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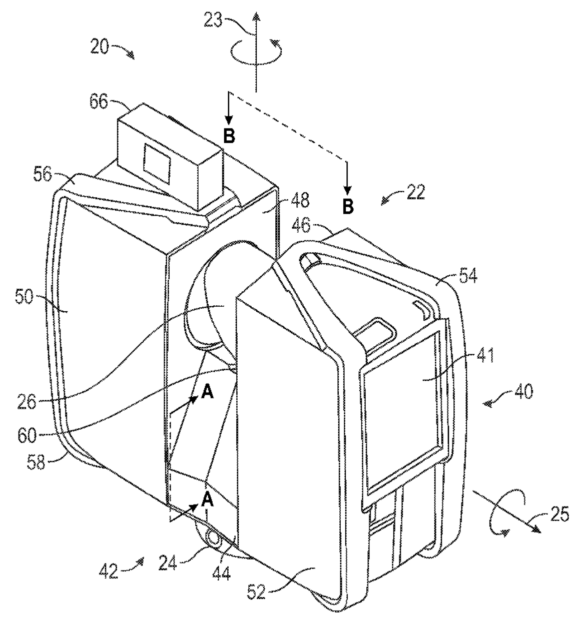

FIG. 1

(57) Abstract: Examples described herein provide a method performed by a processing device. The method includes receiving three-dimensional (3D) data from a 3D coordinate measurement device. The method further includes structuring the 3D data to generate structured data based on a context between points of the 3D data. The method further includes performing a first compression on the structured data to generate first compressed structured data. The method further includes performing a second compression on the first compressed structured data to generate second compressed structured data. The method further includes, responsive to a request, providing the 3D data as uncompressed data by decompressing the second compressed structured data to generate the first uncompressed structured data; and decompressing the first uncompressed structured data to generate the 3D data.

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MULTI-SCHEME THREE-DIMENSIONAL (3D) DATA COMPRESSION

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Patent Application Serial No. 63/430,426, filed December 6, 2022, and entitled "MULTI-SCHEME THREE-DIMENSIONAL (3D) DATA COMPRESSION," the entire contents of which are incorporated by reference herein.

BACKGROUND

[0002] The subject matter disclosed herein relates to multi-scheme three-dimensional (3D) data compression. As an example, 3D data are captured using a three-dimensional (3D) laser scanner time-of-flight (TOF) coordinate measurement device or another suitable device. A 3D laser scanner of this type steers a beam of light to a non-cooperative target such as a diffusely scattering surface of an object. A distance meter in the device measures a distance to the object, and angular encoders measure the angles of rotation of two axles in the device. The measured distance and two angles enable a processor in the device to determine the 3D coordinates of the target.

[0003] A TOF laser scanner is a scanner in which the distance to a target point is determined based on the speed of light in air between the scanner and a target point. Laser scanners are typically used for scanning closed or open spaces such as interior areas of buildings, industrial installations and tunnels. Such scanners are also used, for example, in industrial applications and accident reconstruction applications. A laser scanner optically scans and measures objects in a volume around the scanner through the acquisition of data points representing object surfaces within the volume. Such data points are obtained by transmitting a beam of light onto the objects and collecting the reflected or scattered light to determine the distance, two-angles (i.e., an azimuth and a zenith angle), and optionally a gray-scale value. This raw scan data is collected, stored and sent to a processor or processors to generate a 3D image representing the scanned area or object.

BRIEF DESCRIPTION

[0004] In one embodiment, a method performed by a processing device is provided. The method includes receiving three-dimensional (3D) data from a 3D coordinate measurement device. The method further includes structuring the 3D data to generate structured data based on a context between points of the 3D data. The method further includes performing a first compression on the structured data to generate first compressed structured data. The method further includes performing a second compression on the first compressed structured data to generate second compressed structured data. The method further includes, responsive to receiving a request, providing the 3D data as uncompressed data by decompressing the second compressed structured data to generate the first uncompressed structured data and decompressing the first uncompressed structured data to generate the 3D data.

[0005] In another embodiment, a system is provided. The system includes a three-dimensional (3D) coordinate measurement device to collect 3D data about an environment and compress the 3D data about the environment to generate compressed raw 3D data. The system further includes a processing system that includes a memory having computer readable instructions and at least one processor for executing the computer readable instructions. The computer readable instructions control the at least one processor to perform operations. The operations include receiving the compressed raw 3D data from the 3D coordinate measurement device. The operations further include decompressing the compressed raw 3D data to extract the 3D data. The operations further include structuring the 3D data to generate structured data based on a context between points of the 3D data. The operations further include performing a first compression on the structured data to generate first compressed structured data. The operations further include performing a second compression on the first compressed structured data to generate second compressed structured data. The operations further include, responsive to receiving a request, providing the 3D data as uncompressed data by decompressing the second compressed structured data to generate the first uncompressed structured data and decompressing the first uncompressed structured data to generate the 3D data.

[0006] In yet another embodiment, a non-transitory computer readable medium having program instructions embodied therewith is provided. The program instructions are executed by at least one processor to perform a method for data compression. The method includes receiving the compressed raw 3D data from the 3D coordinate measurement device. The method further includes decompressing the compressed raw 3D data to extract the 3D data. The method further includes structuring the 3D data to generate structured data based on a context between points of the 3D data. The method further includes performing a first compression on the structured data to generate first compressed structured data. The method further includes performing a second compression on the first compressed structured data to generate second compressed structured data. The method further includes, responsive to a request from a user, providing the 3D data as uncompressed data by decompressing the second compressed structured data to generate the first uncompressed structured data and decompressing the first uncompressed structured data to generate the 3D data.

[0007] The above features and advantages, and other features and advantages, of the disclosure are readily apparent from the following detailed description when taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

[0008] The subject matter, which is regarded as the disclosure, is particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The foregoing and other features, and advantages of the disclosure are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

[0009] FIG. 1 is a perspective view of a laser scanner according to one or more embodiments described herein;

[0010] FIG. 2 is a side view of the laser scanner illustrating a method of measurement according to one or more embodiments described herein;

[0011] FIG. 3 is a schematic illustration of the optical, mechanical, and electrical components of the laser scanner according to one or more embodiments described herein;

[0012] FIG. 4 is a schematic illustration of the laser scanner of FIG. 1 according to one or more embodiments described herein;

[0013] FIG. 5 is a schematic illustration of a processing system for multi-scheme 3D data compression according to one or more embodiments described herein;

[0014] FIG. 6 is a flow diagram of a method for multi-scheme 3D data compression according to one or more embodiments described herein;

[0015] FIGS. 7A–7C depict a process for compressing and/or decompressing data according to one or more embodiments described herein; and

[0016] FIG. 8 is a schematic illustration of a processing system for implementing the presently described techniques according to one or more embodiments described herein.

[0017] The detailed description explains embodiments of the disclosure, together with advantages and features, by way of example with reference to the drawings.

DETAILED DESCRIPTION

[0018] Generating an image requires at least three values for each data point. These three values include the distance and two angles, or are transformed values, such as the x, y, z coordinates. In an embodiment, an image is also based on a fourth gray-scale value, which is a value related to irradiance of scattered light returning to the scanner.

[0019] Most TOF scanners direct the beam of light within the measurement volume by steering the light with a beam steering mechanism. According to one or more embodiments, the beam steering mechanism includes a first motor that steers the beam of light about a first axis by a first angle that is measured by a first angular encoder (or another angle transducer). The beam steering mechanism also includes a second motor that steers the beam of light about a second axis by a second angle that is measured by a second angular encoder (or another angle transducer) according to one or more embodiments. Other TOF scanners use a pair of galvanometer mirrors to direct the light according to one or more embodiments.

[0020] Many contemporary laser scanners include a camera for gathering camera digital images of the environment and for presenting the camera digital images to an operator of the laser scanner. By viewing the camera images, the operator of the scanner can determine the field of view of the measured volume and adjust settings on the laser scanner to measure over a larger or smaller region of space. In addition, according to one or more embodiments, the camera digital images are transmitted to a processor to add color to the scanner image by mapping the colors to the measured data points. To generate a color scanner image, at least three positional coordinates (such as x, y, z) and three color values (such as red, green, blue "RGB") are collected for each data point.

[0021] One application where 3D scanners are used is to scan an environment and/or an object.

[0022] Embodiments described herein provide for multi-scheme three-dimensional (3D) data compression. Particularly, one or more embodiments described herein relate to receiving 3D data (such as from a 3D coordinate measurement device), structuring the 3D data, and performing a multi-scheme 3D data compression including performing a first compression on the structured 3D data and performing a second compression on the compressed structured 3D data. One or more embodiments described herein provide for performing an initial compression of the 3D data by the 3D coordinate measurement device prior to transmitting the 3D data to a processing system. In such cases, the processing system decompresses the data before structuring and then applying the multi-scheme 3D data compression.

[0023] 3D coordinate measurement devices, such as laser scanners, are used to capture 3D data about an environment. The 3D data is presented on a device, such as a smartphone, tablet, heads-up display, etc., as a graphical representation. Because the 3D data is very large, the 3D data consumes considerable bandwidth when transferred between devices/systems (e.g., between a 3D coordinate measurement device and a processing system, between the processing system and a user computing device, and/or the like, including combinations and/or multiples thereof) and considerable storage space when storing the data. For example, 3D data collected in an environment includes billions of points (e.g., 40 billion points), with each point being represented in the 3D data. It is difficult and time consuming to transfer such large data sets between two devices.

[0024] Conventional techniques for compressing 3D data do not apply a multi-scheme 3D compression. Accordingly, one or more embodiments described herein that use a multi-scheme 3D compression technique provide improved efficiency of data transfer, storage, visualization, and processing for 3D data, such as data (e.g., a point cloud) collected by 3D coordinate measurement devices.

[0025] Referring now to FIGS. 1–3, a 3D coordinate measurement device, such as a laser scanner 20, is shown for optically scanning and measuring the environment surrounding the laser scanner 20 according to one or more embodiments described herein. The laser scanner 20 has a measuring head 22 and a base 24. The measuring head 22 is mounted on the base 24 such that the laser scanner 20 is rotated about a vertical axis 23. In one embodiment, the measuring head 22 includes a gimbal point 27 that is a center of rotation about the vertical axis 23 and a horizontal axis 25. The measuring head 22 has a rotary mirror 26, which is rotated about the horizontal axis 25 according to one or more embodiments. The rotation about the vertical axis is about the center of the base 24 according to one or more embodiments. The terms vertical axis and horizontal axis refer to the scanner in its normal upright position. It is possible to operate a 3D coordinate measurement device on its side or upside down, and so to avoid confusion, the terms azimuth axis and zenith axis may be substituted for the terms vertical axis and horizontal axis, respectively. The term pan axis or standing axis may also be used as an alternative to vertical axis.

[0026] The measuring head 22 is further provided with an electromagnetic radiation emitter, such as light emitter 28, for example, that emits an emitted light beam 30. In one embodiment, the emitted light beam 30 is a coherent light beam such as a laser beam. According to one or more embodiments, the laser beam has a wavelength range of approximately 300 to 1600 nanometers, for example 790 nanometers, 905 nanometers, 1550 nm, or less than 400 nanometers. It should be appreciated that other electromagnetic radiation beams having greater or smaller wavelengths are used in various embodiments. The emitted light beam 30 is amplitude or intensity modulated, for example, with a sinusoidal waveform or with a rectangular waveform. The emitted light beam 30 is emitted by the light emitter 28 onto a beam steering unit, such as mirror 26, where it is deflected to the environment. A reflected light beam 32 is reflected from the environment by an object 34. The reflected or scattered light is intercepted by the rotary mirror 26 and directed into a light receiver 36. The directions of the emitted light beam 30 and the reflected light beam 32 result from the angular positions of the rotary mirror 26 and the measuring head 22 about the axes 25 and 23, respectively. These angular positions in turn depend on the corresponding rotary drives or motors.

