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Welch et al.

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(54) **PHYSICAL-VIRTUAL PATIENT SYSTEM**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 902 days.

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(74) *Attorney, Agent, or Firm* — Timothy H. Van Dyke; WOLTER, VAN DYKE, DAVIS, PLLC

(21) Appl. No.: **16/786,342**

(57) **ABSTRACT**

(22) Filed: **Feb. 10, 2020**

A patient simulation system for healthcare training is provided. The system includes one or more interchangeable shells comprising a physical anatomical model of at least a portion of a patient's body, the shell adapted to be illuminated from within the shell to provide one or more dynamic images viewable on the outer surface of the shells; wherein the system comprises one or more imaging devices enclosed within the shell and adapted to render the one or more dynamic images on an inner surface of the shell and viewable on the outer surface of the shells; one or more interface devices located about the patient shells to receive input and provide output; and one or more computing units in communication with the image units and interface devices, the computing units adapted to provide an interactive simulation for healthcare training. In other embodiments, the shell is adapted to be illuminated from outside the shell.

(65) **Prior Publication Data**

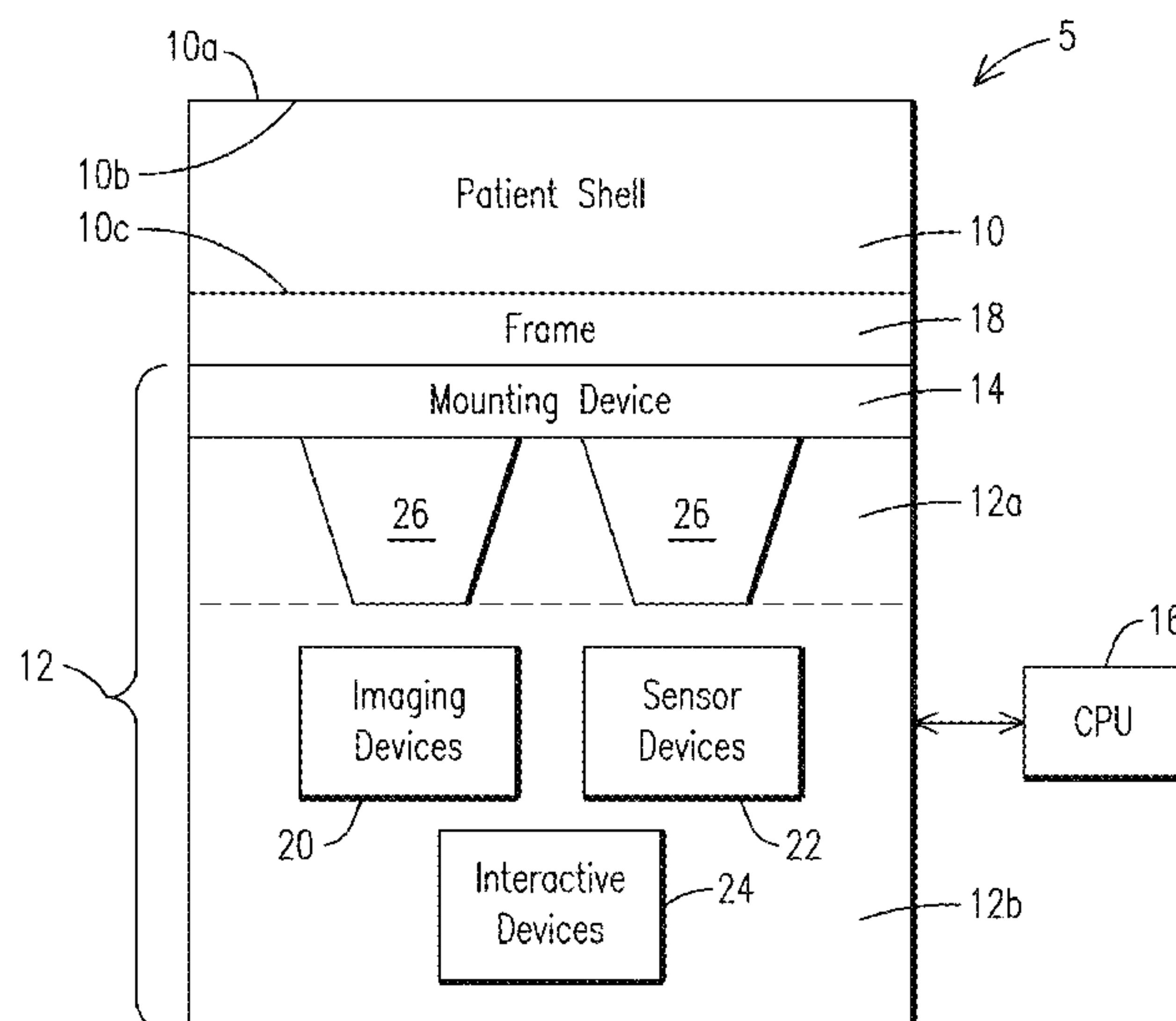
US 2021/0248926 A1 Aug. 12, 2021

(51) **Int. Cl.**
G09B 23/30 (2006.01)
A61B 34/10 (2016.01)
(Continued)

(52) **U.S. Cl.**
CPC **G09B 23/34** (2013.01); **A61B 34/10** (2016.02); **H04N 9/3141** (2013.01);
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(58) **Field of Classification Search**
USPC 434/267
See application file for complete search history.

8 Claims, 30 Drawing Sheets



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G09B 23/34 (2006.01)
H04N 9/31 (2006.01)
H04N 23/698 (2023.01)
G09B 23/28 (2006.01)
G09B 23/32 (2006.01)
- (52) **U.S. Cl.**
 CPC *H04N 23/698* (2023.01); *A61B 2034/107* (2016.02); *G09B 23/285* (2013.01); *G09B 23/303* (2013.01); *G09B 23/32* (2013.01)

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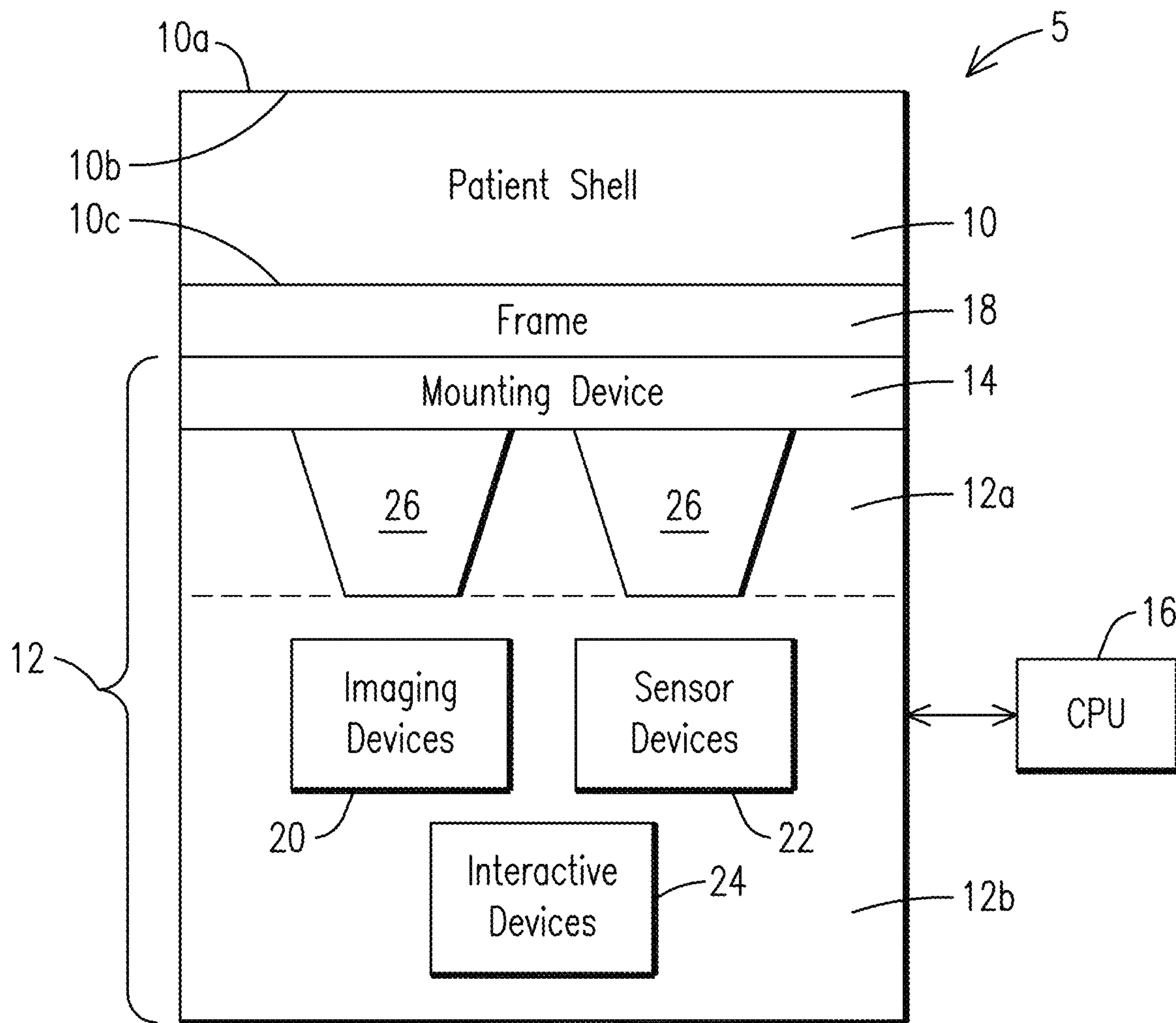


