



US011436792B2

(12) **United States Patent**
Buy

(10) **Patent No.:** **US 11,436,792 B2**
(45) **Date of Patent:** **Sep. 6, 2022**

(54) **THREE-DIMENSIONAL STAGE MAPPING**

(56) **References Cited**

(71) Applicant: **Electronic Theatre Controls, Inc.**,
Middleton, WI (US)
(72) Inventor: **Koen Buys**, Hofstade (BE)
(73) Assignee: **Electronic Theatre Controls, Inc.**,
Middleton, WI (US)
(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.

U.S. PATENT DOCUMENTS

6,549,288	B1	4/2003	Migdal et al.
8,811,767	B2	8/2014	Veeraraghavan et al.
9,606,237	B2	3/2017	Herschbach et al.
9,677,755	B1 *	6/2017	Linnell H05B 47/155
2013/0038881	A1	2/2013	Pesach et al.
2017/0116738	A1 *	4/2017	Iida H04N 13/271
2017/0370706	A1 *	12/2017	Nakatsukasa G06T 7/70
2018/0176521	A1 *	6/2018	Laduke H05B 45/20
2018/0227570	A1 *	8/2018	Page G01B 11/2513
2019/0323831	A1 *	10/2019	Natori H04N 13/128
2019/0362546	A1 *	11/2019	Wayenberg G06T 19/20
2020/0060007	A1 *	2/2020	Harrison H05B 47/105

(21) Appl. No.: **16/874,893**

* cited by examiner

(22) Filed: **May 15, 2020**

Primary Examiner — James A Thompson

(65) **Prior Publication Data**

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

US 2020/0364925 A1 Nov. 19, 2020

Related U.S. Application Data

(60) Provisional application No. 62/848,117, filed on May 15, 2019.

(57) **ABSTRACT**

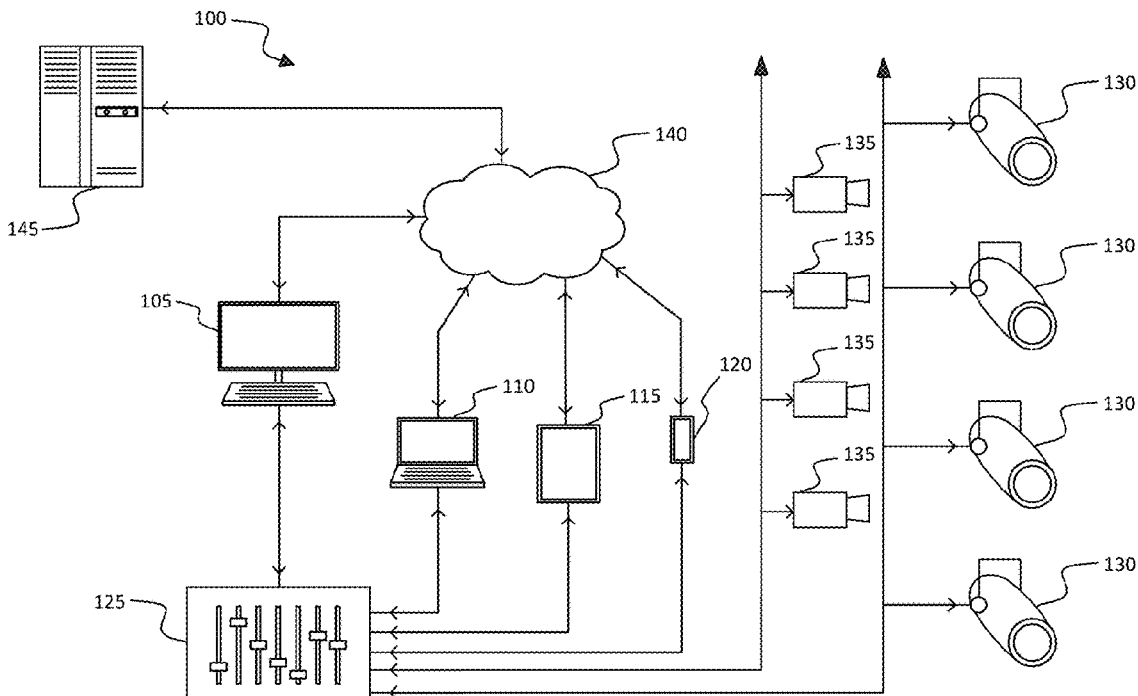
(51) **Int. Cl.**
G06T 15/50 (2011.01)
G06T 7/521 (2017.01)
H05B 47/175 (2020.01)

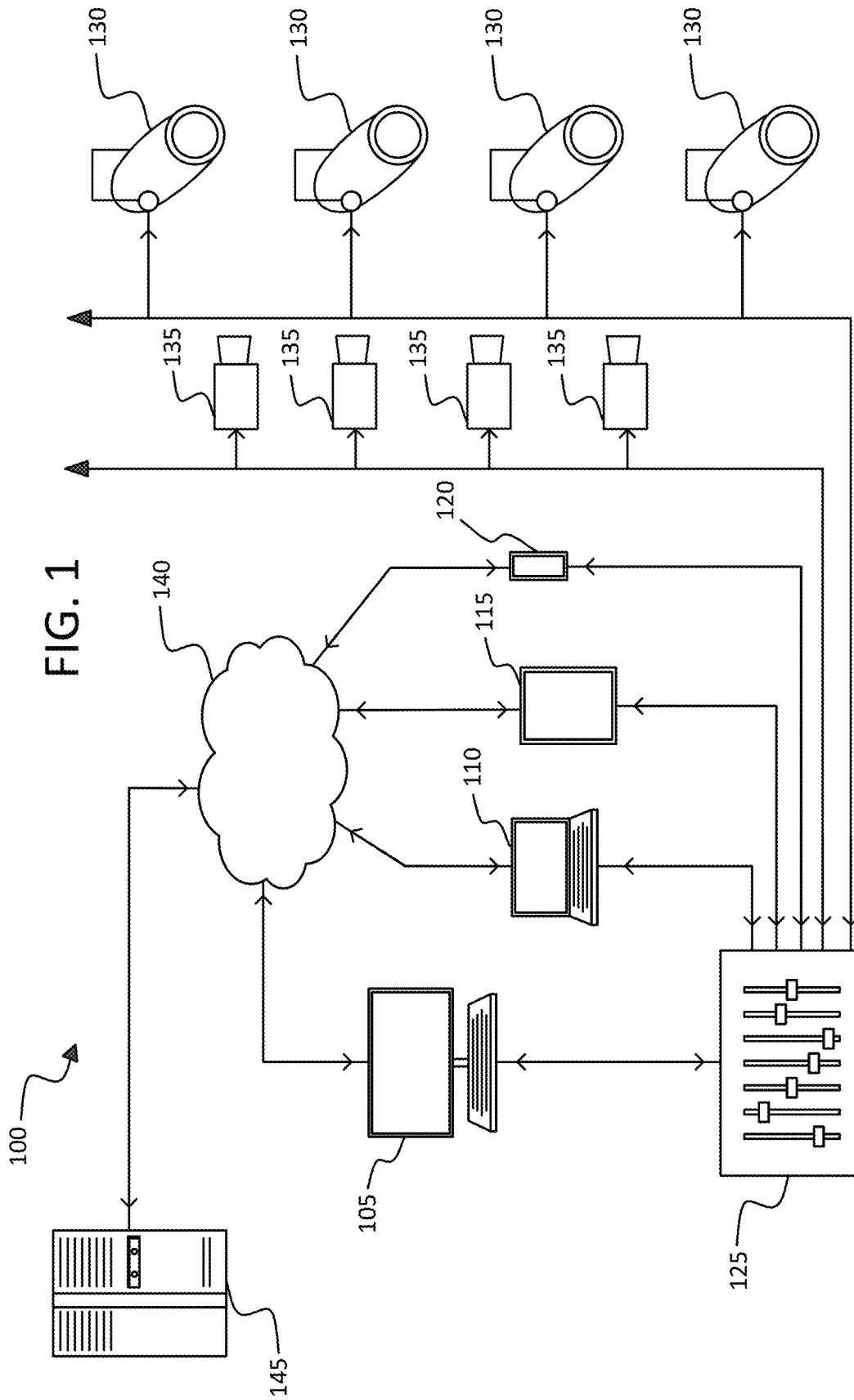
Systems for mapping a stage include a lighting fixture, a scanner, and a controller. The lighting fixture is configured to at least partially illuminate the stage with structured light. The scanner is configured to detect the structured light on the stage. The controller is connected to the lighting fixture and the scanner. The controller is configured to control the lighting fixture to illuminate a portion of the stage with the structured light, control the scanner to scan the structured light on the portion of the stage, receive a signal from the scanner as scan data, and translate the scan data into three-dimensional location data.

