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Buys et al.

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(54) **STAGE MAPPING AND DETECTION USING INFRARED LIGHT**

(71) Applicant: **Electronic Theatre Controls, Inc.**,
Middleton, WI (US)

(72) Inventors: **Koen Buys**, Hofstade (BE); **Dennis Varian**, Middleton, WI (US)

(73) Assignee: **Electronic Theatre Controls, Inc.**,
Middleton, WI (US)

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G01S 7/481 (2006.01)

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CPC **G01S 17/89** (2013.01); **G01S 7/4817** (2013.01); **G01S 17/894** (2020.01); **H05B 47/13** (2020.01)

(58) **Field of Classification Search**
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See application file for complete search history.

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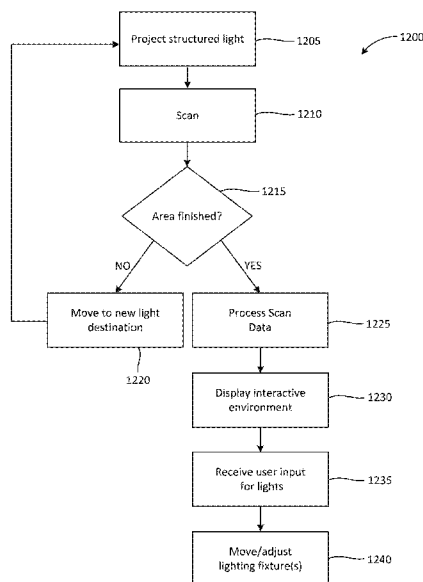
Primary Examiner — Renan Luque

(74) *Attorney, Agent, or Firm* — Michael Best & Friedrich LLP

(57) **ABSTRACT**

A system for mapping a stage includes a lighting fixture, a scanner, and a controller. The lighting fixture includes a visible light source and an infrared light source. The lighting fixture at least partially illuminates the stage with structured infrared light. The scanner detects the structured infrared light on the stage. The controller is connected to the lighting fixture and the scanner. The controller turns on the visible light source in a visible light mode and turns on the infrared light source in an infrared light mode. The infrared light source illuminates at least a portion of the stage with the structured infrared light. The controller also directs the scanner to scan the structured infrared light on the portion of the stage, receives signals from the scanner as scan data, and translates the scan data into three-dimensional location data.

12 Claims, 16 Drawing Sheets



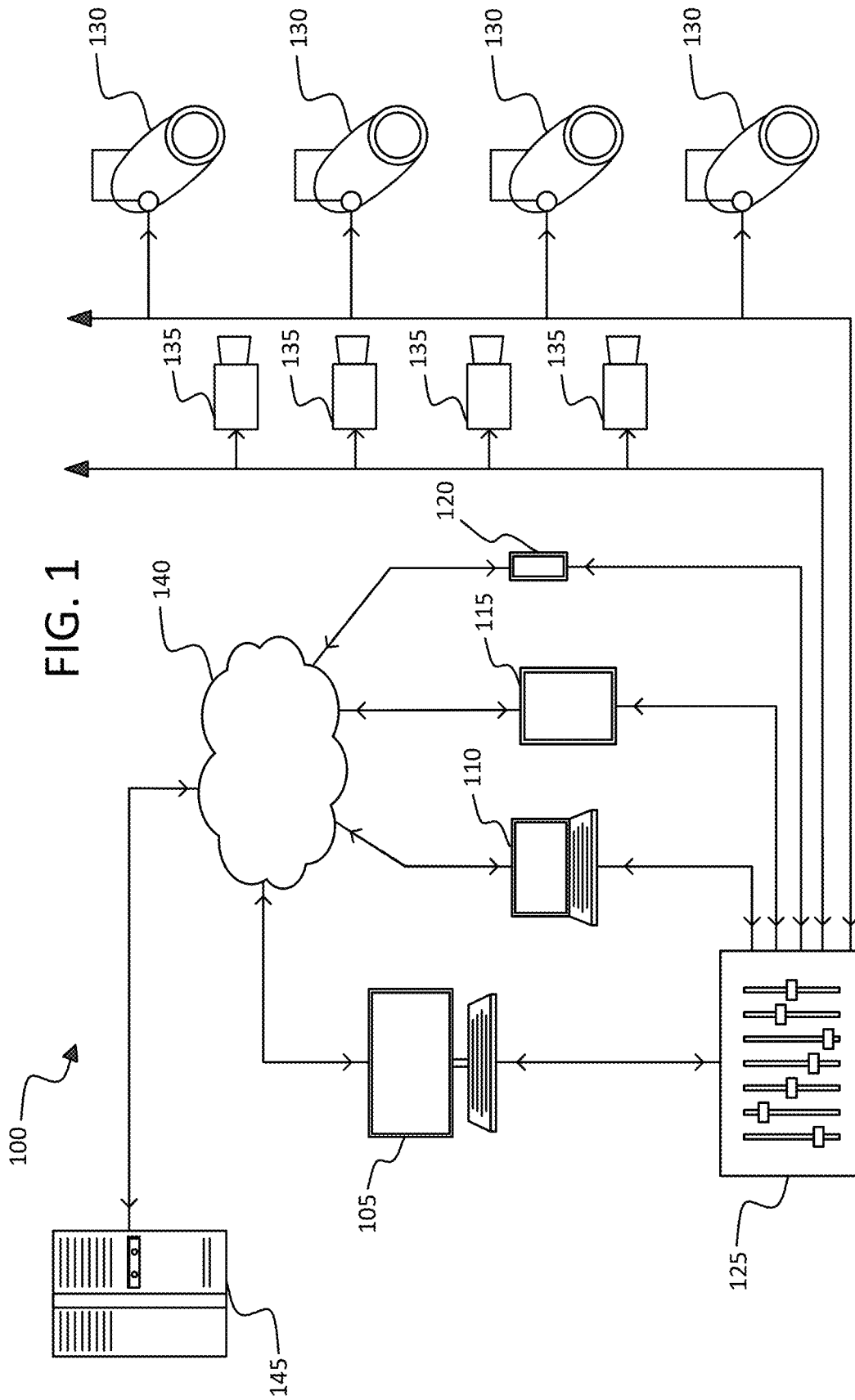
- (51) **Int. Cl.**
G01S 17/894 (2020.01)
G01S 17/89 (2020.01)

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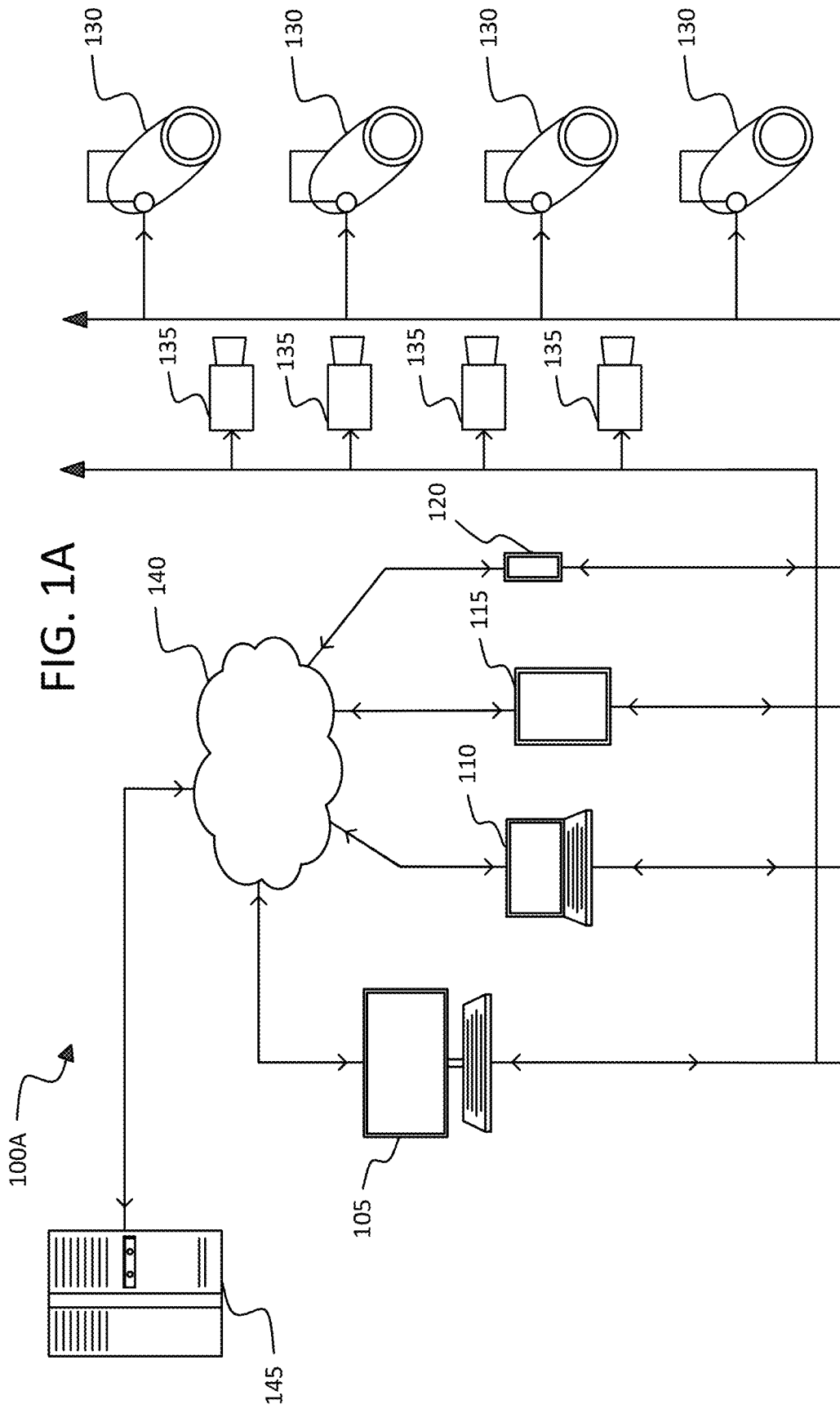