FIG. 1

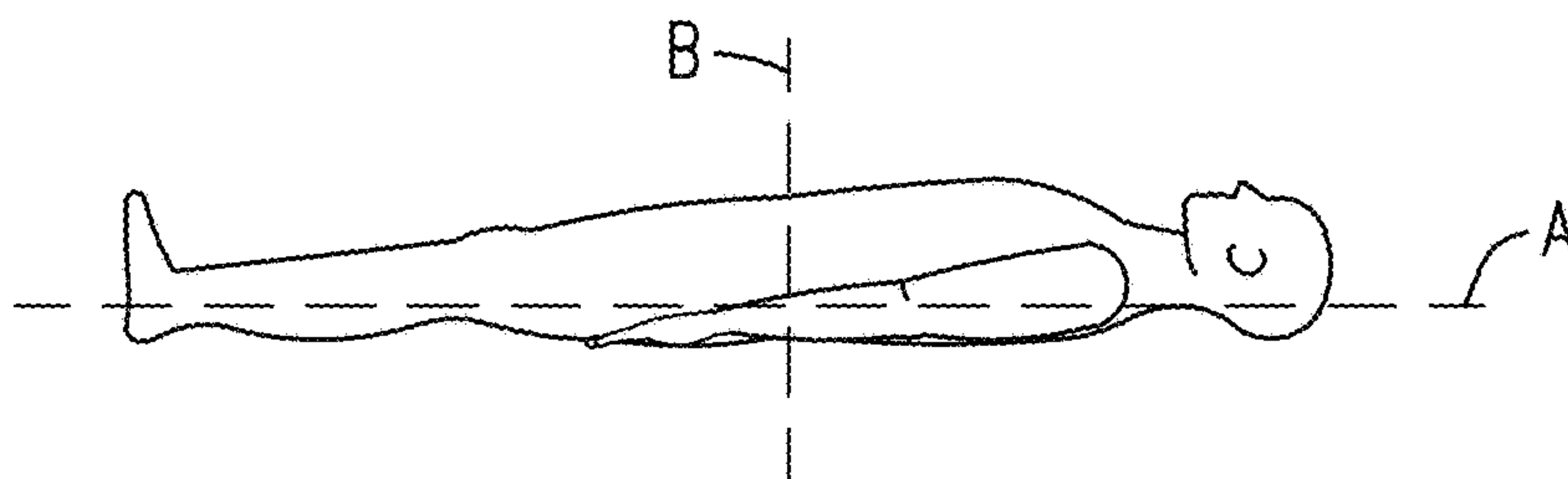


FIG. 2

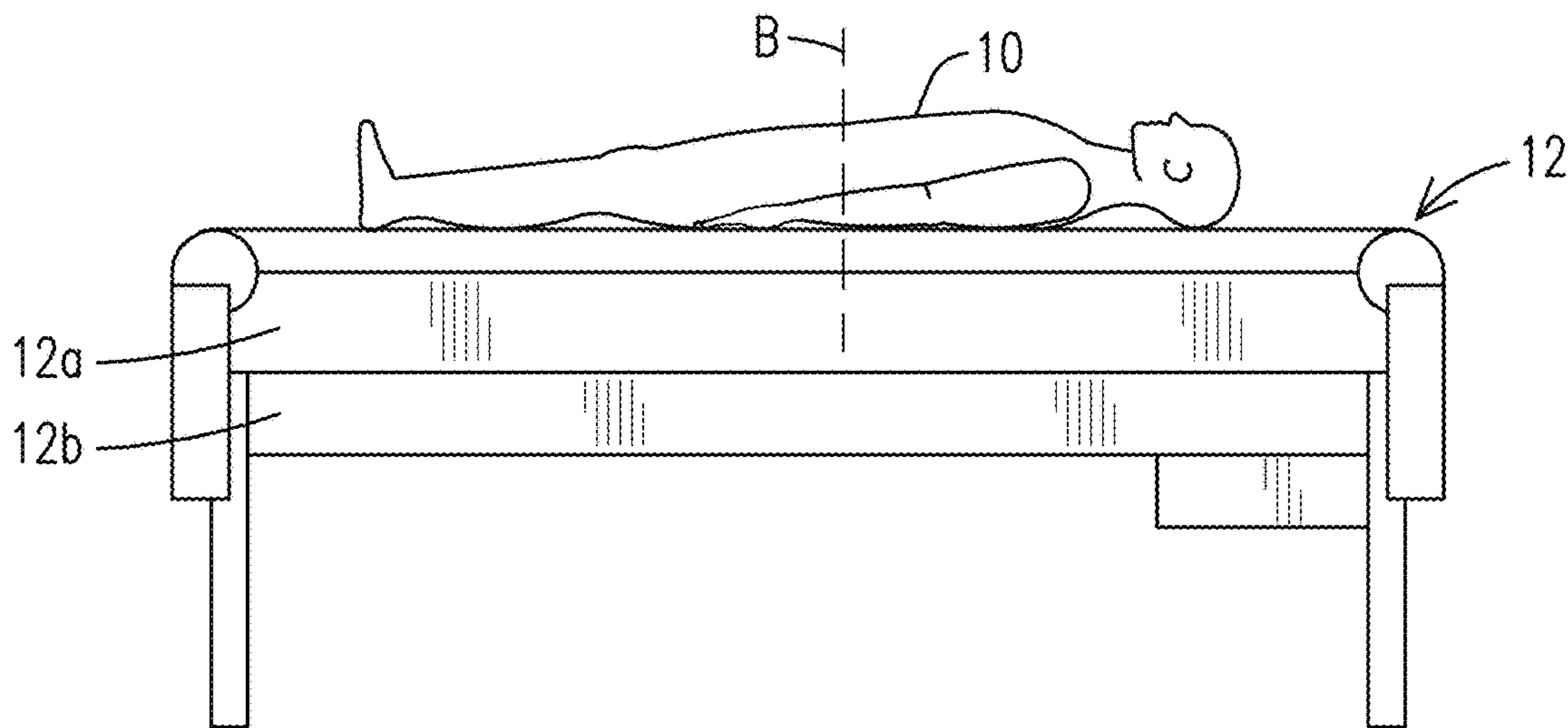


FIG. 3

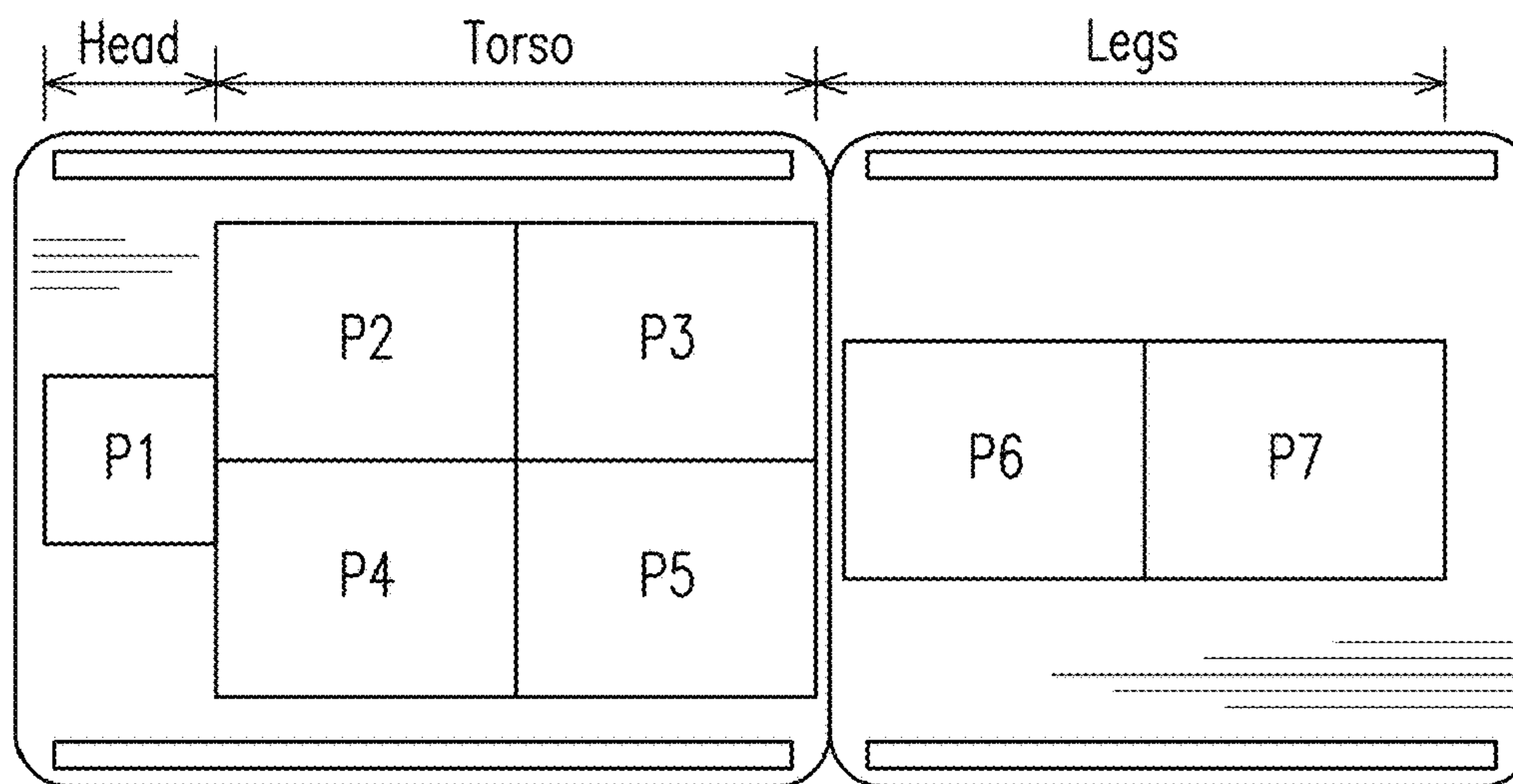


FIG. 4

FIG. 5

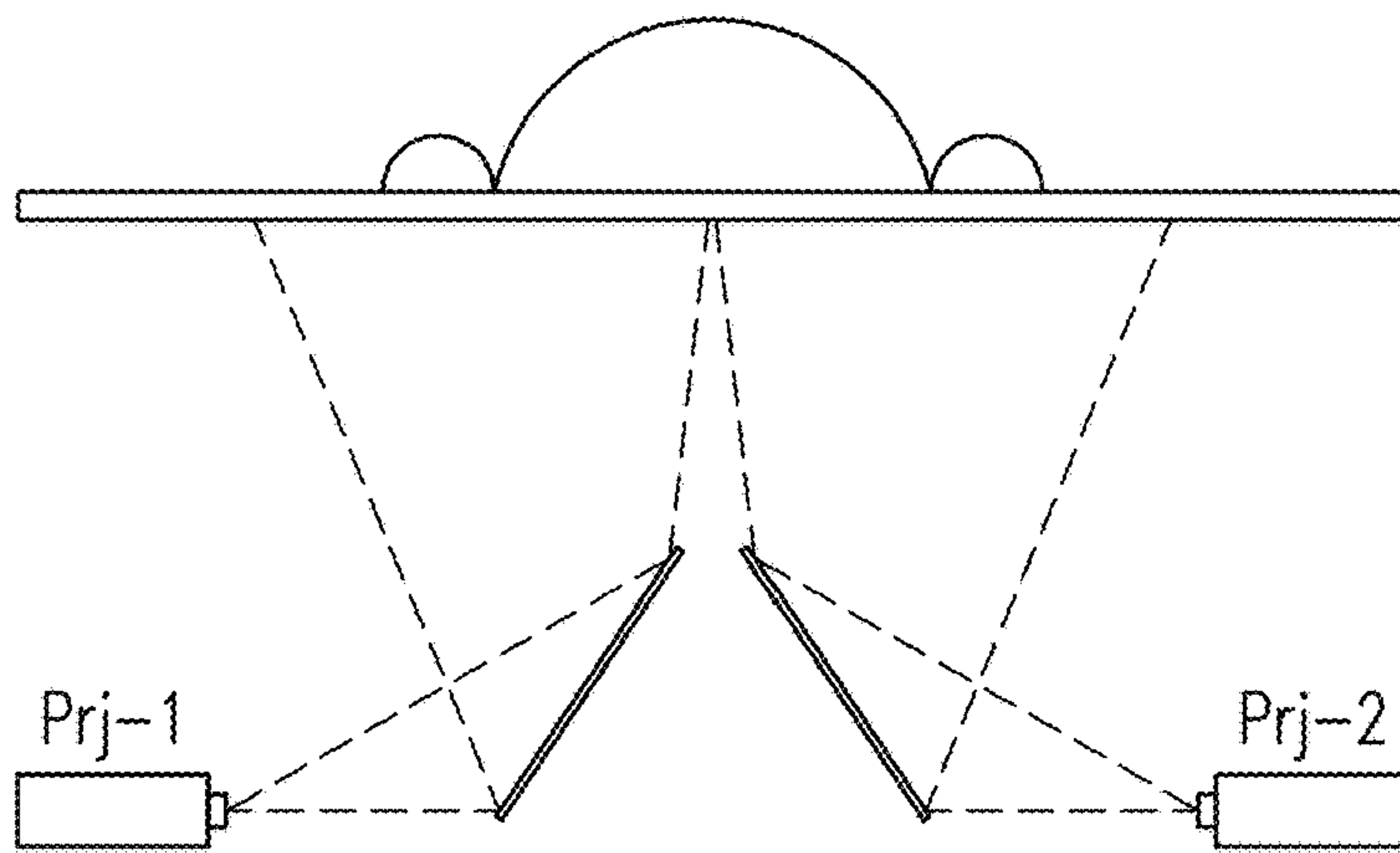
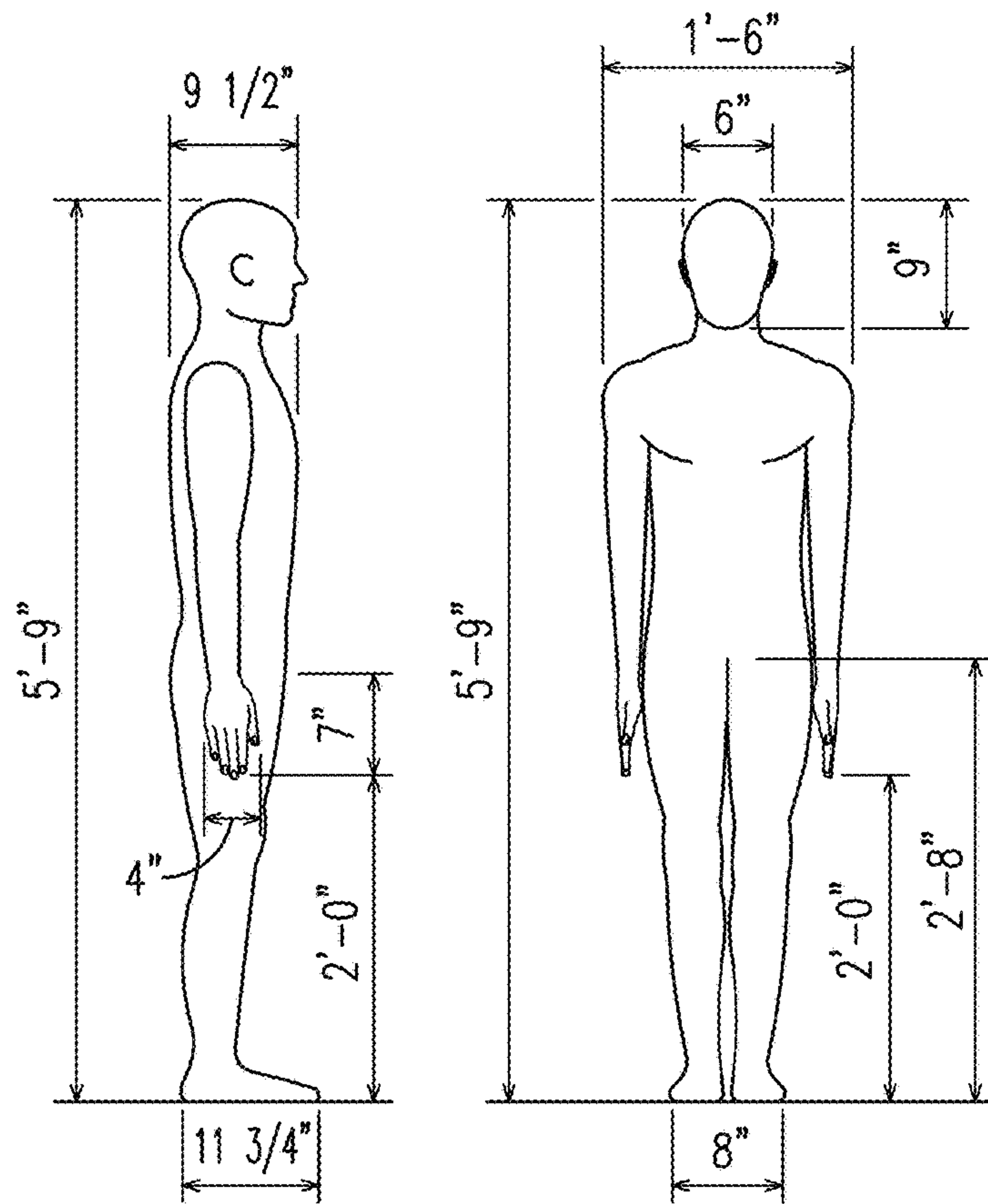