[0027] Coupled to the light emitter 28 and the light receiver 36 is a controller 38. The controller 38 determines, for a multitude of measuring points X, a corresponding number of distances d between the laser scanner 20 and the points X on object 34. The distance to a particular point X is determined based at least in part on the speed of light in air through which electromagnetic radiation propagates from the device to the object point X. In one embodiment the phase shift of modulation in light emitted by the laser scanner 20 and the point X is determined and evaluated to obtain a measured distance d.

[0028] The speed of light in air depends on the properties of the air such as the air temperature, barometric pressure, relative humidity, and concentration of carbon dioxide. Such air properties influence the index of refraction *n* of the air. The speed of light in air is equal to the speed of light in vacuum *c* divided by the index of refraction. In other words, $c_{air} = c / n$. A laser scanner of the type discussed herein is based on the time-of-flight (TOF) of the light in the air (the round-trip time for the light to travel from the device to the object and back to the device). Examples of TOF scanners include scanners that measure round trip time using the time interval between emitted and returning pulses (pulsed TOF scanners), scanners that modulate light sinusoidally and measure phase shift of the returning light (phase-based scanners), as well as many other types. A method of measuring distance based on the time-of-flight of light depends on the speed of light in air and is therefore easily distinguished from methods of measuring distance based on triangulation. Triangulation-based methods involve projecting light from a light source along a particular direction and then intercepting the light on a camera pixel along a particular direction. By knowing the distance between the camera and the projector and by matching a projected angle with a received angle, the method of triangulation enables the distance to the object to be determined based on one known length and two known angles of a triangle. The method of triangulation, therefore, does not directly depend on the speed of light in air.

[0029] In one mode of operation, the scanning of the volume around the laser scanner 20 takes place by rotating the rotary mirror 26 relatively quickly about axis 25 while rotating the measuring head 22 relatively slowly about axis 23, thereby moving the assembly in a spiral pattern. In an exemplary embodiment, the rotary mirror rotates at a maximum speed of 5820 revolutions per minute. For such a scan, the gimbal point 27 defines the origin of the local stationary reference system. The base 24 rests in this local stationary reference system.

[0030] In addition to measuring a distance d from the gimbal point 27 to an object point X, the laser scanner 20 also collects gray-scale information related to the received optical power (equivalent to the term “brightness”) according to one or more embodiments. The gray-scale value are determined at least in part, for example, by integration of the bandpass-filtered and amplified signal in the light receiver 36 over a measuring period attributed to the object point X.

[0031] According to one or more embodiments, the measuring head 22 includes a display device 40 integrated into the laser scanner 20. According to one or more embodiments, the display device 40 includes a graphical touch screen 41, as shown in FIG. 1, which allows the operator to set the parameters or initiate the operation of the laser scanner 20. For example, the screen 41 has a user interface that allows the operator to provide measurement instructions to the device, and the screen also displays measurement results.

[0032] The laser scanner 20 includes a carrying structure 42 that provides a frame for the measuring head 22 and a platform for attaching the components of the laser scanner 20. In one embodiment, the carrying structure 42 is made from a metal such as aluminum. The carrying structure 42 includes a traverse member 44 having a pair of walls 46, 48 on opposing ends. The walls 46, 48 are parallel to each other and extend in a direction opposite the base 24. Shells 50, 52 are coupled to the walls 46, 48 and cover the components of the laser scanner 20. In the exemplary embodiment, the shells 50, 52 are made from a plastic material, such as polycarbonate or polyethylene for example. The shells 50, 52 cooperate with the walls 46, 48 to form a housing for the laser scanner 20.

[0033] On an end of the shells 50, 52 opposite the walls 46, 48 a pair of yokes 54, 56 are arranged to partially cover the respective shells 50, 52. In the exemplary embodiment, the yokes 54, 56 are made from a suitably durable material, such as aluminum for example, that assists in protecting the shells 50, 52 during transport and operation. The yokes 54, 56 each includes a first arm portion 58 that is coupled, such as with a fastener for example, to the traverse 44 adjacent the base 24. The arm portion 58 for each yoke 54, 56 extends from the traverse 44 obliquely to an outer corner of the respective shell 50, 52. From the outer corner of the shell, the yokes 54, 56 extend along the side edge of the shell to an opposite outer corner of the shell. Each yoke 54, 56 further includes a second arm portion that extends obliquely to the walls 46, 48. It should be appreciated that the yokes 54, 56 are coupled to the traverse 42, the walls 46, 48 and the shells 50, 54 at multiple locations according to one or more embodiments.

[0034] The pair of yokes 54, 56 cooperate to circumscribe a convex space within which the two shells 50, 52 are arranged. In the exemplary embodiment, the yokes 54, 56 cooperate to cover all of the outer edges of the shells 50, 54, while the top and bottom arm portions project over at least a portion of the top and bottom edges of the shells 50, 52. This provides advantages in protecting the shells 50, 52 and the measuring head 22 from damage during transportation and operation. In other embodiments, the yokes 54, 56 include additional features, such as handles to facilitate the carrying of the laser scanner 20 or attachment points for accessories for example.

[0035] On top of the traverse 44, a prism 60 is provided. The prism extends parallel to the walls 46, 48. In the exemplary embodiment, the prism 60 is integrally formed as part of the carrying structure 42. In other embodiments, the prism 60 is a separate component that is coupled to the traverse 44. When the mirror 26 rotates, during each rotation the mirror 26 directs the emitted light beam 30 onto the traverse 44 and the prism 60. Due to non-linearities in the electronic components, for example in the light receiver 36, the measured distances d depends on signal strength, which is measured in optical power entering the scanner or optical power entering optical detectors within the light receiver 36, for example. In an embodiment, a distance correction is stored in the scanner as a function (possibly a nonlinear function) of distance to a measured point and optical power (generally unscaled quantity of light power sometimes referred to as “brightness”) returned from the measured point and sent to an optical detector in the light receiver 36. Since the prism 60 is at a known distance from the gimbal point 27, the measured optical power level of light reflected by the prism 60 is used to correct distance measurements for other measured points according to one or more embodiments, thereby allowing for compensation to correct for the effects of environmental variables such as temperature. In the exemplary embodiment, the resulting correction of distance is performed by the controller 38.

[0036] In an embodiment, the base 24 is coupled to a swivel assembly (not shown) such as that described in commonly owned U.S. Patent No. 8,705,012 (‘012), which is incorporated by reference herein. The swivel assembly is housed within the carrying structure 42 and includes a motor 138 that is configured to rotate the measuring head 22 about the axis 23. In an embodiment, the angular/rotational position of the measuring head 22 about the axis 23 is measured by angular encoder 134.

[0037] According to one or more embodiments, an auxiliary image acquisition device 66 is a device that captures and measures a parameter associated with the scanned area or the scanned object and provides a signal representing the measured quantities over an image acquisition area. The auxiliary image acquisition device 66 is, for example, but is not limited to, a pyrometer, a thermal imager, an ionizing radiation detector, or a millimeter-wave detector. In an embodiment, the auxiliary image acquisition device 66 is a color camera.

[0038] In an embodiment, a central color camera (first image acquisition device) 112 is located internally to the scanner and has the same optical axis as the 3D scanner device. In this embodiment, the first image acquisition device 112 is integrated into the measuring head 22 and arranged to acquire images along the same optical pathway as emitted light beam 30 and reflected light beam 32. In this embodiment, the light from the light emitter 28 reflects off a fixed mirror 116 and travels to dichroic beam-splitter 118 that reflects the light 117 from the light emitter 28 onto the rotary mirror 26. In an embodiment, the mirror 26 is rotated by a motor 136 and the angular/rotational position of the mirror is measured by angular encoder 134. The dichroic beam-splitter 118 allows light to pass through at wavelengths different than the wavelength of light 117. For example, the light emitter 28 is a near infrared laser light (for example, light at wavelengths of 780 nm or 1250 nm), with the dichroic beam-splitter 118 configured to reflect the infrared laser light while allowing visible light (e.g., wavelengths of 400 to 700 nm) to transmit through. In other embodiments, the determination of whether the light passes through the beam-splitter 118 or is reflected depends on the polarization of the light. The digital camera 112 obtains 2D images of the scanned area to capture color data to add to the scanned image. In the case of a built-in color camera having an optical axis coincident with that of the 3D scanning device, the direction of the camera view is easily obtained by simply adjusting the steering mechanisms of the scanner – for example, by adjusting the azimuth angle about the axis 23 and by steering the mirror 26 about the axis 25.

[0039] Referring now to FIG. 4 with continuing reference to FIGS. 1–3, elements are shown of the laser scanner 20. Controller 38 is a suitable electronic device capable of accepting data and instructions, executing the instructions to process the data, and presenting the results. The controller 38 includes one or more processing elements 122. The processors are microprocessors, field programmable gate arrays (FPGAs), digital signal processors (DSPs), and/or generally any device capable of performing computing functions. The one or more processors 122 have access to memory 124 for storing information.

[0040] Controller 38 is capable of converting the analog voltage or current level provided by light receiver 36 into a digital signal to determine a distance from the laser scanner 20 to an object in the environment. Controller 38 uses the digital signals that act as input to various processes for controlling the laser scanner 20. The digital signals represent one or more laser scanner 20 data including but not limited to distance to an object, images of the environment, images acquired by panoramic camera 126, angular/rotational measurements by a first or azimuth encoder 132, and angular/rotational measurements by a second axis or zenith encoder 134.

[0041] In general, controller 38 accepts data from encoders 132, 134, light receiver 36, light source 28, and panoramic camera 126 and is given certain instructions for the purpose of generating a 3D point cloud of a scanned environment. Controller 38 provides operating signals to the light source 28, light receiver 36, panoramic camera 126, zenith motor 136 and azimuth motor 138. The controller 38 compares the operational parameters to predetermined variances and if the predetermined variance is exceeded, generates a signal that alerts an operator to a condition. The data received by the controller 38 is displayed on a user interface 40 coupled to controller 38 according to one or more embodiments. The user interface 40 is one or more LEDs (light-emitting diodes) 82, an LCD (liquid-crystal diode) display, a CRT (cathode ray tube) display, a touch-screen display or the like according to one or more embodiments. A keypad is also coupled to the user interface for providing data input to controller 38 according to one or more embodiments. In one embodiment, the user interface is arranged or executed on a mobile computing device that is coupled for communication, such as via a wired or wireless communications medium (e.g. Ethernet, serial, USB, Bluetooth™ or WiFi) for example, to the laser scanner 20.

[0042] The controller 38 is also coupled to external computer networks such as a local area network (LAN) and the Internet according to one or more embodiments. A LAN interconnects one or more remote computers, which are configured to communicate with controller 38 using a well- known computer communications protocol such as TCP/IP (Transmission Control Protocol/Internet(^) Protocol), RS-232, ModBus, and the like. According to one or more embodiments, additional systems 20 are also connected to LAN with the controllers 38 in each of these systems 20 being configured to send and receive data to and from remote computers and other systems 20. The LAN is connected to the Internet in one or more embodiments. This connection allows controller 38 to communicate with one or more remote computers connected to the Internet.