(52) **U.S. Cl.**
CPC **G06T 15/506** (2013.01); **G06T 7/521**
(2017.01); **H05B 47/175** (2020.01); **G06T**
2200/08 (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

21 Claims, 10 Drawing Sheets





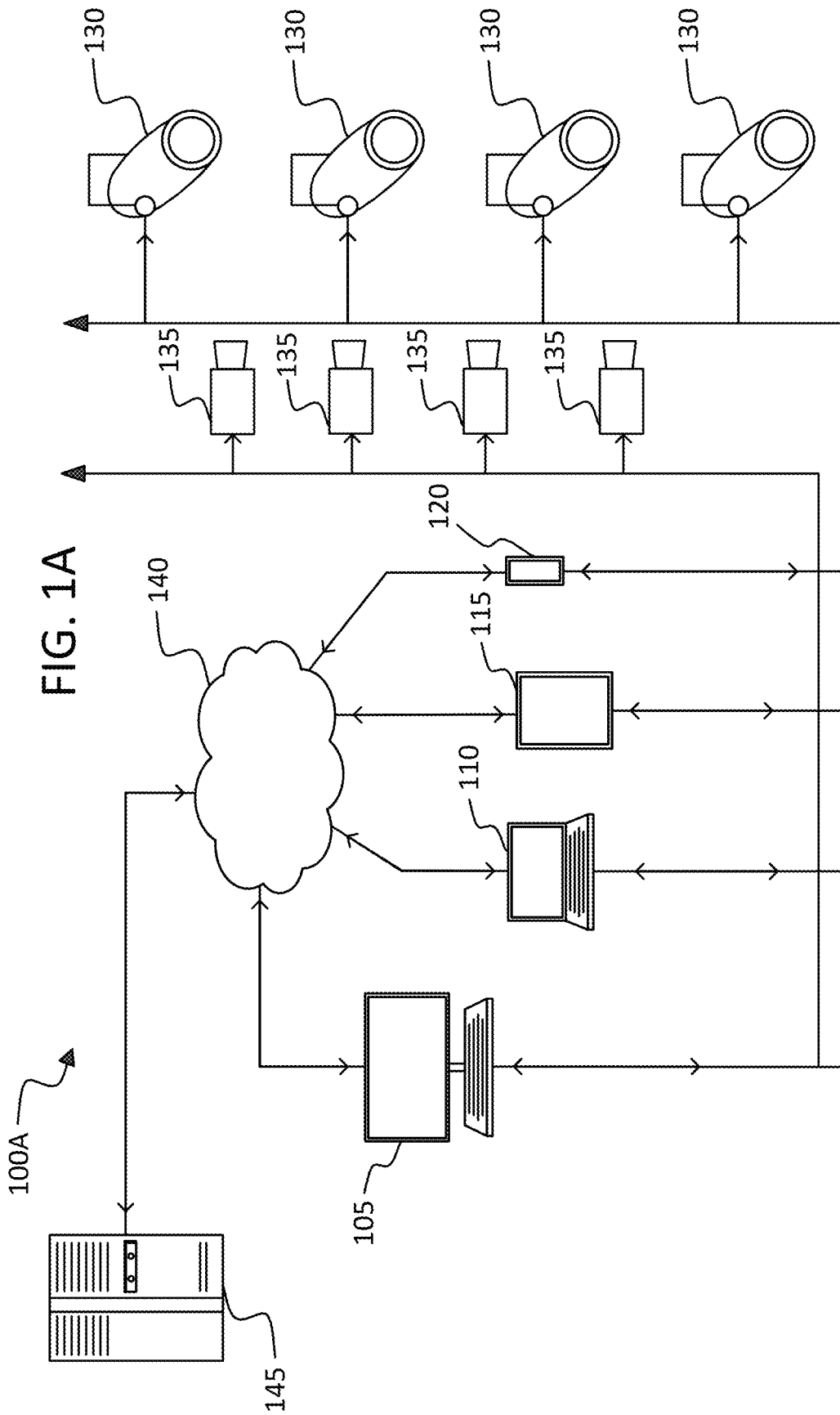


FIG. 2

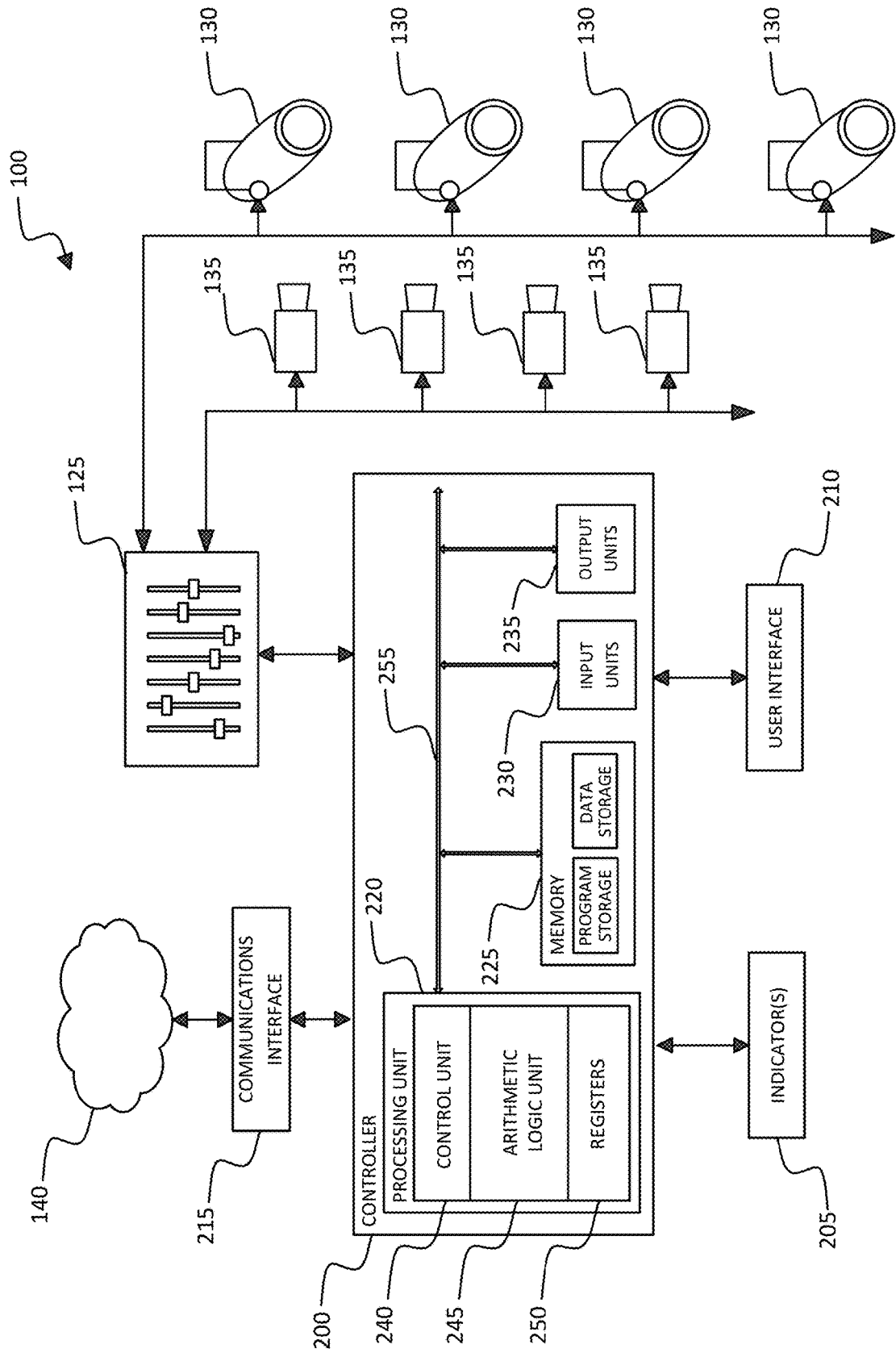
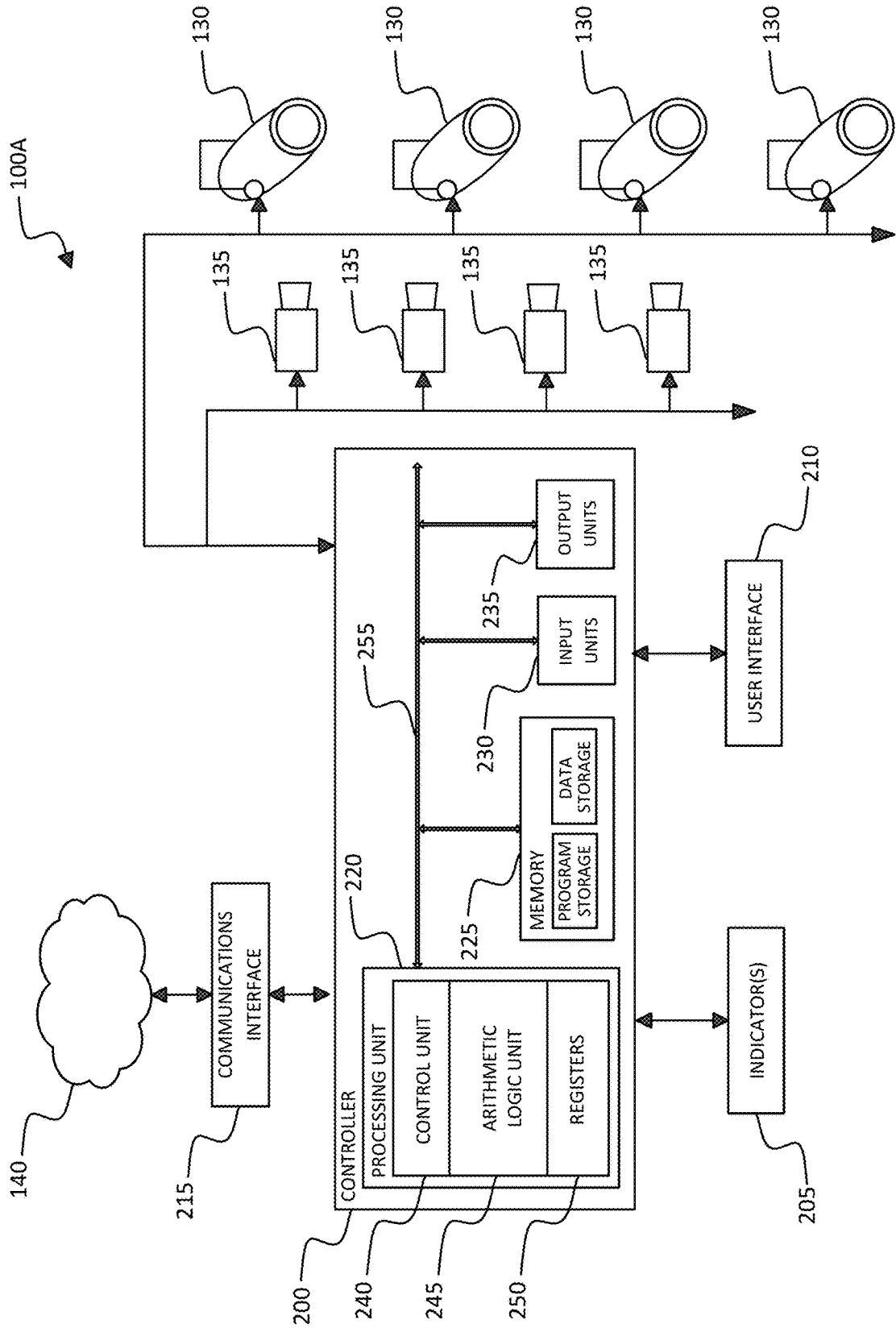