FIG. 6

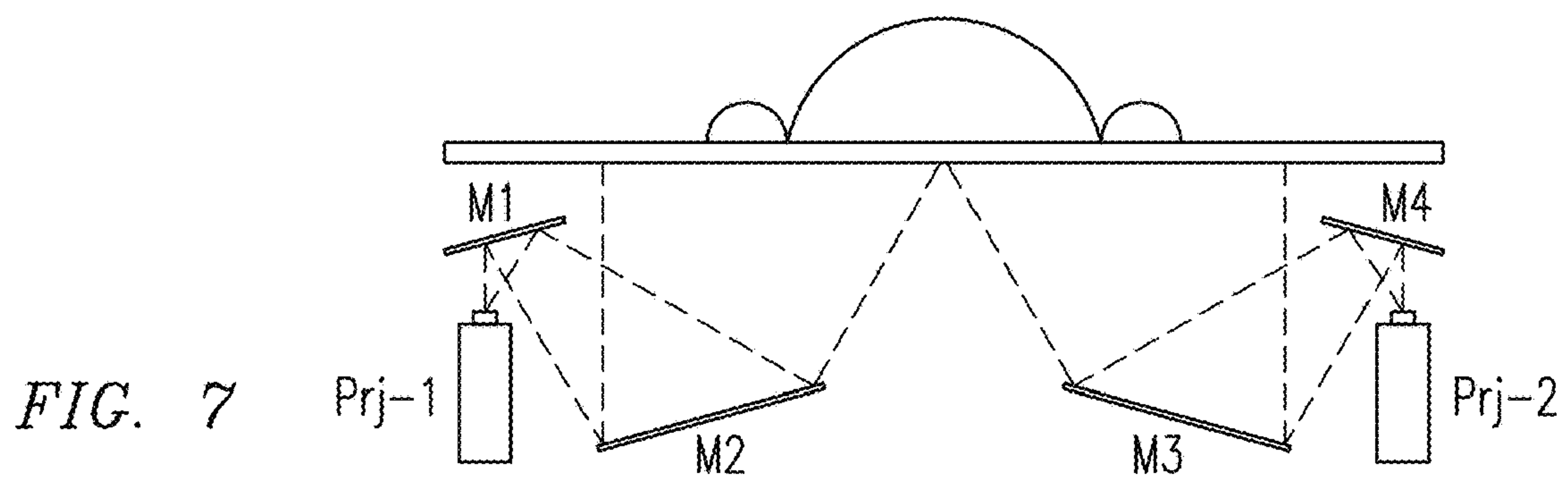


FIG. 7

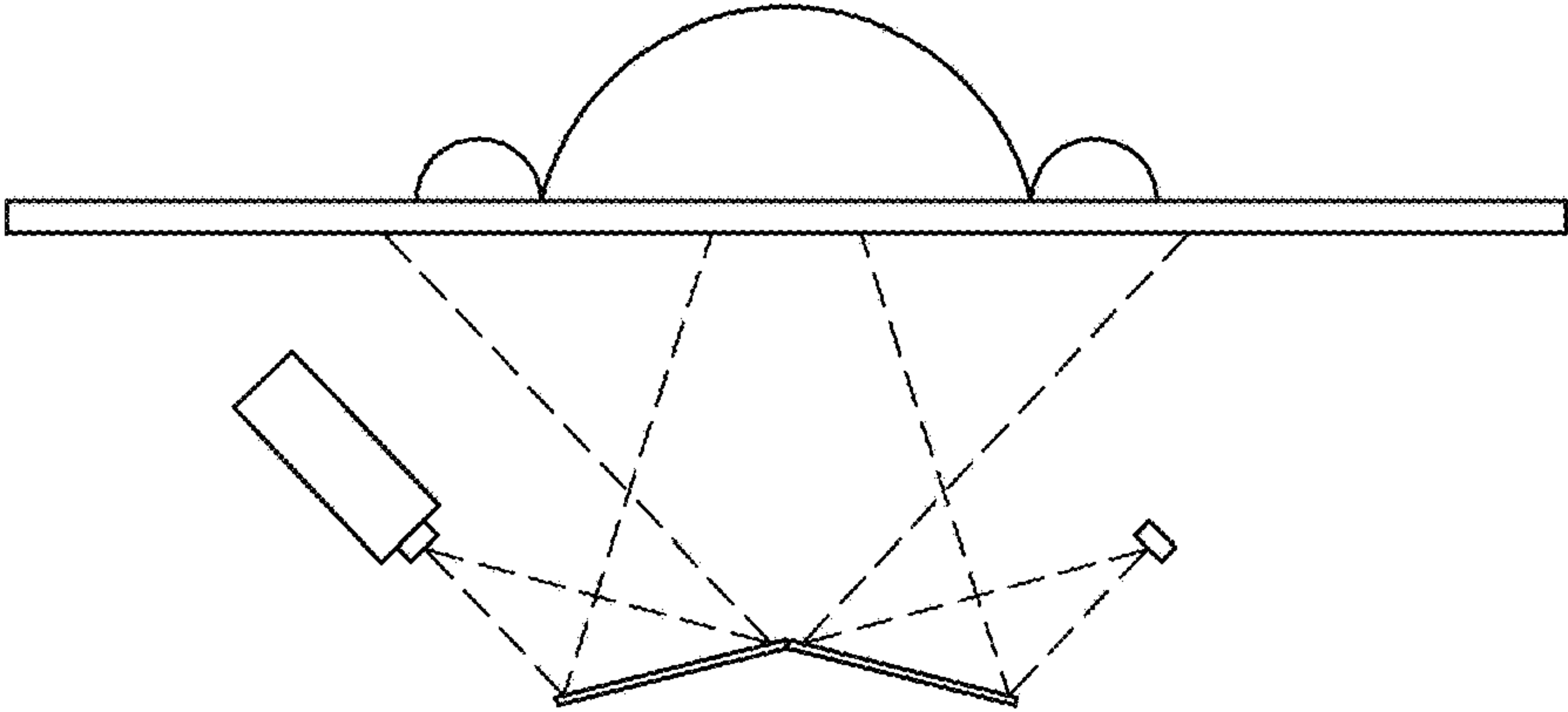


FIG. 8

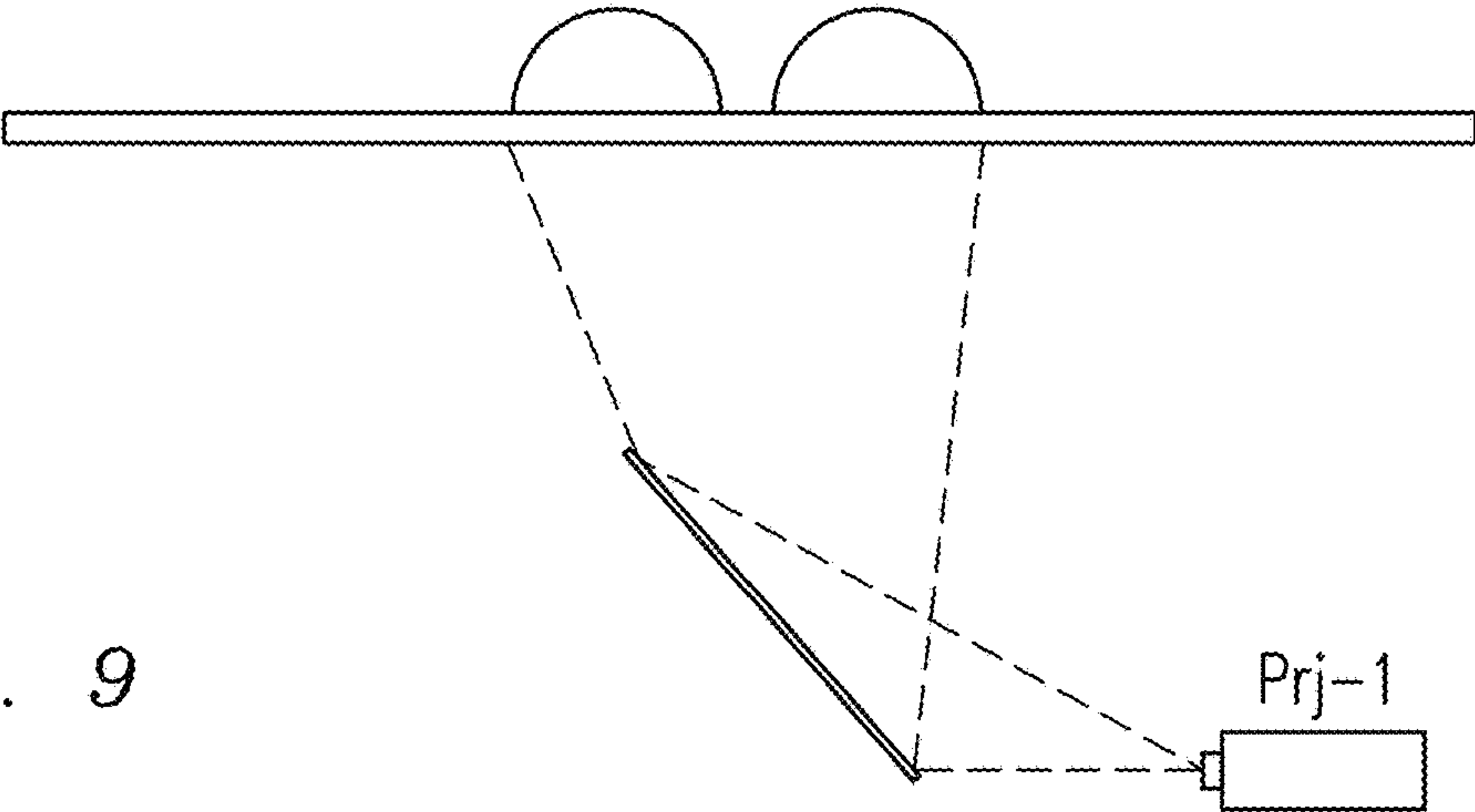


FIG. 9

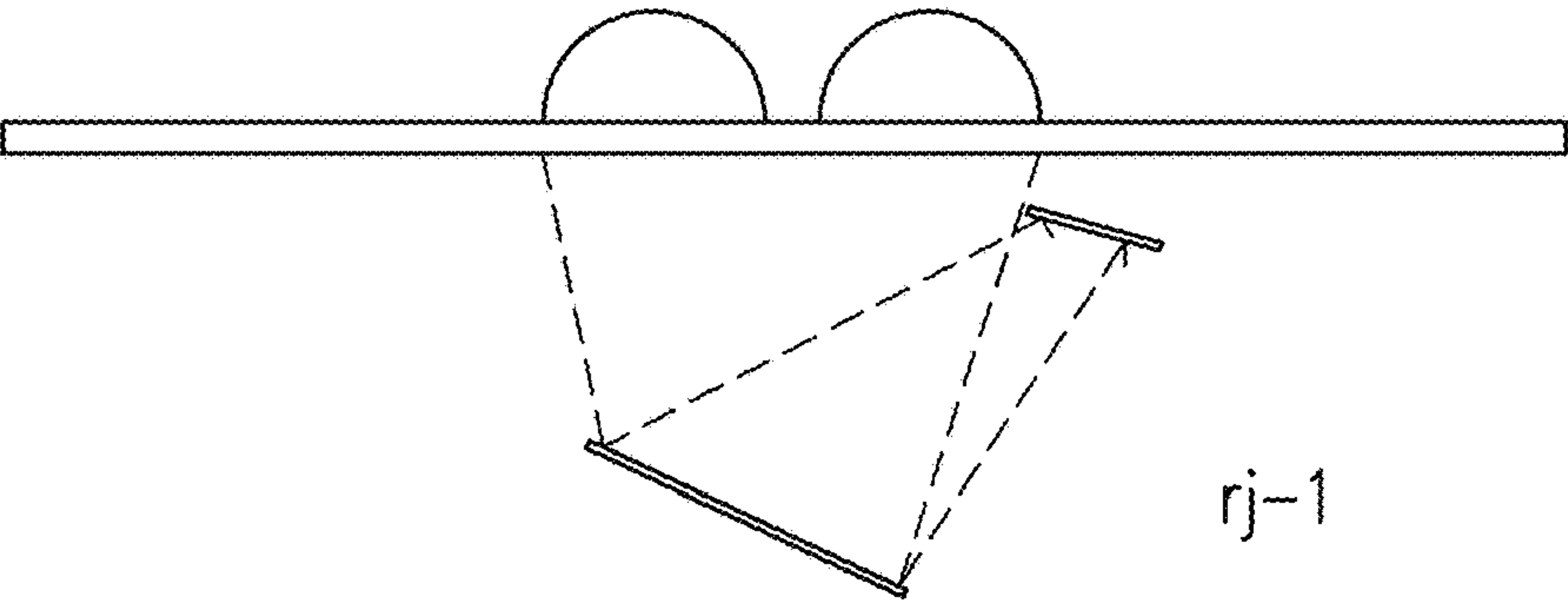


FIG. 10

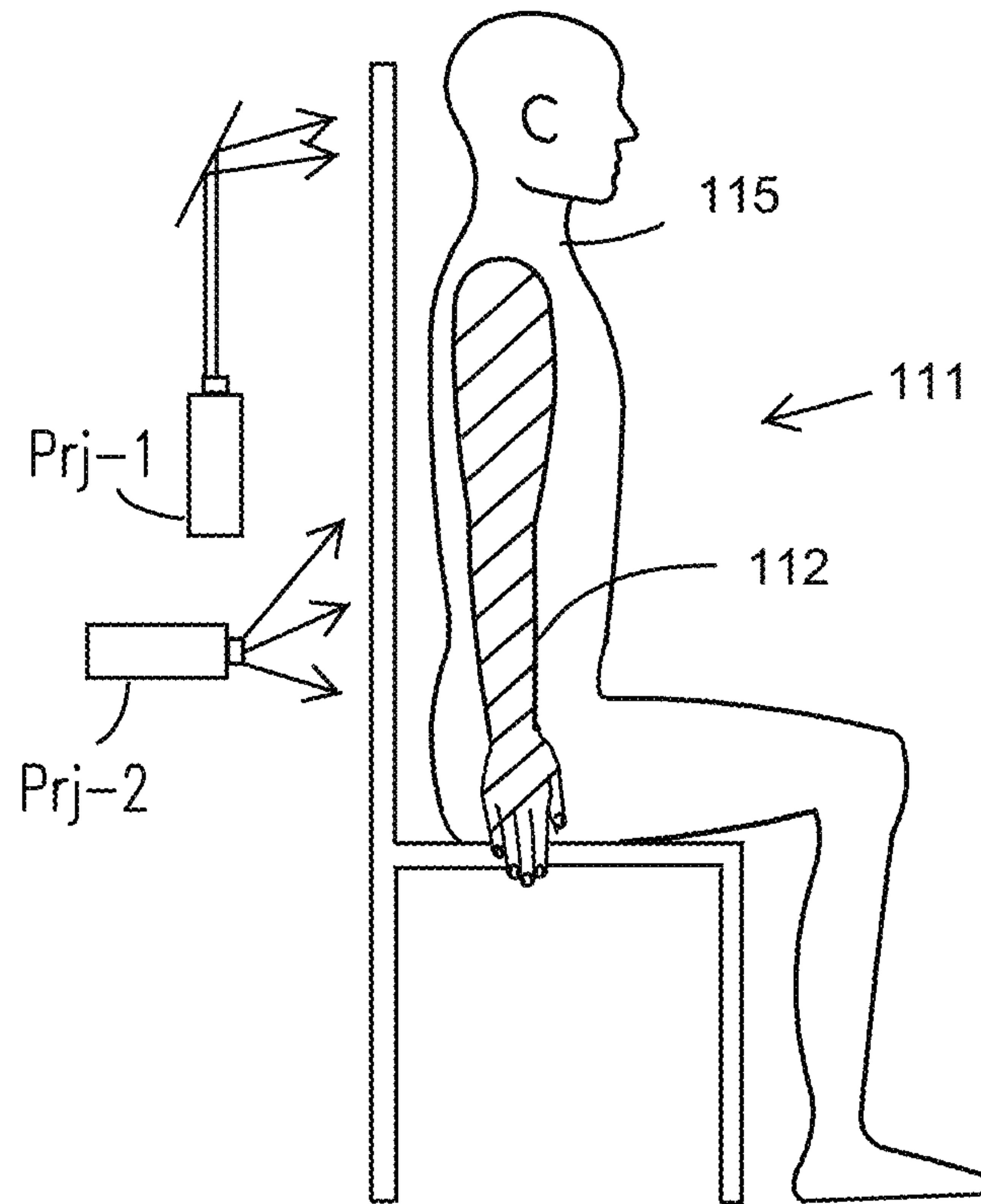


FIG. 11

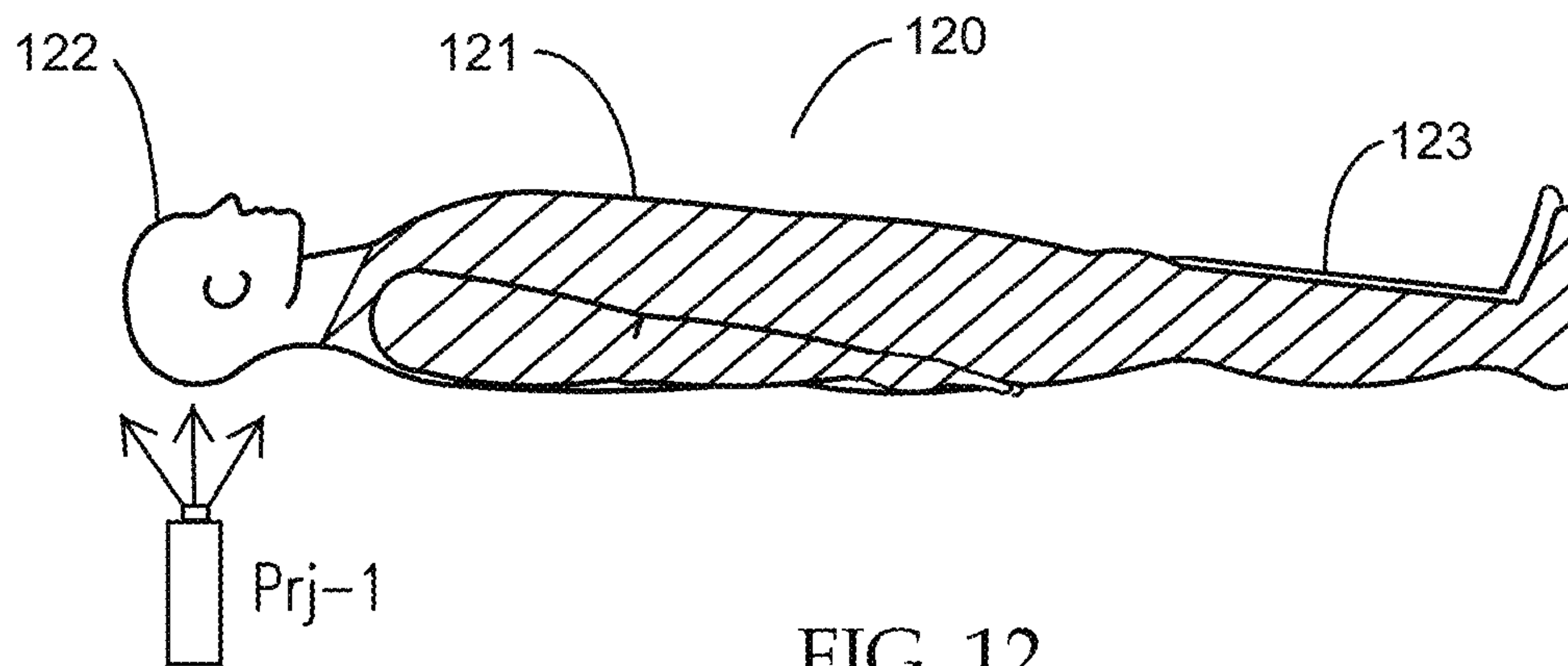


FIG. 12

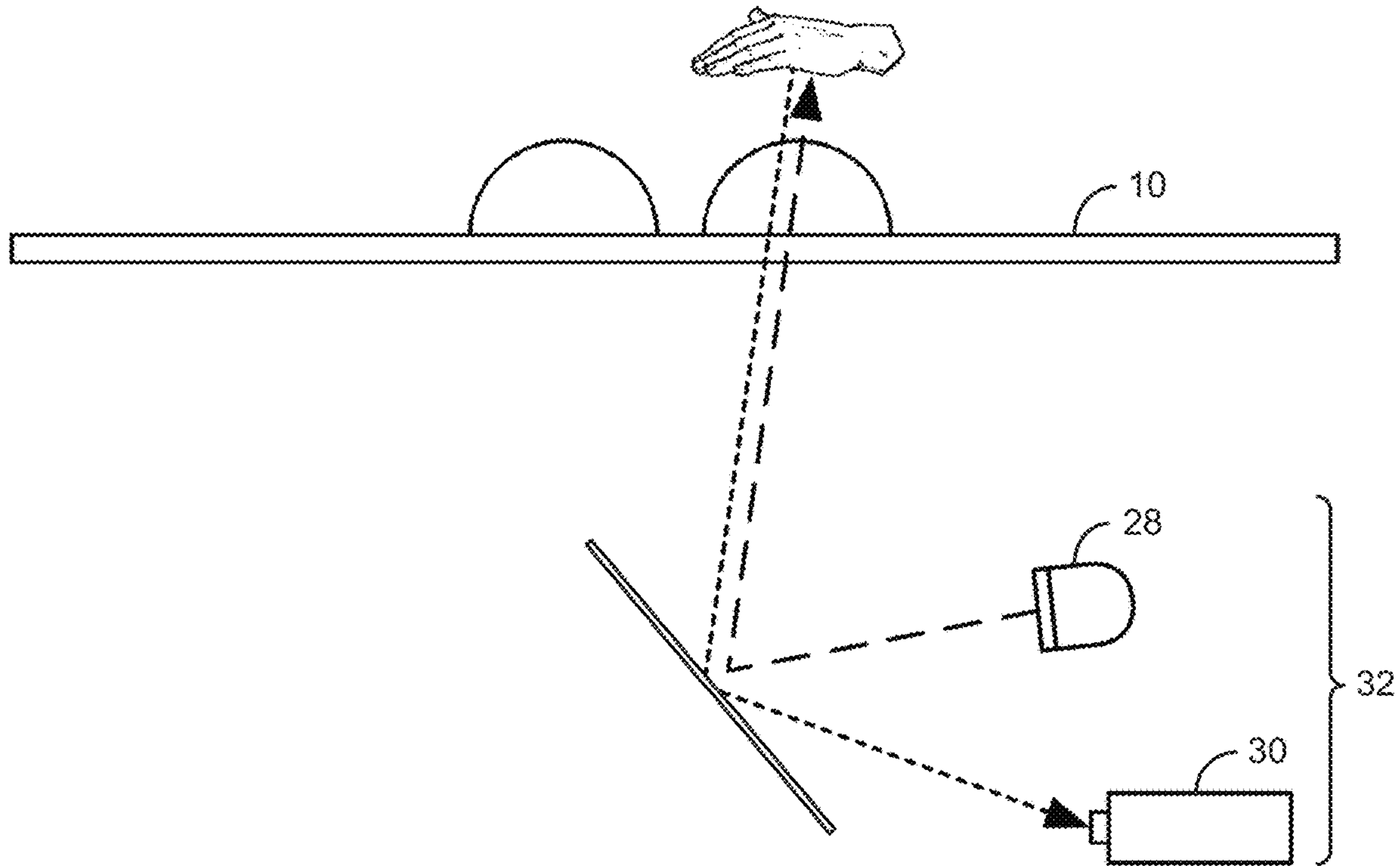


FIG. 13