[0043] The processors 122 are coupled to memory 124. The memory 124 includes random access memory (RAM) device 140, a non-volatile memory (NVM) device 142, and/or a read-only memory (ROM) device 144. In addition, the processors 122 are connected to one or more input/output (I/O) controllers 146 and a communications circuit 148 according to one or more embodiments. In an embodiment, the communications circuit 92 provides an interface that allows wireless or wired communication with one or more external devices or networks, such as the LAN discussed above.

[0044] Controller 38 includes operation control methods embodied in application code (e.g., program instructions executable by a processor to cause the processor to perform operations). These methods are embodied in computer instructions written to be executed by processors 122, typically in the form of software. According to one or more embodiments, the software is encoded in any language, including, but not limited to, assembly language, VHDL (Verilog Hardware Description Language), VHSIC HDL (Very High Speed IC Hardware Description Language), Fortran (formula translation), C, C++, C#, Objective-C, Visual C++, Java, ALGOL (algorithmic language), BASIC (beginners all-purpose symbolic instruction code), visual BASIC, ActiveX, HTML (HyperText Markup Language), Python, Ruby and any combination or derivative of at least one of the foregoing.

[0045] It should be appreciated that while embodiments herein describe the 3D coordinate measurement device as being a laser scanner, this is for example purposes and the claims should not be so limited. In other embodiments, the 3D coordinate measurement device is another type of system that measures a plurality of points on surfaces (i.e., generates a point cloud), such as but not limited to a triangulation scanner, a structured light scanner, a photogrammetry device, TOF scanners using galvanometer mirrors, or a combination of the foregoing for example.

[0046] FIG. 5 is a schematic illustration of a processing system 500 for multi-scheme 3D data compression according to one or more embodiments described herein. The processing system 500 includes a processing device 502 (e.g., one or more of the processing devices 821 of FIG. 8), a system memory 504 (e.g., the RAM 824 and/or the ROM 822 of FIG. 8), a network adapter 506 (e.g., the network adapter 826 of FIG. 8), a data store 508, a display 510, a decompression engine 512, a structuring engine 514, a first compression engine 516, and a second compression engine 518.

[0047] According to one or more embodiments, the various components, modules, engines, etc. described regarding FIG. 5 (e.g., the decompression engine 512, the structuring engine 514, the first compression engine 516, and the second compression engine 518) are implemented as instructions stored on a computer-readable storage medium, as hardware modules, as special-purpose hardware (e.g., application specific hardware, application specific integrated circuits (ASICs), application specific special processors (ASSPs), field programmable gate arrays (FPGAs), as embedded controllers, hardwired circuitry, etc.), or as some combination or combinations of these. According to aspects of the present disclosure, the engine(s) described herein are a combination of hardware and programming. The programming is processor executable instructions stored on a tangible memory, and the hardware includes the processing device 502 for executing those instructions. Thus, the system memory 504 stores program instructions that when executed by the processing device 502 implement the engines described herein. Other engines are also utilized to include other features and functionality described in other examples herein.

[0048] The network adapter 506 enables the processing system 500 to transmit data to and/or receive data from other sources, such as scanners 520. For example, the processing system 500 receives data (e.g., a data set that includes a plurality of three-dimensional coordinates of an environment 522) from one or more of the scanners 520 directly and/or via a network 507. According to one or more embodiments, the data from one or more of the scanners 520 are stored in the data store 508 of the processing system 500 as 3D data 509, which is used to display a point cloud on the display 510 and/or on a user computing device 530 (e.g., a smartphone, a laptop computer, a desktop computer, a wearable computing device, and/or the like, including combinations and/or multiples thereof).

[0049] The network 507 represents any one or a combination of different types of suitable communications networks such as, for example, cable networks, public networks (e.g., the Internet), private networks, wireless networks, cellular networks, or any other suitable private and/or public networks. Further, the network 507 has any suitable communication range associated therewith and includes, for example, global networks (e.g., the Internet), metropolitan area networks (MANs), wide area networks (WANs), local area networks (LANs), or personal area networks (PANs). In addition, according to one or more embodiments, the network 507 includes any type of medium over which network traffic is carried including, but not limited to, coaxial cable, twisted-pair wire, optical fiber, a hybrid fiber coaxial (HFC) medium, microwave terrestrial transceivers, radio frequency communication mediums, satellite communication mediums, or any combination thereof. One or more of the processing system 500, the scanner 520, and/or the user computing device 530 communicates, via the network 507, with another one or more of the processing system 500, the scanner 520, and/or the user computing device 530.

[0050] According to one or more embodiments, one or more scanners 520 (e.g., a laser scanner) are arranged on, in, and/or around the environment 522 to scan the environment 522. It should be appreciated that while embodiments herein refer to a 3D coordinate measurement device as a laser scanner (e.g., the scanners 520), this is for example purposes and the claims should not be so limited. That is, the scanners 520 are any suitable type of 3D coordinate measurement device. For example, in other embodiments, other types of optical measurement devices are used, such as but not limited to triangulation scanners and structured light scanners.

[0051] According to one or more embodiments described herein, one or more of the scanners 520 include a scanner processing system including a scanner controller, a housing, and a three-dimensional (3D) scanner. According to one or more embodiments, the 3D scanner is disposed within the housing and operably coupled to the scanner processing system. The 3D scanner includes a light source, a beam steering unit, a first angle measuring device, a second angle measuring device, and a light receiver. The beam steering unit cooperates with the light source and the light receiver to define a scan area. The light source and the light receiver are configured to cooperate with the scanner processing system to determine a first distance to a first object point based at least in part on a transmitting of a light by the light source and a receiving of a reflected light by the light receiver. The 3D scanner is further configured to cooperate with the scanner processing system to determine 3D coordinates of the first object point based at least in part on the first distance, a first angle of rotation, and a second angle of rotation.

[0052] The scanners 520 perform at least one scan to generate data that includes a plurality of three-dimensional coordinates of the environment 522. It should be appreciated that other numbers of scanners (e.g., one scanner, three scanners, four scanners, six scanners, eight scanners, etc.) are used in other embodiments. According to one or more embodiments described herein, one or more scanners is used to take multiple scans. For example, one of the scanners 520 captures first scan data at a first location and is then moved to a second location, where the one of the scanners 520 captures second scan data.

[0053] In some examples, the data is compressed by the scanners 520 before the data is transmitted to the processing system 500. For example, according to one or more embodiments described herein, one or more of the scanners 520 includes a data compression engine 521. The data compression engine 521 performs data compression on the data captured by the scanners 520 before transmitting the data to the processing system 500. As an example, the data compression engine 521 is a field programmable gate array (FPGA) having embodied thereon instructions for performing data compression. The data compression engine 521 performs any suitable type of data compression using any suitable data compression algorithm. As an example, the data compression engine 521 performs lossless data compression. As an example, the data compression engine 521 performs the lossless data compression using the L4Z lossless data compression algorithm, the Zstandard (Zstd) lossless data compression algorithm, and/or the like, including combinations and/or multiples thereof. The data compression engine 521 performs other types of data compression, and these examples should not be construed to limit the claims.

[0054] According to one or more embodiments, the data collected by the scanner 520 is transmitted, directly or indirectly (such as via a network), to a processing system, such as the processing system 500, which stores the data in the data store 508 as 3D data 509. In some cases, the data is transmitted to the processing system 500 without the scanners 520 performing compression. However, in some other cases, the data is compressed by the scanners 520 using the data compression engine 521, and then subsequent to the compression, the compressed data is transmitted to the processing system 500.

[0055] Using the data received from the scanners 520, the processing system 500 provides the 3D data 509 to the user computing device 530 (e.g., directly and/or indirectly via the network 507). In this way, the processing system 500 acts as a "server" to serve the 3D data 509 to the user computing device 530. According to an embodiment, the processing system 500 displays the 3D data 509 on a display 510 of the processing system 500.

[0056] The processing system 500 also perform actions on the 3D data 509 according to one or more embodiments. For example, using the decompression engine 512, the processing system 500 decompresses the compressed 3D data received from the scanner 520. The processing system 500 then structures the 3D data using the structuring engine 514 and then performs a multi-scheme 3D data compression on the 3D data 509. The features and functions of the processing system 500 are now further described with reference to FIG. 6.

[0057] Particularly, FIG. 6 depicts a flow diagram of a method 600 for a multi-scheme 3D data compression according to one or more embodiments described herein. The method 600 is performed by any suitable system or device, such as the processing system 500 of FIG. 5 and/or the processing system 800 of FIG. 8. The method 600 is now described with further reference to the elements of FIG. 5 but is not so limited.

[0058] At block 602, the processing system 500 receives 3D data (e.g., a point cloud) from a 3D coordinate measurement device (e.g., the scanner 520). For example, the scanner 520 scans the environment 522 and captures data about the environment 522. The data is transmitted to the processing system 500 and stored in the data store 508 as the 3D data 509.

[0059] At block 604, the processing system 500, using the structuring engine 514, structures the 3D data to generate structured data based on a context between points of the 3D data. For example, the structuring engine 514 analyzes the 3D data including properties and/or metadata (e.g., coordinates (xyz), xyz normal, a nearest neighbor, k-means, and/or the like, including combinations and/or multiples thereof) about the 3D data. The structuring engine 514 identifies context between points and/or regions of the 3D data and structures the 3D data accordingly, such as into clusters. For example, points within a similar region are grouped into a cluster and compressed together as a leaf/node of a tree-like structure (see, e.g., FIG. 7A).

[0060] At block 606, the processing system 500, using the first compression engine 516, performs a first compression on the structured data to generate first compressed structured data. As an example, the first compression engine 516 applies a 3D data compression technique, such as the Draco open-source library for compressing and decompressing 3D geometric meshes and point clouds (e.g., 3D data), the moving picture experts group (MPEG) geometry based point cloud compression (GPCC), and/or the like, including combinations and/or multiples thereof. Draco supports compressing points of 3D data, connectivity information (for connections between points), texture coordinates, color information, normal, attributes associated with geometry, and/or the like, including combinations and/or multiples thereof. As an example, each leaf/node of the tree-like structure is compressed using the first compression (see, e.g. FIG. 7B).

[0061] At block 608, the processing system 500, using the second compression engine 518, performs a second compression on the first compressed structured data to generate second compressed structured data. According to one or more embodiments, the second compression is a lossless compression, such as the L4Z lossless data compression algorithm, the Zstandard (Zstd) lossless data compression algorithm, and/or the like, including combinations and/or multiples thereof. As an example, each leaf/node of the tree-like structure is further compressed using the second compression (see, e.g., FIG. 7C).

[0062] At block 610, the processing system 500, responsive to receiving a request (e.g., from the user computing device 530), provides the 3D data as uncompressed data. To do this, the processing system 500, using the second compression engine 518 and the first compression engine 516, reverses the compression. For example, the processing system 500 uses the second compression engine 518 to decompress the second compressed structured data (e.g., the further compressed leaves/nodes) to generate the first uncompressed structured data (e.g., compressed leaves/nodes). The processing system 500 then uses the first compression engine 516 to decompress the first uncompressed structured data (e.g., compressed leaves/nodes) to generate the 3D data (e.g., an uncompressed point cloud). According to one or more embodiments described herein, the 3D data (e.g., the uncompressed point cloud) is then transmitted to the user computing device 530 for display, analysis, and/or the like, including combinations and/or multiples thereof. According to one or more embodiments described herein, the 3D data is displayed, such as via a web server (not shown) of the processing system 500, on a web browser at the user computing device.

