality (AR) headset and/or a mixed reality (MR) headset. In these embodiments, the VR headset **105** augments views of a physical, real-world environment with computer-generated content (e.g., images, video, sound, etc.).

[0015] In some embodiments, the VR headset **105** includes an electronic display **115**, an optics block **118**, one or more position sensors **125**, an inertial measurement unit (IMU) **130**, and an imaging device **135**. The electronic display **115** displays images to the user in accordance with data received from the VR console **110**. In various embodiments, the electronic display **115** may comprise a single electronic display or multiple electronic displays (e.g., a display for each eye of a user). Examples of the electronic display **115** include: a liquid crystal display (LCD), an organic light emitting diode (OLED) display, an active-matrix organic light-emitting diode display (AMOLED), some other display, or some combination thereof.

[0016] The optics block **118** magnifies received image light, corrects optical errors associated with the image light, and presents the corrected image light to a user of the VR headset **105**. In various embodiments, the optics block **118** includes one or more optical elements. Example optical elements included in the optics block **118** include: an aperture, a Fresnel lens, a convex lens, a concave lens, a filter, or any other suitable optical element that affects image light. Moreover, the optics block **118** may include combinations of different optical elements. In some embodiments, one or more of the optical elements in the optics block **118** may have one or more coatings, such as anti-reflective coatings.

[0017] Magnification of the image light by the optics block **118** allows the electronic display **115** to be physically smaller, weigh less, and consume less power than larger displays. Additionally, magnification may increase a field of view of the content presented by the electronic display **115**. For example, the field of view of the displayed content is such that the displayed content is presented using almost all (e.g., 110 degrees diagonal), and in some cases all, of the user's field of view. In some embodiments, the amount of magnification may be adjusted by adding or removing optical elements.

[0018] The optics block **118** may be designed to correct one or more types of optical error. Examples of optical error include two dimensional optical errors, three dimensional optical errors, or some combination thereof. Two dimensional errors are optical aberrations that occur in two dimensions. Example types of two dimensional errors include: barrel distortion, pincushion distortion, longitudinal chromatic aberration, transverse chromatic aberration, or any other type of two-dimensional optical error. Three dimensional errors are optical errors that occur in three dimensions. Example types of three dimensional errors include spherical aberration, comatic aberration, field curvature, astigmatism, or any other type of three-dimensional optical error. In some embodiments, content provided to the electronic display **115** for display is pre-distorted, so the optics block **118** corrects the distortion when it receives image light from the electronic display **115** generated based on the content.

[0019] The IMU **130** is an electronic device that generates fast calibration data indicating an estimated position of the VR headset **105** relative to an initial position of the VR headset **105** based on measurement signals received from one or more of the position sensors **125**. A position sensor **125** generates one or more measurement signals in response to motion of the VR headset **105**. Examples of position sensors **125** include: one or more accelerometers, one or more gyroscopes, one or more magnetometers, another suitable type of sensor that detects motion, a type of sensor used for error correction of the IMU **130**, or some combination thereof. The position sensors **125** may be located external to the IMU **130**, internal to the IMU **130**, or some combination thereof.

[0020] Based on the one or more measurement signals generated by the one or more position sensors **125**, the IMU **130** generates fast calibration data indicating an estimated position of the VR headset **105** relative to an initial position of the VR headset **105**. For example, the position sensors **125** include multiple accelerometers to measure translational motion (forward/back, up/down, left/right) and multiple gyroscopes to measure rotational motion (e.g., pitch, yaw, roll). In some embodiments, the IMU **130** rapidly samples the measurement signals from various position sensors **125** and calculates the estimated position of the VR headset **105** from the sampled data. For example, the IMU **130** integrates the measurement signals received from one or more accelerometers over time to estimate a velocity vector and integrates the velocity vector over time to determine an estimated position of a reference point on the VR headset **105**. Alternatively, the IMU **130** provides the sampled measurement signals to the VR console **110**, which determines the fast calibration data. The reference point is a point that may be used to describe the position of the VR headset **105**. While the reference point may generally be defined as a point in space, in practice the reference point is defined as a point within the VR headset **105** (e.g., a center of the IMU **130**).