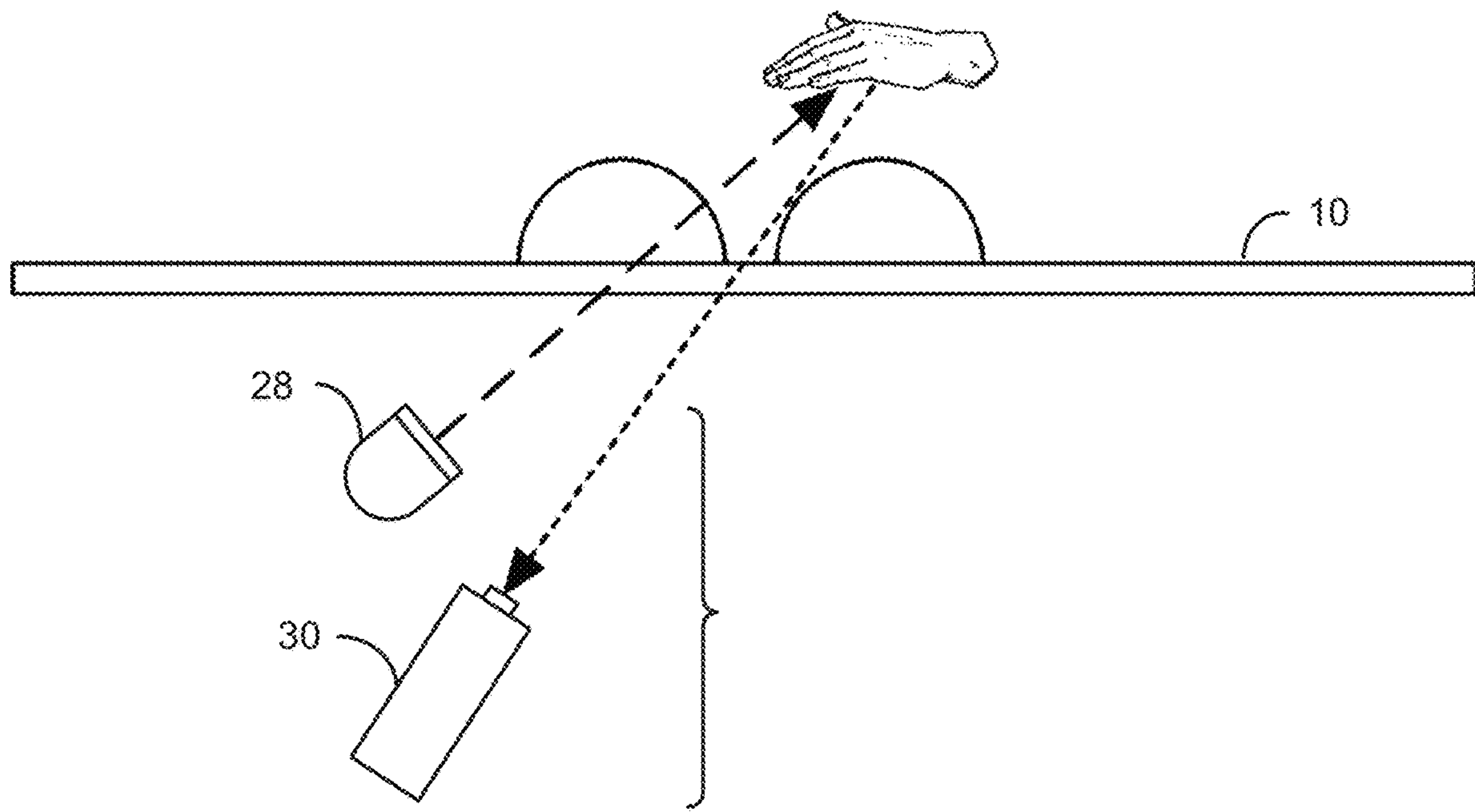


FIG. 14

FIG. 15A

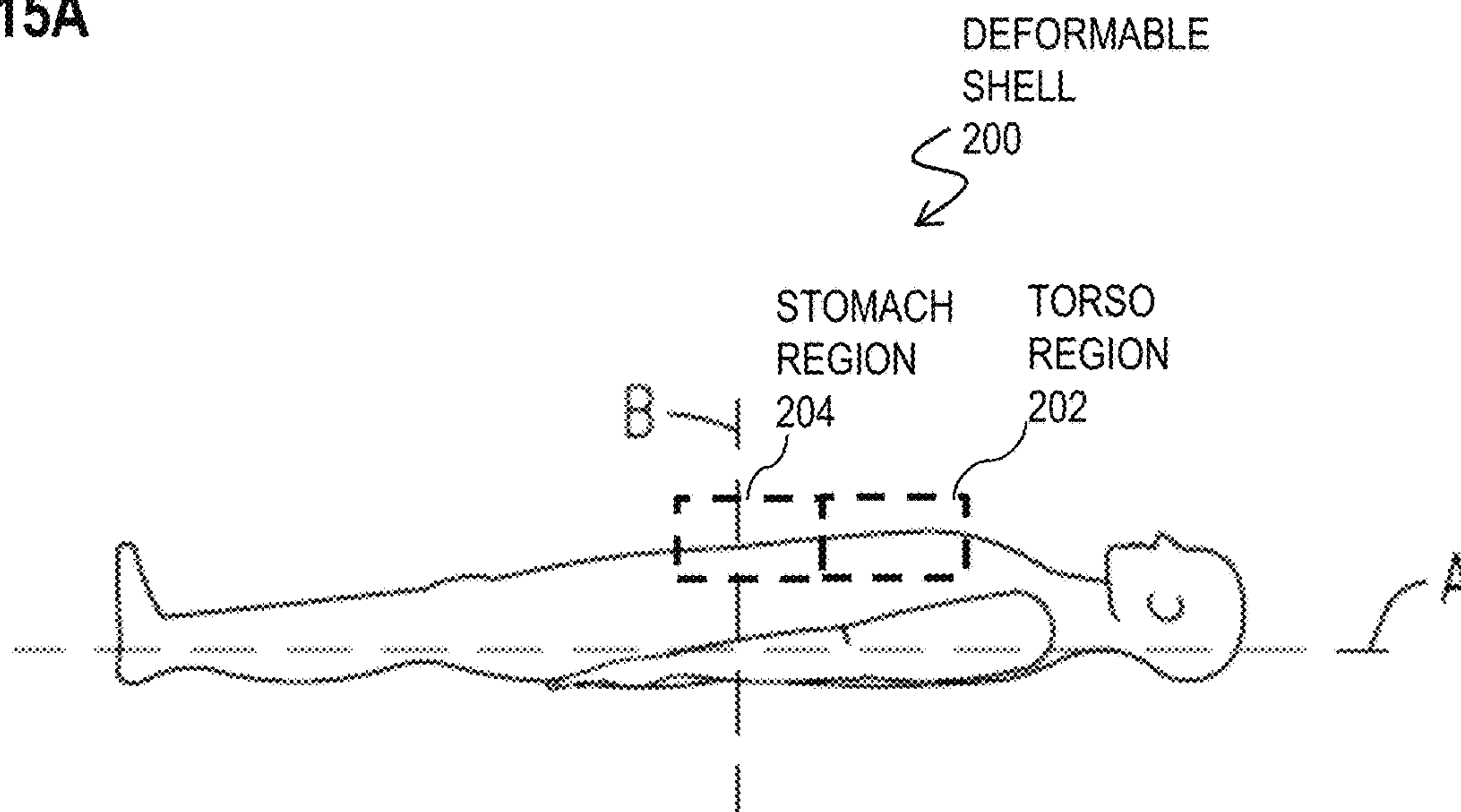


FIG. 15B

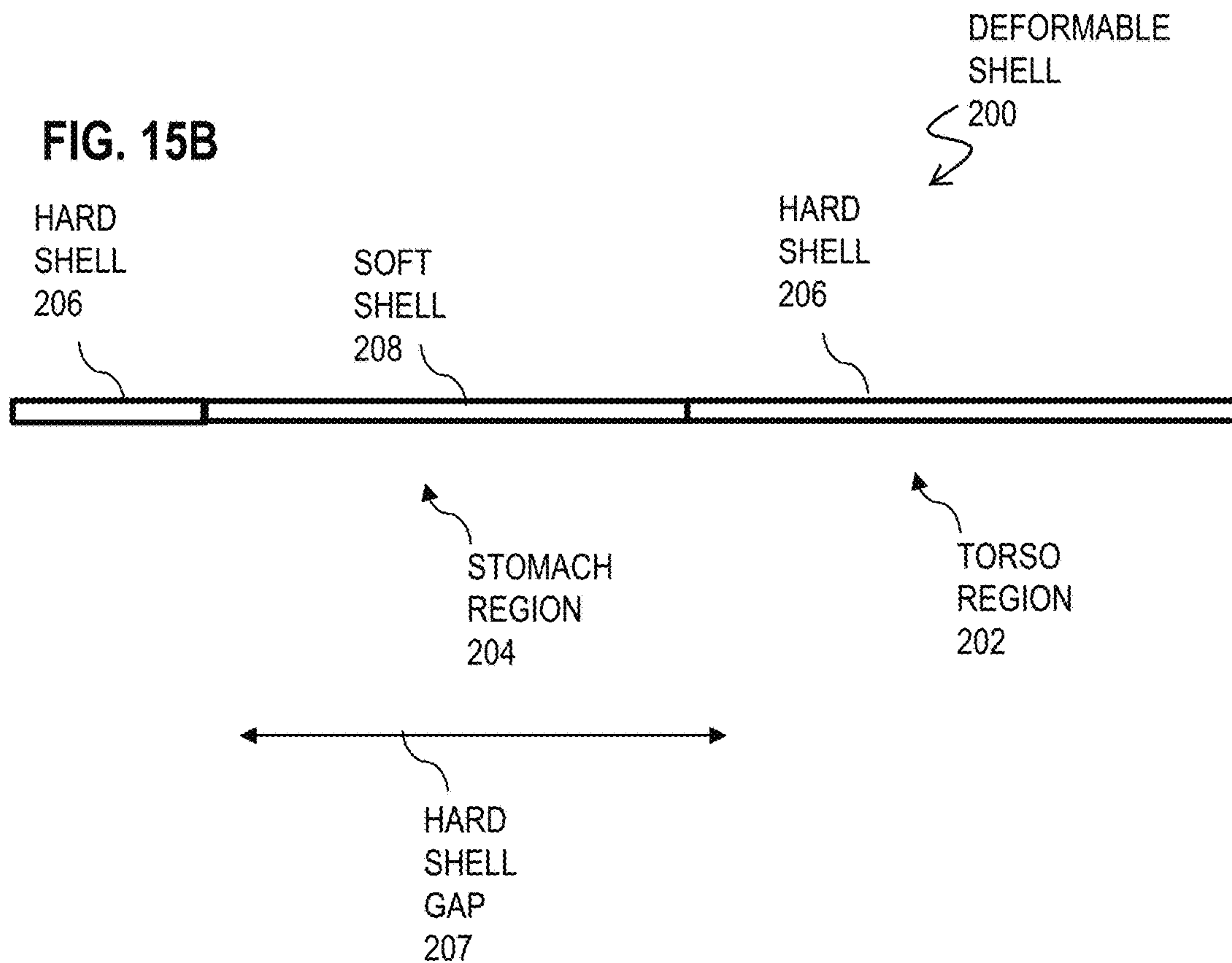


FIG. 16A

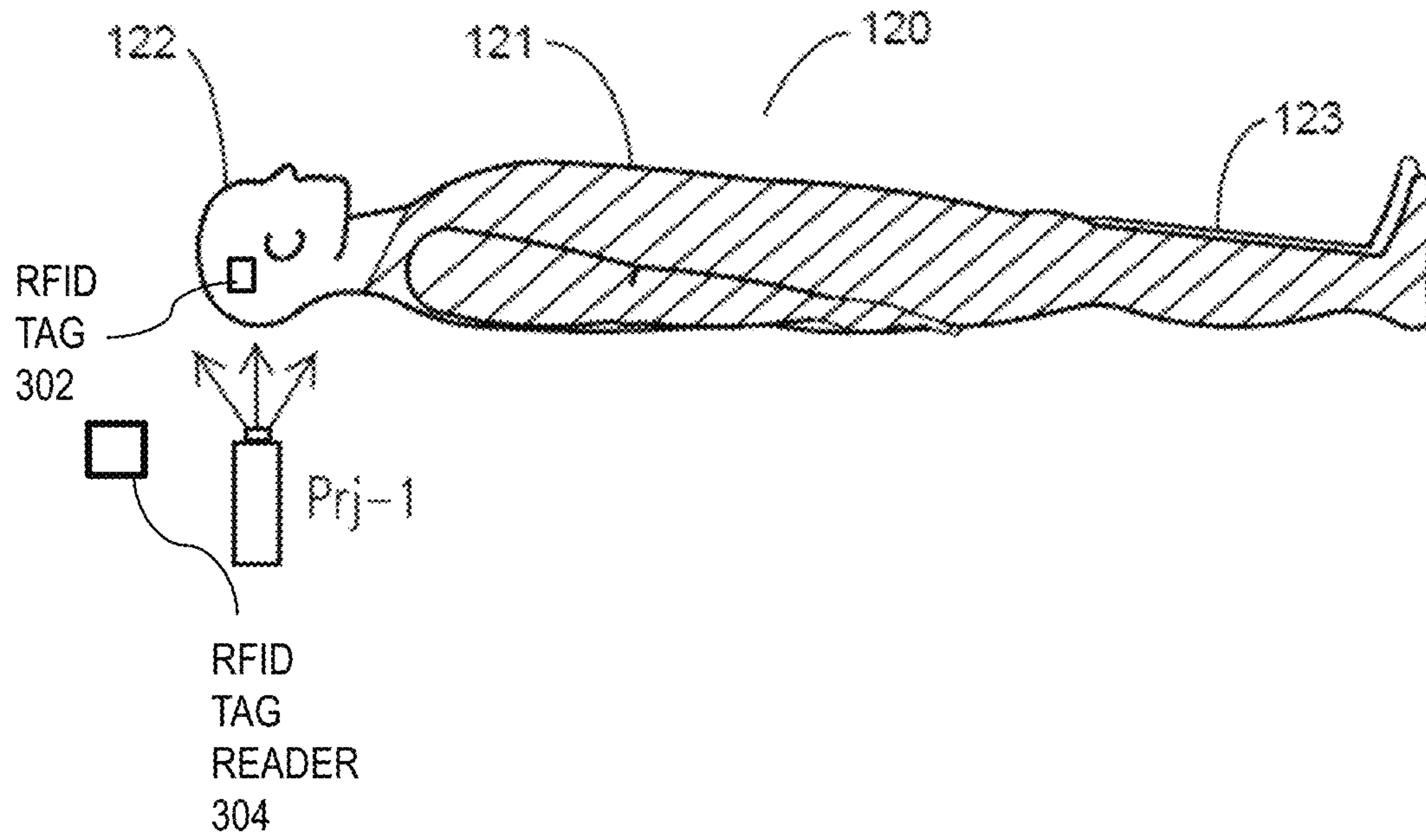


FIG. 16B

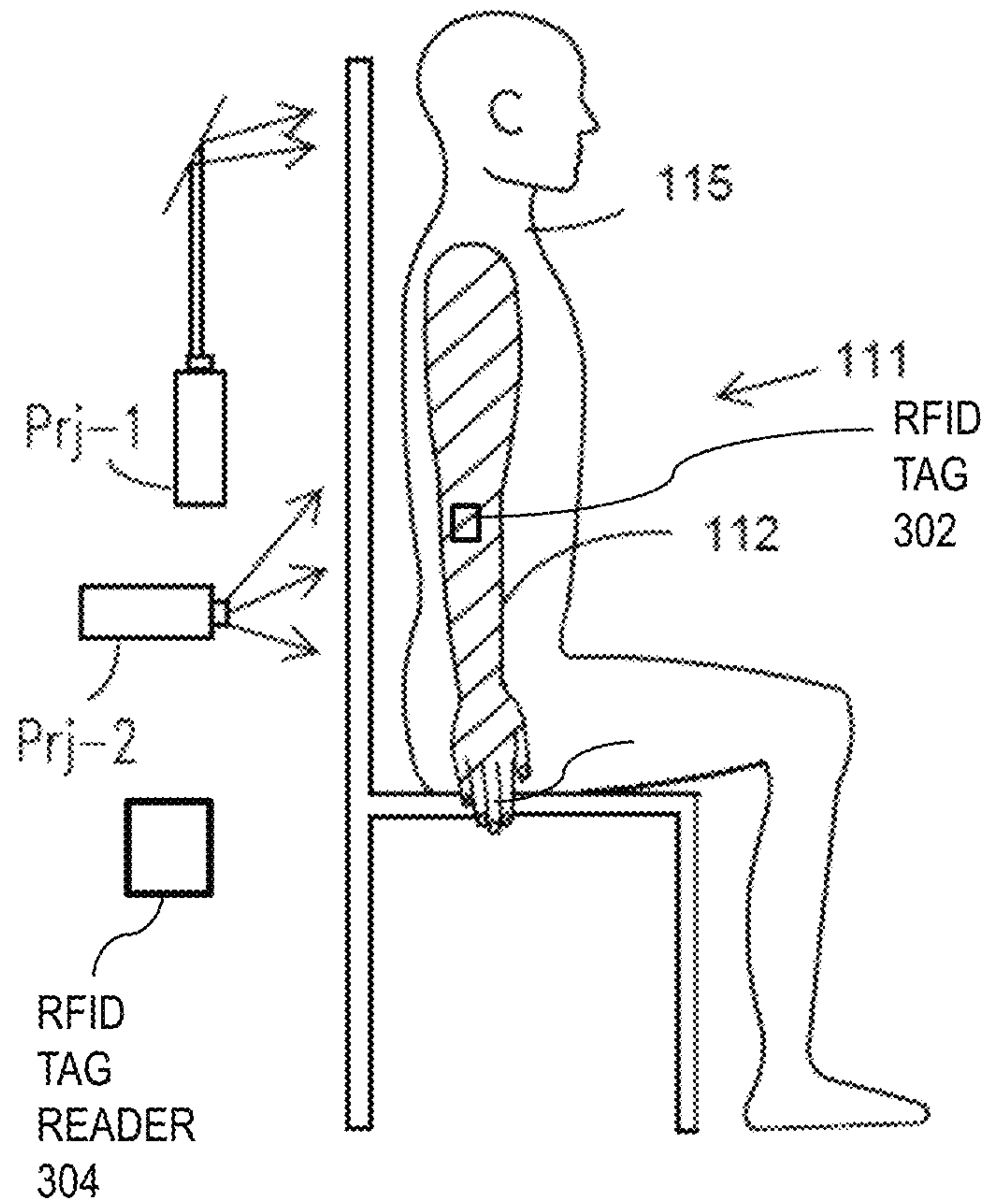


FIG. 17

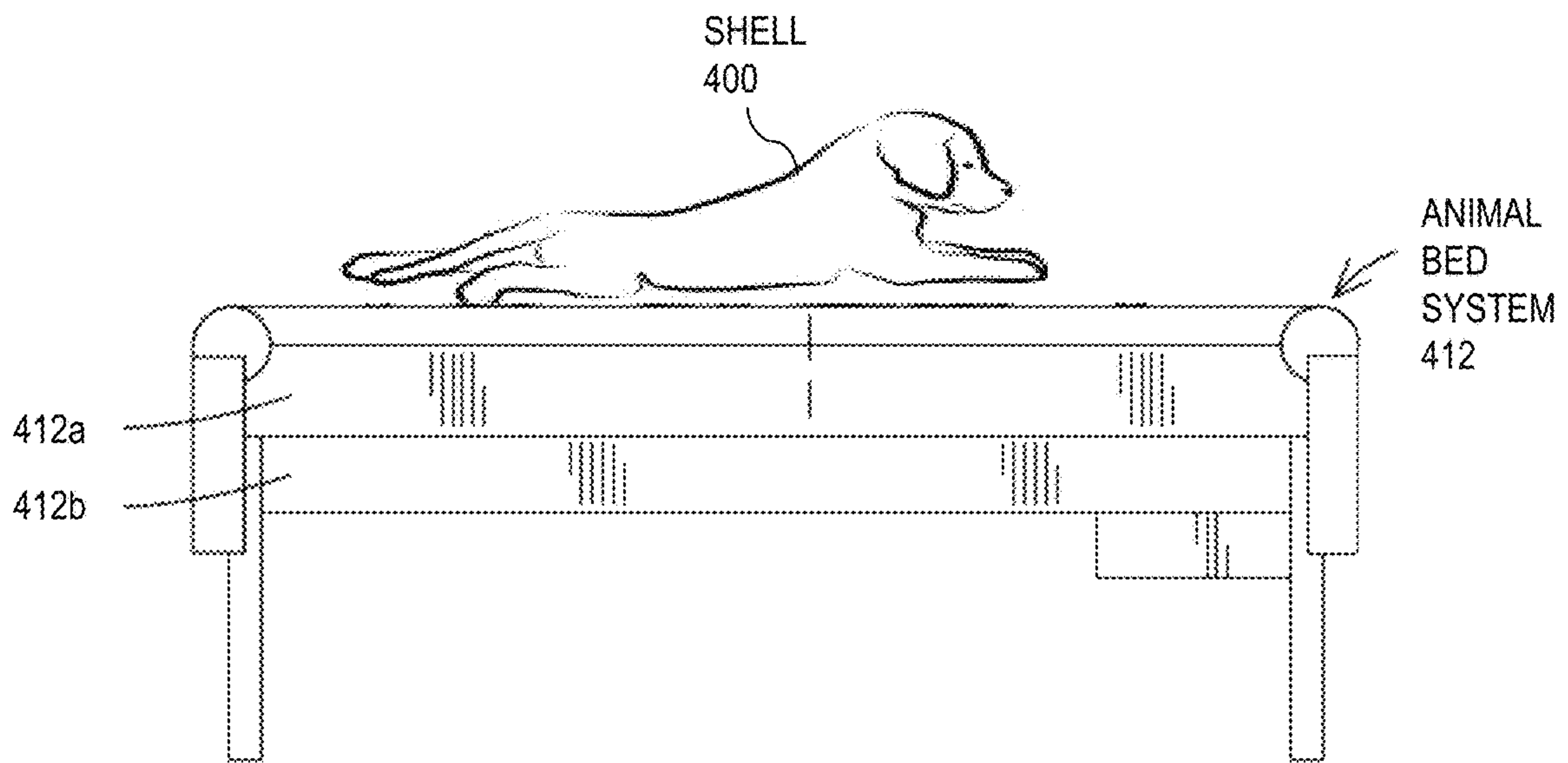


FIG. 18A

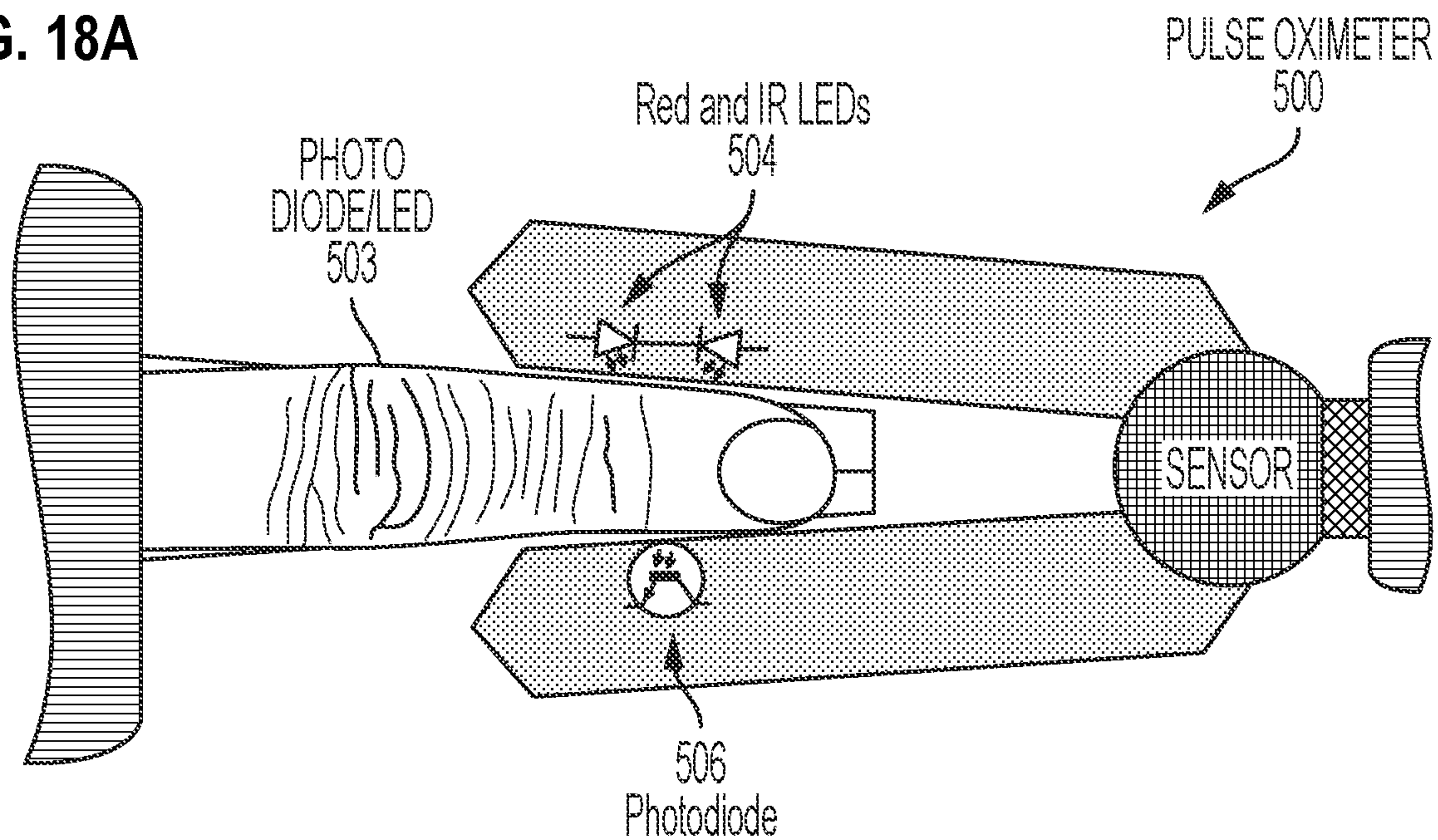


FIG. 18B
(prior art)