[0063] As an example, a user of the user computing device 530 requests, from the processing system 500, a point cloud (e.g., the 3D data 509) or a specific part of a point cloud to view. The processing system 500 accesses the point cloud (e.g., the 3D data 509) or specific part of the point cloud and decompress, using the decompression engine 512, part or all of the 3D data 509 based on the request. According to one or more embodiments described herein, the decompression engine 512 decompresses second compressed data back into first compressed data (see, e.g., decompression 702a of FIG. 7C) and then decompresses the first compressed data into uncompressed structured data (see, e.g., decompression 702b of FIG. 7B). The processing system 500 then transmits the data to the user computing device 530 for display to the user.

[0064] According to one or more embodiments, additional processes are also included, and it should be understood that the process depicted in FIG. 6 represents an illustration, and that other processes are added or existing processes are removed, modified, or rearranged without departing from the scope of the present disclosure.

[0065] FIGS. 7A–7C depict a process 700 for compressing and/or decompressing data according to one or more embodiments described herein. FIG. 7A depicts 3D data 710 and structured data 720, FIG. 7B depicts the structured data 720 and first compressed data 730, and FIG. 7C depicts the first compressed data 730 and second compressed data 740, according to one or more embodiments described herein. FIGS. 7A–7C show a compression 701a, 701b, 701c (collectively “compression 701) and a decompression 702a, 702b, 702c (collectively “decompression 702”). For example, the compression 701 compresses the 3D data 710 into second compressed data 740, and the decompression 702 decompresses the second compressed data 740 into the 3D data 710.

[0066] The compression 701 is now described in more detail. In FIG. 7A, the 3D data 710 is structured, such as by the structuring engine 514, into structured data 720. The structured data 720 includes nodes 721, 722, 723 as leaves in a tree-like structure. The nodes 721 represent cluster of related points from the 3D data 710. For example, the structuring engine 514 analyzes context of the points of the 3D data and clusters points within a similar region of the 3D data 710. These clusters are represented by the nodes 721, 722, 723. It should be appreciated that, although three nodes are shown, this is for example purposes and the number of nodes are other than three in other embodiments.

[0067] In FIG. 7B, the structured data 720 is compressed, by the first compression engine 516, into the first compressed data 730. According to one or more embodiments described herein, the first compression engine 516 applies a 3D data compression technique, such as the Draco open-source library, the MPEG GPCC, and/or the like, including combinations and/or multiples thereof. The first compressed data 730 includes nodes 731, 732, 733. As shown in FIG. 7B, the relative size of the nodes 731, 732, 733 are reduced compared to the nodes 721, 722, 723 of the structured data 720, which is uncompressed.

[0068] In FIG. 7C, the first compressed data 730 is further compressed, by the second compression engine 518, into the second compressed data 740. According to one or more embodiments described herein, the second compression engine 518 applies a lossless data compression technique, such as the L4Z lossless data compression algorithm, the Zstandard (Zstd) lossless data compression algorithm, and/or the like, including combinations and/or multiples thereof. The second compressed data 740 includes nodes 741, 742, 743. As shown in FIG. 7C, the shape of the nodes 741, 742, 743 are changed as compared to the nodes 721, 722, 723 of the structured data 720 to represent the additional compression.

[0069] It is understood that one or more embodiments described herein is capable of being implemented in conjunction with any other type of computing environment now known or later developed. For example, FIG. 8 depicts a block diagram of a processing system 800 for implementing the techniques described herein. In accordance with one or more embodiments described herein, the processing system 800 is an example of a cloud computing node of a cloud computing environment. In examples, processing system 800 has one or more central processing units ("processors" or "processing resources" or "processing devices") 821a, 821b, 821c, etc. (collectively or generically referred to as processor(s) 821 and/or as processing device(s)). In aspects of the present disclosure, each processor 821 includes a reduced instruction set computer (RISC) microprocessor. Processors 821 are coupled to system memory (e.g., random access memory (RAM) 824) and various other components via a system bus 833. Read only memory (ROM) 822 is coupled to system bus 833 and include a basic input/output system (BIOS), which controls certain basic functions of processing system 800.

[0070] Further depicted are an input/output (I/O) adapter 827 and a network adapter 826 coupled to system bus 833. I/O adapter 827 is, for example, a small computer system interface (SCSI) adapter that communicates with a hard disk 823 and/or a storage device 825 or any other similar component. I/O adapter 827, hard disk 823, and storage device 825 are collectively referred to herein as mass storage 834. Operating system 840 for execution on processing system 800 are stored in mass storage 834, for example. The network adapter 826 interconnects system bus 833 with an outside network 836 enabling processing system 800 to communicate with other such systems.

[0071] A display (e.g., a display monitor) 835 is connected to system bus 833 by display adapter 832, which includes, for example, a graphics adapter to improve the performance of graphics intensive applications and a video controller. In one aspect of the present disclosure, adapters 826, 827, and/or 832 are connected to one or more I/O busses that are connected to system bus 833 via an intermediate bus bridge (not shown). Suitable I/O buses for connecting peripheral devices such as hard disk controllers, network adapters, and graphics adapters typically include common protocols, such as the Peripheral Component Interconnect (PCI). Additional input/output devices are shown as connected to system bus 833 via user interface adapter 828 and display adapter 832. A keyboard 829, mouse 830, and speaker 831 are interconnected to system bus 833 via user interface adapter 828, which includes, for example, a Super I/O chip integrating multiple device adapters into a single integrated circuit.

[0072] In some aspects of the present disclosure, processing system 800 includes a graphics processing unit 837. Graphics processing unit 837 is a specialized electronic circuit designed to manipulate and alter memory to accelerate the creation of images in a frame buffer intended for output to a display. In general, graphics processing unit 837 is very efficient at manipulating computer graphics and image processing, and has a highly parallel structure that makes it more effective than general-purpose CPUs for algorithms where processing of large blocks of data is done in parallel.

[0073] Thus, as configured herein, processing system 800 includes processing capability in the form of processors 821, storage capability including system memory (e.g., RAM 824) and mass storage 834, input means such as keyboard 829 and mouse 830, and output capability including speaker 831 and display 835. In some aspects of the present disclosure, a portion of system memory (e.g., RAM 824) and mass storage 834 collectively store the operating system 840 to coordinate the functions of the various components shown in processing system 800.

[0074] In addition to one or more of the features described herein, or as an alternative, further embodiments of the method include the first compression comprising applying a 3D data compression.

[0075] In addition to one or more of the features described herein, or as an alternative, further embodiments of the method include that the 3D data compression is a draco compression.

[0076] In addition to one or more of the features described herein, or as an alternative, further embodiments of the method include that the 3D data compression is a moving picture experts group (MPEG) geometry-based point cloud compression.

[0077] In addition to one or more of the features described herein, or as an alternative, further embodiments of the method include the second compression comprising applying a lossless data compression.

[0078] In addition to one or more of the features described herein, or as an alternative, further embodiments of the method include that the lossless compression is performed using at least one of a L4Z lossless data compression algorithm and a Zstandard lossless data compression algorithm.

[0079] In addition to one or more of the features described herein, or as an alternative, further embodiments of the method include that the 3D coordinate measurement device is a laser scanner that captures the 3D data.

[0080] In addition to one or more of the features described herein, or as an alternative, further embodiments of the method include that the 3D coordinate measurement device captures the 3D data, compresses the 3D data to generate compressed raw 3D data and transmits the compressed raw data to the processing device, and the 3D data received by the processing device from the 3D coordinate measurement device is the compressed raw 3D data.

[0081] In addition to one or more of the features described herein, or as an alternative, further embodiments of the method include, subsequent to receiving the compressed raw 3D data and prior to structuring the 3D data, decompressing the compressed raw 3D data to generate the 3D data.

[0082] In addition to one or more of the features described herein, or as an alternative, further embodiments of the system include the 3D coordinate measurement device comprising a field programmable gate array (FPGA), and the 3D coordinate measurement device uses the FPGA to compress the 3D data about the environment to generate the compressed raw 3D data.

[0083] In addition to one or more of the features described herein, or as an alternative, further embodiments of the system include that the FPGA applies a lossless data compression to compress the 3D data about the environment to generate the compressed raw 3D data.

[0084] In addition to one or more of the features described herein, or as an alternative, further embodiments of the system include the lossless data compression using at least one of a L4Z lossless data compression algorithm and a Zstandard lossless data compression algorithm.

[0085] In addition to one or more of the features described herein, or as an alternative, further embodiments of the system include the first compression comprising applying a 3D data compression.

[0086] In addition to one or more of the features described herein, or as an alternative, further embodiments of the system include that the 3D data compression is a draco compression.

[0087] In addition to one or more of the features described herein, or as an alternative, further embodiments of the system include that the 3D data compression is a moving picture experts group (MPEG) geometry-based point cloud compression.

[0088] In addition to one or more of the features described herein, or as an alternative, further embodiments of the system include that the second compression comprising applying a lossless data compression.

[0089] In addition to one or more of the features described herein, or as an alternative, further embodiments of the system include that the lossless compression is performed using at least one of an L4Z lossless data compression algorithm and a Zstandard lossless data compression algorithm.

[0090] In addition to one or more of the features described herein, or as an alternative, further embodiments of the system include that the 3D coordinate measurement device is a laser scanner.

[0091] It will be appreciated that one or more embodiments described herein are embodied as a system, method, or computer program product and take the form of a hardware embodiment, a software embodiment (including firmware, resident software, micro-code, etc.), or a combination thereof. Furthermore, one or more embodiments described herein take the form of a computer program product embodied in one or more computer readable medium(s) having computer readable program code embodied thereon.

[0092] The term “about” is intended to include the degree of error associated with measurement of the particular quantity based upon the equipment available at the time of filing the application. For example, “about” can include a range of ± 8% or 5%, or 2% of a given value.

[0093] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the disclosure. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, element components, and/or groups thereof.

[0094] While the disclosure is provided in detail in connection with only a limited number of embodiments, it should be readily understood that the disclosure is not limited to such disclosed embodiments. Rather, the disclosure can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the disclosure. Additionally, while various embodiments of the disclosure have been described, it is to be understood that the exemplary embodiment(s) may include only some of the described exemplary aspects. Accordingly, the disclosure is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

WHAT IS CLAIMED IS:

1. A method performed by a processing device, the method comprising:

receiving three-dimensional (3D) data from a 3D coordinate measurement device;

structuring the 3D data to generate structured data based on a context between points of the 3D data;

performing a first compression on the structured data to generate first compressed structured data;

performing a second compression on the first compressed structured data to generate second compressed structured data; and

responsive to a request, providing the 3D data as uncompressed data by decompressing the second compressed structured data to generate the first uncompressed structured data; and decompressing the first uncompressed structured data to generate the 3D data.

2. The method of claim 1, the first compression comprising applying a 3D data compression.

3. The method of claim 2, wherein the 3D data compression is a draco compression.

4. The method of claim 2, wherein the 3D data compression is a moving picture experts group (MPEG) geometry-based point cloud compression.

5. The method of claim 1, the second compression comprising applying a lossless data compression.

6. The method of claim 5, wherein the lossless compression is performed using at least one of a L4Z lossless data compression algorithm and a Zstandard lossless data compression algorithm.