[0021] The IMU **130** receives one or more calibration parameters from the VR console **110**. As further discussed below, the one or more calibration parameters are used to maintain tracking of the VR headset **105**. Based on a received calibration parameter, the IMU **130** may adjust one or more IMU parameters (e.g., sample rate). In some embodiments, certain calibration parameters cause the IMU **130** to update an initial position of the reference point so the initial position of the reference point corresponds to a next calibrated position of the reference point. Updating the initial position of the reference point as the next calibrated position of the reference

point helps reduce accumulated error associated with the determined estimated position. The accumulated error, also referred to as drift error, causes the estimated position of the reference point to "drift" away from the actual position of the reference point over time.

[0022] The imaging device **135** captures one or more images of the local area including the VR headset **105**, with at least a set of the captured images including at least one cluster. In various embodiments, the imaging device **135** may include one or more cameras, one or more video cameras, any other device capable of capturing images of the clusters, or some combination thereof. Additionally, the imaging device **135** may include one or more filters (e.g., for increasing signal to noise ratio). The imaging device **135** is configured to detect clusters in a field of view of the imaging device **135**. In various embodiments, the images captured by the imaging device **135** are slow calibration data that is communicated from the imaging device **135** to the VR console **110**. The imaging device **135** receives one or more calibration parameters from the VR console **110** to adjust one or more imaging parameters (e.g., focal length, focus, frame rate, ISO, sensor temperature, shutter speed, aperture, etc.) for capturing images of the local area. In alternate embodiments, the imaging device **135** is separate from the VR headset **105**.

[0023] The VR input interface **140** is a device that allows a user to send action requests to the VR console **110**. An action request is a request to perform a particular action. For example, an action request may be to start an application, to end an application, or to perform a particular action within the application. The VR input interface **140** may include one or more input devices. Example input devices include: a keyboard, a mouse, a game controller, a joystick, a yoke, or any other suitable device for receiving action requests and communicating the received action requests to the VR console **110**. An action request received by the VR input interface **140** is communicated to the VR console **110**, which performs an action corresponding to the action request. In some embodiments, the VR input interface **140** may also include an imaging device **135** that captures images of one or more clusters and provides the images to the VR console **110**.

[0024] The VR input interface **140** may also include an IMU **130** that captures fast calibration data indicating an estimated position of the VR input interface **140** relative to an initial position of the VR interface **140** and provides the fast calibration data to the VR console **110**. The IMU **130** receives one or more calibration parameters from the VR console **110**. As further discussed below, the one or more calibration parameters are used to maintain tracking of the VR interface **140**.

[0025] The VR input interface **140** may provide haptic feedback to the user in accordance with instructions received from the VR console **110** in some embodiments. For example, haptic feedback is provided to the user when an action request is received. As another example, the VR input interface **140** provides haptic feedback to the user when the VR console **110** communicates instructions to the VR input interface **140** causing the VR input interface **140** to generate haptic feedback when the VR console **110** performs an action.

[0026] The VR console **110** provides content to the VR headset **105** for presentation to the user in accordance with information received from one or more of: the imaging device **135**, the VR headset **105**, and the VR input interface **140**. In the example shown in FIG. **1**, the VR console **110** includes an application store **145**, a feature database **147**, a mapping module **148**, a tracking module **150**, and a virtual reality (VR) engine **155**. Some embodiments of the VR console **110** have different components than those described in conjunction with FIG. **1**. Similarly, the functions further described below may be distributed among components of the VR console **110** in different manners than described here in various embodiments.

[0027] The application store **145** stores one or more applications for execution by the VR console **110**. An application is a group of instructions, that when executed by a processor, generates content for presentation to the user. Content generated by an application may be in response to inputs received from the user via movement of the VR headset **105** or of the VR interface device **140**. Examples of applications include: gaming applications, conferencing applications, video playback application, or other suitable applications.