FIG. 2

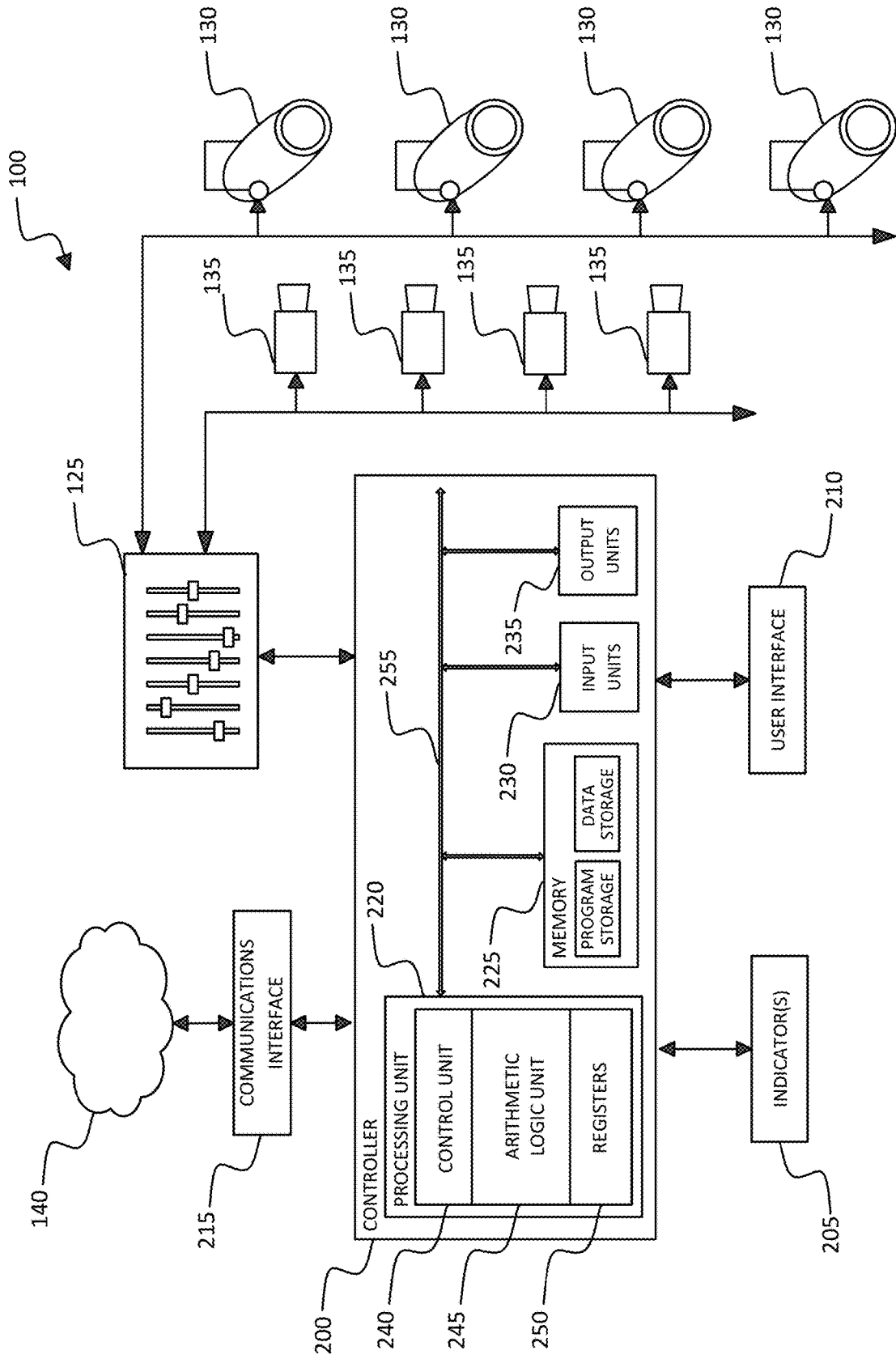
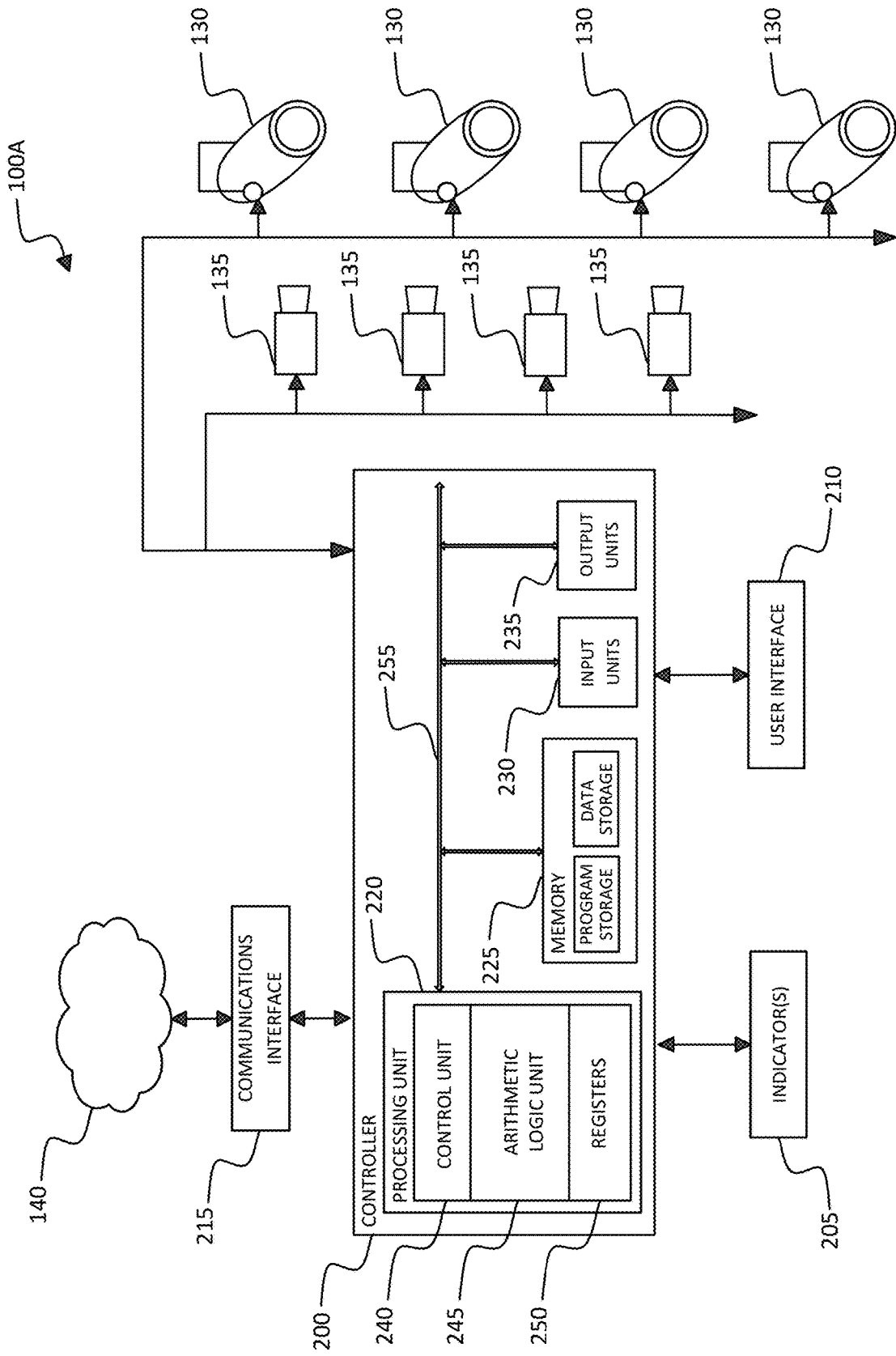