7. The method of claim 1, wherein the 3D coordinate measurement device is a laser scanner that captures the 3D data.

8. The method of claim 1, wherein the 3D coordinate measurement device captures the 3D data, compresses the 3D data to generate compressed raw 3D data and transmits the compressed raw data to the processing device, and the 3D data received by the processing device from the 3D coordinate measurement device is the compressed raw 3D data.

9. The method of claim 8, further comprising, subsequent to receiving the compressed raw 3D data and prior to structuring the 3D data, decompressing the compressed raw 3D data to generate the 3D data.

10. A system, comprising:

a three-dimensional (3D) coordinate measurement device to collect 3D data about an environment and compress the 3D data about the environment to generate compressed raw 3D data; and

a processing system comprising:

a memory comprising computer readable instructions; and

at least one processor for executing the computer readable instructions, the computer readable instructions controlling the at least one processor to perform operations comprising:

receiving the compressed raw 3D data from the 3D coordinate measurement device;

decompressing the compressed raw 3D data to extract the 3D data;

structuring the 3D data to generate structured data based on a context between points of the 3D data;

performing a first compression on the structured data to generate first compressed structured data;

performing a second compression on the first compressed structured data to generate second compressed structured data; and

responsive to a request, providing the 3D data as uncompressed data by decompressing the second compressed structured data to generate the first uncompressed structured data and decompressing the first uncompressed structured data to generate the 3D data.

11. The system of claim 10, the 3D coordinate measurement device comprising a field programmable gate array (FPGA), and the 3D coordinate measurement device uses the FPGA to compress the 3D data about the environment to generate the compressed raw 3D data.

12. The system of claim 11, wherein the FPGA applies a lossless data compression to compress the 3D data about the environment to generate the compressed raw 3D data.

13. The system of claim 12, the lossless data compression using at least one of a L4Z lossless data compression algorithm and a Zstandard lossless data compression algorithm.

14. The system of claim 10, the first compression comprising applying a 3D data compression.

15. The system of claim 14, wherein the 3D data compression is a draco compression.

16. The system of claim 14, wherein the 3D data compression is a moving picture experts group (MPEG) geometry-based point cloud compression.

17. The system of claim 10, the second compression comprising applying a lossless data compression.

18. The system of claim 17, wherein the lossless compression is performed using at least one of an L4Z lossless data compression algorithm and a Zstandard lossless data compression algorithm.

19. The system of claim 10, wherein the 3D coordinate measurement device is a laser scanner.

20. A non-transitory computer readable medium having program instructions embodied therewith, the program instructions executed by at least one processor to perform a method for data compression comprising:

receiving the compressed raw 3D data from the 3D coordinate measurement device;

decompressing the compressed raw 3D data to extract the 3D data;

structuring the 3D data to generate structured data based on a context between points of the 3D data;

performing a first compression on the structured data to generate first compressed structured data;

performing a second compression on the first compressed structured data to generate second compressed structured data; and

responsive to a request from a user, providing the 3D data as uncompressed data by decompressing the second compressed structured data to generate the first uncompressed structured data and decompressing the first uncompressed structured data to generate the 3D data.