[0028] The feature database **147** stores a mapping of cross ratios to corresponding clusters in a virtual mapping of the local area. A cross ratio of a cluster is based on distances between various illuminated regions within the cluster. For example, a cross ratio of a cluster is determined from distances between pairs of coplanar illuminated regions within the cluster. As a specific example, for a cluster, a product of a distance between a first illuminated region and a second illuminated region and a distance between a third illuminated region and a fourth illuminated region is determined as well as an additional product of a distance between the first illuminated region and the fourth illuminated region and a distance between the third illuminated region and the second illuminated region. A cross ratio for the cluster is determined as a ratio of the product to the additional product, with the cross ratio stored in the feature database **147** in association with a cluster identifier associated with the cluster. Additionally, in some embodiments, a cross ratio is also associated with a reflectance type (e.g., a particular band in the IR). Accordingly, in some embodiments, a cross ratio and an additional cross ratio have the same spatial configurations, but have different reflectance types, so the cross ratio and the additional cross ratio map to different areas in the local area. Each cluster in a virtual mapping of a local area is uniquely identified by a cluster identifier. Hence, the feature database **147** stores a mapping between various cluster identifiers and their respective cross ratios.

[0029] The mapping module **148** generates a virtual mapping of the local area based on the images of projected clusters received from the VR headset **105** or from the VR input interface **140**. Additionally, the mapping module **148** determines a location of each cluster in the local area relative to the sparse projection system **136** and to the VR headset **105**. For example, the mapping module **148** uses slow calibration information (e.g., images of portions of the local area) from the VR headset **105** to calculate distances from imaged clusters to the VR headset **105**. From the information received from the VR headset **105** and the cluster information from the sparse projection system **136**, the mapping module **148** generates a virtual mapping by assigning each cluster to a specific location in a virtual space that overlays the local area via the cluster identifiers associated with different clusters.

[0030] The tracking module **150** calibrates the system environment **100** using one or more calibration parameters and may adjust one or more calibration parameters to reduce error in determination of the position of the VR headset **105**. For example, the tracking module **150** adjusts the focus of the imaging device **135** to obtain a more accurate position for

observed clusters. Moreover, calibration performed by the tracking module **150** also accounts for information received from the IMU **130** in the VR headset **105** or in the VR input interface **140**. Additionally, if tracking of the VR headset **105** or of the VR input interface **140** is lost (e.g., the imaging device **135** loses line of sight of at least a threshold number of clusters), the tracking module **150** may re-calibrate some or all of the system environment **100**.

[0031] The tracking module **150** tracks movements of the VR headset **105** or the VR input device **140** using slow calibration information from one or more imaging devices **135**. For example, the tracking module **150** determines a position of a reference point of the VR headset **105** in the virtual mapping using at least one observed cluster from the slow calibration information and the feature database **147**. For example, the tracking module **150** determines a cross ratio of the observed cluster and compares the determined cross ratio to cross ratios stored in the feature database **147**. The tracking module **150** identifies a cluster identifier from the feature database **147** associated with a cross ratio matching the determined cross ratio then determines a location in the local area corresponding to the identified cluster identifier from the mapping module **148**. In embodiments where the VR input interface **140** includes an imaging device **135**, the tracking module **150** determines a location of the VR input interface **140** in a similar manner to that described above for the VR headset **105**.

[0032] The tracking module **150** may also determine positions of the reference point of the VR headset **105** or a reference point of the VR input interface **140** using position information from the fast calibration information. Additionally, in some embodiments, the tracking module **150** may use portions of the fast calibration information, the slow calibration information, or some combination thereof, to predict a future location of the VR headset **105** or a future location of the VR input interface **140**. The tracking module **150** provides the estimated or predicted future position of the VR headset **105** or of the VR input interface **140** to the VR engine **155**.

[0033] The VR engine **155** executes applications within the system environment **100** and receives position information, acceleration information, velocity information, predicted future positions, or some combination thereof, of the VR headset **105** from the tracking module **150**. Based on the received information, the VR engine **155** determines content to provide to the VR headset **105** for presentation to the user. Content may include video information, one or more images, virtual objects, audio information, or some combination thereof. For example, if the received information indicates that the user has looked to the left, the VR engine **155** generates content for the VR headset **105** that mirrors the user's movement in a virtual environment. Additionally, the VR engine **155** performs an action within an application executing on the VR console **110** in response to an action request received from the VR input interface **140** and provides feedback to the user that the action was performed. The provided feedback may be visual or audible feedback via the VR headset **105** or haptic feedback via the VR input interface **140**.