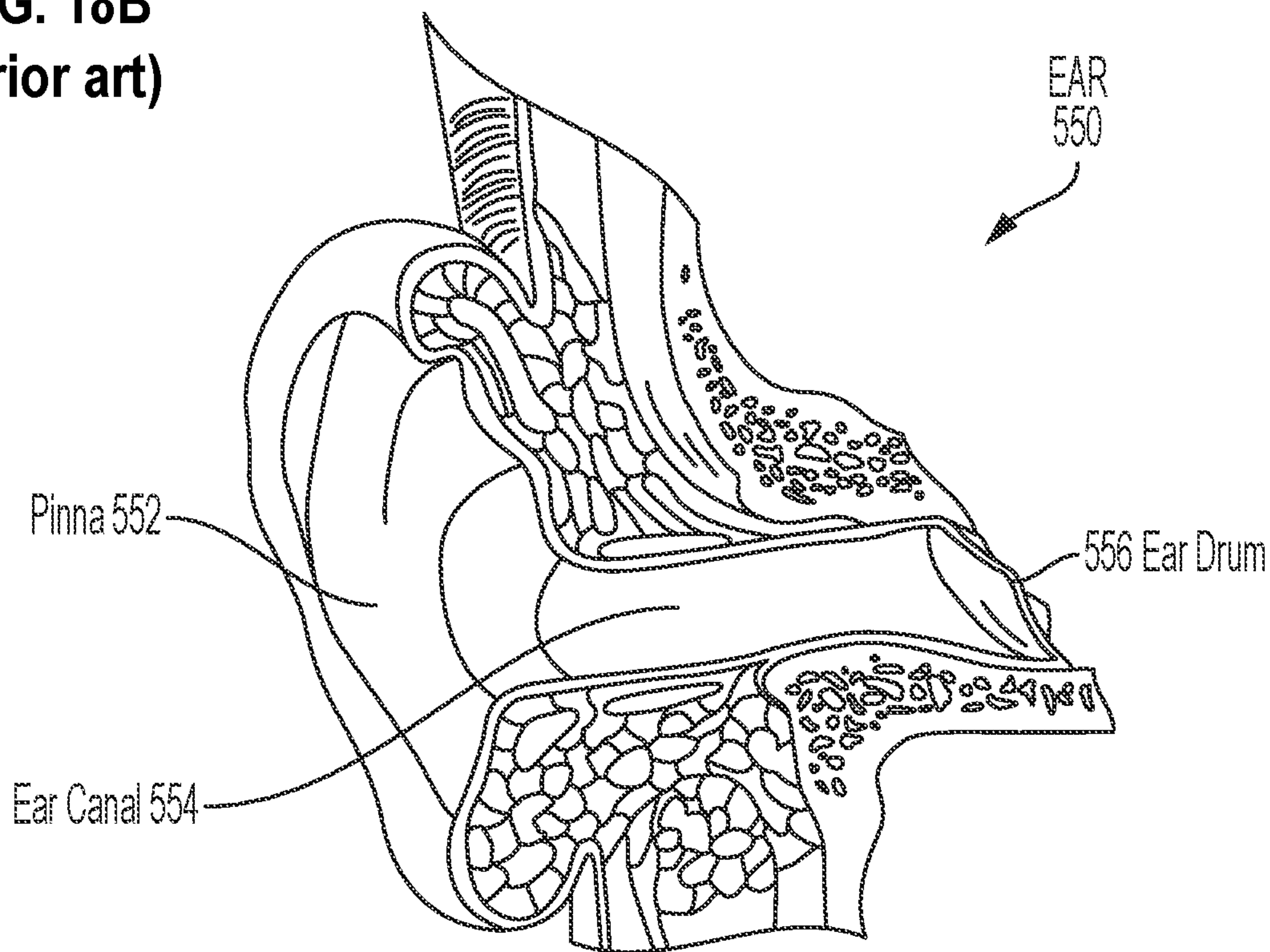


FIG. 19A

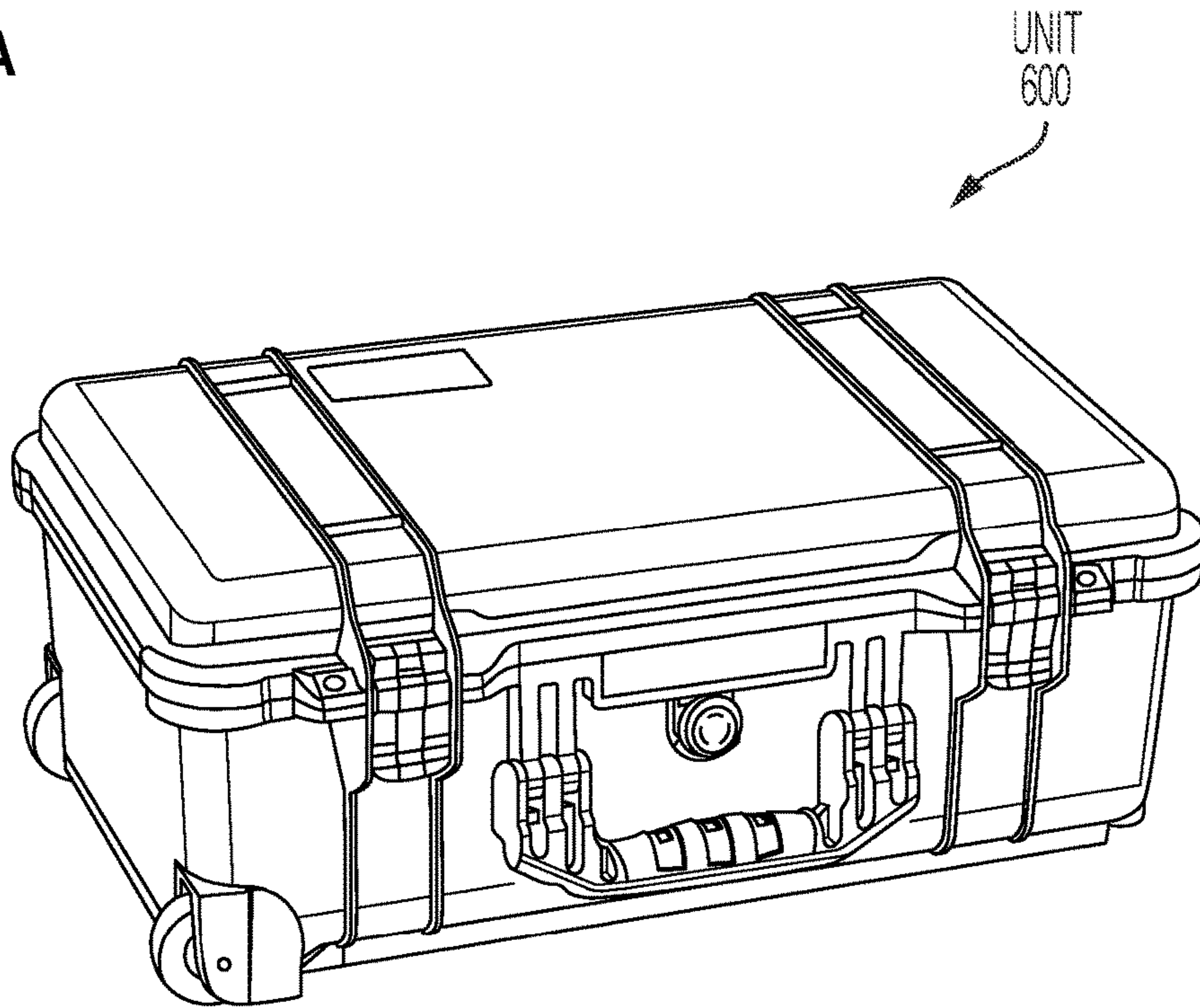


FIG. 19B

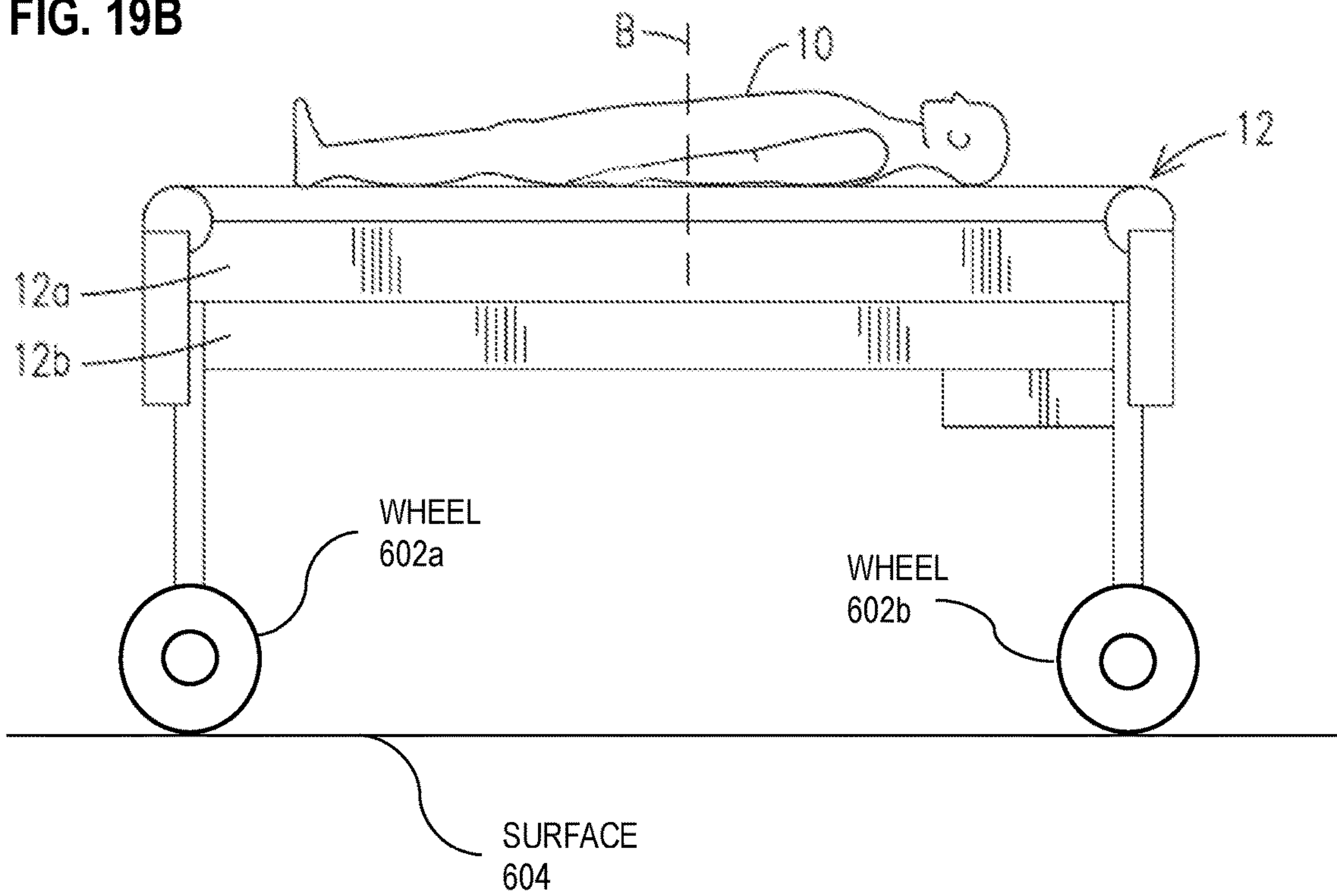


FIG. 20

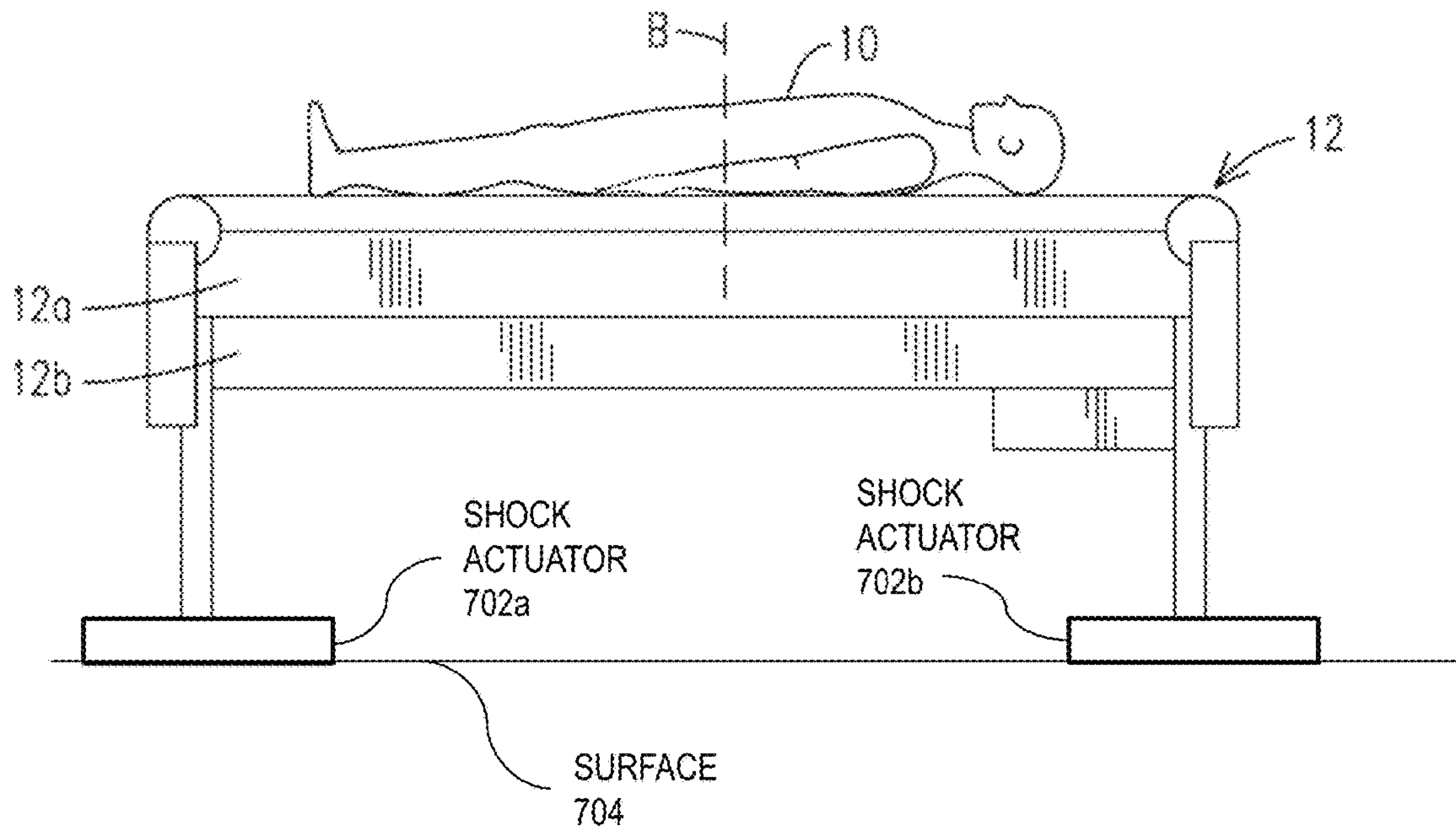


FIG. 21A

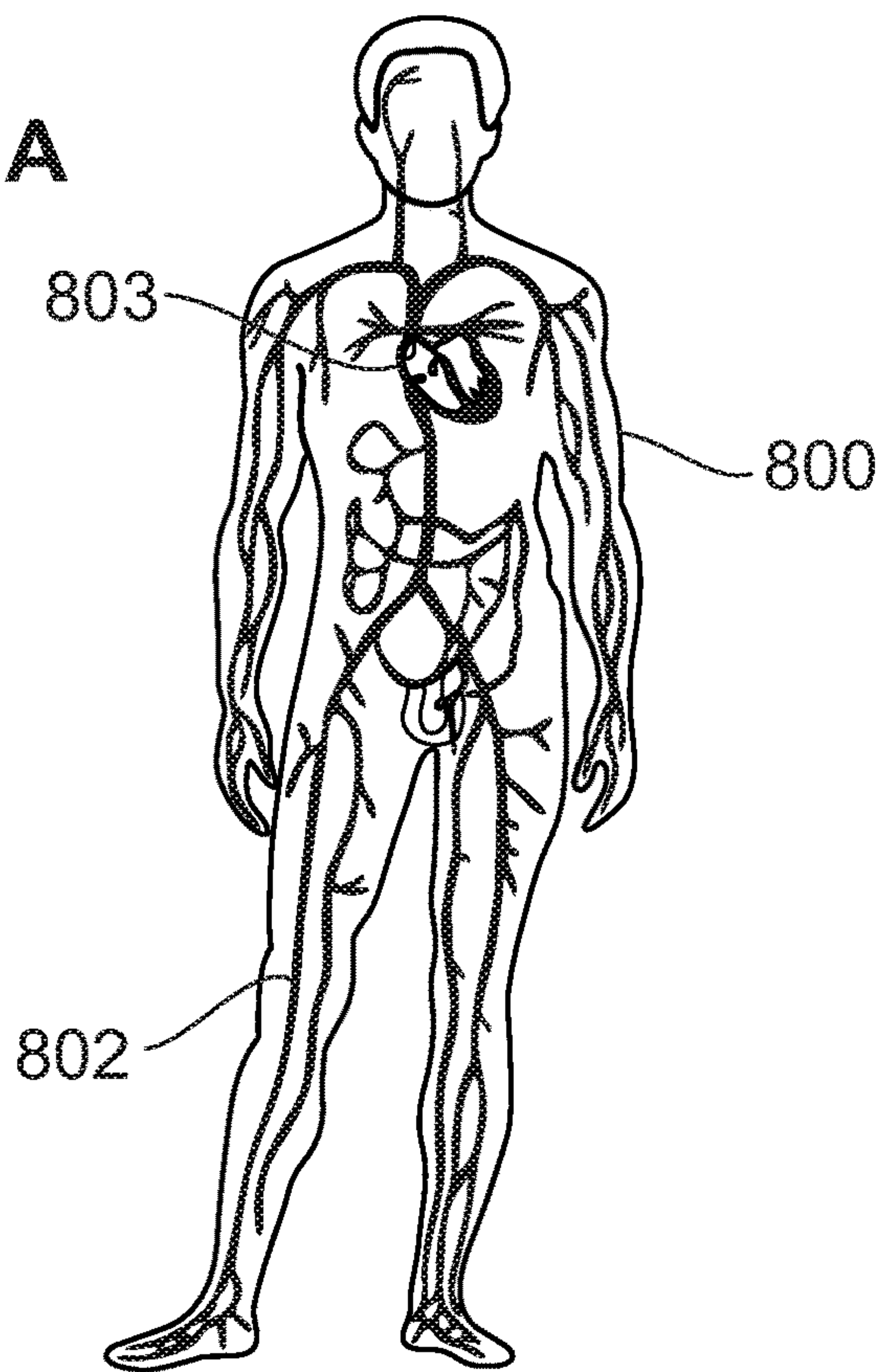