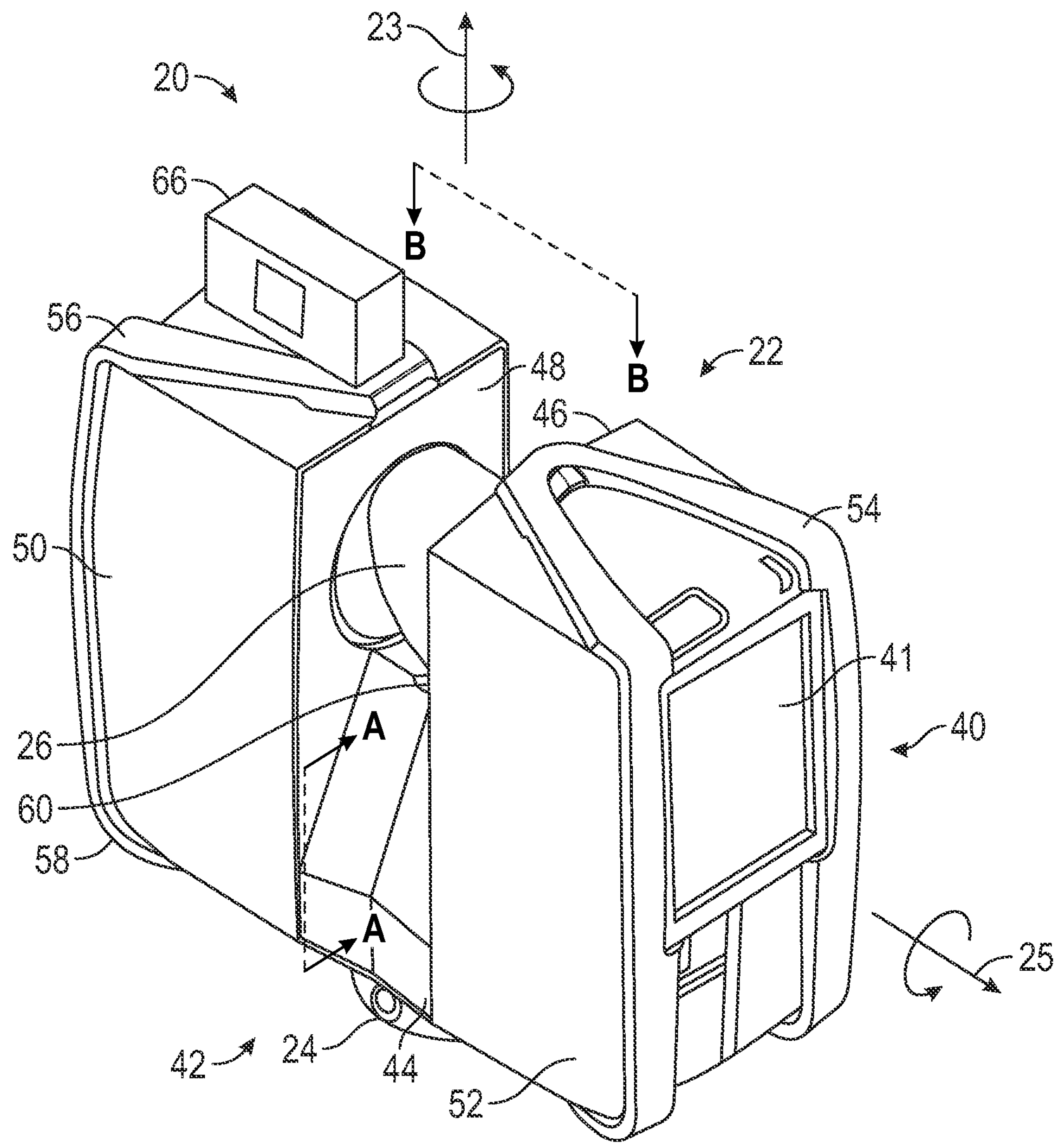

FIG. 1

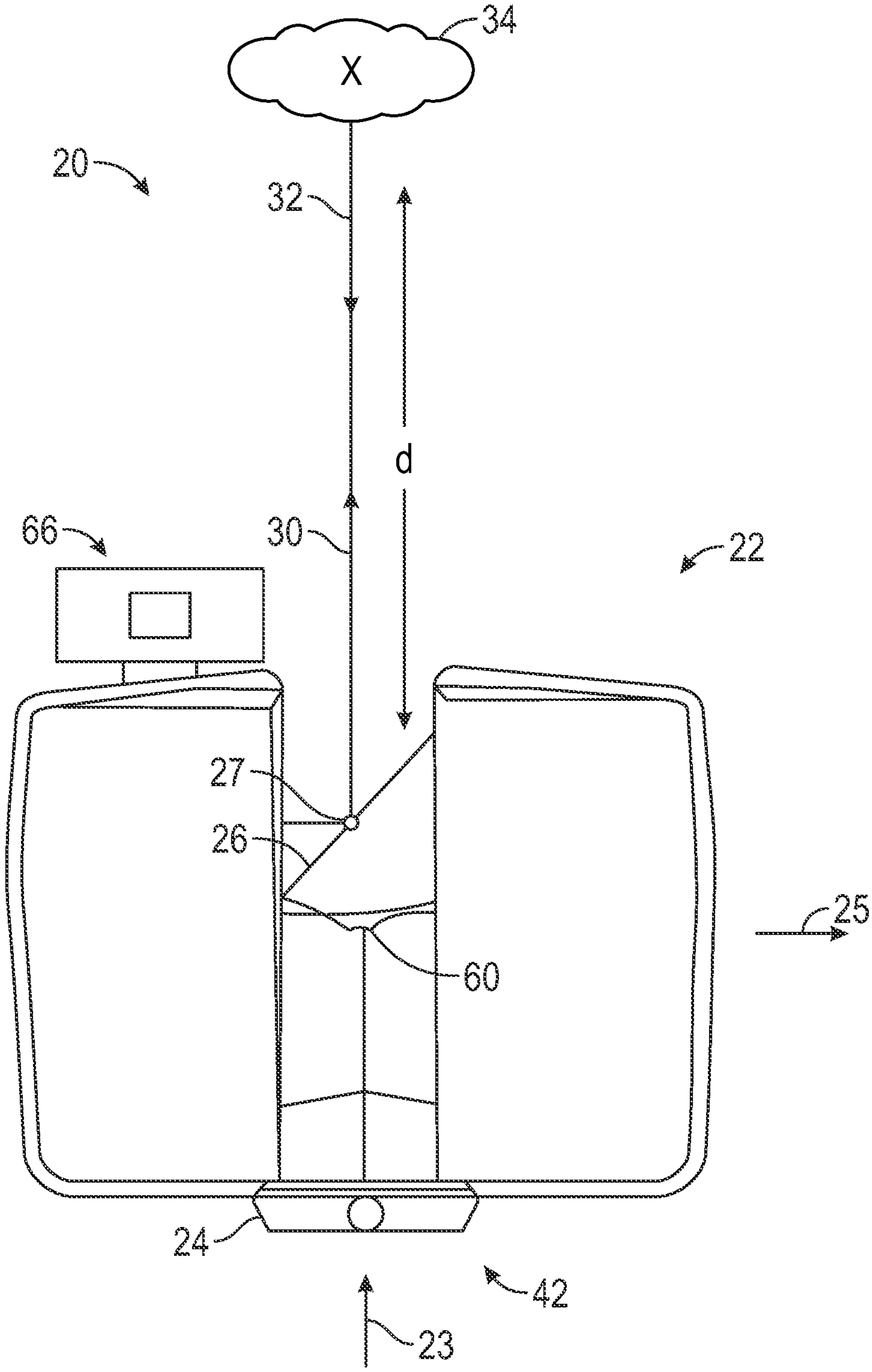

FIG. 2

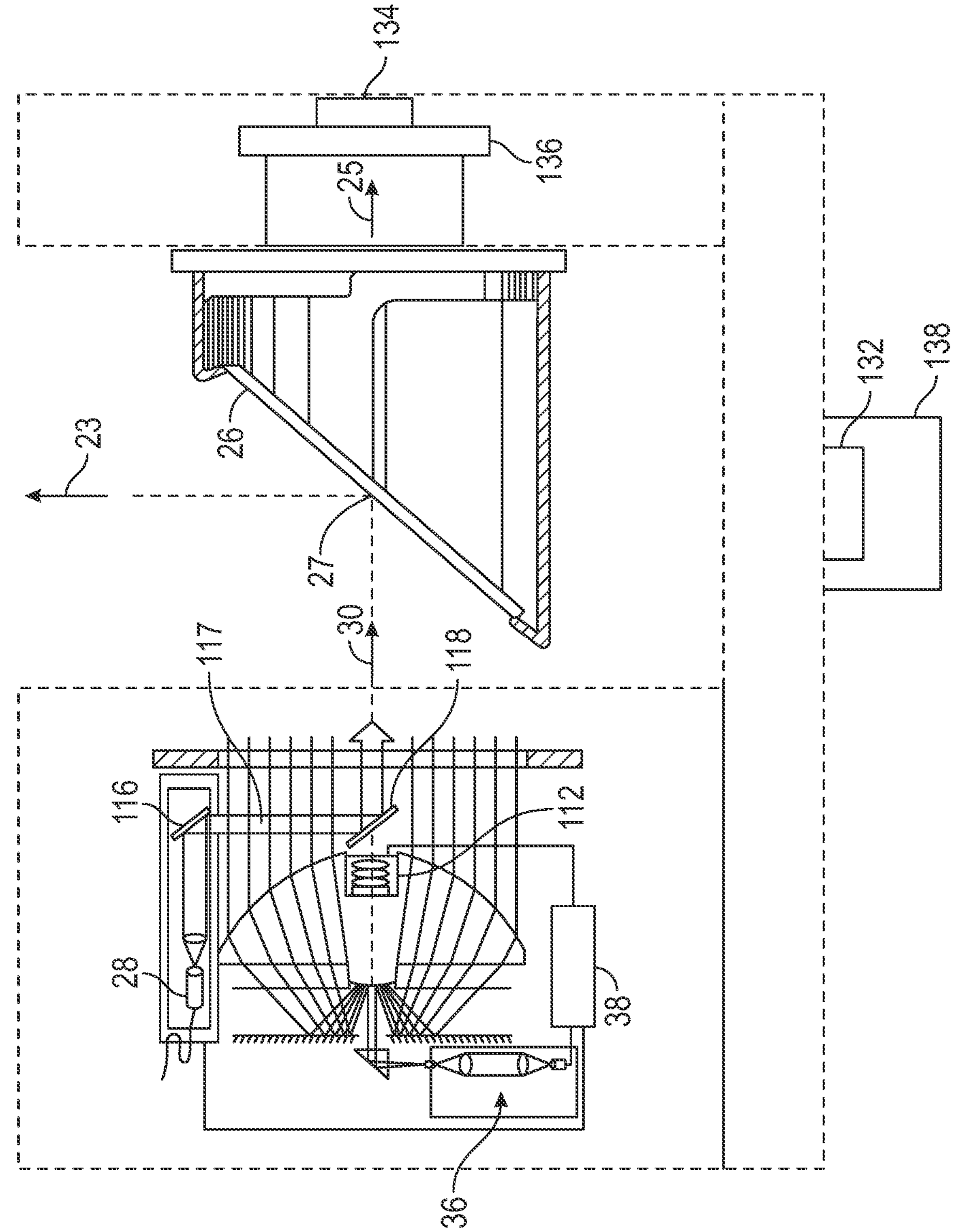

FIG. 3

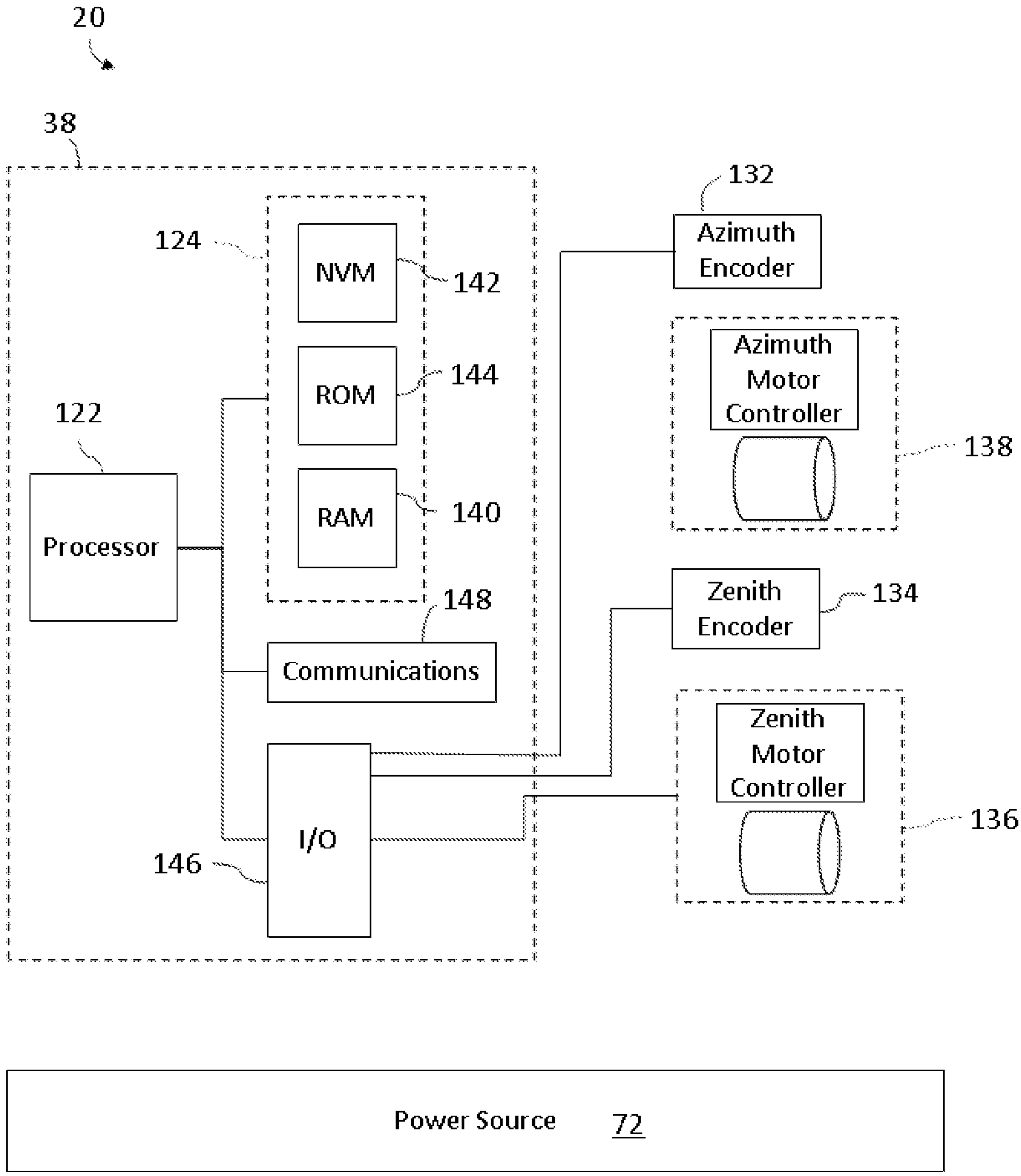
20
38
124
NVM
142
ROM
144
122
RAM
140
Processor
148
Communications
I/O
146
132
Azimuth Encoder
Azimuth Motor Controller
138
Zenith Encoder
134
Zenith Motor Controller
136
Power Source 72

FIG. 4

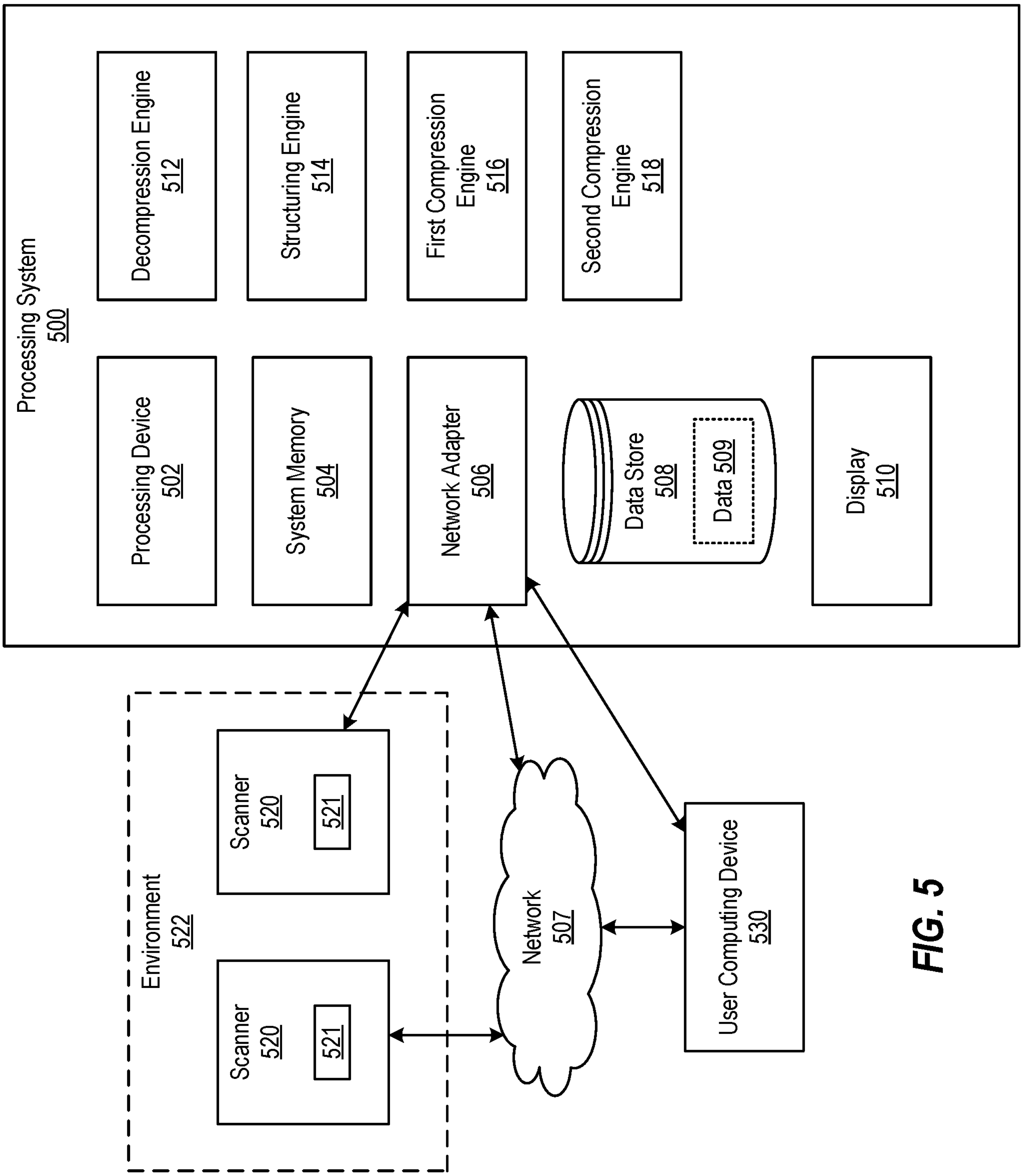
Processing System
500
Decompression Engine
512
Structuring Engine
514
First Compression Engine
516
Second Compression Engine
518
Processing Device
502
System Memory
504
Network Adapter
506
Data Store
508
Data 509
Display
510
Environment
522
Scanner
520
521
Scanner
520
521
Network
507
User Computing Device
530