[0034] FIG. **2** is a wire diagram of a virtual reality (VR) headset **200**, in accordance with an embodiment. The VR headset **200** is an embodiment of the VR headset **105**, and includes a front rigid body **205** and a band **210**. The front rigid body **205** includes one or more electronic display elements of the electronic display **115** (not shown), the IMU **130**, the one or more position sensors **125**, and the imaging device **135**. In some embodiments, the imaging device **135** is two different cameras, so separated images produced by the two cameras are used to determine distance from the VR headset **200** to a cluster projected by the sparse projection system **136** imaged by both cameras. In alternate embodiments, the imaging device **135** is a single camera that includes a range finder for determining distance to a cluster projected by the sparse projection system **136** being imaged. Additionally, in alternate embodiments, one or more imaging devices may be separate from the VR headset **200**. For example, one or more imaging devices may be configured to view the local area including the VR headset **200** from different vantage points.

[0035] FIG. **3** is an example of illumination of a local area **300** by a sparse projection system **136**. In the example of FIG. **3**, the local area **300** includes a sparse projector **310** that generates and projects a plurality of clusters **340** throughout the local area **300**. As described above in conjunction with FIG. **1**, each cluster has a unique location configuration describing a spatial configuration and a reflectance type of a cluster. For example, cluster **340**A has a spatial configuration that is different from the spatial configuration of cluster **340**B. As another example, cluster **340**A and cluster **340**B have a common spatial configuration but different reflectance types. As described above in conjunction with FIG.**1**, because each cluster corresponds to a unique location in the virtual mapping of the local area **300**, capturing an image including a single cluster allows identification of a location of the VR headset **105** within the virtual mapping of the local area **300**.

[0036] In some instances, the local area **300** includes one or more items (chairs, tables, couches, people, etc.). In the example of FIG. **3**, the local area **300** includes a table **320** onto which the sparse projector **310** projects certain clusters. The positioning of the table **320** relative to the sparse projector **310** creates a shadow region **330** behind the table **310** where no clusters **340** are projected. In some embodiments, to project clusters **340** into the shadow region **310**, one or more additional sparse projectors **310** are included in the local area **300** at different locations. For example, including a second sparse projector mounted to the ceiling above the table **320** in the local area **300** of FIG. **3** projects clusters into the shadow region **330**, allowing the VR console **110** to generate a better virtual mapping of the local area **300**.

[0037] FIG. **4** is a block diagram of an embodiment of a sparse projector **400** including a projection assembly **410**. In the embodiment shown in FIG. **4**, the sparse projector **400** includes a source assembly **405** and a projection assembly **410**. The source assembly **405** is a coherent light source configured to emit a coherent beam of light **412** directed to the projection assembly **410**. Examples of the source assembly **405** include a laser diode, a vertical cavity surface emitting laser, a tunable laser, or another light source that emits coherent light. In various embodiments, the source assembly **405** emits light in the IR band; however, in other embodiments, the source assembly **405** emits light in the visible band, in the UV band, or in any other suitable band. In some embodiments, the beam of light **412** may be relatively collimated. However, in some embodiments, the source assembly **405** emits a beam of light **412** that is not collimated. For example, the light emitted by the source assembly **405** may be diverging or converging. Hence, in some embodiments, the source assembly **405** also includes a collimator that collimates light from a light source into the beam of light **412**.

[0038] The projection assembly **410** receives the beam of light **412** emitted from the source assembly **405** and outputs a

plurality of clusters. In one embodiment, the projection assembly **410** includes a beam expander assembly **420**, a diffractive optical element **430**, and a transform assembly **440**. However, in other embodiments, the projection assembly **410** may include different and/or additional components than those described in conjunction with FIG. **4**.