FIG. 2A



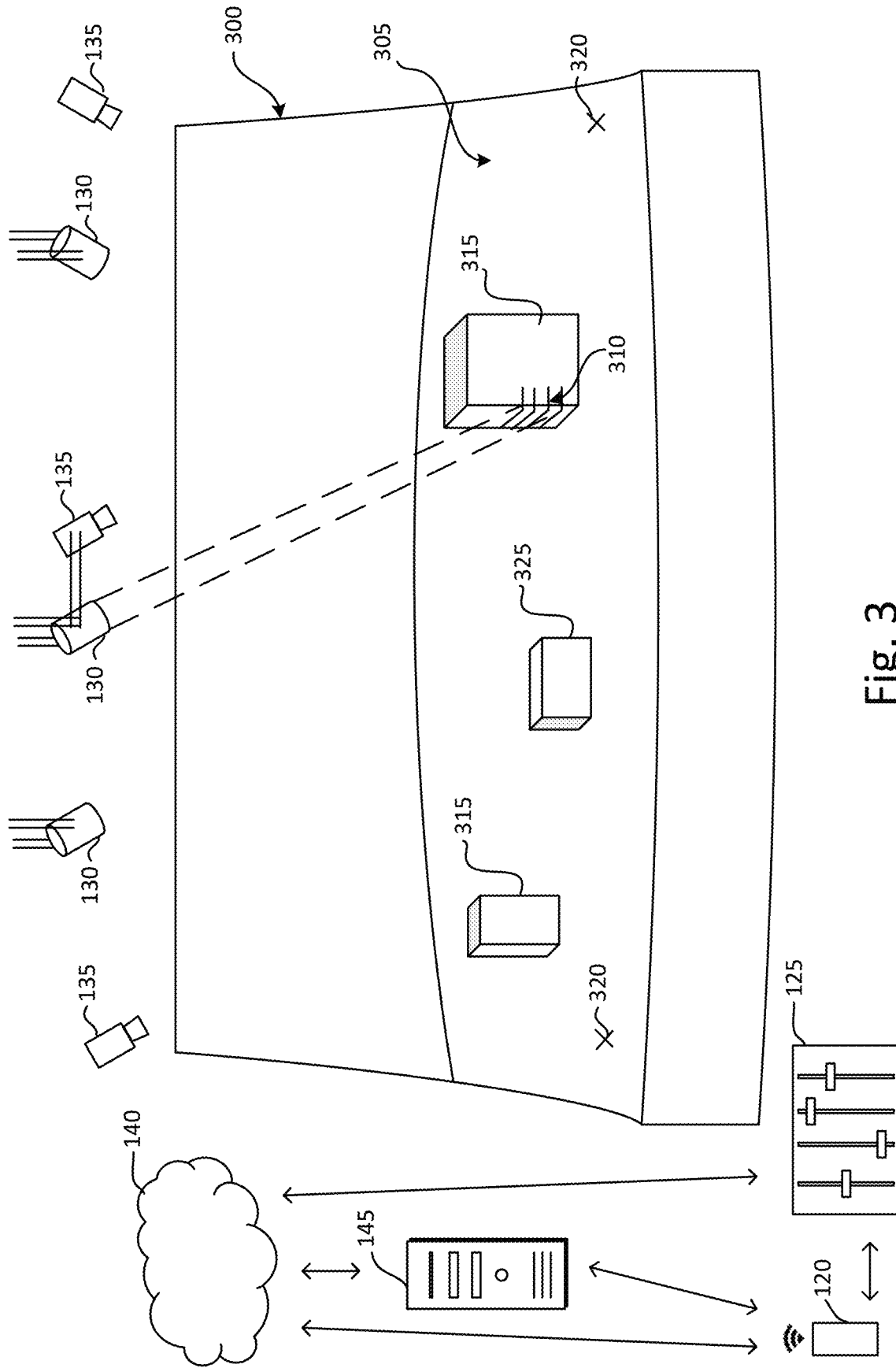
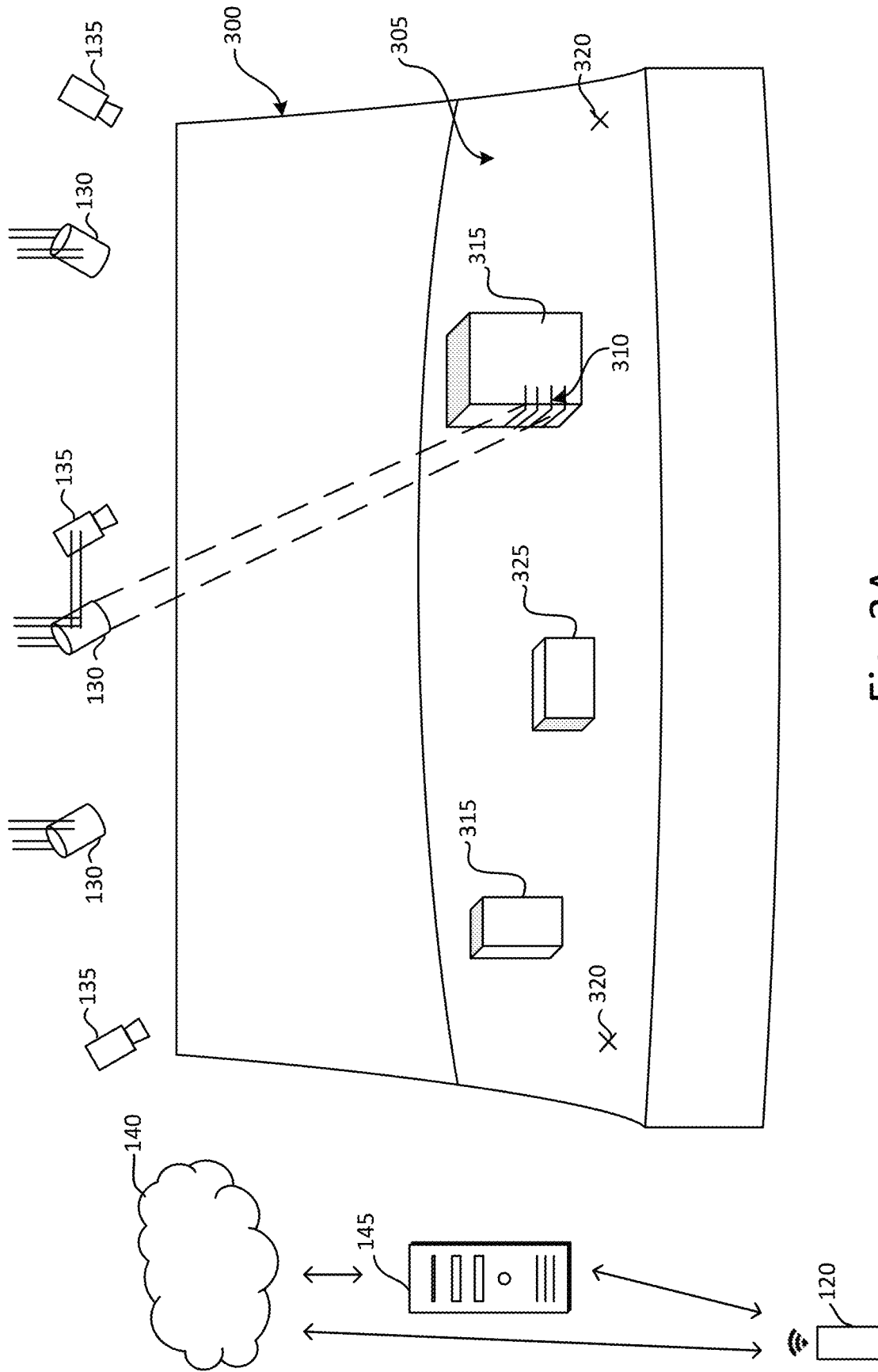