FIG. 5

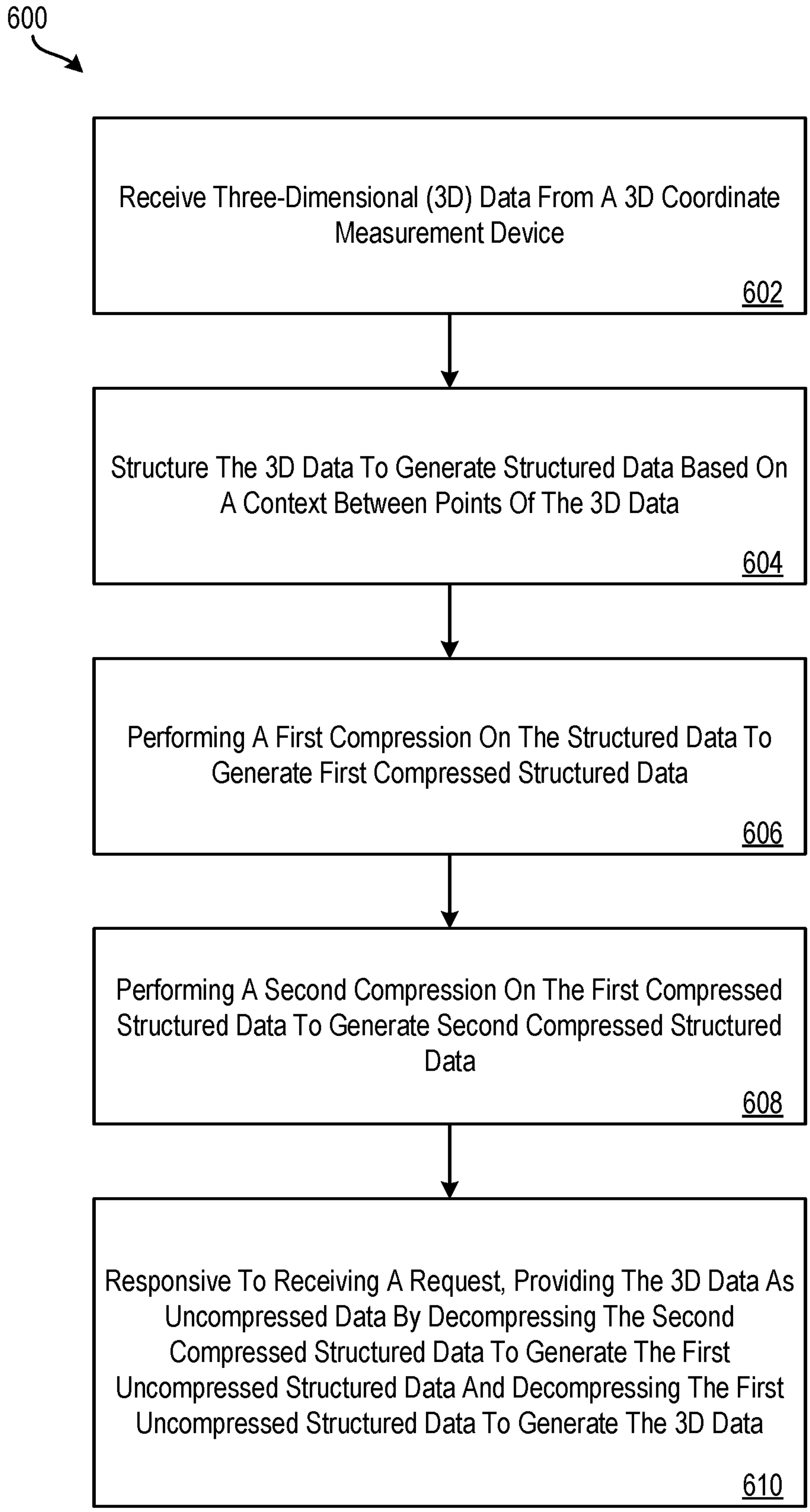
600
Receive Three-Dimensional (3D) Data From A 3D Coordinate Measurement Device
602
Structure The 3D Data To Generate Structured Data Based On A Context Between Points Of The 3D Data
604
Performing A First Compression On The Structured Data To Generate First Compressed Structured Data
606
Performing A Second Compression On The First Compressed Structured Data To Generate Second Compressed Structured Data
608
Responsive To Receiving A Request, Providing The 3D Data As Uncompressed Data By Decompressing The Second Compressed Structured Data To Generate The First Uncompressed Structured Data And Decompressing The First Uncompressed Structured Data To Generate The 3D Data
610

FIG. 6

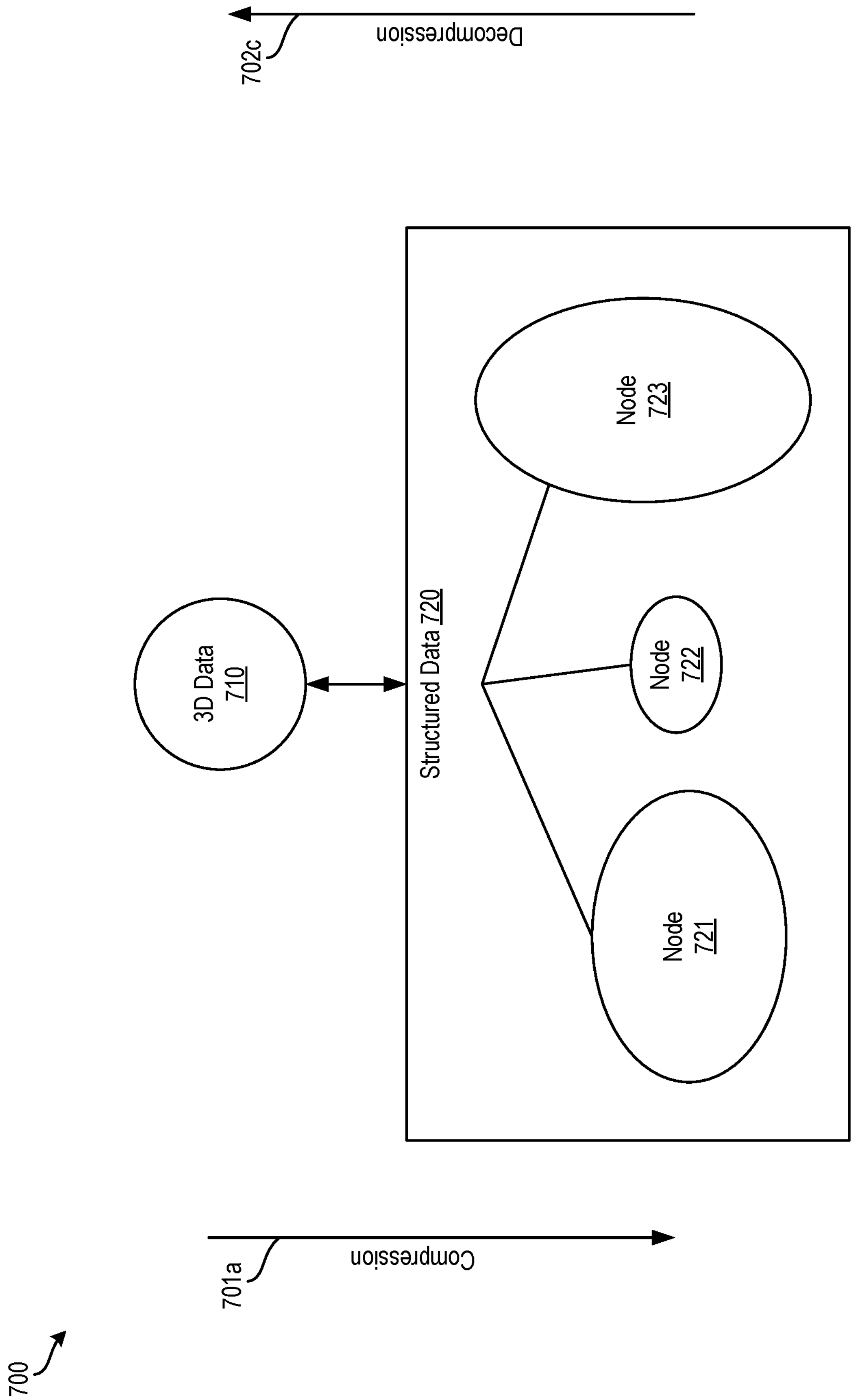
Decompression
702c
3D Data
710
Structured Data 720
Node
721
Node
722
Node
723
Compression
701a
700

FIG. 7A

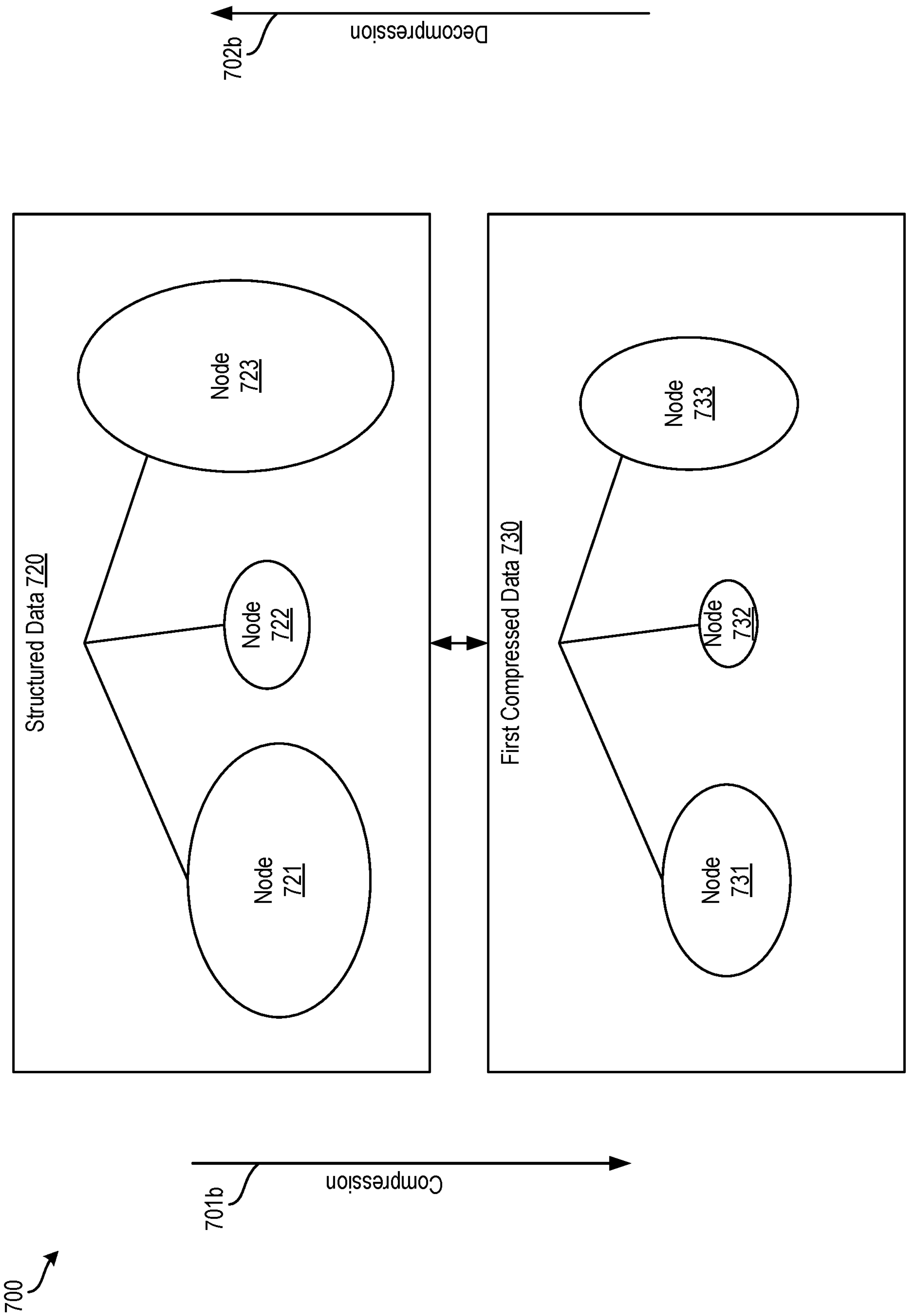
702b
Decompression
Structured Data 720
Node 721
Node 722
Node 723
First Compressed Data 730
Node 731
Node 732
Node 733
701b
Compression
700