[0039] The beam expander assembly **420** expands the beam of coherent light **412** received from the source assembly **405** to generate an expanded beam of light **422** having dimensions sufficient to fully illuminate the diffractive optical element **430**. The beam expander assembly **420** may be Galilean, Keplarian, or some other structure configured to generate an expanded beam of light **422** that fully illuminates the diffractive optical element **430** from the beam **412**. In some embodiments, a single diffractive optical element **430** may be deposited on a substrate so the beam of coherent light **412** illuminates just the single diffractive optical element **430**. In other embodiments, the substrate may include multiple diffractive optical elements **430** that each correspond to different sets of clusters, so the beam of coherent light **412** simultaneously illuminates some or all of the multiple diffractive optical elements **430**.

[0040] The diffractive optical element **430** is a two-dimensional (**2**D) Fourier transform of the plurality of clusters for projection into the local area. In various embodiments, the diffractive optical element **430** is a computer generated hologram generated using computer generated holography, such as Fourier Transform Holography. In some embodiments, the computer generated hologram is presented on a spatial light modulator (e.g., operating in phase-modulation mode). Alternatively, the computer generated hologram is a film applied to an optical element. Computer generated holography digitally generates a holographic interference pattern and applies the generated pattern to an optical element, such as the diffractive optical element **430**. Various methods may be used to encode the diffractive optical element **430** with the 2D Fourier Transform of the plurality of clusters, examples of which are described in: Brown, Byron R.; Lohmann, Adolf W., "Complex spatial filtering with binary masks," Applied Optics (Optical Society of America) Volume 5, Number 6, June 1966; and J. J. Burch (1967); and "A Computer Algorithm for the Synthesis of Spatial Frequency Filters," Proceedings of IEEE (IEEE) 55: 599-601; Burrchardt, C. B., "A Simplification of Lee's Method of Generating Holograms by Computer," Applied Optics, Volume 9, Number 8, August 1970; Lee, Wai Hon, "Sampled Fourier Transform Hologram Generated by Computer," Applied Optics, Volume 9, Number 3, March 1970, Lohmann, A. W., Paris, D. P. "Binary Fraunhofer Holograms, Generated by Computer," Applied Optics, Volume 6, Number 10, October 1967, Lohmann, A. W., Sinzinger, S. "Graphic Codes for Computer Holography," Applied Optics, Volume 34, Number 17, June 1995, which are all hereby incorporated by reference in their entirety. FIG. **4** includes a representation of an example diffractive optical element **430** that is a 2D Fourier transform of the plurality of clusters. For purposes of illustration, a portion **440** of the diffractive optical element **430** is magnified to better illustrate encoding of the diffractive optical element **430**. The vertical bars shown in the magnified portion **440** of the diffractive optical element **430** are representative of a Fourier transform of a single cluster whose amplitude and phase information have been quantized and encoded onto the portion **440** of the diffractive optical element **430**.

[0041] The diffractive optical element **430** attenuates optical power less than a mask, which is an inverse of the desired image in the far field. For example, the desired image in the far field is a plurality of clusters including one or more illuminated regions, so a mask for the desired image is transparent in locations corresponding to the illuminated regions and is opaque in other locations. For example, FIG. **4** shows a portion of a mask **450** corresponding to a single cluster. However, in practice, a mask blocks a significant portion of light, which wastes a large portion of optical power. As shown in FIG. **4**, the magnified portion **440** of the diffractive optical element **430** blocks significantly less light than the portion of the mask **450** and also corresponds to a single cluster. Accordingly, using a diffractive optical element **430** reduces the optical power needed to produce clusters **442** relative to use of a mask.

[0042] The transform assembly **440** takes an inverse Fourier transform of light **432** output from the diffractive optical element **430** to generate a plurality of clusters **442**, and projects the plurality of clusters **442** into a local area including the sparse projector **400**. For example, the transform assembly **440** includes a transform lens and a projection component. The transform lens is a positive lens that takes a **2**D inverse Fourier transform of the output **432** from the diffractive optical element **430** and outputs an image of a plurality of clusters **442** as it would appear in a far field at a back focal plane of the transform lens. As noted above, in some embodiments, multiple diffractive optical elements **430** that correspond to different sets of clusters may be illuminated at the same time, so in some instances the transform assembly **440** causes the sets of clusters to be superimposed in the far field.