FIG. 2A



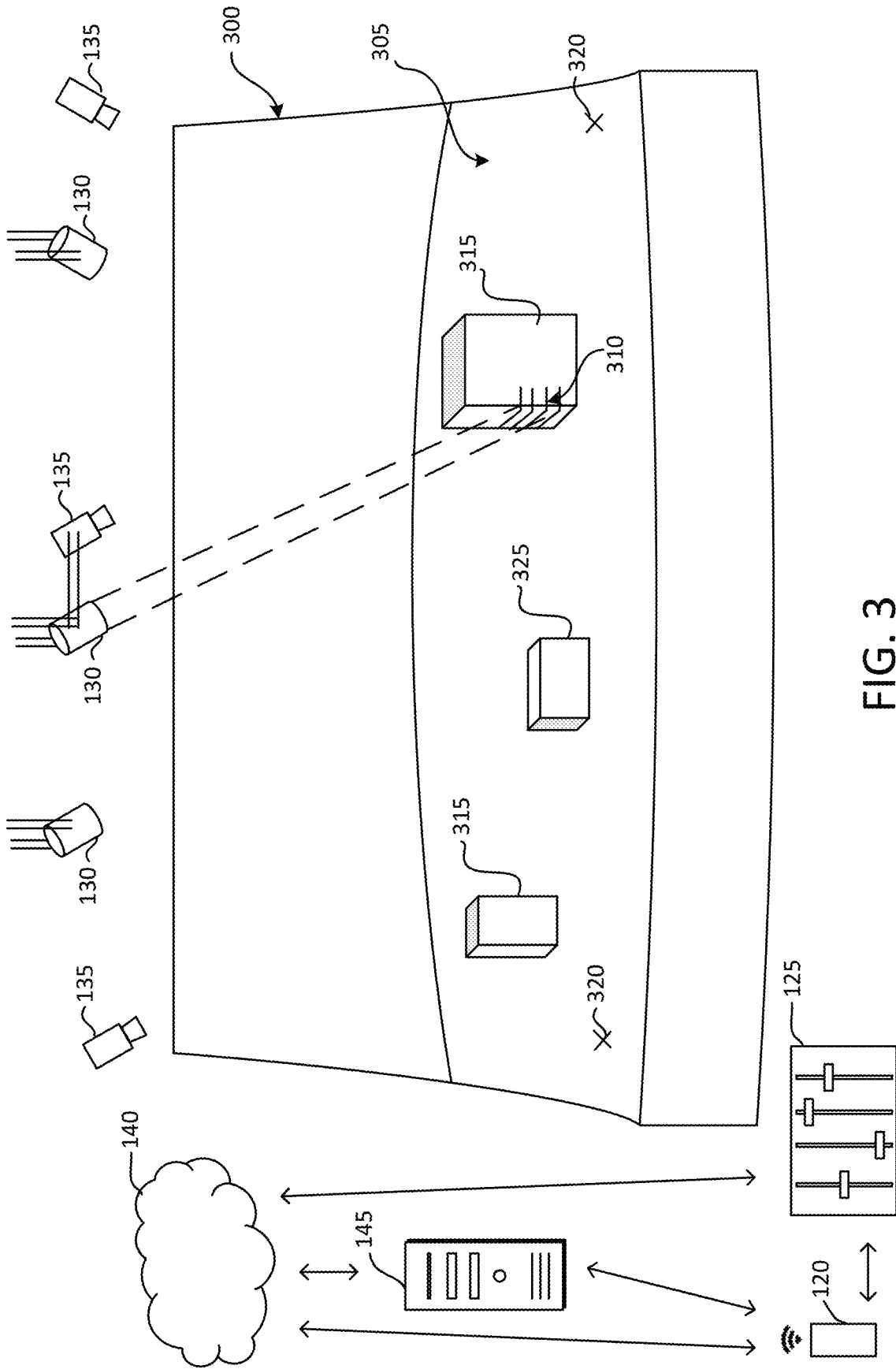


FIG. 3

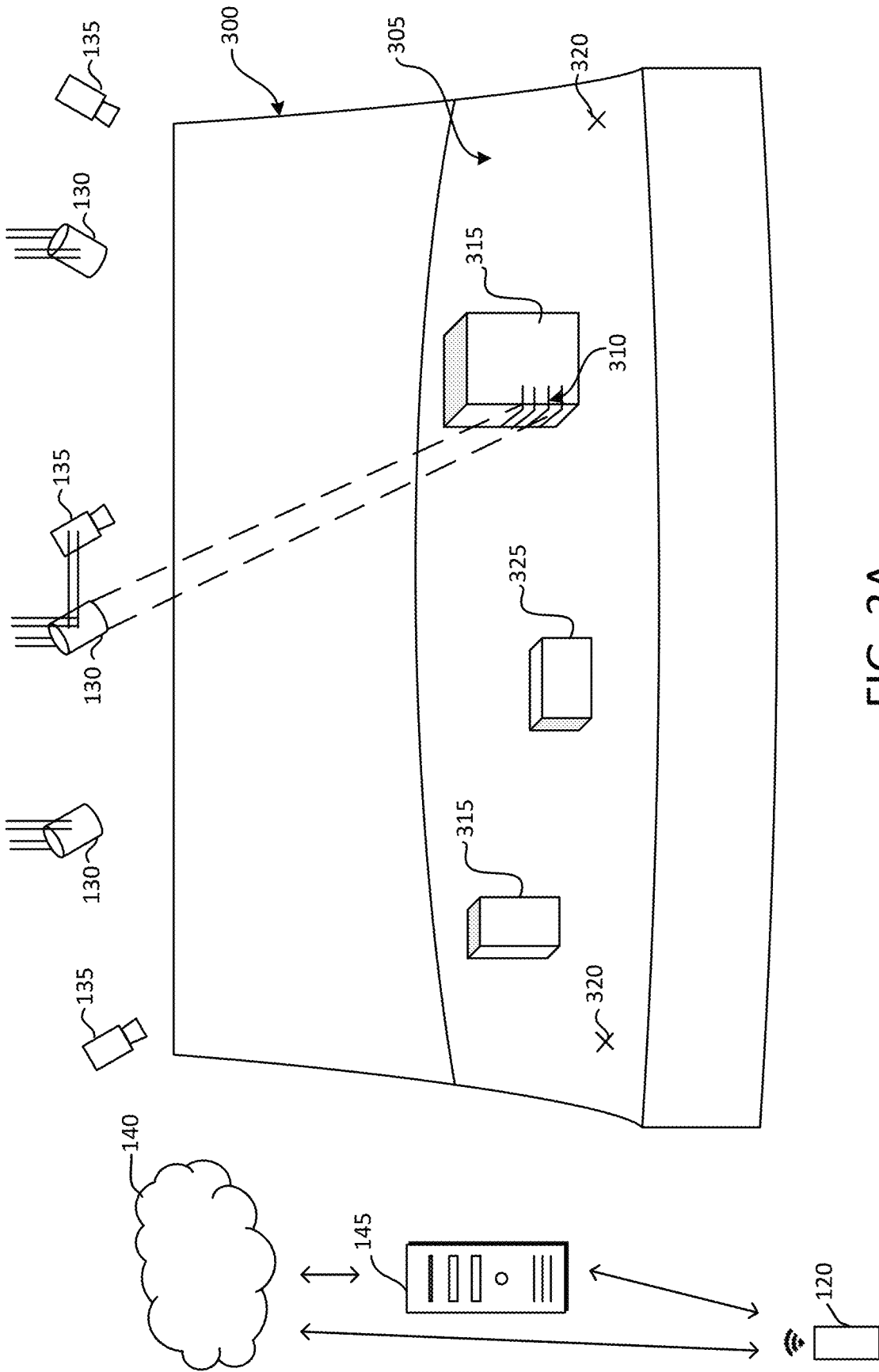


FIG. 3A

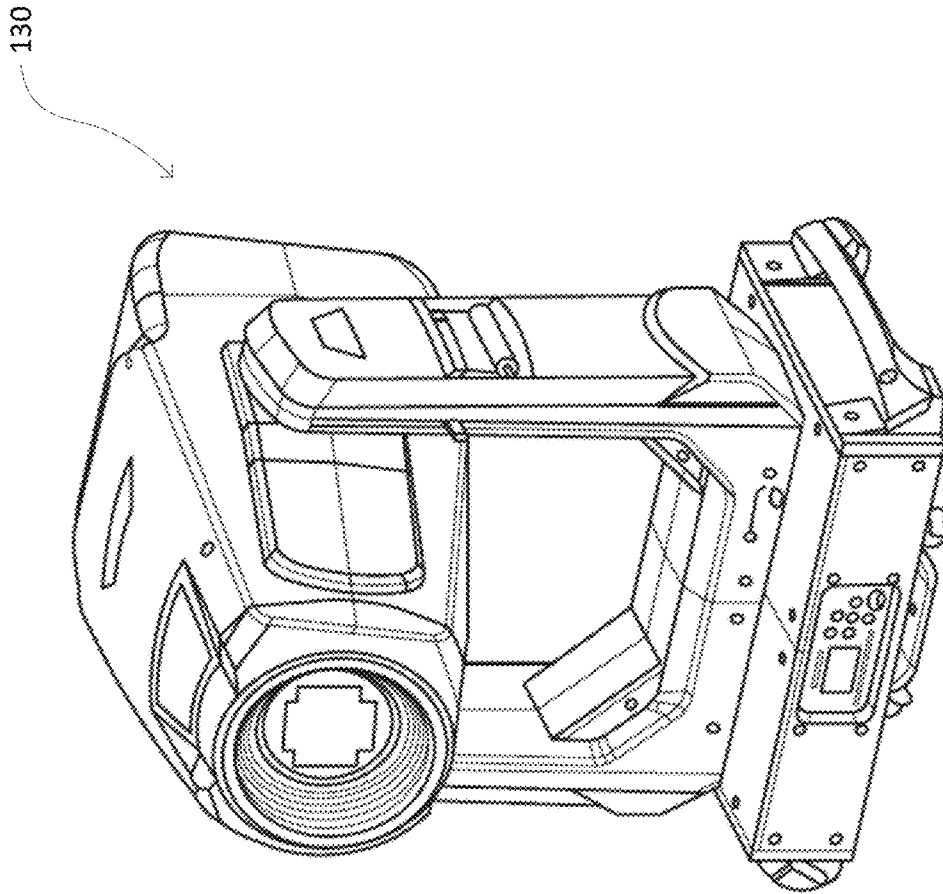


FIG. 4

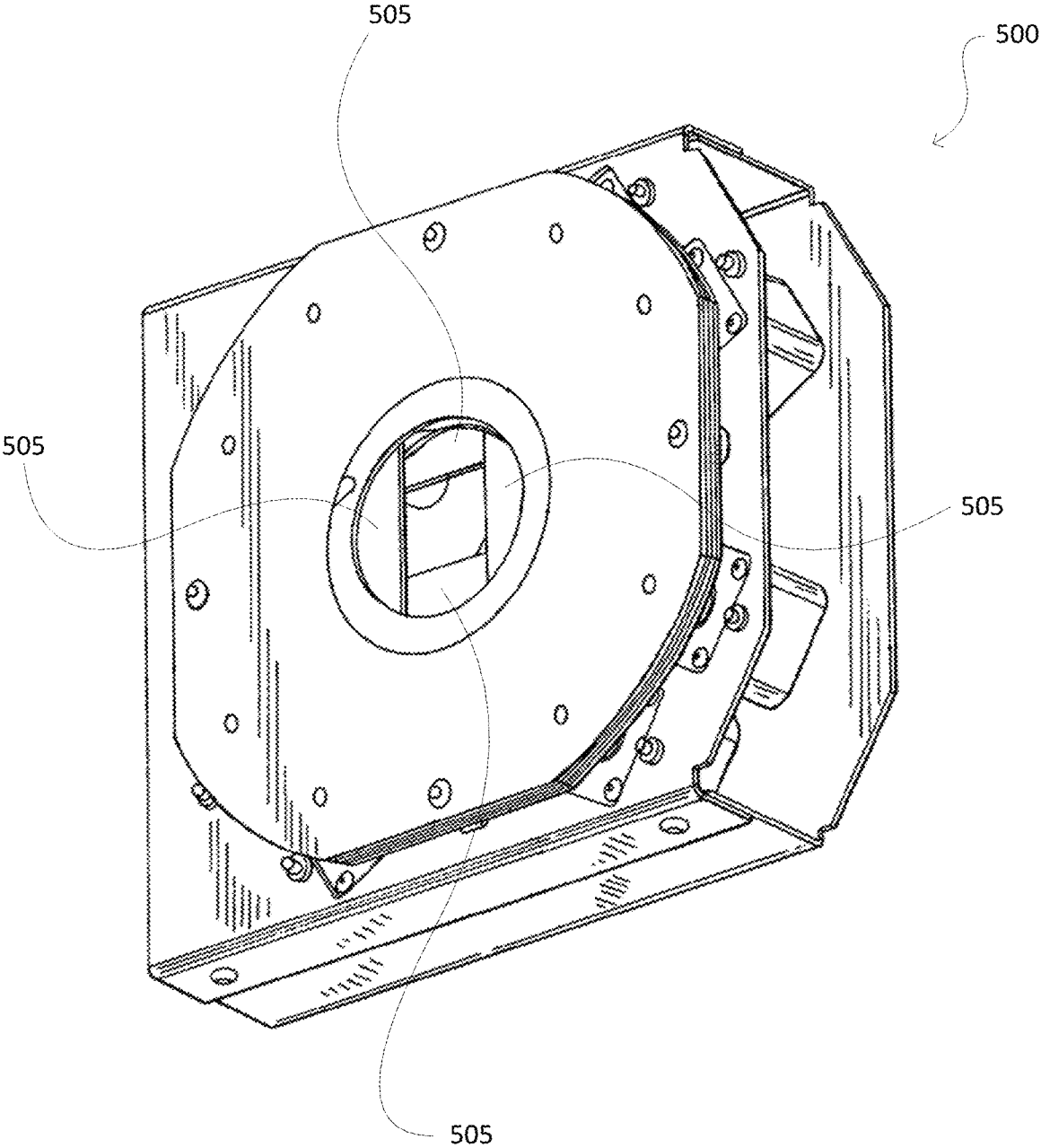


FIG. 5

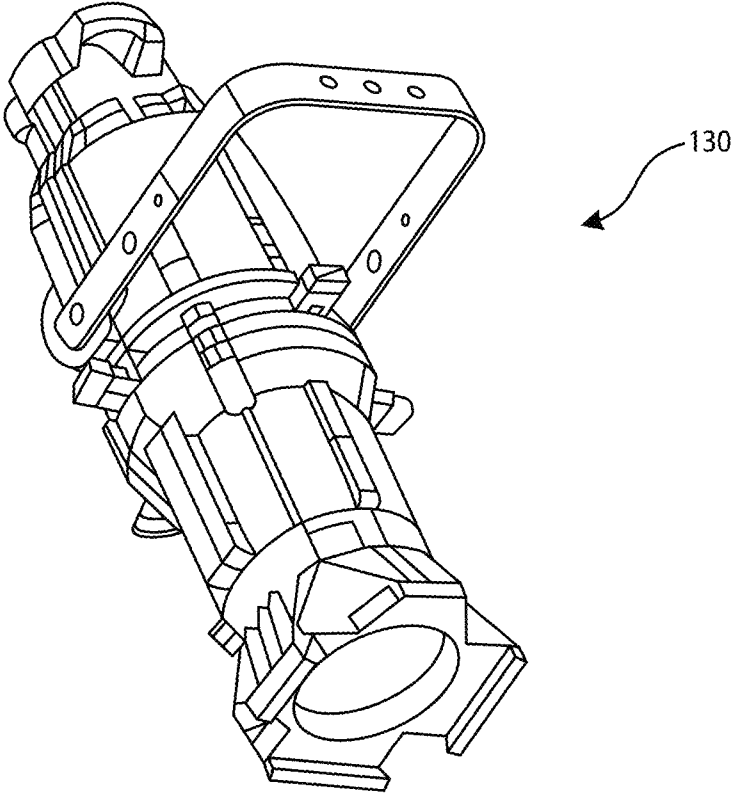


FIG. 6

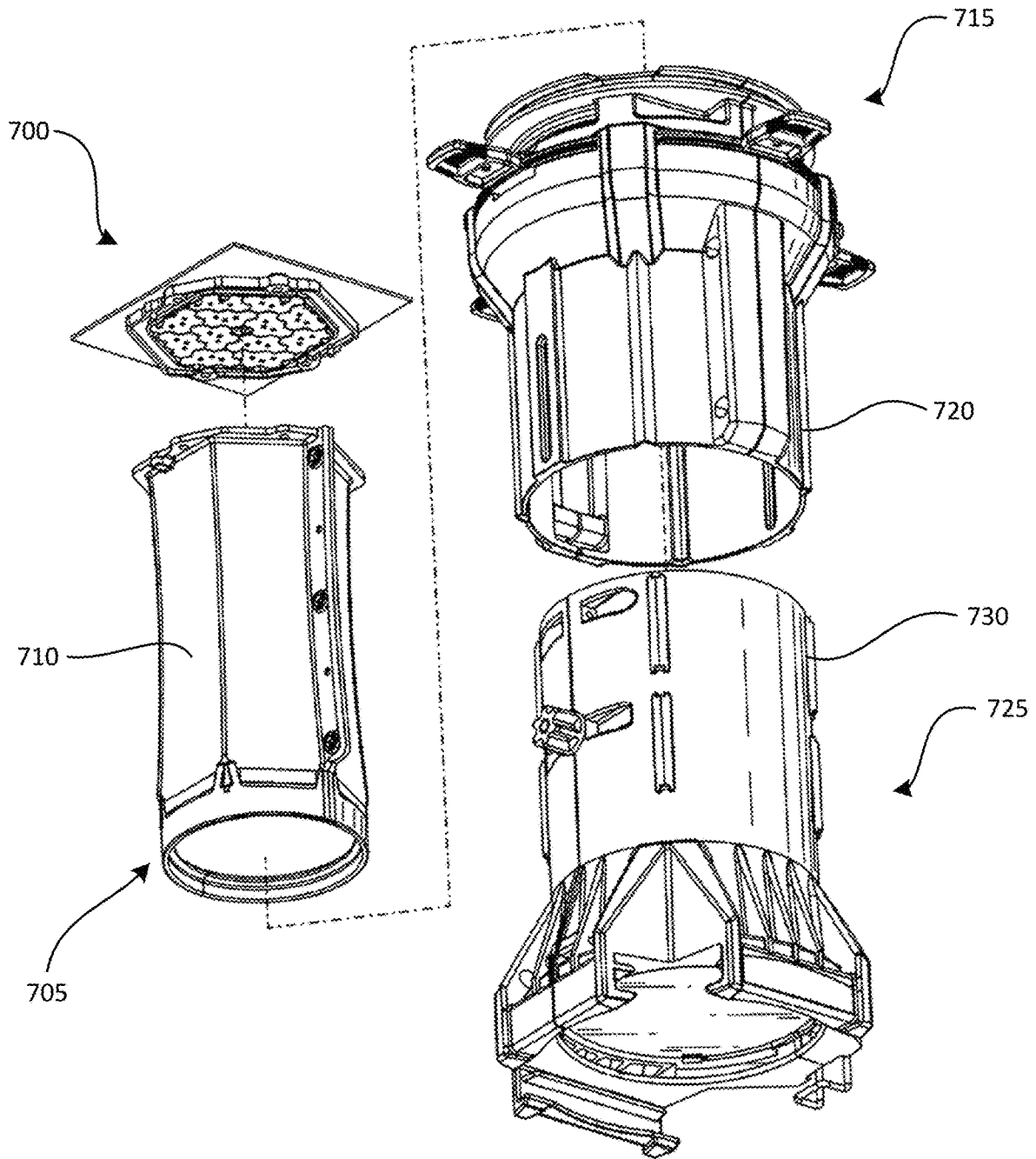


FIG. 7

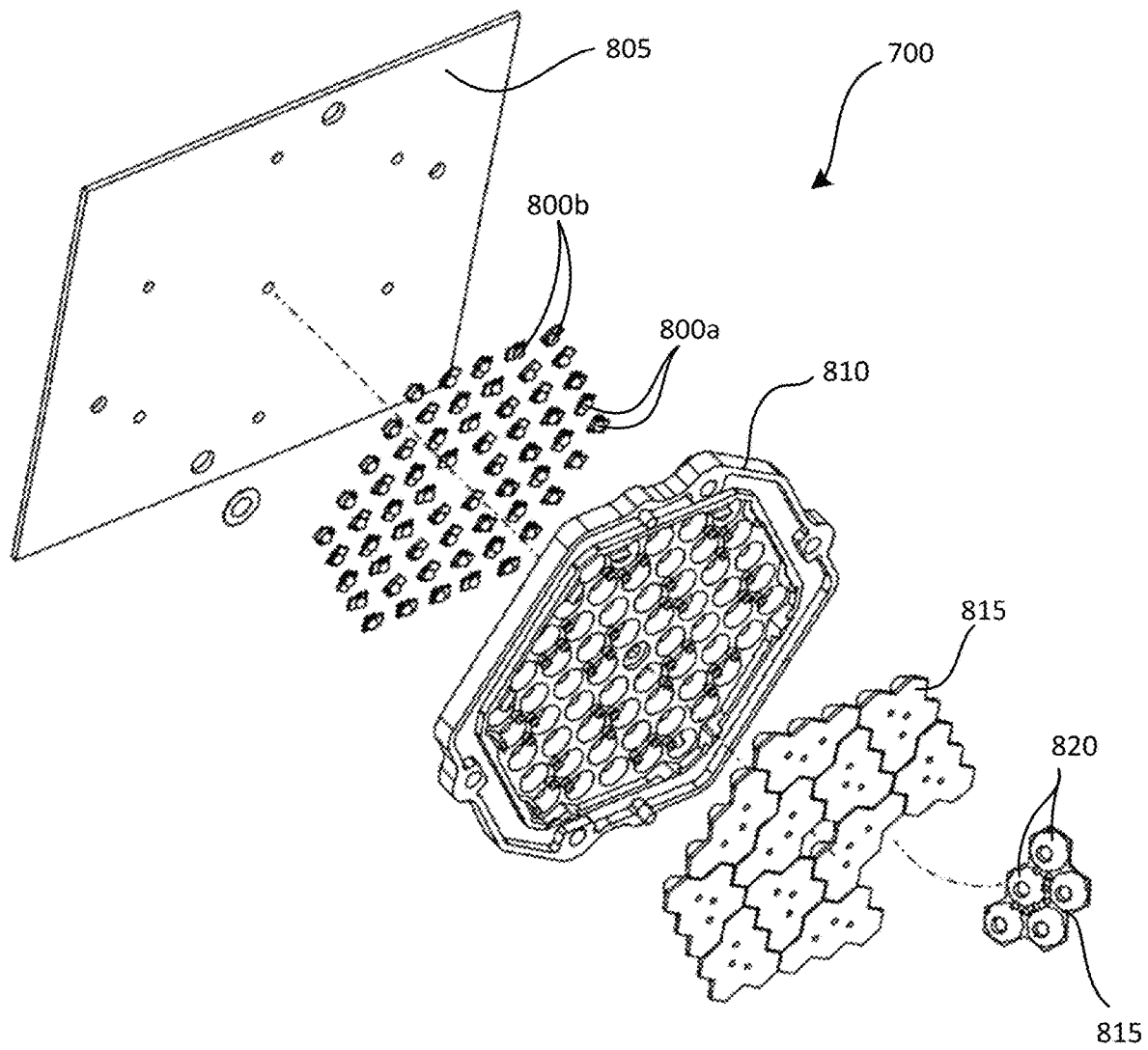


FIG. 8

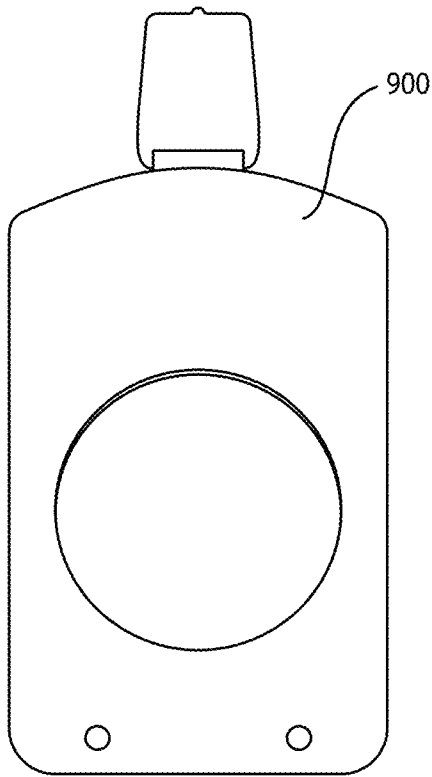


FIG. 9A

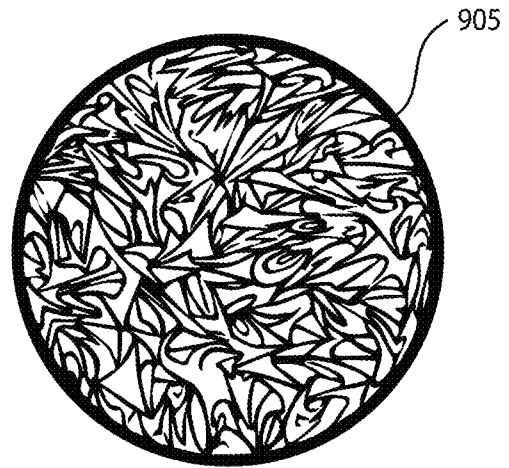


FIG. 9B

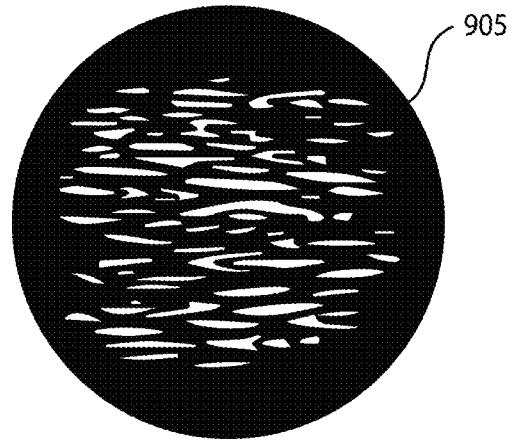


FIG. 9C

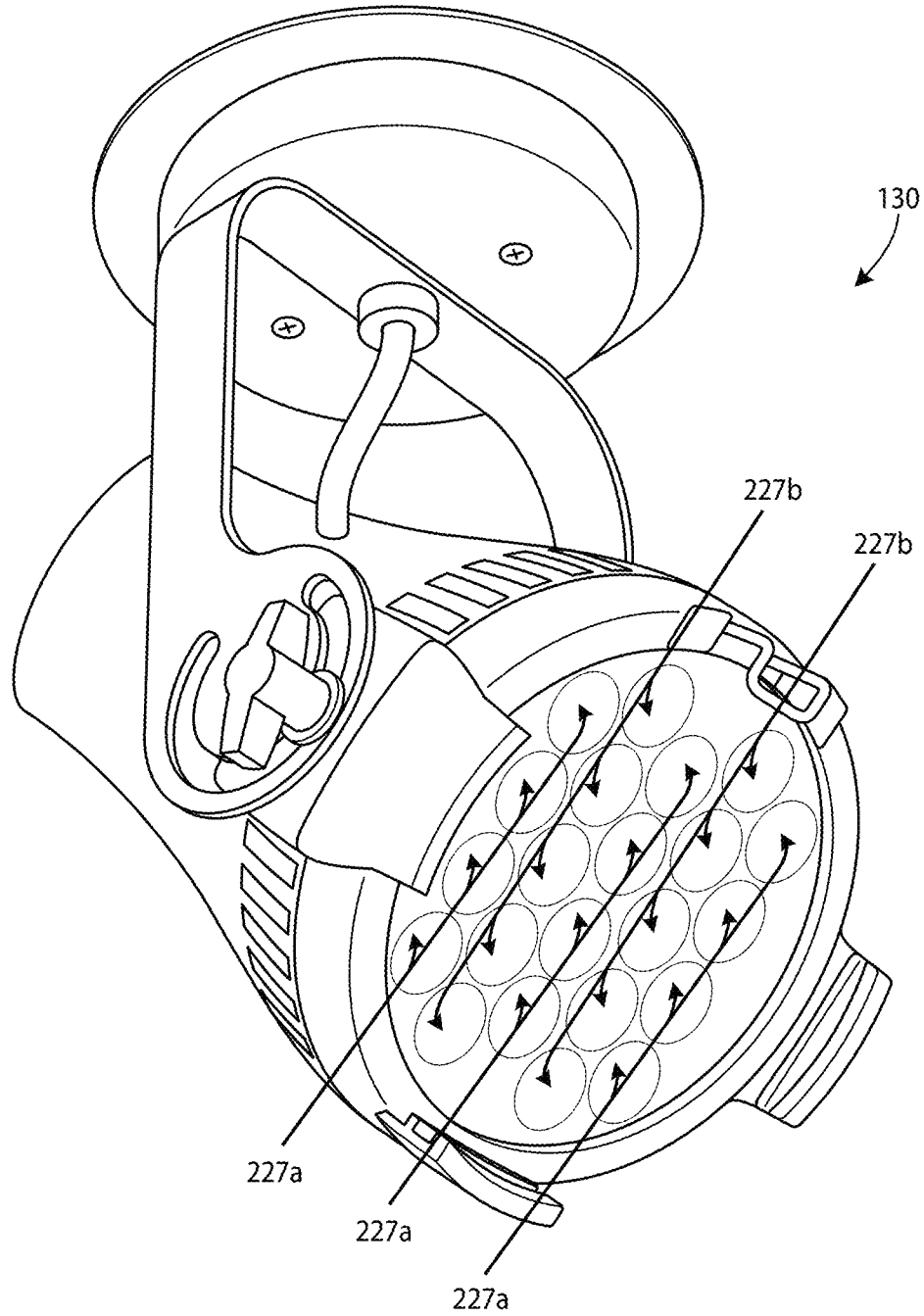


FIG. 10

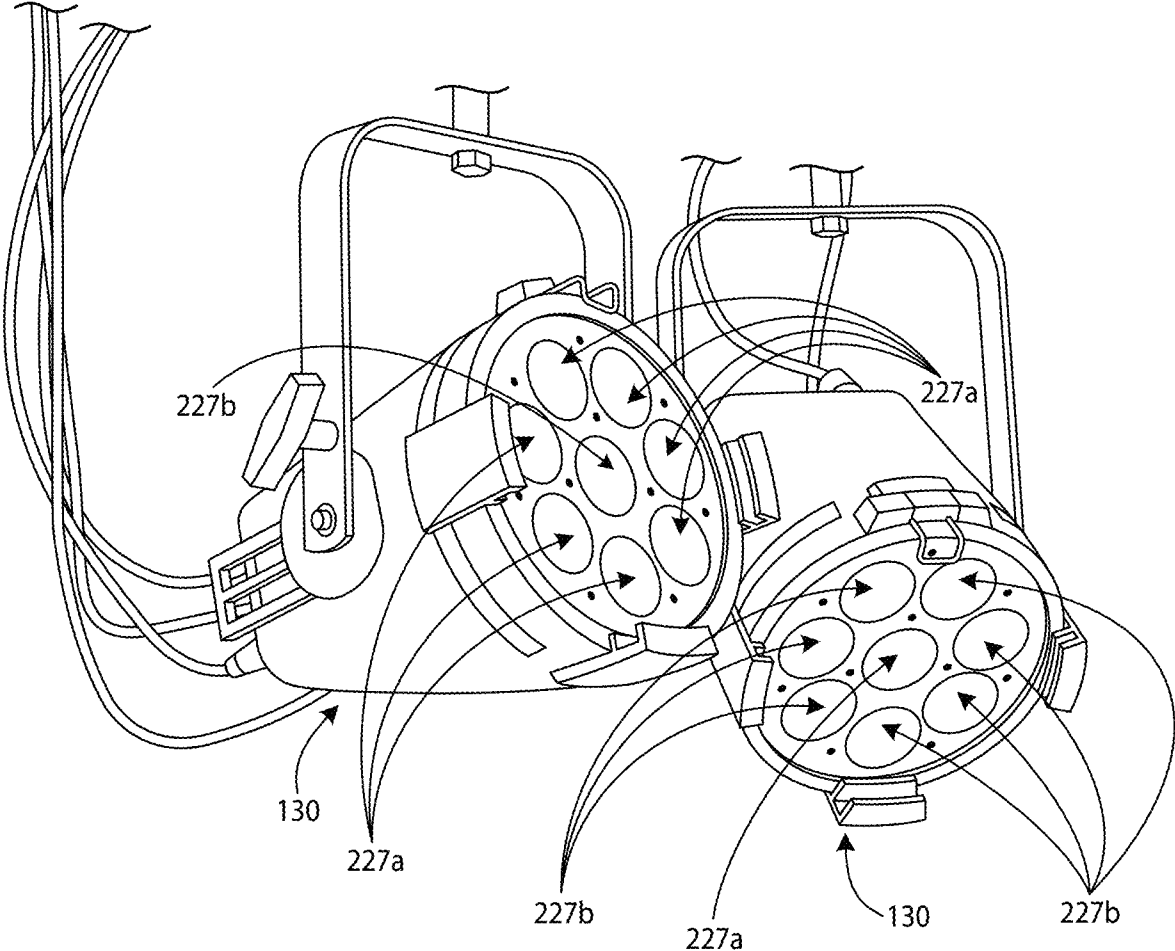


FIG. 11

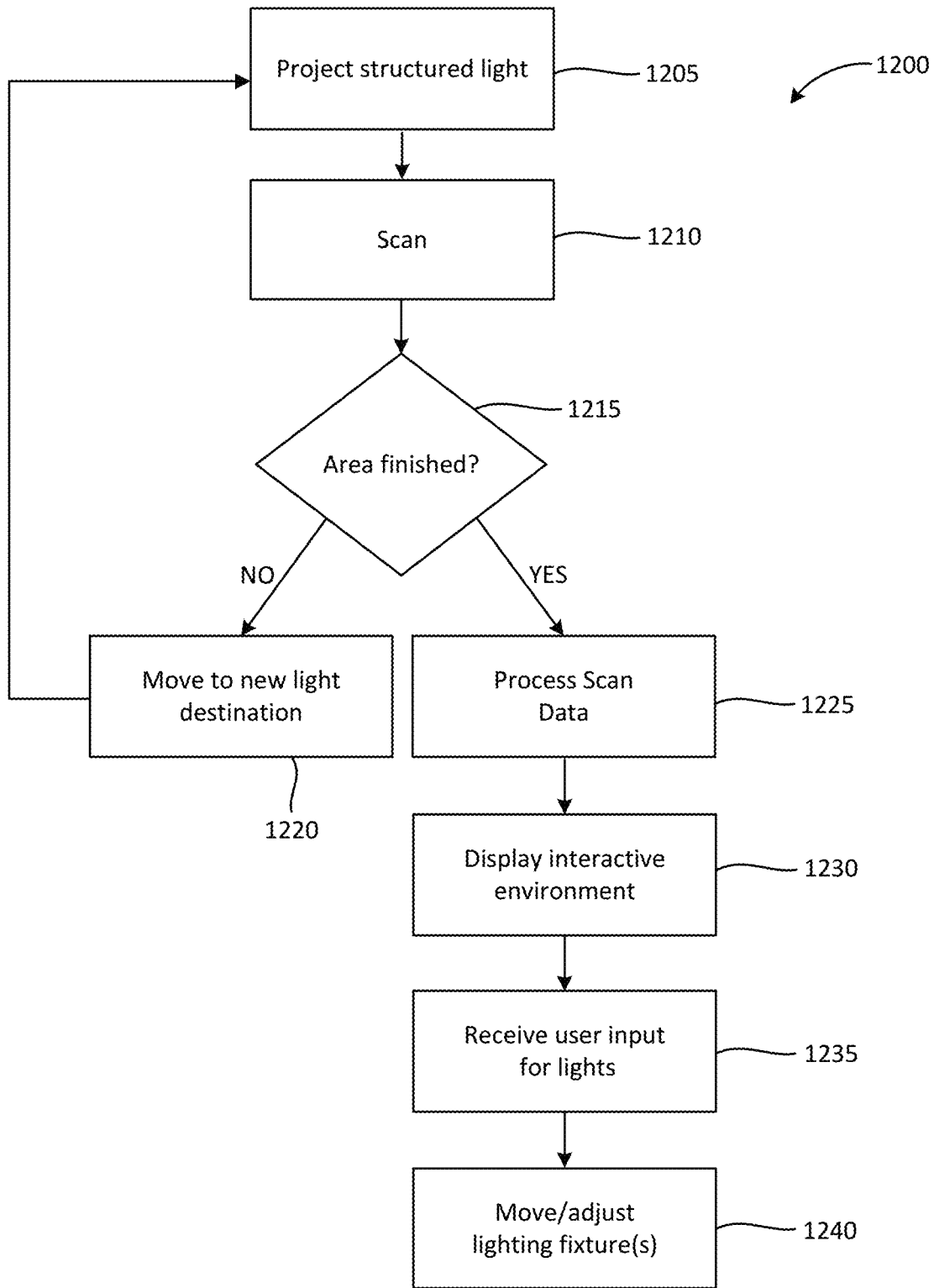


Fig. 12

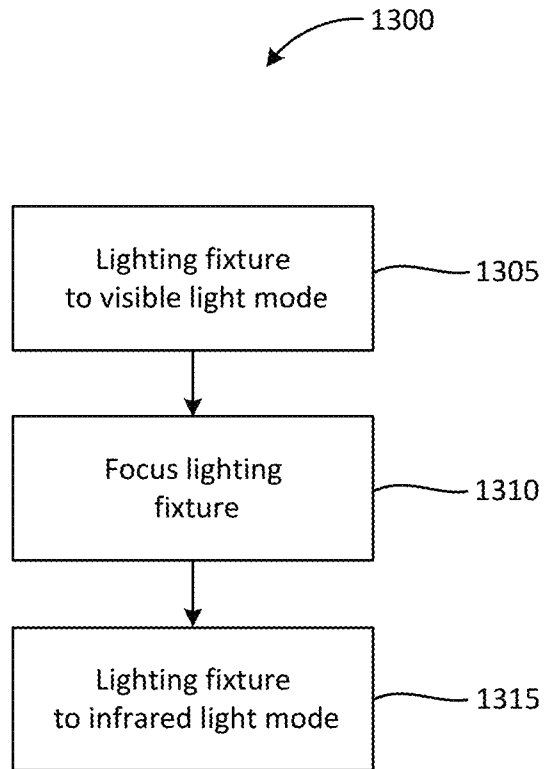


FIG. 13

STAGE MAPPING AND DETECTION USING INFRARED LIGHT

RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application No. 62/848,125, filed May 15, 2019, the entire content of which is hereby incorporated by reference.

FIELD

Embodiments described herein relate to object detection.

SUMMARY

It would be beneficial to be able to map a stage in three dimensions. Information gathered from mapping the stage can be used to create a three-dimensional (“3D”) model of the stage in a digital form. Such digital 3D models could be used in interactive digital environments.

Currently, a user must physically measure the dimensions of a stage with manual tools, such as a measuring tape, in order to accurately gather dimension data of the stage. The user must then keep this dimension data written down or memorized in order to use it for determining lighting arrangements and the like. The dimension data is difficult to visualize when not viewing the stage itself, and creating a representation of the stage, digital or otherwise, would be prohibitively time consuming due to the number of measurements that must be made and recorded by hand. To make the use of such an interactive three-dimensional environment practical, however, the dimension data must be gathered more quickly and easily than what can be done by hand.

However, detecting or tracking one or more objects on a stage, such as scenery elements and performers, is also difficult due to the various lighting conditions during a performance. Fully dark scenes prevent visible light cameras from detecting the objects due to a lack of visible input. Very bright or light-saturated scenes can similarly prevent visible light cameras from detecting the objects due to ambient light interference.

Therefore, the dimension data gathering must be effective regardless of lighting conditions in order to capture the stage and objects during, for instance, a performance.