Fig. 3



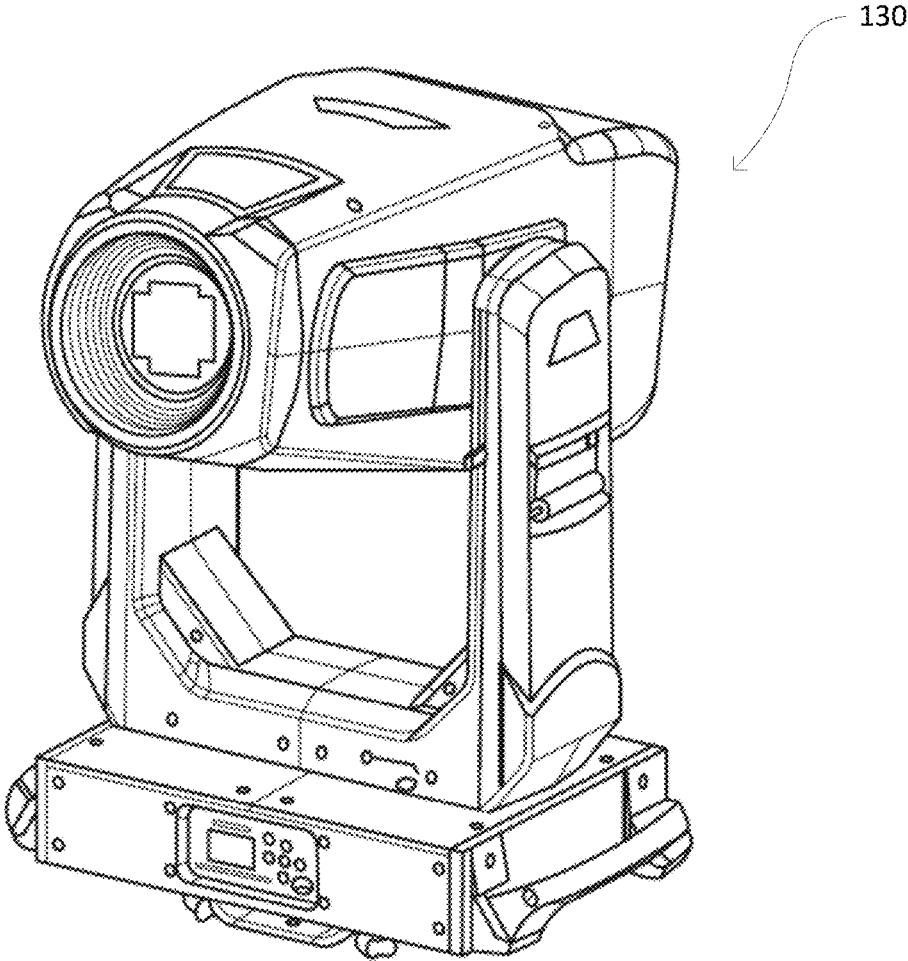


Fig. 4

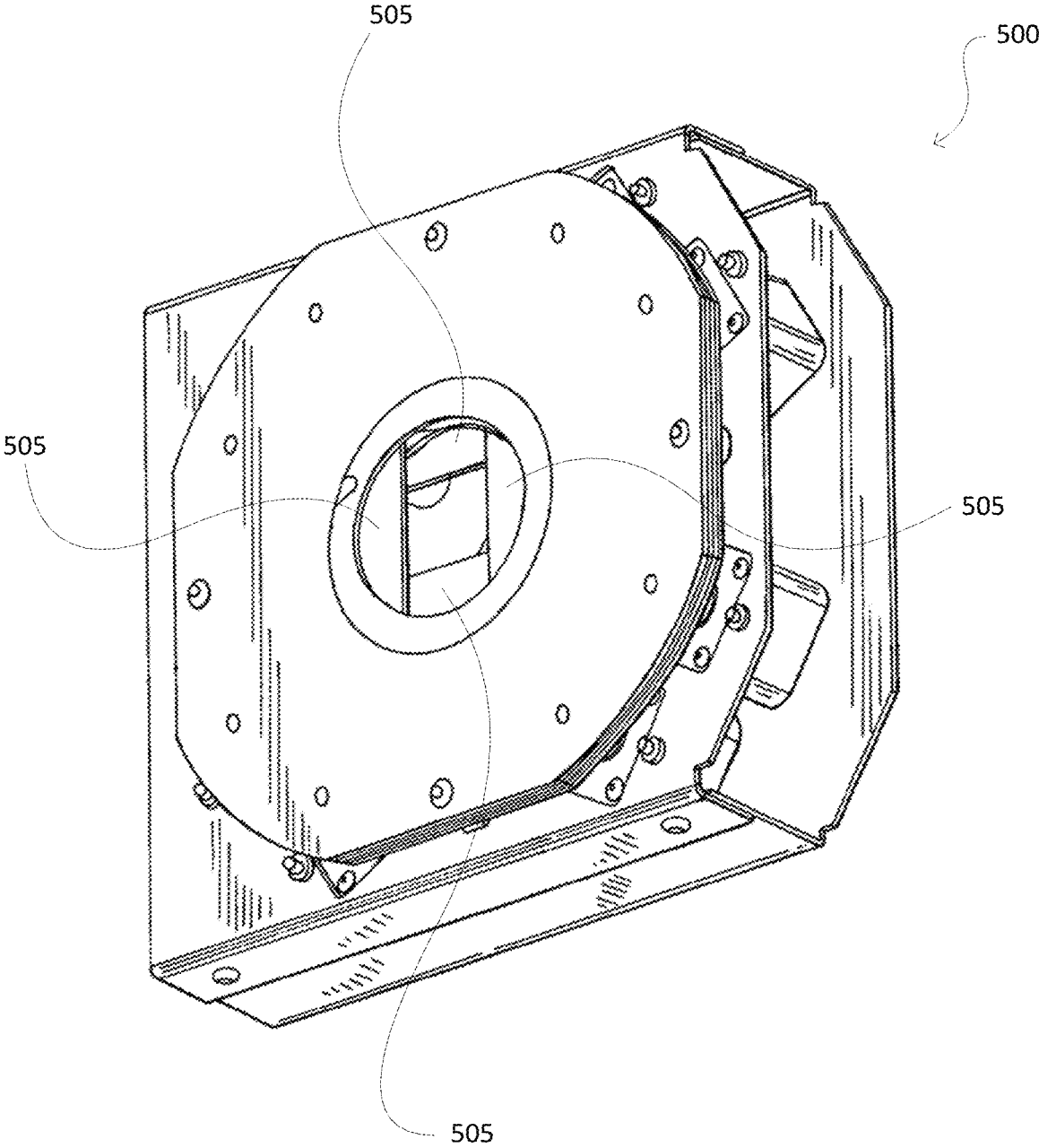


Fig. 5

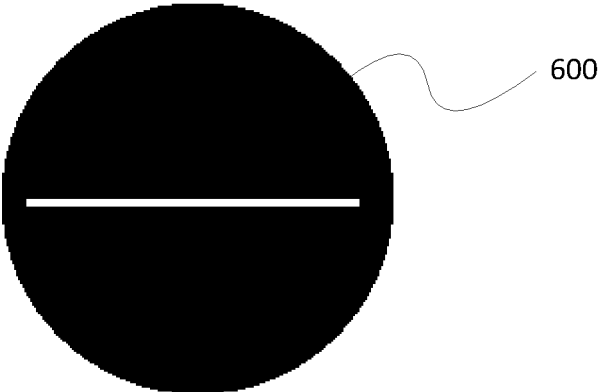


Fig. 6A

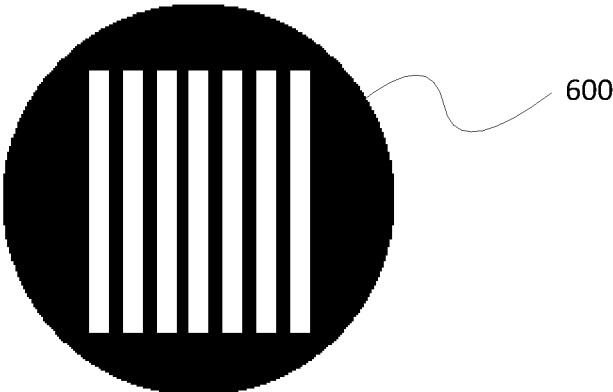


Fig. 6B

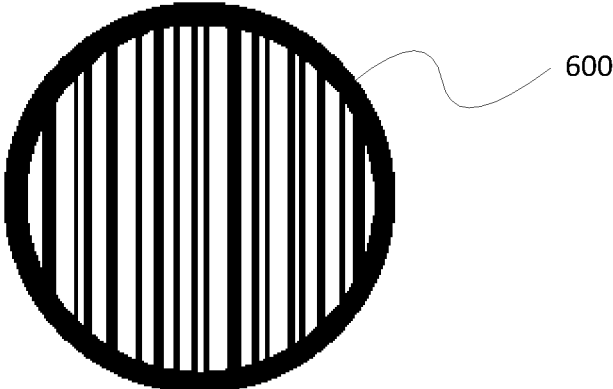


Fig. 6C

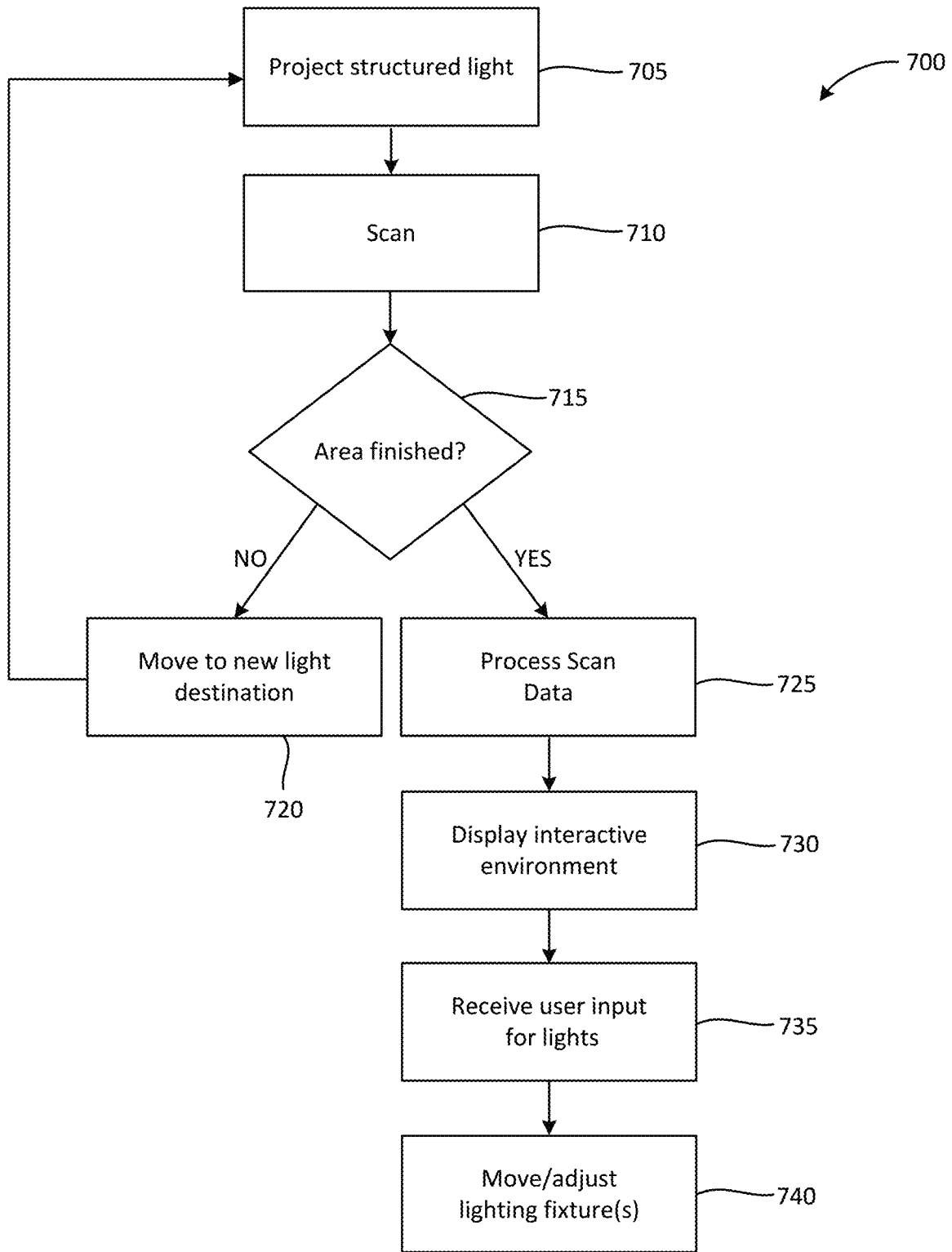


Fig. 7

THREE-DIMENSIONAL STAGE MAPPING**CROSS-REFERENCE TO RELATED APPLICATION**

This application claims the benefit of U.S. Provisional Application No. 62/848,117, filed May 15, 2019, the entire content of which is hereby incorporated by reference.

FIELD

Embodiments described herein relate to mapping an object through the use of structured light in combination with a camera.

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 address the above concerns, a system and method for mapping a stage are implemented to 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 are then imported into a specialized 3D modeling software program in the form of an interactive three-dimensional stage model that may alter its display based on user input. This model may then be used to control one or more lights. 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. Further, some embodiments of the system and method for mapping a stage may include use of only the lighting fixtures that are already present at the venue with little to no customization done to the lighting fixtures.

Accordingly, to address these and other technical problems associated with gathering dimension data of a stage and controlling one or more lights associated with the stage, embodiments described herein provide, among other things, systems and methods of mapping a stage in three dimensions to create an interactive three-dimensional environment and to control one or more lights associated with the stage.

Systems described herein for mapping a stage include a lighting fixture, a scanner, and a controller. The lighting fixture is configured to at least partially illuminate the stage with structured light. The scanner is configured to detect the structured light on the stage. The controller is connected to the lighting fixture and the scanner. The controller is configured to control the lighting fixture to illuminate a portion of the stage with the structured light, control the scanner to scan the structured light on the portion of the stage, receive a signal from the scanner as scan data, and translate the scan data into three-dimensional location data.

Methods described herein for mapping a stage include transmitting an illumination control signal to a lighting

fixture to illuminate at least a portion of the stage with structured light, transmitting a scan control signal to a scanner to scan the structured light, receiving a scan data signal from the scanner corresponding to the scanned structured light, translating the scan data signal into three-dimensional location data, and transmitting a display control signal to a display to display the three-dimensional location data.