[0043] The projection component of the transform assembly **440** projects the image of the clusters **442** over a large field of view (e.g., ~a hemisphere) into the local area. In various embodiments, the projection component includes one or more lenses that are positioned in relation to the image of the clusters **442** to project the clusters **442** over a large field of view. In some embodiments, a fish eye optic is used so the field of view on which the clusters **442** are projected approaches a hemisphere (e.g., 180 degrees). Additionally, in some embodiments, one or more filters and/or baffles may be used to block lower order representations of the image of the clusters **442** from being projected into the local area.

[0044] FIG. **5** is a block diagram of an embodiment of a sparse projector **500** including multiple projection assemblies **510**A, **510**B, and **510**C. In the example shown by FIG. **5**, the sparse projector **500** includes a source assembly **505** and projection assemblies **510**A, **510**B, and **510**C. The source assembly **505** is substantially similar to the source assembly **405**, which is described above in conjunction with FIG. **4**; however, the source assembly **505** is configured to output multiple beams of light **515**A, **515**B, **515**C instead of a single beam of light. In some embodiments, different beams of light **515**A, **515**B, **515**C output by the source assembly **505** are in the same ranges of wavelengths. Alternatively, different beams of light **515**A, **515**B, **515**C output by the source assembly **505** are in different ranges of wavelengths.

[0045] The projection assemblies **510**A, **510**B, and **510**C are each substantially similar to the projection assembly **410** described above in conjunction with FIG. **4**. In some embodiments, each of the projection assemblies **510**A, **510**B, and **510**C include different diffractive optical elements, so each projection assembly **510**A, **510**B, and **510**C outputs a differ-

ent set of clusters **542**A, **542**B, and **542**C, respectively. Additionally, each cluster within each set of clusters **542**A, **542**B, and **542**C is unique, so a specific cluster appears a single time in the set of clusters **542**A, **542**B, and **542**C. In alternate embodiments, the diffractive optical element in each of the projection assemblies **510**A, **510**B, and **510**C is the same, but each projection assembly **510**A, **510**B, **510**C is illuminated using a different range of wavelengths. For example, beam of light **515**A is a particular range of wavelengths, beam of light **515**B is a different range of wavelengths, and beam of light **515**C is another range of wavelengths. Accordingly, clusters in different sets of clusters **542**A, **542**B, and **542**C may have the same spatial configuration, but have different reflectance types; thus, each cluster in the sets of clusters **542**A, **542**B, **542**C, still has a unique location configuration.

[0046] Using multiple projection assemblies **510**A, **510**B, and **510**C allows an increase in the density of clusters in sets of clusters **542**A, **542**B, and **542**C within their respective fields of view of the projection assemblies **510**A, **510**B, and **510**C (~60 degrees each), because a given set of clusters **542**A, **542**B, and **542**C is not spread across the total field of view (e.g., ~180 degrees) of the sparse projector **500**. In contrast, the projection assembly **410** in FIG. **4** outputs a single set of clusters **442** over the same field of view (e.g., ~180 degrees). Accordingly, the distance between adjacent clusters in the sets of clusters **542**A, **542**B, and **542**C is smaller, potentially allowing a more accurate virtual mapping of the local area.

Additional Configuration Information

[0047] The foregoing description of the embodiments of the disclosure have been presented for the purpose of illustration; it is not intended to be exhaustive or to limit the disclosure to the precise forms disclosed. Persons skilled in the relevant art can appreciate that many modifications and variations are possible in light of the above disclosure.

[0048] Some portions of this description describe the embodiments of the disclosure in terms of algorithms and symbolic representations of operations on information. These algorithmic descriptions and representations are commonly used by those skilled in the data processing arts to convey the substance of their work effectively to others skilled in the art. These operations, while described functionally, computationally, or logically, are understood to be implemented by computer programs or equivalent electrical circuits, microcode, or the like. Furthermore, it has also proven convenient at times, to refer to these arrangements of operations as modules, without loss of generality. The described operations and their associated modules may be embodied in software, firmware, hardware, or any combinations thereof.