Accordingly, to address these and other technical problems, embodiments described herein provide, among other things, a system and a method for mapping a stage and detecting objects to quickly gather multiple data points. The system and method gather multiple data points in a fraction of the time it would take one or more individuals to measure the stage by hand. These data points could then be imported into specialized 3D modeling software in the form of an interactive three-dimensional stage model. This model may then be used to control one or more lights. In some embodiments, the system and method gather these data points regardless of lighting conditions, which allows a user to access real-time or nearly real-time data during a live performance. For example, a user may control one or more lights associated with the stage in an intuitive and accurate manner during a performance. Also, tracking and/or detecting objects on the stage during a performance would allow a user to control one or more lights through the interactive three-dimensional environment while taking into account the objects on the stage.

Systems described herein for mapping a stage include a lighting fixture, a scanner, and a controller. The lighting fixture includes a visible light source and an infrared light

source. The lighting fixture at least partially illuminates the stage with structured infrared light. The scanner detects the structured infrared light on the stage. The controller is connected to the lighting fixture and the scanner. The controller turns on the visible light source in a visible light mode and turns on the infrared light source in an infrared light mode. The infrared light source illuminates at least a portion of the stage with the structured infrared light. The controller also controls the scanner to scan the structured infrared light on the portion of the stage, receives a signal from the scanner as scan data, and translates the scan data into three-dimensional location data.

Systems described herein for mapping a stage include a first lighting fixture, a second lighting fixture, a scanner, and a controller. The first lighting fixture includes an infrared light source. The first lighting fixture at least partially illuminates the stage with structured infrared light. The second lighting fixture includes a visible light source. The scanner detects the structured infrared light on the stage. The controller is connected to the first lighting fixture, the second lighting fixture, and the scanner. The controller turns on the infrared light source of the first lighting fixture. The infrared light source illuminates at least a portion of the stage with the structured infrared light. The controller also directs the scanner to scan the structured infrared light on the portion of the stage, receives a signal from the scanner as scan data, translates the scan data into three-dimensional location data, receives a user input based on the three-dimensional location data, and adjusts a lighting setting of the second lighting fixture based on the user input.