FIG. 21B

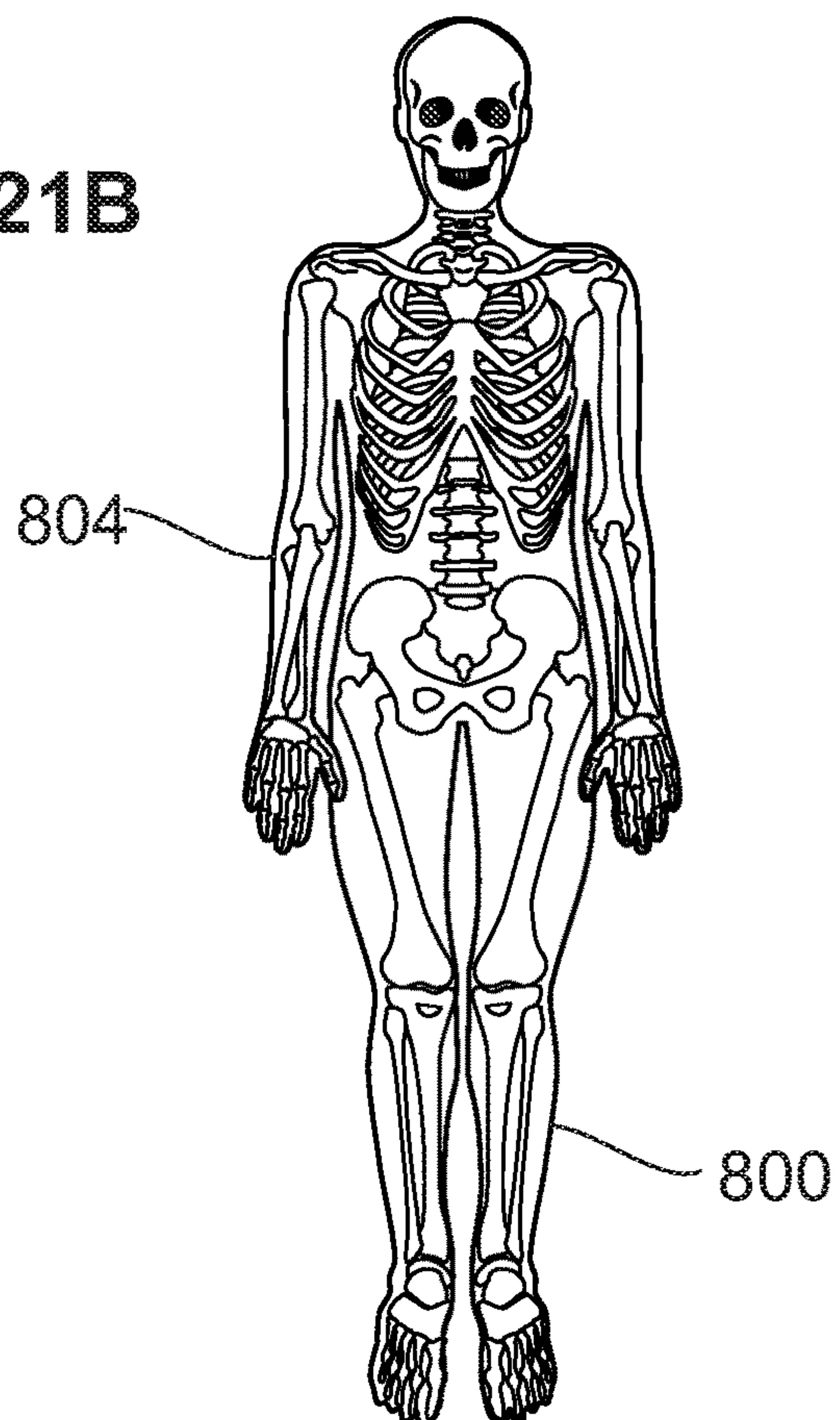


FIG. 22

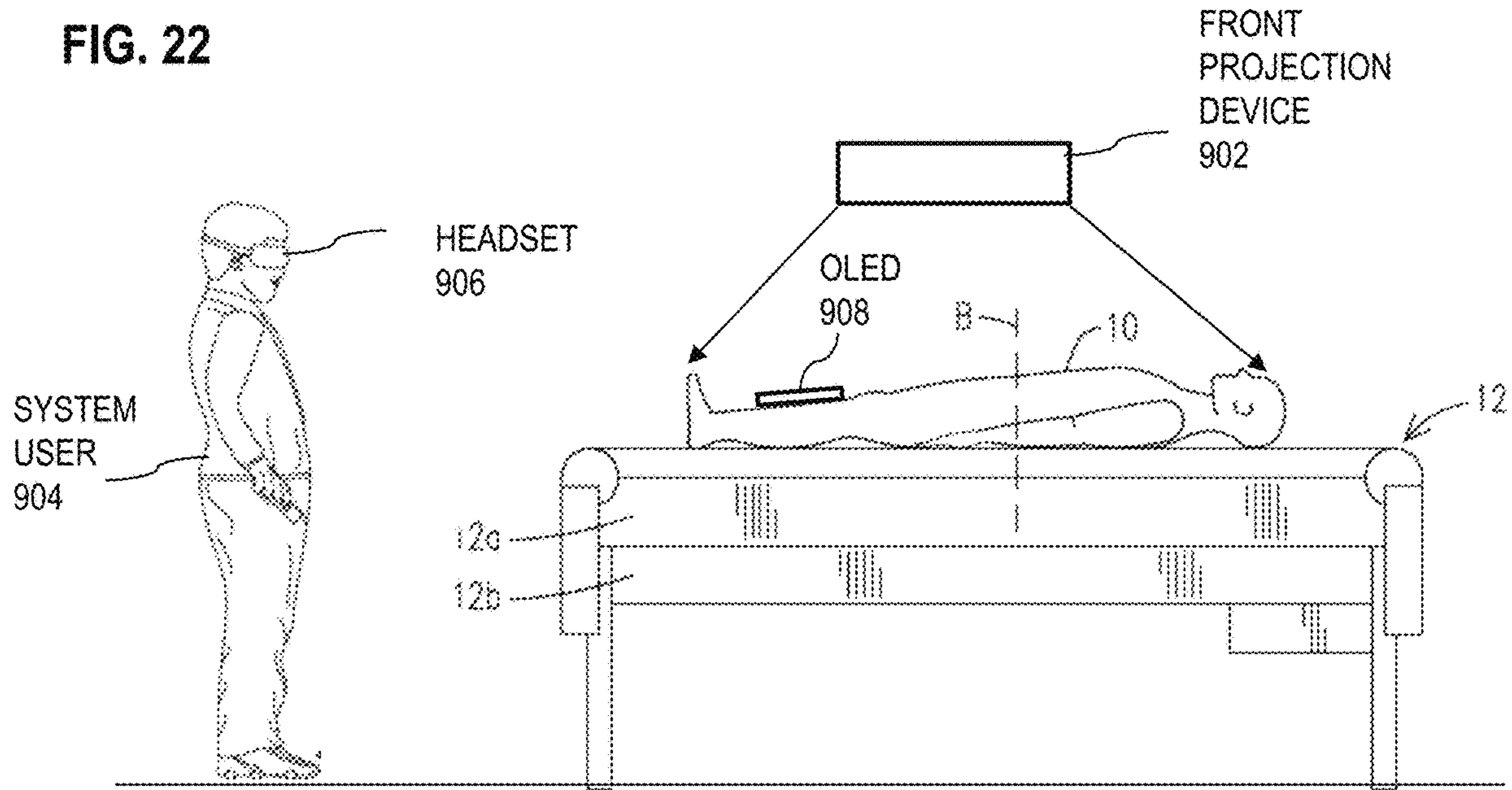
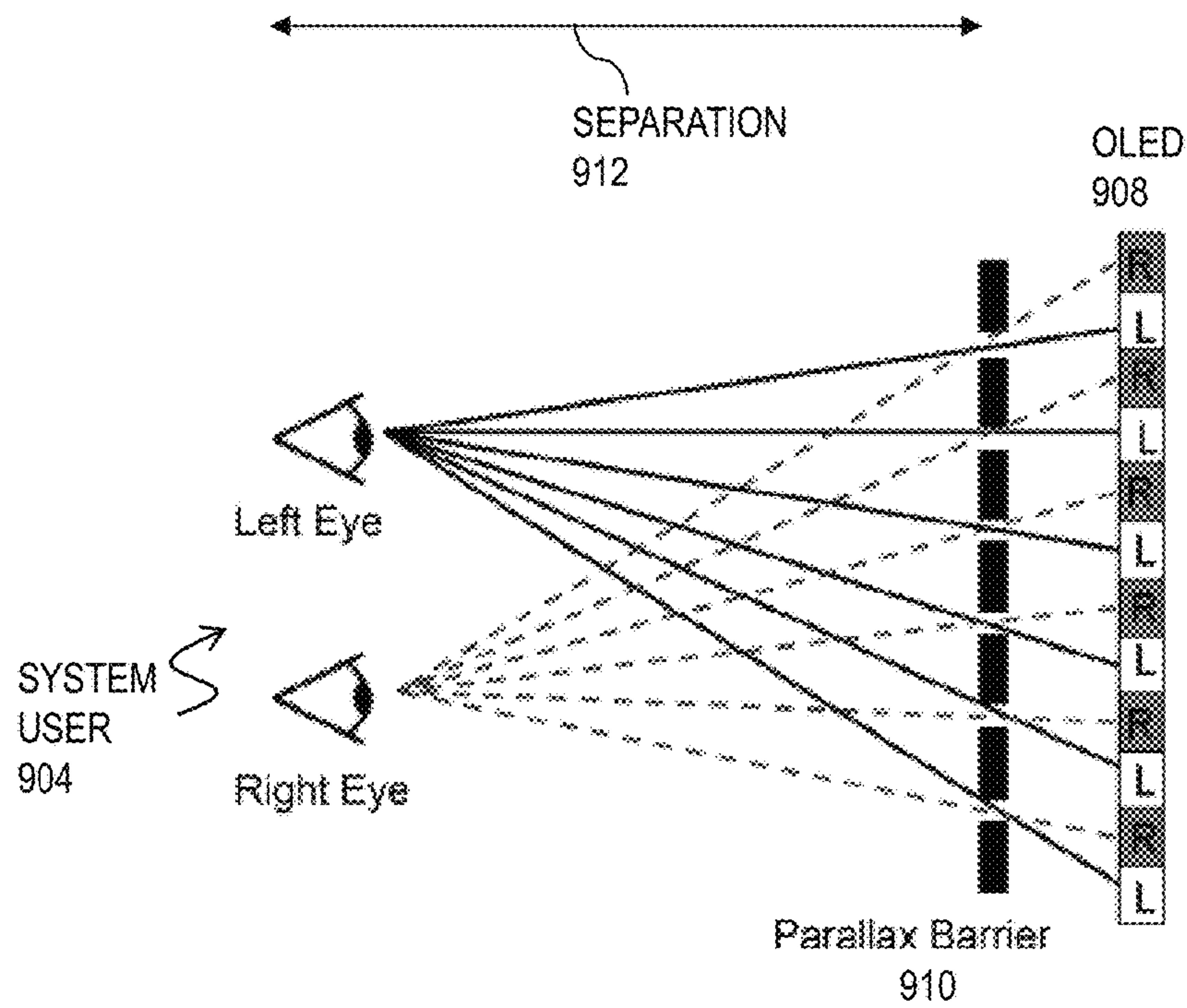
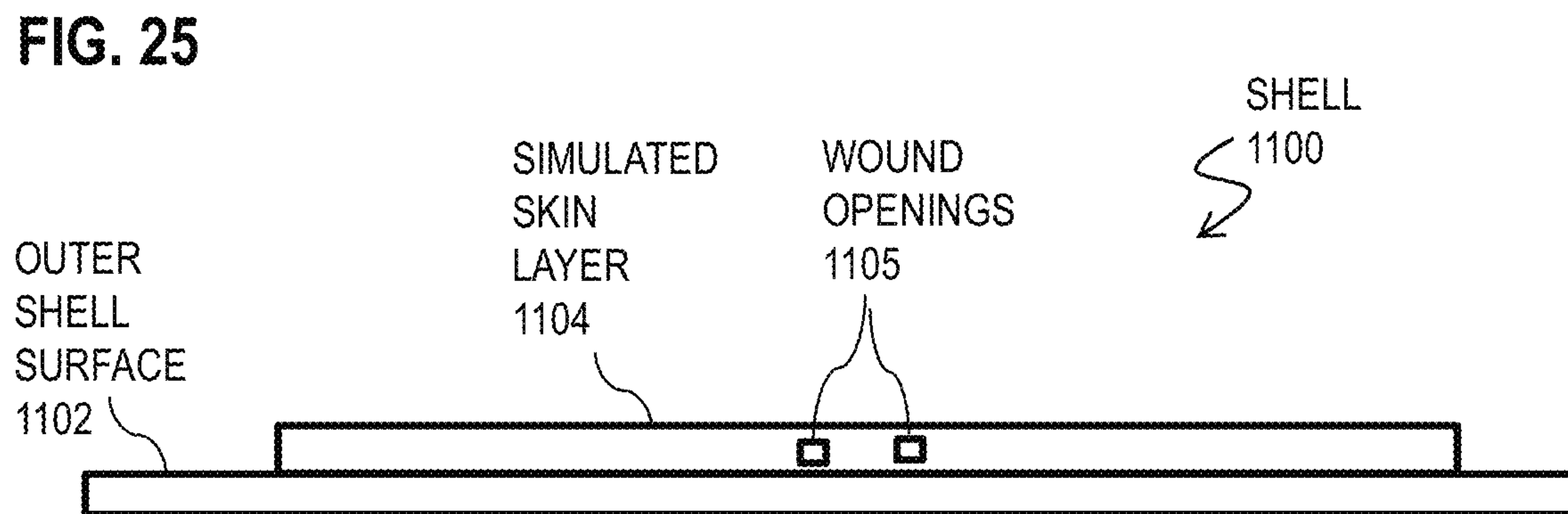
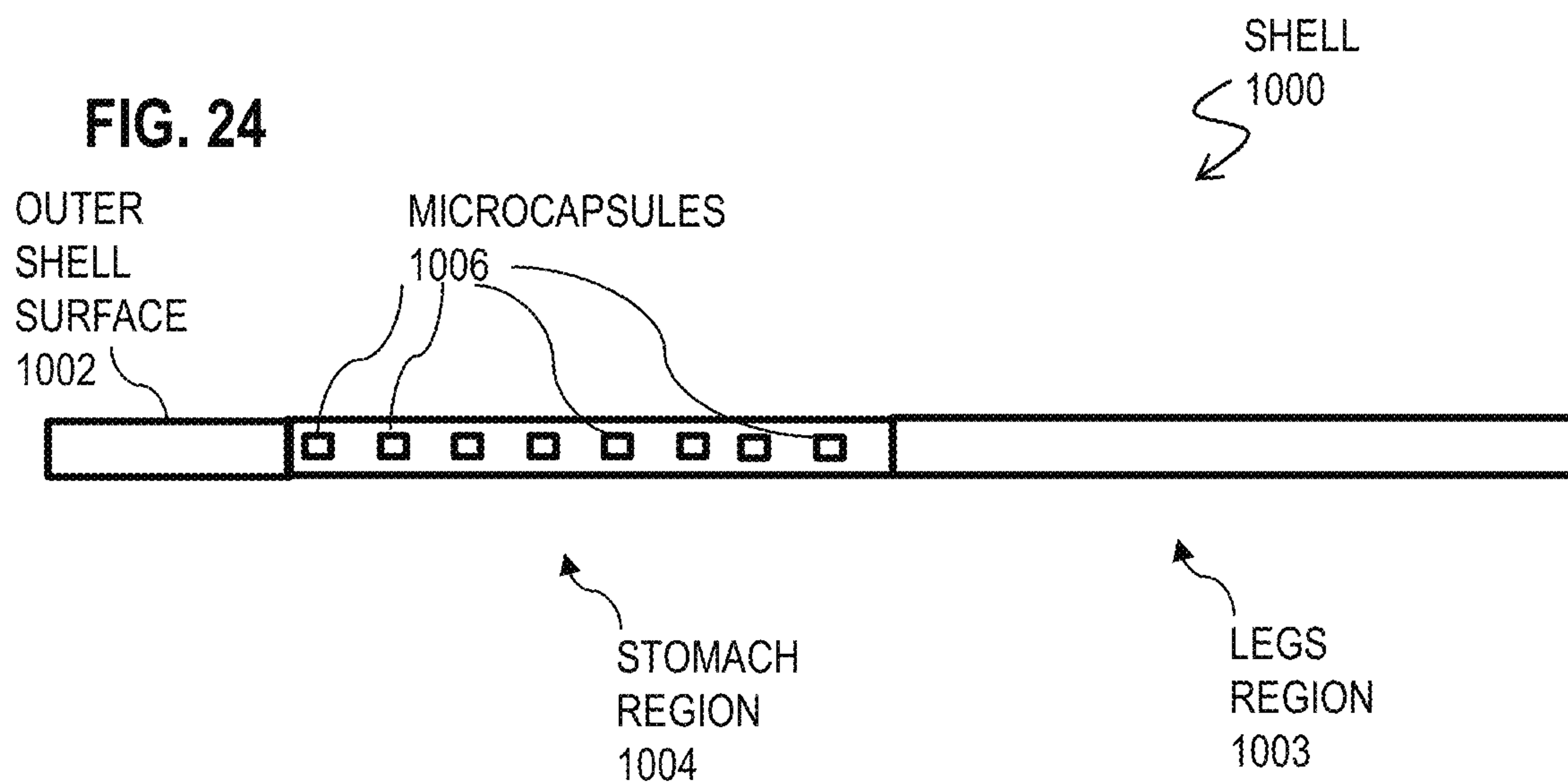