[0049] Any of the steps, operations, or processes described herein may be performed or implemented with one or more hardware or software modules, alone or in combination with other devices. In one embodiment, a software module is implemented with a computer program product comprising a computer-readable medium containing computer program code, which can be executed by a computer processor for performing any or all of the steps, operations, or processes described.

[0050] Embodiments of the disclosure may also relate to an apparatus for performing the operations herein. This apparatus may be specially constructed for the required purposes, and/or it may comprise a general-purpose computing device selectively activated or reconfigured by a computer program stored in the computer. Such a computer program may be stored in a non-transitory, tangible computer readable storage medium, or any type of media suitable for storing electronic instructions, which may be coupled to a computer system bus. Furthermore, any computing systems referred to in the specification may include a single processor or may be architectures employing multiple processor designs for increased computing capability.

[0051] Embodiments of the disclosure may also relate to a product that is produced by a computing process described herein. Such a product may comprise information resulting from a computing process, where the information is stored on a non-transitory, tangible computer readable storage medium and may include any embodiment of a computer program product or other data combination described herein.

[0052] Finally, the language used in the specification has been principally selected for readability and instructional purposes, and it may not have been selected to delineate or circumscribe the inventive subject matter. It is therefore intended that the scope of the disclosure be limited not by this detailed description, but rather by any claims that issue on an application based hereon. Accordingly, the disclosure of the embodiments is intended to be illustrative, but not limiting, of the scope of the disclosure, which is set forth in the following claims.

What is claimed is:

1. A system comprising:

a sparse projection system configured to:

generate a plurality of clusters using one or more diffractive optical elements, each cluster having a unique configuration that corresponds to a unique location in a virtual mapping of a local area, and

project the generated clusters throughout the local area; and

a virtual reality (VR) headset comprising:

an imaging device configured capture a series of images of portions of the local area, at least one image including at least one cluster, and

an electronic display configured to output video information based at least in part on the virtual mapping of the local area; and

a VR console comprising:

a processor; and

a memory coupled to the processor and including instructions that, when executed by the processor, cause the processor to:

receive the series of images from the imaging device;

determine a location of the VR headset within the virtual mapping of the local area based at least in part on a configuration of the at least one cluster;

generate content based at least in part on the determined location of the VR headset within the virtual mapping of the local area; and

provide the content to the VR headset for presentation by the electronic display.

2. The system of claim **1**, wherein a diffractive optical element of the one or more diffractive optical elements, is a computer generated hologram, and the sparse projection system is configured to generate a plurality of clusters by performing an inverse Fourier transform of light output from the diffractive optical element.

3. The system of claim **1**, wherein the unique configuration for a given cluster is a combination of a spatial configuration that describes a number and arrangement of illuminated

regions within the given cluster and a reflectance type that specifies a band of light used to generate the given cluster.

4. The system of claim **3**, wherein the sparse projection system comprises:

a source assembly configured to generate a beam of light and an additional beam of light;

a projection assembly configured to:

generate a set of clusters of the plurality of clusters using a diffractive optical element of the one or more diffractive optical elements and the beam of light, and

project the generated set of clusters throughout a portion of the local area; and

a second projection assembly configured to:

generate an additional set of clusters of the plurality of clusters using an additional diffractive optical element of the one or more diffractive optical elements and the additional beam of light, and

project the generated additional set of clusters throughout an additional portion of the local area.

5. The system of claim **4**, wherein the beam of light and the additional beam of light have different wavelengths so a reflectance type associated with the set of clusters is different from a reflectance type associated with the additional set of clusters.

6. The system of claim **5**, wherein the diffractive optical element and the additional diffractive optical elements are configured so spatial configurations for the first set of clusters are the same as spatial configurations for the additional set of clusters.

7. The system of claim **4**, wherein the beam of light and the additional beam of light are configured a reflectance type associated with the set of clusters is the same as a reflectance type associated with the additional set of clusters.

8. The system of claim **7**, wherein the diffractive optical element and the additional diffractive optical element are different, so spatial configurations for the set of clusters differ from and spatial configurations for the additional set of clusters.