Methods described herein for mapping a stage include illuminating at least a portion of the stage with structured light, scanning the structured light on the portion of the stage, translating scan data from scanning the structured light into three-dimensional location data, displaying the three-dimensional location data as an interactive three-dimensional environment, receiving an input related to a lighting fixture setting based on an interaction with the interactive three-dimensional environment, and adjusting the lighting fixture setting of a lighting fixture based on the input.

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 and controlling at least one lighting fixture.

FIG. 1A schematically illustrates an alternative system for mapping a stage in three dimensions 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. 6A illustrates a single line gobo for use with a lighting fixture of the system of FIG. 1 or the system of FIG. 1A.

FIG. 6B illustrates a uniform line pattern gobo for use with a lighting fixture of the system of FIG. 1 or the system of FIG. 1A.

FIG. 6C illustrates an irregular line pattern gobo for use with a lighting fixture of the system of FIG. 1 or the system of FIG. 1A.

FIG. 7 illustrates a method of operating the system of FIG. 1 or the system of FIG. 1A.

DETAILED DESCRIPTION

Embodiments described herein relate to gathering dimension data of a stage and utilizing the dimension data to 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.

5

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

6

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 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. 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 24 using, for instance, the processing unit 220. This processing of the characteristics of the structured light 310 into dimension and location data is accomplished using an algorithm including, for instance, 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. 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**. 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 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 light **310**. In some embodiments, only a single edge of the projected light is used as the structured 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 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 light **310** may advantageously be rotated to create a dynamic structured light **310** to improve the scan accuracy.