FIG. 23





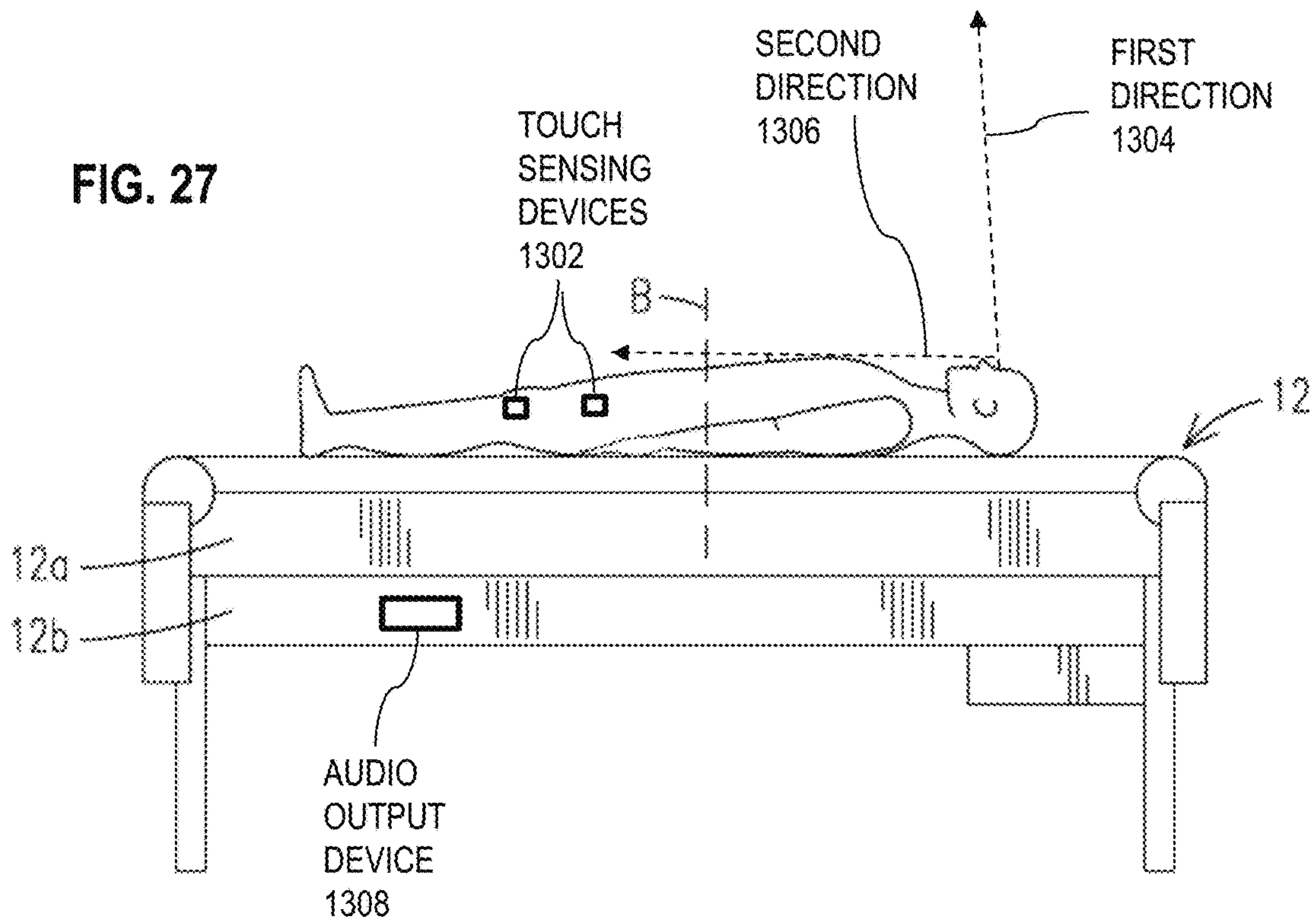
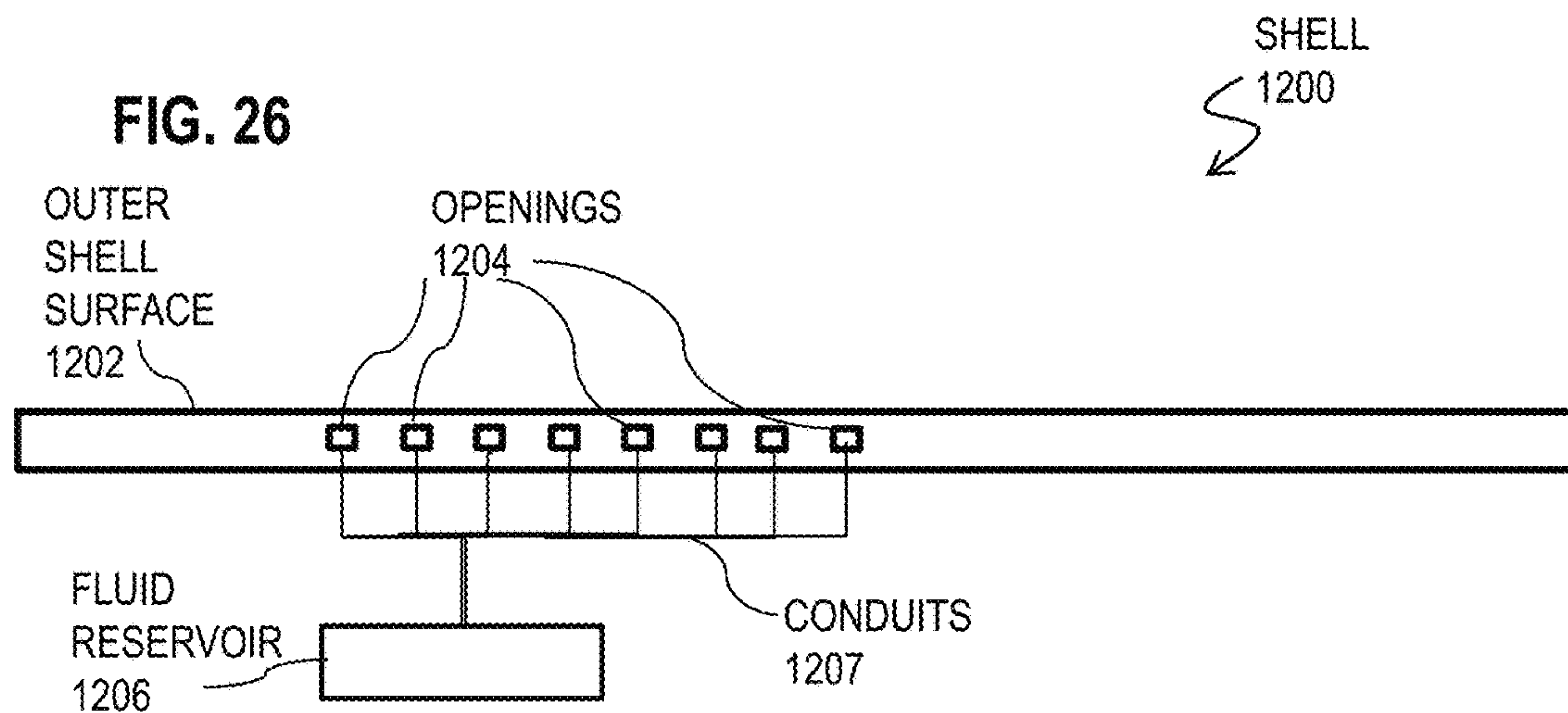