9. A system comprising:

a sparse projection system comprising:

a source assembly configured to generate one or more beams of light, and

a projection assembly configured to:

generate a plurality of clusters using a diffractive optical element and a beam of the one or more beams of light, each cluster having a unique configuration that corresponds to a unique location in a virtual mapping of a local area, and

project the generated clusters throughout the local area; and

a virtual reality (VR) headset comprising

an imaging device configured capture a series of images of portions of the local area, at least one image including at least one cluster, and

an electronic display configured to output content based at least in part on the virtual mapping of the local area; and

a VR console comprising:

a processor; and

a memory coupled to the processor and including instructions that, when executed by the processor, cause the processor to:

receive the series of images from the imaging device;

determine a location of the VR headset within the virtual mapping of the local area based at least in part on a configuration of the at least one cluster;

generate content based at least in part on the determined location of the VR headset within the virtual mapping of the local area; and

provide the content to the VR headset for presentation by the electronic display.

10. The system of claim **9**, wherein the diffractive optical element is a computer generated hologram, and the sparse projection system is configured to generate the plurality of clusters by performing an inverse Fourier transform of light output from the diffractive optical element.

11. The system of claim **9**, wherein the unique configuration for a given cluster is a combination of a spatial configuration that describes a number and arrangement of illuminated regions within the given cluster and a reflectance type that specifies a band of light used to generate the given cluster.

12. The system of claim **11**, wherein the sparse projection system further comprises:

an additional projection assembly configured to:

generate an additional plurality of clusters using an additional diffractive optical element and an additional beam of light of the one or more beams of light, and

project the generated additional plurality of clusters throughout the local area.

13. The system of claim **12**, wherein the beam of light and the additional beam of light are different wavelengths such that a reflectance type associated with the plurality of clusters is different from a reflectance type associated with the additional plurality of clusters.

14. The system of claim **13**, wherein the diffractive optical element and the additional diffractive optical element are the same, so spatial configurations for the plurality of clusters and spatial configurations for the additional plurality of clusters are the same.

15. The system of claim **12**, wherein the beam of light and the additional beam of light are the same such that a reflectance type associated with the set of clusters is the same as a reflectance type associated with the additional set of clusters.

16. The system of claim **15**, wherein the diffractive optical element and the additional diffractive optical element are different, so spatial configurations for the plurality of clusters and spatial configurations for the additional plurality of clusters are different.

17. A system comprising:

a sparse projection system comprising:

a source assembly configured to generate one or more beams of light, and

a projection assembly configured to:

generate a plurality of clusters using a diffractive optical element and a beam of the one or more beams of light, each cluster having a unique configuration that corresponds to a unique location in a virtual mapping of a local area, and

project the generated clusters throughout the local area; and

a VR console comprising:

a processor; and

a memory coupled to the processor and including instructions that, when executed by the processor, cause the processor to:

receive the series of images from an imaging device, at least one image including at least one cluster;

determine a location of a VR headset within the virtual mapping of the local area based at least in part on a configuration of the at least one cluster;

generate content based at least in part on the determined location of the VR headset within the virtual mapping of the local area; and

provide the content to the VR headset for presentation by the electronic display.

18. The system of claim **17**, wherein a diffractive optical element of the one or more diffractive optical elements is a computer generated hologram, and the sparse projection system is configured to generate the plurality of clusters by taking an inverse Fourier transform of light output from the diffractive optical element.

19. The system of claim **17**, wherein the sparse projection system further comprises:

a source assembly configured to generate the beam of light and an additional beam of light;

a projection assembly configured to:

generate a set of clusters of the plurality of clusters using a diffractive optical element of the one or more diffractive optical elements and the beam of light, and

project the generated set of clusters throughout a portion of the local area; and

an additional projection assembly configured to:

generate an additional set of clusters of the plurality of clusters using an additional diffractive optical element of the one or more diffractive optical elements and the additional beam of light, and

project the generated additional set of clusters throughout an additional portion of the local area.

20. The system of claim **17**, wherein the unique configuration for a given cluster is a combination of a spatial configuration that describes a number and arrangement of illuminated regions within the given cluster and a reflectance type that specifies a band of light used to generate the given cluster.

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