Methods described herein for mapping a stage include operating a lighting fixture in a visible light mode, focusing the lighting fixture, switching the lighting fixture to an infrared light mode, illuminating at least a portion of the stage with structured infrared light from the lighting fixture in the infrared light mode, scanning the structured infrared light on the stage, translating scan data into three-dimensional location data, and displaying the three-dimensional location data as an interactive three-dimensional environment.

Before any embodiments are explained in detail, it is to be understood that the embodiments are not limited in its application to the details of the configuration and arrangement of components set forth in the following description or illustrated in the accompanying drawings. The embodiments are capable of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein are for the purpose of description and should not be regarded as limiting. The use of “including,” “comprising,” or “having” and variations thereof are meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Unless specified or limited otherwise, the terms “mounted,” “connected,” “supported,” and “coupled” and variations thereof are used broadly and encompass both direct and indirect mountings, connections, supports, and couplings.

In addition, it should be understood that embodiments may include hardware, software, and electronic components or modules that, for purposes of discussion, may be illustrated and described as if the majority of the components were implemented solely in hardware. However, one of ordinary skill in the art, and based on a reading of this detailed description, would recognize that, in at least one embodiment, the electronic-based aspects may be implemented in software (e.g., stored on non-transitory computer-readable medium) executable by one or more processing units, such as a microprocessor and/or application specific

integrated circuits (“ASICs”). As such, it should be noted that a plurality of hardware and software based devices, as well as a plurality of different structural components, may be utilized to implement the embodiments. For example, “servers” and “computing devices” described in the specification can include one or more processing units, one or more computer-readable medium modules, one or more input/output interfaces, and various connections (e.g., a system bus) connecting the components.