Alternative embodiments of the lighting fixtures **130** include a gobo **600**, such as those shown in FIGS. **6A-6C**, positioned in front of the lighting fixture **130** to project, for instance, a single line, a uniform line pattern, or an irregular line pattern. The embodiments discussed herein include lighting fixtures **130** configured to project light such that structured light **310** in the visible portion of the electromagnetic spectrum, the infrared portion of the electromagnetic spectrum, some combination thereof, or the like is projected.

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 light **310** onto the stage **305**. The cameras **135** scan a portion of the stage illuminated by the structured light **310**. The controller **200** further interprets signals from the cameras **135** representing distortion of the shape and/or pattern of the structured 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.

FIG. **7** illustrates a method **700** 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 **700** includes illuminating a portion of the stage **305** and/or objects **315** on the stage **305** with structured light **310** projected by the lighting fixtures **130** (step **705**). 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 600 (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. Objects 315 that may be present on the stage 305 include, for example, scenery elements. The structured 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 710).

The method 700 further includes the controller 200 determining whether the lighting fixtures 130 have directed the structured 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 715). 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 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 700, 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 715 is no, the method 700 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 light 310 to a different portion of the area to be mapped (step 720). 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 light 310 in order to move the structured 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 light 310 have moved and/or the subset of lighting fixtures 130 projecting the structured light have changed, the structured light 310 arrives at its new illumi-

nation portion of the stage 305 and/or objects 315 on the stage 305 at step 705. The method 700 then continues again through steps 710 and 715.

If the result at step 715 is yes (either on the first time arriving at step 715 in the method 700 or after having repeated steps 705 and 710 one or more times), the method 700 includes the controller 200 processing the scan data received from the cameras 135 to determine three-dimensional spatial locations for points where the structured light 310 reflects from the stage 305 and/or objects 315 on the stage 305 (step 725).