FIG. 7B

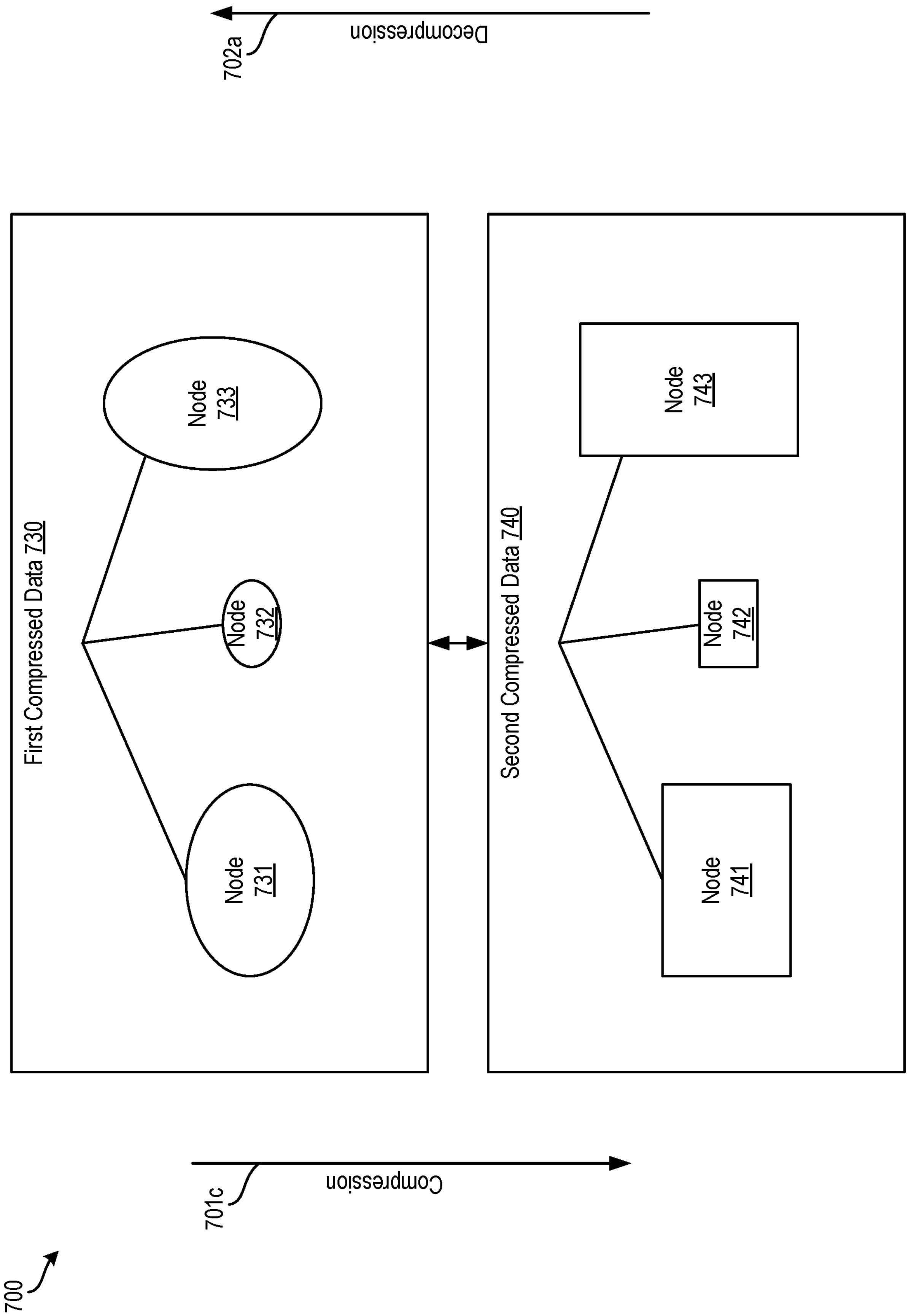
700
701c
Compression
First Compressed Data 730
Node 731
Node 732
Node 733
Second Compressed Data 740
Node 741
Node 742
Node 743
702a
Decompression

FIG. 7C

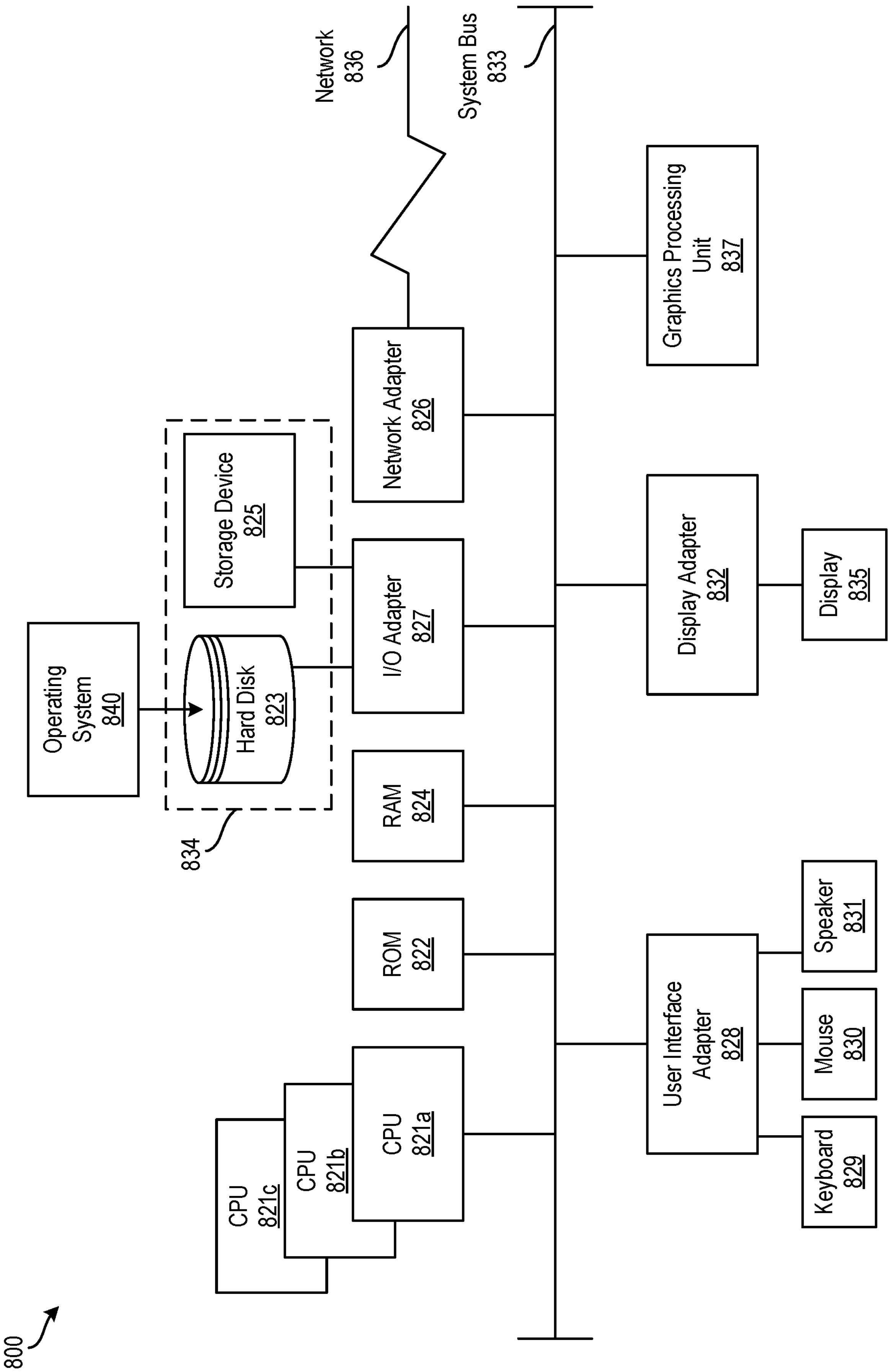
800
Network
836
System Bus
833
Operating
System
840
Hard Disk
823
Storage Device
825
834
CPU
821c
CPU
821b
CPU
821a
ROM
822
RAM
824
I/O Adapter
827
Network Adapter
826
Graphics Processing
Unit
837
Display Adapter
832
Display
835
User Interface
Adapter
828
Keyboard
829
Mouse
830
Speaker
831

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2023/082456

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06T9/00 H04N19/12 H04N19/597 H04N19/91
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06T H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SUN XUEBIN ET AL: "A Novel Point Cloud Compression Algorithm Based on Clustering", IEEE ROBOTICS AND AUTOMATION LETTERS, IEEE, vol. 4, no. 2, 1 April 2019 (2019-04-01), pages 2132-2139, XP011713472, DOI: 10.1109/LRA.2019.2900747 [retrieved on 2019-03-05] page 2132 - page 2136; figure 1 -----	1-20

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[X] Further documents are listed in the continuation of Box C.

[ ] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 February 2024	21/02/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Di Cagno, Gianluca

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CHAKRABORTY SUBHAS ET AL: "A Two Stage Data Compression and Decompression Technique for Point Cloud Data", 2018 WORLD SYMPOSIUM ON DIGITAL INTELLIGENCE FOR SYSTEMS AND MACHINES (DISA), IEEE, 23 August 2018 (2018-08-23), pages 297-302, XP033419978, DOI: 10.1109/DISA.2018.8490525 [retrieved on 2018-10-11] pages 297-299; figure 1 -----	1-4,6-20
A	GRAZIOSI D. ET AL: "An overview of ongoing point cloud compression standardization activities: video-based (V-PCC) and geometry-based (G-PCC)", APSIPA TRANSACTIONS ON SIGNAL AND INFORMATION PROCESSING, vol. 9, no. 1, 1 January 2020 (2020-01-01), XP093012170, ISSN: 2048-7703, DOI: 10.1017/ATSIP.2020.12 Retrieved from the Internet: URL:https://www.cambridge.org/core/services/aop-cambridge-core/content/view/56FCAF660DD44348BCB1BCA9B5EC56CF/S2048770320000128a.pdf/div-class-title-an-overview-of-ongoing-point-cloud-compression-standardization-activities-video-based-v-pcc-and-geometry-based-g-pcc-div.pdf> [retrieved on 2024-01-30] pages 1-15 -----	1-20

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