Other aspects of the embodiments will become apparent by consideration of the detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 schematically illustrates a system for mapping a stage in three dimensions, detecting objects, and controlling at least one lighting fixture.

FIG. 1A schematically illustrates an alternative system for mapping a stage in three dimensions, detecting objects, and controlling at least one lighting fixture.

FIG. 2 illustrates a controller for the system of FIG. 1.

FIG. 2A illustrates a controller for the system of FIG. 1A.

FIG. 3 illustrates cameras and lighting fixtures of the system of FIG. 1 in a venue.

FIG. 3A illustrates cameras and lighting fixtures of the system of FIG. 1A in a venue.

FIG. 4 illustrates a lighting fixture for use in the system of FIG. 1 or the system of FIG. 1A.

FIG. 5 illustrates a framing shutter assembly of the lighting fixture of FIG. 4.

FIG. 6 illustrates an alternative lighting fixture for use in the system of FIG. 1 or the system of FIG. 1A.

FIG. 7 illustrates an exploded view of the lighting fixture of FIG. 6.

FIG. 8 illustrates an exploded view of components of the lighting fixture of FIG. 6.

FIG. 9A illustrates a gobo holder to be used with the lighting fixture of FIG. 6.

FIG. 9B illustrates a gobo to be placed in the gobo holder of FIG. 9A.

FIG. 9C illustrates an alternative gobo to be placed in the gobo holder of FIG. 9A.

FIG. 10 illustrates an alternative lighting fixture for use in the system of FIG. 1 or the system of FIG. 1A.

FIG. 11 illustrates alternative lighting fixtures for use in the system of FIG. 1 or the system of FIG. 1A.

FIG. 12 illustrates a method of operating the system of FIG. 1 or the system of FIG. 1A.

FIG. 13 illustrates another method of operating the system of FIG. 1 or the system of FIG. 1A.

DETAILED DESCRIPTION

Embodiments described herein relate to mapping a stage in three dimensions to locate stage surfaces and objects and create an interactive three-dimensional (“3D”) environment. Some embodiments further relate to mapping a stage in three dimensions to create an interactive three-dimensional environment for testing and controlling lighting visuals. The 3D environment allows a user to control one or more lights associated with the stage in an intuitive and accurate manner.

FIG. 1 illustrates a system 100 for gathering dimension data of a stage, including any objects that may be present on the stage such as performers or stage scenery elements, and controlling lighting fixtures according to the dimension data. The system 100 is provided as an example and, in some

embodiments, the system 100 includes additional components. The illustrated system 100 includes a user input device 105-120, a control board or control panel 125, at least one lighting fixture 130, at least one camera 135, a communications network 140, and a server-side mainframe computer or server 145. The user input device 105-120 includes, for example, a personal or desktop computer 105, a laptop computer 110, a tablet computer 115, or a mobile phone (e.g., a smart phone) 120. Other user input devices may include, for example, an augmented reality headset or glasses. The camera 135 may be integrated with the user input device 105-120, such as the camera of the mobile phone 120, or the camera 135 may be entirely separate from the user input device 105-120.

The user input device 105-120 is configured to communicatively connect to the server 145 through the network 140 and provide information to, or receive information from, the server 145 related to the control or operation of the system 100. The user input device 105-120 is also configured to communicatively connect to the control board 125 to provide information to, or receive information from, the control board 125. The connections between the user input device 105-120 and the control board 125 or network 140 are, for example, wired connections, wireless connections, or a combination of wireless and wired connections. Similarly, the connections between the server 145 and the network 140, the control board 125 and the lighting fixtures 130, or the control board 125 and the camera 135 are wired connections, wireless connections, or a combination of wireless and wired connections.

The network 140 is, for example, a wide area network (“WAN”) (e.g., a TCP/IP based network), a local area network (“LAN”), a neighborhood area network (“NAN”), a home area network (“HAN”), or personal area network (“PAN”) employing any of a variety of communications protocols, such as Wi-Fi, Bluetooth, ZigBee, etc. In some implementations, the network 140 is a cellular network, such as, for example, a Global System for Mobile Communications (“GSM”) network, a General Packet Radio Service (“GPRS”) network, a Code Division Multiple Access (“CDMA”) network, an Evolution-Data Optimized (“EV-DO”) network, an Enhanced Data Rates for GSM Evolution (“EDGE”) network, a 3GSM network, a 4GSM network, a 4G LTE network, a 5G New Radio, a Digital Enhanced Cordless Telecommunications (“DECT”) network, a Digital AMPS (“IS-136/TDMA”) network, or an Integrated Digital Enhanced Network (“iDEN”) network, etc.

FIG. 1A illustrates an alternative system 100A for gathering dimension data of a stage, including any objects that may be present on the stage such as performers or stage scenery elements, and controlling lighting fixtures according to the dimension data. The hardware of the alternative system 100A is identical to the above system 100 in every way, except the control board or control panel 125 is omitted. As such, the user input device 105-120 is configured to communicatively connect to the lighting fixtures 130 and to the camera 135. The connections between the user input device 105-120 and the lighting fixtures 130 and the connections between the user input device 105-120 and the camera 135 are wired connections, wireless connections, or a combination of wireless and wired connections.

FIG. 2 illustrates a controller 200 for the system 100. The controller 200 is electrically and/or communicatively connected to a variety of modules or components of the system 100. For example, the illustrated controller 200 is connected to one or more indicators 205 (e.g., LEDs, a liquid crystal display [“LCD”], etc.), a user input or user interface 210

(e.g., a user interface of the user input device **105-120** in FIG. **1**), and a communications interface **215**. The controller **200** is also connected to the control board **125**. The communications interface **215** is connected to the network **140** to enable the controller **200** to communicate with the server **145**. The controller **200** includes combinations of hardware and software that are operable to, among other things, control the operation of the system **100**, control the operation of the lighting fixture **130**, control the operation of the camera **135**, receive one or more signals from the camera **135**, communicate over the network **140**, communicate with the control board **125**, receive input from a user via the user interface **210**, provide information to a user via the indicators **205**, etc. In some embodiments, the indicator **205** and the user interface **210** may be integrated together in the form of, for instance, a touch-screen.

In the embodiment illustrated in FIG. **2**, the controller **200** would be associated with the user input device **105-120**. As a result, the controller **200** is illustrated in FIG. **2** as being connected to the control board **125** which is, in turn, connected to the lighting fixture **130** and the camera **135**. In other embodiments, the controller **200** is included within the control board **125**, and, for example, the controller **200** can provide control signals directly to the lighting fixture **130** and the camera **135**. In other embodiments, the controller **200** is associated with the server **145** and communicates through the network **140** to provide control signals to the control board **125**, the lighting fixture **130**, and the camera **135**.

The controller **200** includes a plurality of electrical and electronic components that provide power, operational control, and protection to the components and modules within the controller **200** and/or the system **100**. For example, the controller **200** includes, among other things, a processing unit **220** (e.g., a microprocessor, a microcontroller, or another suitable programmable device), a memory **225**, input units **230**, and output units **235**. The processing unit **220** includes, among other things, a control unit **240**, an arithmetic logic unit (“ALU”) **245**, and a plurality of registers **250** (shown as a group of registers in FIG. **2**), and is implemented using a known computer architecture (e.g., a modified Harvard architecture, a von Neumann architecture, etc.). The processing unit **220**, the memory **225**, the input units **230**, and the output units **235**, as well as the various modules or circuits connected to the controller **200** are connected by one or more control and/or data buses (e.g., common bus **255**). The control and/or data buses are shown generally in FIG. **2** for illustrative purposes. The use of one or more control and/or data buses for the interconnection between and communication among the various modules, circuits, and components would be known to a person skilled in the art in view of the invention described herein.

The memory **225** is a non-transitory computer readable medium and includes, for example, a program storage area and a data storage area. The program storage area and the data storage area can include combinations of different types of memory, such as a ROM, a RAM (e.g., DRAM, SDRAM, etc.), EEPROM, flash memory, a hard disk, an SD card, or other suitable magnetic, optical, physical, or electronic memory devices. The processing unit **220** is connected to the memory **225** and executes software instructions that are capable of being stored in a RAM of the memory **225** (e.g., during execution), a ROM of the memory **225** (e.g., on a generally permanent basis), or another non-transitory computer readable medium such as another memory or a disc. Software included in the implementation of the system **100** and controller **200** can be stored in the memory **225** of the

controller **200**. The software includes, for example, firmware, one or more applications, program data, filters, rules, one or more program modules, and other executable instructions. The controller **200** is configured to retrieve from the memory **225** and execute, among other things, instructions related to the control processes and methods described herein. In other embodiments, the controller **200** includes additional, fewer, or different components.

The user interface **210** is included to provide user control of the system **100**, the lighting fixture **130**, and/or the camera **135**. The user interface **210** is operably coupled to the controller **200** to control, for example, drive signals provided to the lighting fixture **130** and/or drive signals provided to the camera **135**. The user interface **210** can include any combination of digital and analog input devices required to achieve a desired level of control for the system **100**. For example, the user interface **210** can include a computer having a display and input devices, a touch-screen display, a plurality of knobs, dials, switches, buttons, faders, or the like. In the embodiment illustrated in FIG. **2**, the user interface **210** is separate from the control board **125**. In other embodiments, the user interface **210** is included in the control board **125**.

The controller **200** is configured to work in combination with the control board **125** to provide direct drive signals to the lighting fixtures **130** and/or the cameras **135**. As described above, in some embodiments, the controller **200** is configured to provide direct drive signals to the lighting fixtures **130** and/or the cameras **135** without separately interacting with the control board **125** (e.g., the control board **125** includes the controller **200**). The direct drive signals that are provided to the lighting fixtures **130** and/or the cameras **135** are provided, for example, based on a user input received by the controller **200** from the user interface **210**. The controller **200** is also configured to receive one or more signals from the camera(s) **135** related to scan data.

As shown in FIG. **2A** and described above, the system **100A** includes the controller **200** configured to work without the control board **125**, such that the controller **200** is configured to provide signals to the lighting fixtures **130** and/or the cameras **135** and to receive one or more signals from the camera(s) **135** related to scan data.

FIG. **3** illustrates the control board **125**, the lighting fixtures **130**, the cameras **135**, and the user input device **120** of the system **100** in a venue **300** including a stage **305**. At least one of the lighting fixtures **130** is configured to project structured infrared light **310** onto the stage **305** and/or an object **315**, as described in more detail below. In this embodiment, the system **100** further utilizes reference points **320** and a reference object **325** for calibration purposes.

FIG. **3A** illustrates the system **100A** in a venue **300** including a stage **305**. As discussed above, the system **100A** omits the control board **125**, and the user input device **120** is configured to directly communicate with the lighting fixtures **130** and the camera **135**.

The controller **200** receives signals from the cameras **135**. The controller **200** also processes the signals and interprets the same as input data related to the dimensions and location of the stage **305**. The controller **200** outputs a display of the stage **305** representing the dimension and location data to, for instance, the indicators **205**. The controller **200** receives user input regarding user selected lighting visuals and lighting settings to be used via, for instance, the user interface **210**. The indicators **205** further display the stage in an interactive three-dimensional environment as being altered aesthetically by the selected lighting visuals/lighting settings. The controller **200** outputs a command signal based on

the entered lighting preferences. The controller **200** also controls the lighting fixtures **130** according to the command signal either directly or through the control panel **125**.

The cameras **135** may include any type of scanner, include any number of scanners, and include any arrangement of scanners relative to each other. In some embodiments, the cameras **135** are configured to detect infrared light. The cameras **135** are rigidly connected to and configured to move with respective lighting fixtures **130**, or are separate from the lighting fixtures **130**. Examples of the cameras **135** include, for instance, a single camera mounted in a known location with a known controllable orientation, stereo cameras mounted to detect an overlapping area, or the like. In some embodiments, a single camera **135** mounted in a known location with a known controllable orientation is rigidly connected to one of the lighting fixtures **130** by members of a known length such that controlled movement of the lighting fixture **130** results in controlled movement of the camera **135**. Geometric calculations can then be used to determine the location and orientation of the camera **135** at any given time based on the control input sent to the corresponding lighting fixture **130**. In other embodiments, stand-alone cameras **135** are used and controlled in a manner similar to motorized lighting fixtures **130**.