Step 725 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 light 310. With this information, the location of each point in the set of points that make up the structured 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 light 310.

In some embodiments, step 725 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 light 310, a pattern or grid of structured 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 light 310 includes a plurality of lines, a distinct and non-repeating series of shapes and/or colors, or the like. Such a pattern or grid of structured light 310 is formed by equipping the lighting fixtures 130 with a designated gobo 600.

Once the scan data has been processed (step 725), the method 700 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 730). 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 700 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 735). 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

11

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, or the like.

Once the user input data has been received (step 735), the method 700 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 740). 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 700 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 735. The user then makes further adjustments or confirms the lighting scheme that has been selected. Once the lighting scheme has been confirmed, the method 700 then moves to step 740 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 700 include the controller 200 processing the scan data (as is done at step 725) in a more segmented manner by processing the scan data acquired each instance after step 710 has been completed. This processed scan data is augmented with further input from the cameras 135 after each additional instance of step 710 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 700.

Some embodiments of the method 700 utilize a number of lighting fixtures 130 projecting the structured light 310 and a number of cameras 135 to capture images of the structured 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 700 do not require step 715 or step 720.

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).

Thus, embodiments described herein provide, among other things, systems and methods of mapping a stage in three dimensions 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 configured to at least partially illuminate the stage with structured light including a plane of light projected from the lighting fixture;
 a scanner directed toward the stage and configured to detect the structured light on the stage; and
 a controller connected to the lighting fixture and the scanner, the controller configured to:

12

control the lighting fixture to illuminate a portion of the stage with the structured light,
 control the scanner to scan a shape of the structured light on the portion of the stage,
 receive a signal from the scanner as scan data, the scan data corresponding to the shape of the structured light on the portion of the stage, and
 translate the scan data into three-dimensional location data that is representative of a shape of the portion of the stage.

2. The system of claim 1, wherein the controller is further configured to generate an interactive environment based on the three-dimensional location data.

3. The system of claim 2, wherein the controller is further configured to receive user input, the user input including user interaction with the interactive environment.

4. The system of claim 3, wherein the controller is further configured to adjust a lighting setting of the lighting fixture based on the user input.

5. The system of claim 3, further comprising a second lighting fixture, and

wherein the controller is further configured to adjust a lighting setting of the second lighting fixture based on the user input.

6. The system of claim 1, wherein:

the portion of the stage is a first portion of the stage, and the controller is further configured to:

direct the lighting fixture to illuminate a second portion of the stage with structured light,

direct the scanner to scan the structured light on the second portion of the stage,

receive a second signal from the scanner as second scan data, and

translate the second scan data into second three-dimensional location data.

7. The system of claim 6, wherein the controller is further configured to:

determine if a first predetermined area of the stage has been completely scanned;

indicate scan completion of the predetermined area if the predetermined area has been completely scanned; and

control the lighting fixture and the scanner to a second predetermined area of the stage if the first predetermined area has been completely scanned.

8. The system of claim 7, wherein the controller is configured to determine if the first predetermined area of the stage has been completely scanned based on movement control signals sent to the lighting fixture.

9. The system of claim 1, further comprising a second lighting fixture, and

wherein the controller is further configured to:

control the second lighting fixture to illuminate a second portion of the stage with structured light,

control the scanner to scan the structured light on the second portion of the stage,

receive a second signal from the scanner as second scan data, and

translate the second scan data into second three-dimensional location data.

10. The system of claim 1, wherein the controller is further configured to

automatically control the lighting fixture to illuminate the portion of the stage with the structured light, and automatically control the scanner to scan the shape of the structured light on the portion of the stage.

13

11. A method of mapping a stage, the method comprising:
 transmitting an illumination control signal to a lighting
 fixture to illuminate at least a portion of the stage with
 structured light including a plane of light projected
 from the lighting fixture;
 transmitting a scan control signal to a scanner directed
 toward the stage to scan a shape of the structured light;
 receiving a scan data signal from the scanner correspond-
 ing to the shape of the scanned structured light;
 translating the scan data signal into three-dimensional
 location data that is representative of a shape of the
 portion of the stage; and
 transmitting a display control signal to a display to display
 the three-dimensional location data as a representation
 of the portion of the stage.
 12. The method of claim 11, further comprising:
 receiving an input signal corresponding to a user input,
 and
 transmitting an updated display control signal to the
 display based on the input signal.
 13. The method of claim 12, wherein:
 the display displays the three-dimensional location data as
 an interactive three-dimensional environment, and
 the input signal corresponds to an interaction with the
 interactive three-dimensional environment.
 14. The method of claim 11, further comprising:
 receiving an input signal corresponding to a user input,
 and
 transmitting an updated illumination control signal to the
 lighting fixture based on the input signal to illuminate
 at least the portion of the stage with light based on the
 user input.
 15. The method of claim 14, wherein the updated illumi-
 nation control signal causes the lighting fixture to illuminate
 at least the portion of the stage with light different from the
 structured light.
 16. The method of claim 11, further comprising:
 receiving an input signal corresponding to a user input,
 and
 transmitting a second illumination control signal to a
 second lighting fixture based on the input signal to
 illuminate at least a second portion of the stage with
 light based on the user input.

14

17. The method of claim 11, further comprising:
 transmitting a second illumination control signal to the
 lighting fixture to illuminate a second portion of the
 stage with the structured light;
 transmitting a second scan control signal to the scanner to
 scan the structured light at the second portion of the
 stage;
 receiving a second scan data signal from the scanner
 corresponding to the scanned structured light at the
 second portion of the stage,
 translating the second scan data signal into second three-
 dimensional location data, and
 transmitting a second display control signal to the display
 to show both the three-dimensional location data and
 the second three-dimensional location data.
 18. A method of mapping a stage, the method comprising:
 illuminating at least a portion of the stage with structured
 light including a plane of light projected onto the
 portion of the stage;
 scanning a shape of the structured light on the portion of
 the stage from a position away from the stage;
 translating scan data from scanning the shape of the
 structured light into three-dimensional location data
 that is representative of a shape of the portion of the
 stage;
 displaying the three-dimensional location data as an inter-
 active three-dimensional environment functioning as a
 representation of the portion of the stage;
 receiving an input related to a lighting fixture setting
 based on an interaction with the interactive three-
 dimensional environment; and
 adjusting the lighting fixture setting of a lighting fixture
 based on the input.
 19. The method of claim 18, wherein illuminating at least
 the portion of the stage with structured light includes mul-
 tiple lighting fixtures.
 20. The method of claim 18, wherein scanning the struc-
 tured light on the portion of the stage includes multiple
 scanners.
 21. The method of claim 18, further comprising projecting
 the structured light from the lighting fixture.

* * * * *