The controller **200** processes the dimension and location data obtained by the cameras **135** using, for instance, the processing unit **220**. This processing of the characteristics of the structured infrared light **310** into dimension and location data is accomplished using an algorithm including, for instance, a band-pass filter that passes light frequencies in the infrared part of the electromagnetic spectrum and blocks light frequencies in the visible part of the electromagnetic spectrum, light intensity gradient analysis, comparison of scan data between multiple cameras **135**, comparison of scan data from a single camera **135** at different positions, or the like. Some embodiments include use of a physical band-pass filter instead of a digital band-pass filter. In such embodiments, an example of a suitable physical band-pass filter is the Lee Polyester 87 Infrared band-pass filter. Once processed, each surface of the stage **305** is digitally rendered or digitized as part of one or more three-dimensional bodies. This digitization is accomplished by an algorithm for analyzing and interpreting the dimension and location data.

Additional sensors or markers can be used to augment the data that is recorded with the cameras **135** to improve accuracy. For instance, the reference points **320** are indicated with a marker to be detected by the cameras **135**. In some embodiments, the marker for each of the reference points **320** is an infrared light source, a reflector for reflecting infrared light at an increased brightness relative to the surroundings, or the like. These reference points **320** can establish relative locations of the features of the stage **305** and can be helpful in calibration of the lighting fixtures **130** and/or cameras **135**. A reference object **325** is also placed on the stage **305** in some embodiments. The reference object **325** has known dimensions and can be illuminated by the lighting fixtures **130** and scanned by the cameras **135** to calibrate a dimension discovery application (stored within the memory, for instance). This calibration is accomplished by a user inputting the known dimensions of the reference object **325** or commanding the system **100**, **100A** to operate in a calibration mode, which is preprogrammed to designate an object to be scanned in a particular location as the reference object **325**. Once the reference object **325** has been scanned, the dimension discovery application can reset to

designate the scan data of the reference object **325** as corresponding to the known dimension measurement values of the reference object **325**.

As shown in FIGS. **3** and **3A**, one or more lighting fixtures **130** are used as part of the system **100**, **100A**. In some embodiments, the lighting fixtures **130** are existing lighting fixtures **130** already installed at the venue **300**. In such embodiments, the system **100**, **100A** may not require additional new moving lighting fixtures **130** beyond what is already present about the stage **305**. The lighting fixtures **130** are movable to cast the structured infrared light **310** on various portions of the stage **305** and/or objects **315** on the stage **305**. The lighting fixtures **130** may move through a plurality of discrete positions, or they may move through a continuous movement path. In some embodiments, the lighting fixtures **130** are movable by one or more motors associated with the lighting fixtures **130**, such as the type of lighting fixture **130** shown in FIG. **4**. The lighting fixtures **130** project either static or dynamic structured infrared light **310**. In some embodiments, only a single edge of the projected light is used as the structured infrared light **310**. These embodiments reduce complexity and increase repeatability of the system **100**, **100A**.

The lighting fixtures **130** are further configured, in some embodiments, to project a plane of light such that a line of structured infrared light **310** appears on the stage **305** and/or the objects **315** on the stage **305**. In some embodiments, this plane of light is formed through a shutter assembly **500**, shown in FIG. **5**, located within the lighting fixture **130** and controlling the position of framing shutters **505**. In such embodiments, the structured infrared light **310** may advantageously be rotated to create a dynamic structured infrared light **310** to improve the scan accuracy.

With reference to FIGS. **6-8**, another example embodiment of the lighting fixture **130** for use with the system **100**, **100A** is shown. As shown in FIG. **7**, the lighting fixture **130** includes a light panel **700**, a mixing assembly **705** including a reflective mixing tube **710**, a gate assembly **715** including a gate housing **720** with at least one gate disposed therein, and a lens assembly **725** including a lens housing **730** with at least one lens disposed therein.

As shown in FIG. **8**, the light panel **700** includes multiple light sources **800a**, **800b**, such as light emitting diodes (LEDs). The light sources **800a**, **800b** are disposed on a printed circuit board **805** and held by an optic holder **810**. Collimator packs **815** including collimator lenses **820** narrow the respective beams of light projected from the light sources **800a**, **800b**.

While some of the lighting fixtures **130** include a visible light source **800a**, such as a visible light LED, the lighting fixtures **130** further include an infrared light source **800b**, such as an infrared LED. In some embodiments, the light sources **800a**, **800b** of the lighting fixture **130** include only one infrared light source **800b**, and the remaining light sources are visible light sources **800a**. In other embodiments, up to half of the light sources **800a**, **800b** of the lighting fixture **130** are infrared light sources **800b**. In other embodiments, a majority of the light sources **800a**, **800b** of the lighting fixture **130** are infrared light sources **800b**. In some embodiments, the light sources **800a**, **800b** of the lighting fixture **130** include only one visible light source **800a**, and the remaining light sources are infrared light sources **800b**. The light emitted from the infrared light sources **800b** is shaped to produce, for instance, an irregular and non-repetitive pattern of infrared light projected on the stage **305** and any objects **315** thereon.

Shaping the light emitted from the infrared light sources **800b** may be accomplished with framing shutters (as discussed above), a gobo holder **900** (shown in FIG. 9A) with a corresponding gobo **905** (e.g., a plate or screen to project a shape or pattern such as those shown in FIGS. 9B and 9C) over the infrared light sources **800b**, or the like. In embodiments utilizing framing shutters and/or gobos **905**, existing equipment present at the venue **300** may be utilized instead of specialty equipment.

With reference to FIGS. **10** and **11**, other embodiments of a lighting fixture **130** are shown. In these embodiments, the visible light source(s) **800a** and the infrared light source(s) **800b** are disposed adjacent a projecting end of the lighting fixtures **130** instead of being positioned to project light through various assemblies such as those discussed above.

Returning to FIGS. **2** and **3**, many functions are performed according to the dimension discovery application executed by, for instance, the electronic processing unit **220**. The lighting fixtures **130** project either static or dynamic structured infrared light **310** onto the stage **305**. The cameras **135** scan a portion of the stage illuminated by the structured infrared light **310**. The controller **200** further interprets signals from the cameras **135** representing distortion of the shape and/or pattern of the structured infrared light **310** due to the contours of the stage **305** and/or objects **315** on the stage **305**. The controller **200** sends signals representing dimension data from the dimension discovery application to the lighting interactive environment application. Many further functions are performed according to the lighting interactive environment application executed by, for instance, the electronic processing unit **220**. The controller **200** sends signals representing display data of an interactive three-dimensional environment depicting the stage **305** and/or objects **315** on the stage **305** to one or more indicators **205**. The controller **200** receives signals representing user input data via the user interface **210** regarding lighting visuals and/or lighting settings. The controller **200** then outputs one of a control signal to adjust the lighting fixtures **130** and an updated display signal to update the display shown on the one or more indicators **205** of the interactive three-dimensional environment. The updated display of the stage **305** and/or objects **315** on the stage **305** shows the change in lighting either statically or dynamically.

With control inputs through the user interface **210**, the user coordinates multiple lighting fixtures **130** to produce a desired lighting effect in the interactive three-dimensional environment, which is displayed on a computer screen, the user's phone screen, an augmented reality interface, or the like. As changes are made by the user through interaction with the controls within the interactive three-dimensional environment, virtual light beams within the interactive three-dimensional environment change to reflect these interactions, thereby altering the way the virtual light beams interact with the three-dimensional rendering of the stage **305** and/or objects **315** on the stage **305**. Once the user input controls are finalized in the interactive three-dimensional environment, the altered appearance of the three-dimensional rendering of the stage **305** and/or objects **315** on the stage **305** can be saved or archived as a file. This file can be revisited and further altered and/or shared amongst the lighting designers, lighting console operators, lighting/system technicians, or the like.

Additionally or alternatively, with control inputs through the user interface **210**, the user coordinates the multiple lighting fixtures **130** to produce a desired lighting effect on the actual stage **305** and/or objects **315** on the stage **305** by indicating illumination locations in the interactive three-

dimensional environment. These directions can cause the designated lighting fixtures **130** (selected as a subset or all of the available lighting fixtures **130**) to move such that the light projected therefrom strikes the stage **305** and/or objects **315** on the stage **305** in the real world at the location corresponding to the location the user designated in the interactive three-dimensional environment. In some embodiments, the user may further select a follow-spot mode with control inputs through the user interface **210**. In such a mode, the lighting fixtures **130** automatically illuminate a particular selected object **315** regardless of its location on the stage **305**. In some embodiments, the lighting fixture(s) **130** acting as the follow-spot automatically shut off if the selected object **315** leaves the stage **305**.

FIG. 7 illustrates a method **1200** of mapping the stage **305** in three dimensions to create an interactive three-dimensional environment and to control the lighting fixtures **130** associated with the stage **305**. The method **1200** includes illuminating a portion of the stage **305** and/or objects **315** on the stage **305** with structured infrared light **310** projected by the lighting fixtures **130** (step **1205**). This step includes projecting, for instance, a plane of light against the stage **305** and/or objects **315** on the stage **305** which displays a line on the stage **305** and/or objects **315** on the stage **305**. This plane of light is formed by a designated positioning of framing shutters **505** inside a moving head of the lighting fixture **130** or by a line pattern gobo **905** (e.g., a plate or screen placed in front of a lighting fixture **130** to project a shape or pattern) coupled to the lighting fixture **130**. This line is then reflected, in an example instance, as a curvilinear-shaped set of points describing a contour line of the stage **305** and/or objects **315** on the stage **305**. Other embodiments include projecting, for instance, a pattern or grid of infrared light against the stage **305** and/or objects **315** on the stage **305**. Objects **315** that may be present on the stage **305** include, for example, scenery elements. The structured infrared light **310**, as it appears on the stage **305** and/or objects **315** on the stage **305**, is then captured by scanning equipment including, for instance, cameras **135** (step **1210**).

The method **1200** further includes the controller **200** determining whether the lighting fixtures **130** have directed the structured infrared light **310** to all the required locations to map the entire desired area, such as the entire stage **305** and/or all the objects **315** on the stage **305** (step **1215**). The controller **200** determines whether the lighting fixtures **130** have followed an entire dimension discovery control string for the movement about a designated area. As an example, the lighting fixtures **130** are controlled to move each lighting fixture **130** a designated percentage of the overall pan angle capability and/or a designated percentage of the overall tilt angle capability of the lighting fixture **130** to a series of intermediate positions. The user designates the outer bounds for these angles, or the outer bounds may simply be the limits on the physical capabilities of each lighting fixture **130**. Additionally or alternatively, the cameras **135** provide feedback regarding if and when the structured infrared light **310** appears in the same scan image as the reference points **320**. The reference points **320** could designate an outer perimeter of the scan area. In some embodiments of the method **1200**, the user inputs via the user interface **210**, for instance, that the lighting fixture **130** has moved as far as is necessary for the desired area. This user input can be with regard to a single direction of the movement of the lighting fixtures **130** or it can be with regard to the overall movement of the lighting fixtures **130**.

If the result at step **1215** is no, the method **1200** proceeds with moving the lighting fixtures **130** (or switching from a

first lighting fixture **130** to a second lighting fixture **130** in order to move the structured infrared light **310** to a different portion of the area to be mapped (step **1220**). In embodiments including moving lighting fixtures **130**, the movement is enacted by a dimension discovery control string (executed by, for instance, the electronic processing unit **220**) automatically directing motors of each respective lighting fixture **130**, by a user manually manipulating the lighting fixture **130** directly, or by a user manually inputting controls in the user interface **210** for the motors of each respective lighting fixture **130**. In embodiments including switching which lighting fixture **130** projects the structured infrared light **310** in order to move the structured infrared light **310**, the switching on or off of respective lighting fixtures **130** is enacted by a dimension discovery control string (executed by, for instance, the electronic processing unit **220**) automatically activating and deactivating the lighting fixtures **130**, by a user manually connecting and disconnecting the lighting fixtures **130** from a power source, or by a user manually inputting controls in the user interface **210** for switching on or off respective lighting fixtures **130**. Once the lighting fixtures **130** projecting the structured infrared light **310** have moved and/or the subset of lighting fixtures **130** projecting the structured infrared light have changed, the structured infrared light **310** arrives at its new illumination portion of the stage **305** and/or objects **315** on the stage **305** at step **1205**. The method **1200** then continues again through steps **1210** and **1215**.

If the result at step **1215** is yes (either on the first time arriving at step **1215** in the method **1200** or after having repeated steps **1205** and **1210** one or more times), the method **1200** includes the controller **200** processing the scan data received from the cameras **135** to determine three-dimensional spatial locations for points where the structured infrared light **310** reflects from the stage **305** and/or objects **315** on the stage **305** (step **1225**).

Step **1225** is completed utilizing known distances of the lighting fixtures **130** from the cameras **135**, the positions of the lighting fixtures **130** and the cameras **135** relative to the stage **305** (such as relative to a reference point **320** on or around the stage **305**), and the direction of the beam projecting the structured infrared light **310**. With this information, the location of each point in the set of points that make up the structured infrared light **310** at a given position can be determined by trigonometric triangulation. Some embodiments utilizing these known distances are also used as part of a closed system calibration routine for adjusting the lighting fixtures **130**. Further, some embodiments utilize a frequency analysis of the image captured by the camera **135** to locate a single side of the projected light with a sliding window approach to efficiently locate the edge. This approach avoids depending on uncertainty in the shape and control of components such as framing systems and gobos in projecting the structured infrared light **310**.

In some embodiments, step **1225** includes the use of multiple cameras **135** located at known distances from each other. The images captured by the multiple cameras **135** are processed with a pattern recognition system which locates matching points among the different images of the same portion of the stage **305** and/or objects **315** on the stage **305**. The pattern recognition system includes analysis methods such as random sample consensus (RANSAC), iterative closest point (ICP), or the like. The contours and shape of the stage **305** and/or objects **315** on the stage **305** are determined using this group of images that are connected at the matching points by the pattern recognition system. In instances including a flat and smooth surface that offers no contour or

shape to recognize with the pattern recognition system using a single line of the structured infrared light **310**, a pattern or grid of structured infrared light **310** is projected instead of the single line in order to allow the pattern recognition system to locate matching points among the various images captured by the multiple cameras **135**. Such a pattern or grid of structured infrared light **310** includes a plurality of lines, a distinct and non-repeating series of shapes, or the like. Such a pattern or grid of structured infrared light **310** is formed by equipping the lighting fixtures **130** with a designated gobo **600**. The scan data may also be run through a band-pass filter that passes signals corresponding to light that is in the infrared portion of the electromagnetic spectrum, while rejecting signals corresponding to light that is in the visible portion of the electromagnetic spectrum. In this manner, the method **1200** operates effectively regardless of the amount of visible light present on or about the stage **305**.

Once the scan data has been processed (step **1225**), the method **1200** further includes generating and displaying the stage **305** and/or objects **315** on the stage **305** in an interactive three-dimensional environment based on the scan data (step **1230**). As described above, this interactive three-dimensional environment is displayed with, for instance, the indicators **205** (e.g., a screen of the user input device **120**).

The method **1200** also includes receiving user input data from a user regarding lighting visuals and/or lighting settings for the lighting fixtures **130** via, for instance, the user interface **210** (step **1235**). The user input, in some embodiments, includes an interaction by the user with features of the display of the interactive three-dimensional environment. These interactions include, for instance, directing beams of light to a destination indicated in the interactive three-dimensional environment, changing a brightness or color of a light by adjusting dials or other controls displayed in the interactive three-dimensional environment, indicating a light destination by selecting locations on the stage **305** and/or objects **315** on the stage **305** displayed within the interactive three-dimensional environment, indicating a movable object **315** on the stage **305** displayed within the interactive three-dimensional environment to be followed with one or more follow-spots, or the like.

Once the user input data has been received (step **1235**), the method **1200** also includes controlling the lighting fixtures **130** to move and otherwise adjust in order to match the desired results indicated by the user through the user input (step **1240**). This step is accomplished by generating and transmitting a command signal (or a command string) to the lighting fixtures **130** either directly or indirectly through a control panel **125** to control the lighting fixtures **130**.

Some embodiments of the method **1200** described above further include updating the display of the stage **305** and/or objects **315** on the stage **305** within the interactive three-dimensional environment to reflect the user input received at step **1235**. The user then makes further adjustments or confirms the lighting scheme that has been selected. Once the lighting scheme has been confirmed, the method **1200** then moves to step **1240** to control the lighting fixtures **130**. In some embodiments, the controller **200** catalogs the user input data in the form of a lighting command string. This lighting command string includes all the lighting commands for a single static lighting visual, lighting commands for multiple lighting visuals in sequence, lighting commands for a dynamic lighting visual, or the like.

Some embodiments of the method **1200** include the controller **200** processing the scan data (as is done at step **1225**) in a more segmented manner by processing the scan data acquired each instance after step **1210** has been com-

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pleted. This processed scan data is augmented with further input from the cameras **135** after each additional instance of step **1210** is performed. Some embodiments include rendering the interactive three-dimensional environment a portion at a time as the processed scan data is acquired, allowing the user to view the progress of the data gathering portions of the method **1200**.

Some embodiments of the method **1200** utilize a number of lighting fixtures **130** projecting the structured infrared light **310** and a number of cameras **135** to capture images of the structured infrared light **310** that is sufficient to gather adequate scan data for the entire stage **305**, including any and all objects **315** on the stage **305**, in a single pass or scan. Such embodiments of the method **1200** do not require step **1215** or step **1220**.

Some embodiments further include labeling multiple features of the interactive three-dimensional environment according to semantic mapping techniques (e.g., a program that is trained to recognize common stage items and label these objects in the interactive 3D environment).

FIG. **13** illustrates another exemplary method **1300** of mapping a stage **305**, potentially including objects **315** on the stage **305**, in three dimensions. This method **1300** may be performed in conjunction with the method **1200** described above, or it may be performed separately from the method **1200**.

As illustrated in FIG. **13**, the method **1300** includes operating lighting fixtures **130** in a visible light mode (step **1305**). The visible light mode includes a visible light source **800a** of the lighting fixture **130** being illuminated. In some embodiments, no infrared light source **800b** is illuminated in the visible light mode. Other embodiments, however, include infrared light sources **800b** also illuminated in the visible light mode.

The method **1300** further includes focusing the lighting fixture **130** while the lighting fixture **130** is in the visible light mode (step **1310**). With visible light sources **800a** illuminated, a user focuses the lighting fixture **130**. In some embodiments, the user evaluates the characteristics of the light projected from the visible light source(s) **800a** in order to properly focus the lighting fixture **130**.

The method **1300** also includes switching the lighting fixture **130** to an infrared light mode (step **1315**). The infrared light mode includes infrared light sources **800b** being illuminated. The infrared light mode, in some embodiments, includes no visible light source **800a** being illuminated. Since the lighting fixture **130** was focused while in the visible light mode (at step **1310**), structured infrared light **310** projected from the infrared light sources **800b** will be in focus.

In some embodiments, the method **1300** continues on from step **1315** to next begin step **1205** of the method **1200** described above. For example, if no visible light sources **800a** of the lighting fixture(s) **130** are illuminated in the infrared light mode, the method **1200** is carried out during, for instance, a live performance on the stage **305** without disrupting the lighting that is visible to the audience.

In some embodiments, the lighting fixtures **130** used for projecting the structured infrared light **310** in the method **1200** are used only for projecting the structured infrared light **310**, while other lighting fixtures **130** having no infrared light sources **800b** perform the normal lighting functions during a performance on the stage **305**. In such embodiments, the inclusion of the visible light sources **800a** in the lighting fixtures **130** used for projecting the structured infrared light **310** is for focusing the lighting fixtures **130**.

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In other embodiments, the lighting fixtures **130** used for projecting the structured infrared light **310** in the method **1200** also utilize the visible light sources **800a** found in each respective lighting fixture **130** for lighting the stage **305** during a performance. In such embodiments, the method **1200** is performed only once, or the method **1200** is performed more than once.

In embodiments including the method **1200** occurring only once, the lighting fixtures **130** including the infrared light sources **800b** shut off the infrared light sources **800b** after the method **1200** has been completed and continue on with only the visible light sources **800a** illuminated when necessary during the performance. Alternatively, the infrared light sources **800b** may be left on, even when no camera **135** is being activated to detect the structured infrared light **310**.

In embodiments including the method **1200** occurring periodically (even during a performance), the visible light sources **800a** are illuminated when necessary during the performance until the method **1200** is required. During the method **1200**, the visible light sources **800a** are off such that the motion and/or positioning of the lighting fixture **130** having the infrared light sources **800b** can move freely for the method **1200** without disrupting the aesthetic of the performance.

In embodiments including the method **1200** occurring frequently or continuously, the visible light sources **800a** are illuminated when necessary during the performance while the infrared light sources **800b** are selectively illuminated when the positioning of the respective lighting fixtures **130** is appropriate for the method **1200** to benefit from structured infrared light **310** being projected from the particular lighting fixtures **130**. The lighting fixtures **130** including infrared light sources **800b** move according to any upcoming visual light cues in the performance, and the system **100**, **100A** must use whatever lighting fixtures **130** are pointing in a position that is helpful to the method **1200**. Since the system **100**, **100A** is able to remove visible light from the scan data with a band-pass filter, even the lighting fixture **130** projecting the structured infrared light **310** may also project visible light for the performance. If a particular lighting fixture **130** that includes infrared light sources **800b** is not needed for an upcoming visual cue for a sufficient amount of time, that lighting fixture **130** may move freely for the method **1200** until it is needed for the next visual light cue. While moving freely, only the infrared light sources **800b** of the particular lighting fixture **130** would be illuminated so as to not disrupt the aesthetic of the performance. In such embodiments, the system **100**, **100A** would likely include more lighting fixtures **130** equipped with infrared light sources **800b** when compared to other embodiments of the system **100**, **100A** described herein.

Thus, embodiments described herein provide, among other things, systems and methods of mapping a stage in three dimensions and object detection to create an interactive three-dimensional environment and to control one or more lights associated with the stage. Various features and advantages of some embodiments are set forth in the following claims.

What is claimed is:

1. A system for mapping a stage, the system comprising:
 - a lighting fixture including a visible light source and an infrared light source, the lighting fixture configured to at least partially illuminate the stage with structured infrared light in an infrared light mode;
 - a scanner configured to detect the structured infrared light on the stage; and

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- a controller connected to the lighting fixture and the scanner, the controller configured to:
 - turn on the visible light source in a visible light mode to allow a user to focus the lighting fixture,
 - turn off the visible light source and turn on the infrared light source in the infrared light mode to illuminate at least a portion of the stage with the structured infrared light, the visible light source being continuously off during a majority of the infrared light mode,
 - control the scanner to scan the structured infrared light on the portion of the stage,
 - receive a signal from the scanner as scan data corresponding to the structured infrared light on the portion of the stage that was scanned, and
 - translate the scan data into three-dimensional location data.
- 2. The system of claim 1, wherein the controller is further configured to generate a display of the three-dimensional location data as an interactive three-dimensional environment.
- 3. The system of claim 2, wherein the controller is further configured to:
 - receive a user input, and
 - adjust a lighting setting of the visible light source of the lighting fixture based on the user input.
- 4. The system of claim 1, wherein the controller is further configured to adjust a focus of the lighting fixture with the lighting fixture in the visible light mode.
- 5. The system of claim 1, wherein the scanner includes an infrared band-pass filter.
- 6. The system of claim 1, wherein the controller is further configured to translate portions of the scan data corresponding only to infrared light scanned by the scanner and omit portions of the scan data corresponding to visible light scanned by the scanner.

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- 7. A method of mapping a stage, the method comprising:
 - operating a lighting fixture in a visible light mode;
 - allowing a user to focus the lighting fixture while the lighting fixture is in the visible light mode;
 - switching the lighting fixture from the visible light mode to an infrared light mode by turning off a visible light source and turning on an infrared light source;
 - illuminating at least a portion of the stage with structured infrared light from the lighting fixture in the infrared light mode;
 - scanning the structured infrared light on the stage, thereby producing scan data;
 - translating the scan data into three-dimensional location data; and
 - displaying the three-dimensional location data as an interactive three-dimensional environment.
- 8. The method of claim 7, further comprising switching the lighting fixture back into the visible light mode to illuminate at least the portion of the stage with visible light.
- 9. The method of claim 8, further comprising:
 - interacting with the interactive three-dimensional environment, and
 - changing a lighting setting of the lighting fixture in the visible light mode based on the interaction with the interactive three-dimensional environment.
- 10. The method of claim 7, wherein the infrared light mode includes no visible light projecting from the lighting fixture.
- 11. The method of claim 7, wherein the visible light mode includes no infrared light projecting from the lighting fixture.
- 12. The method of claim 7, wherein the three-dimensional location data is based only on the scanned structured infrared light.

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