FIG. 28A

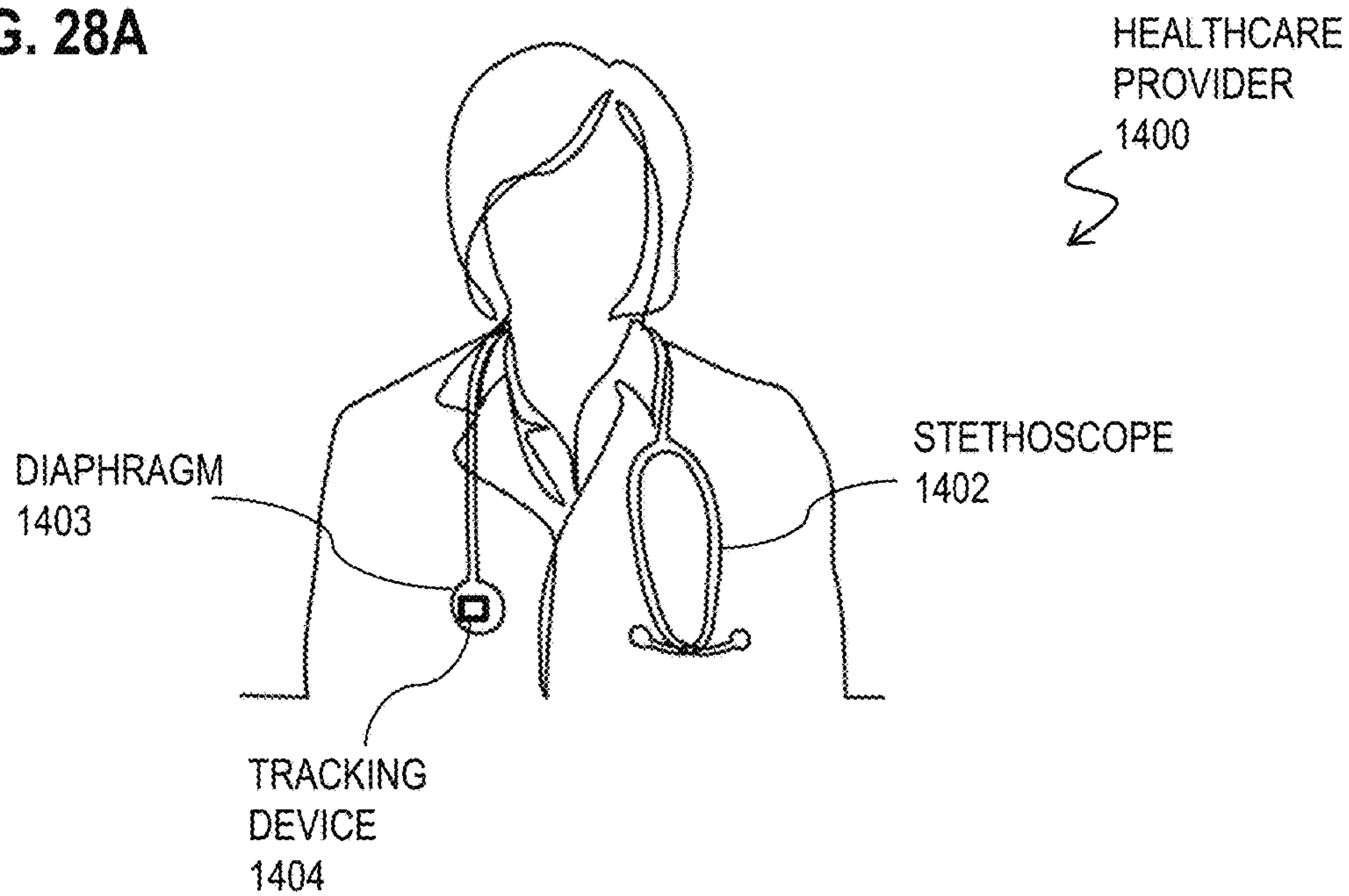


FIG. 28B

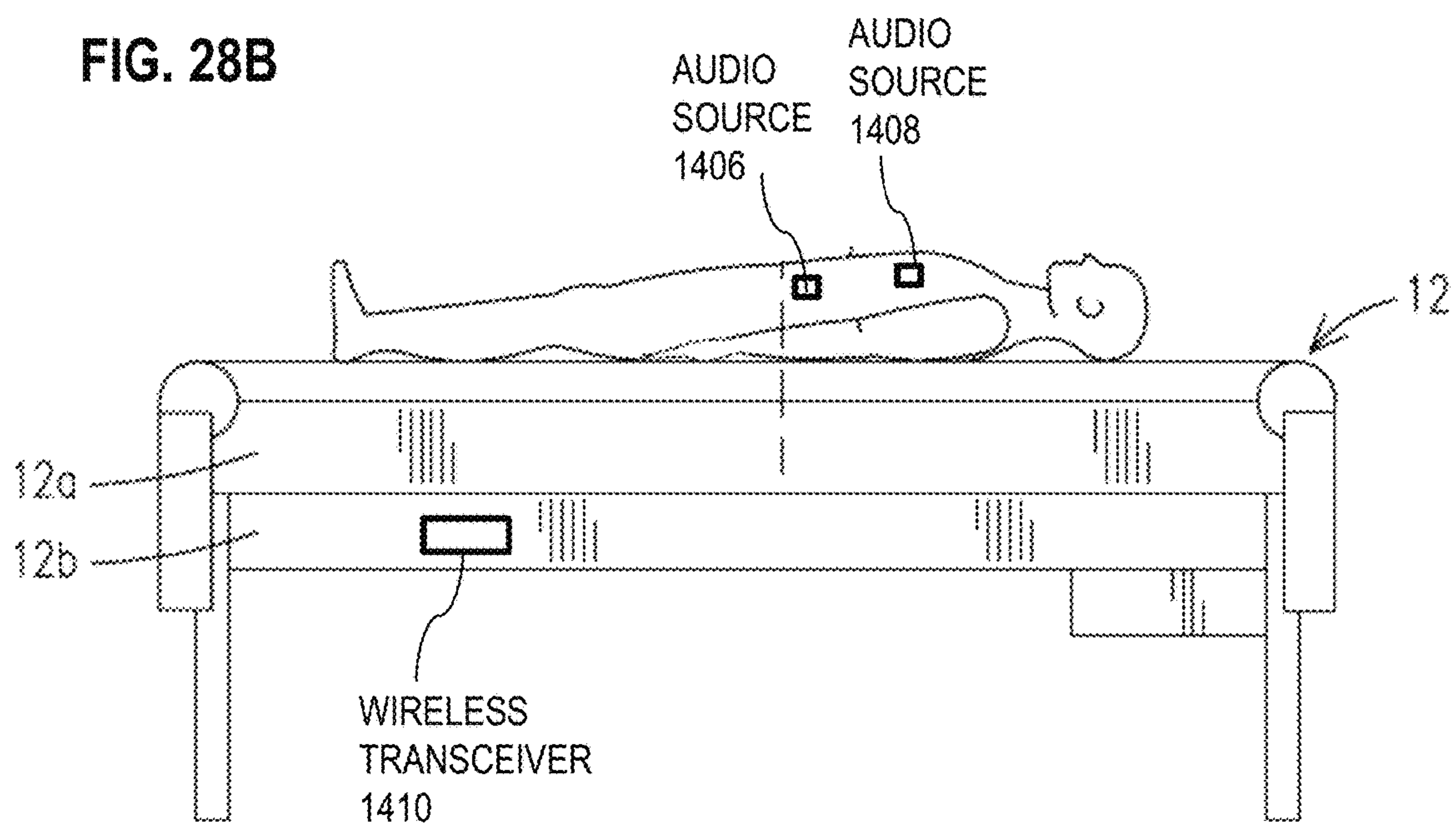


FIG. 29

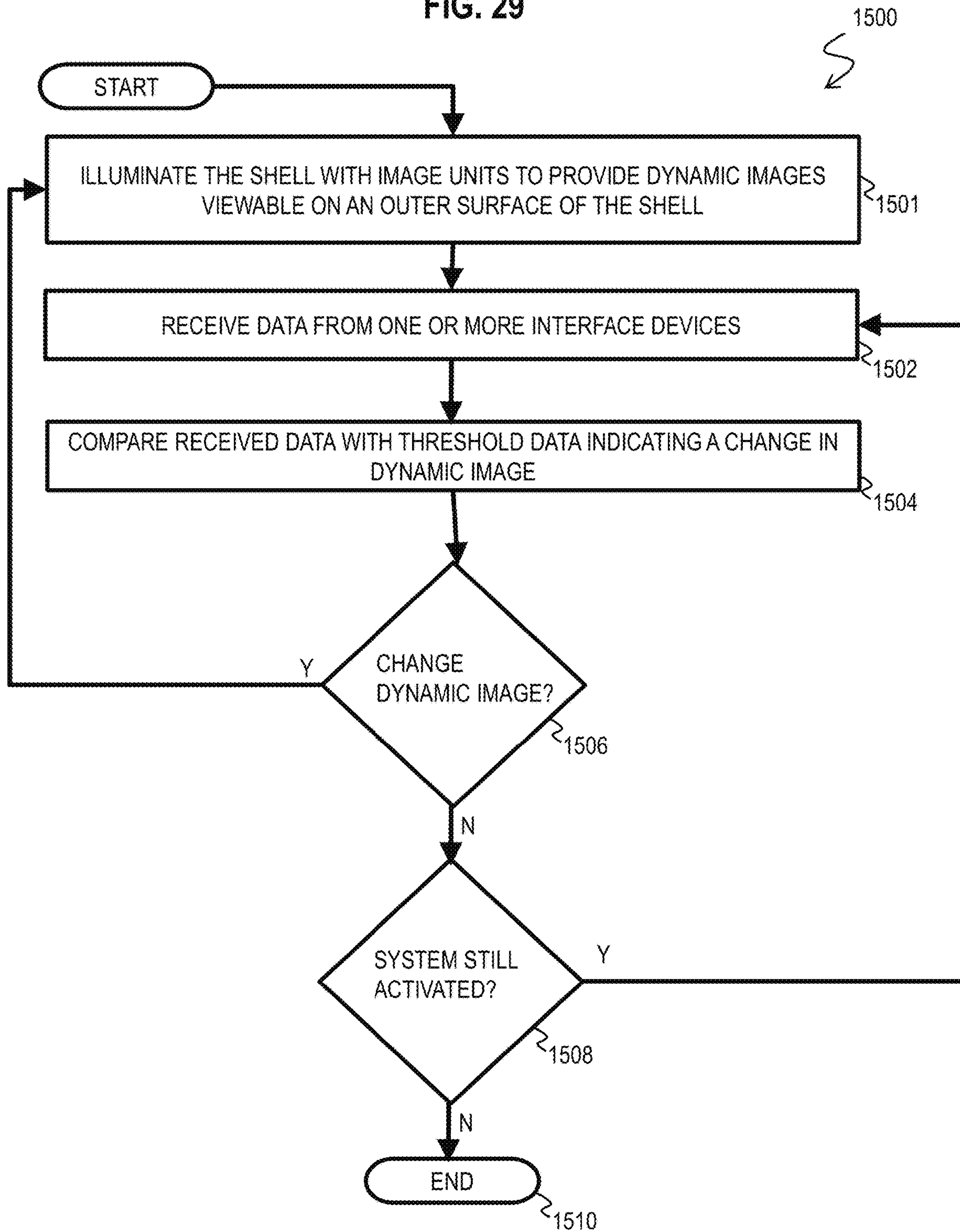


FIG. 30

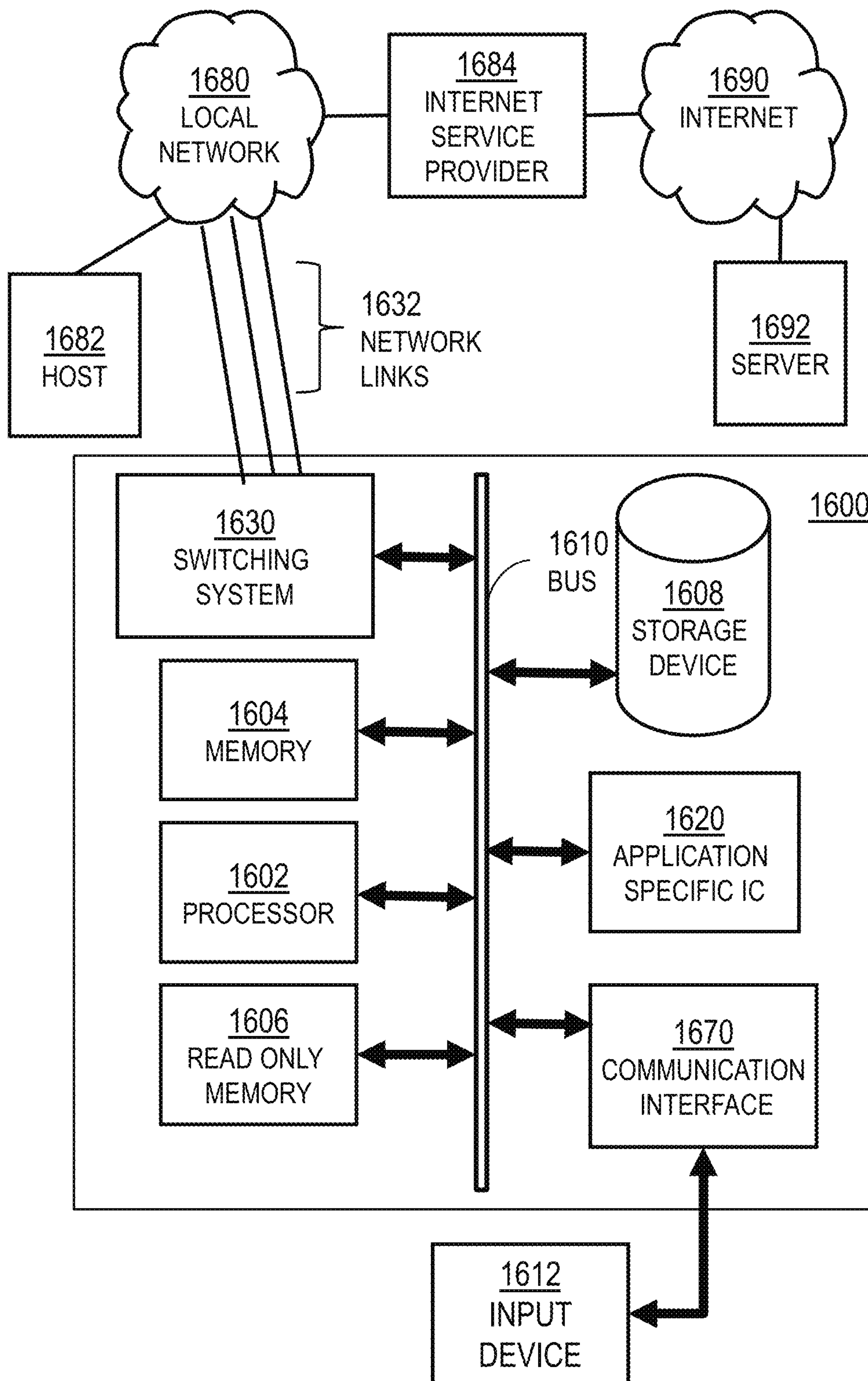


FIG. 31

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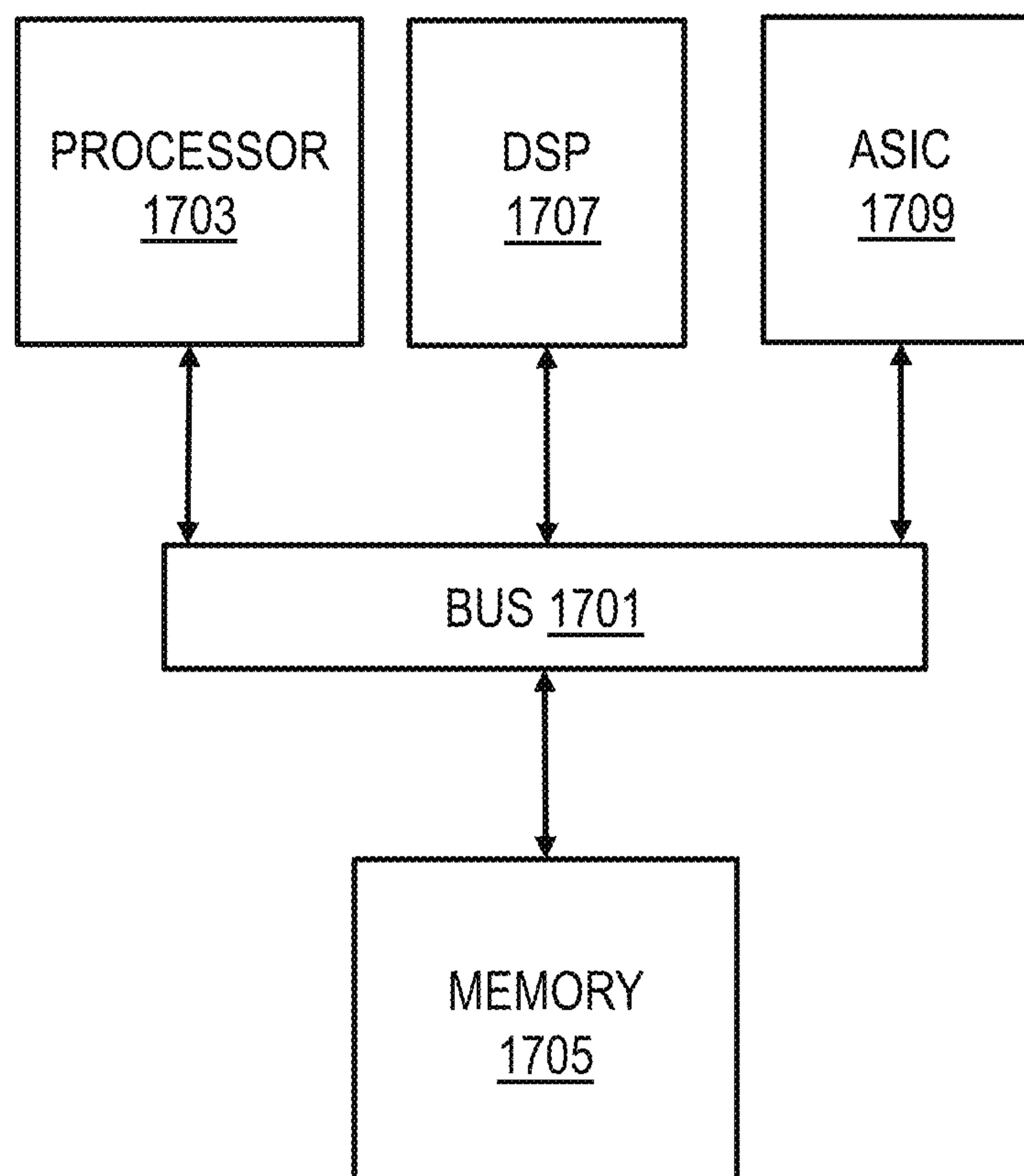



FIG. 32

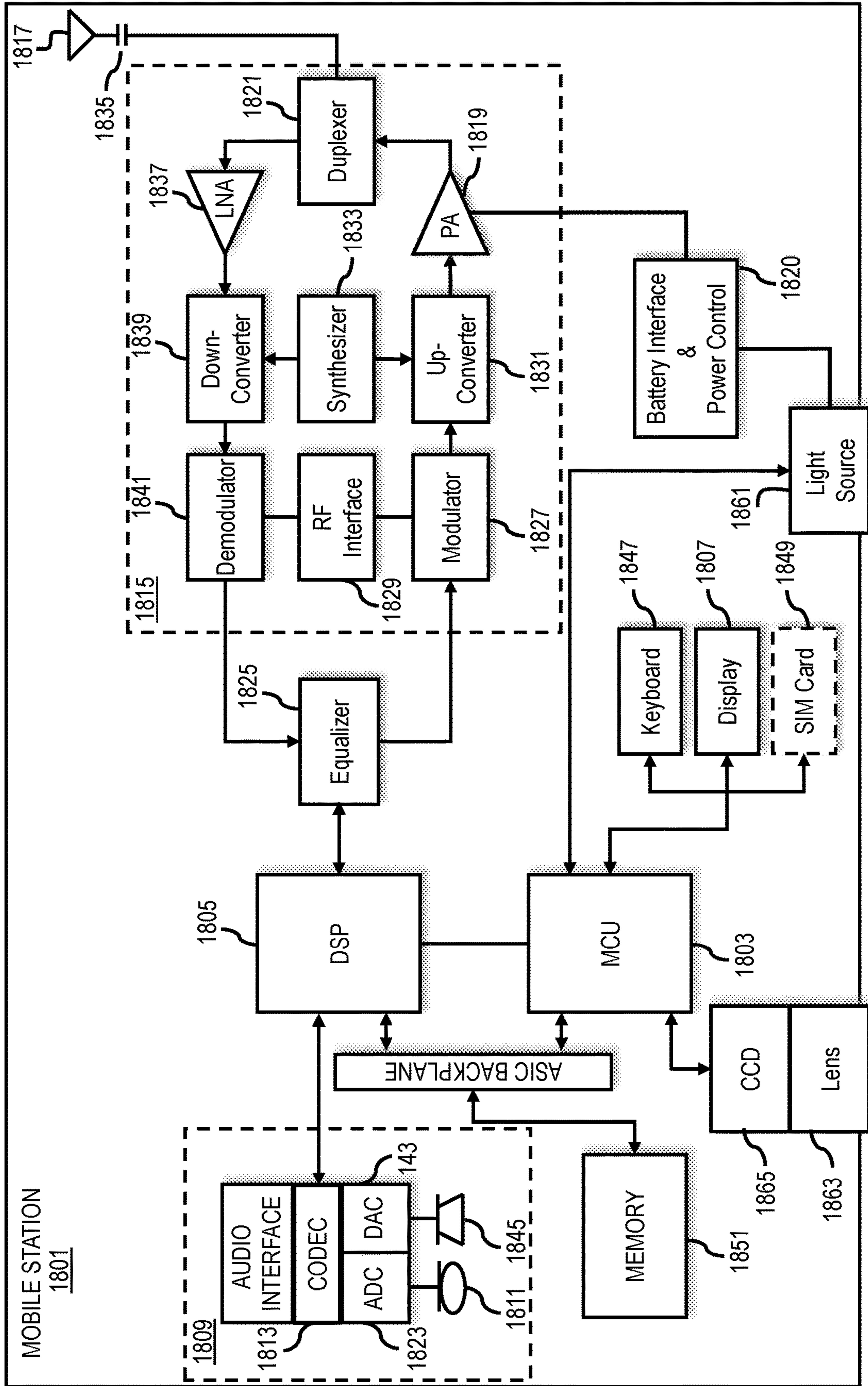


FIG. 33A

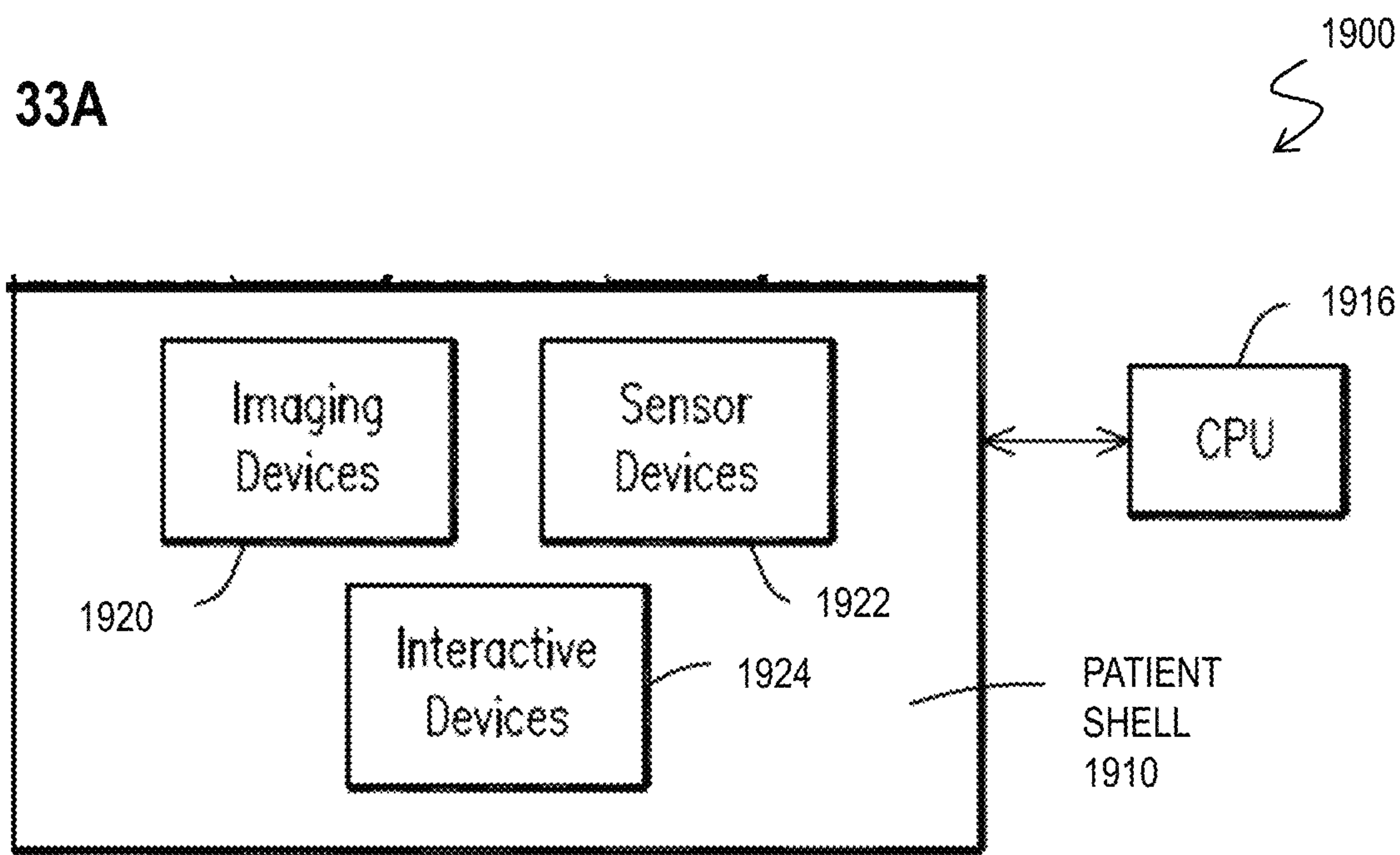


FIG. 33B

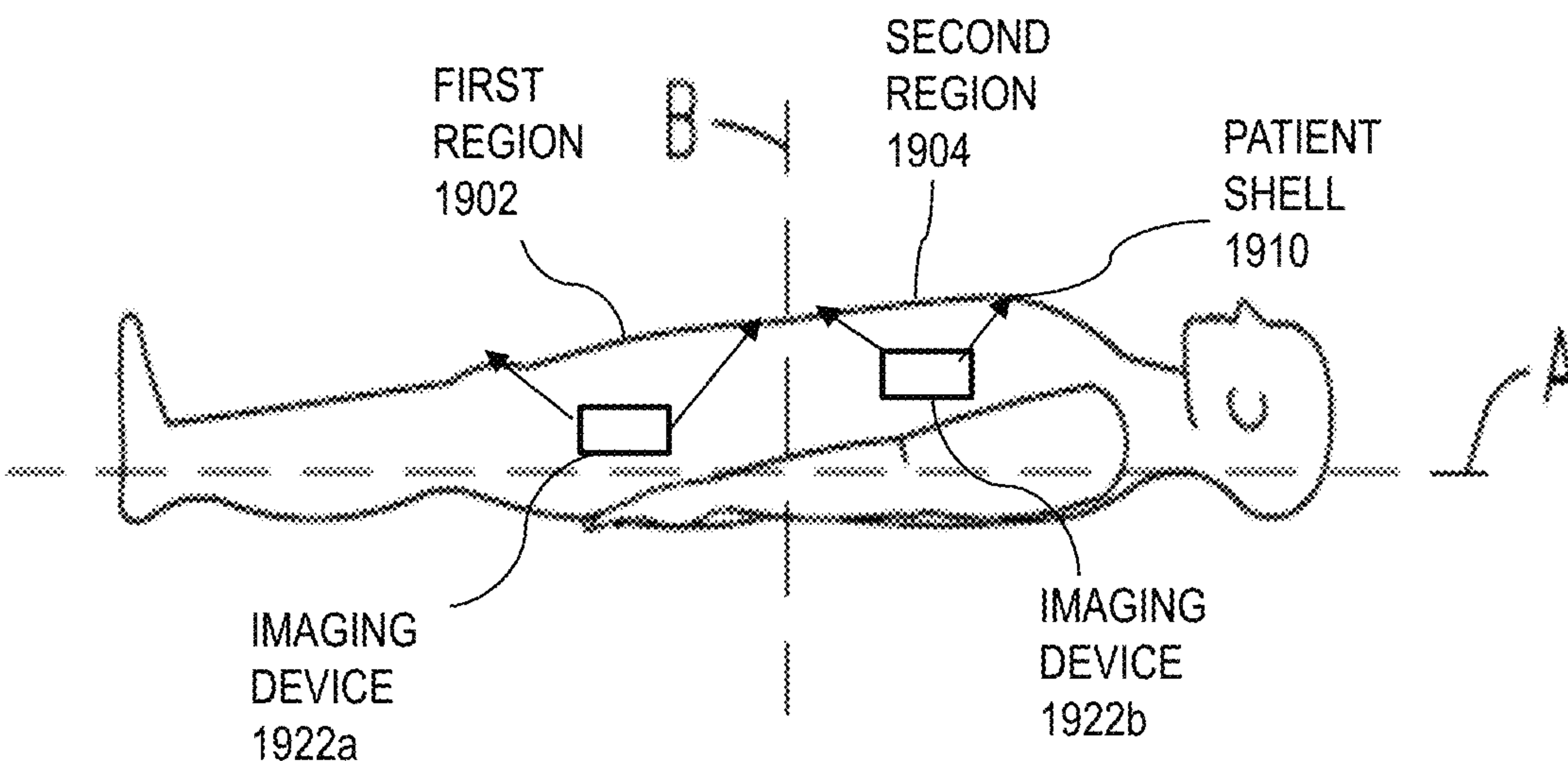


FIG. 33C

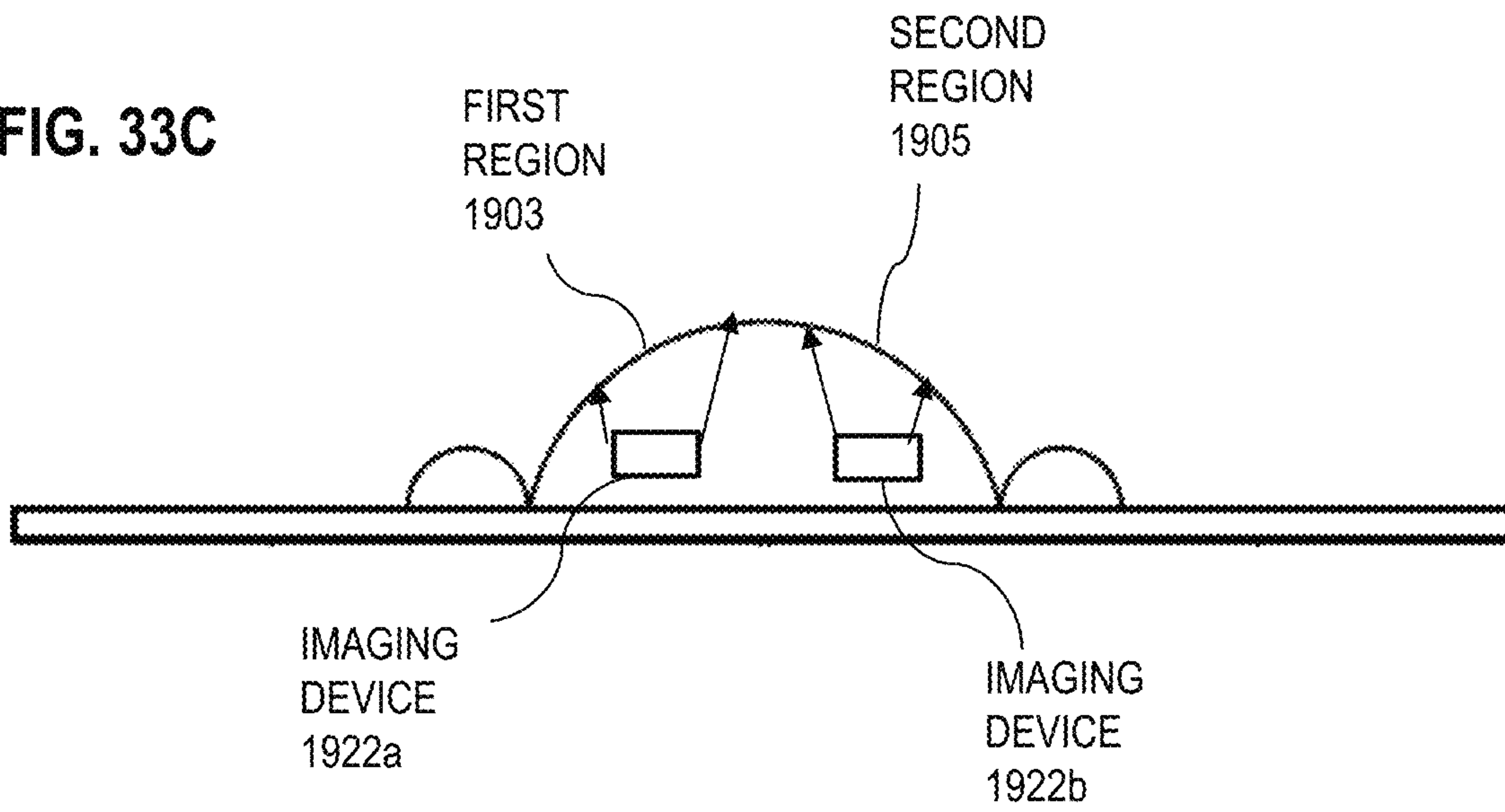


FIG. 34A

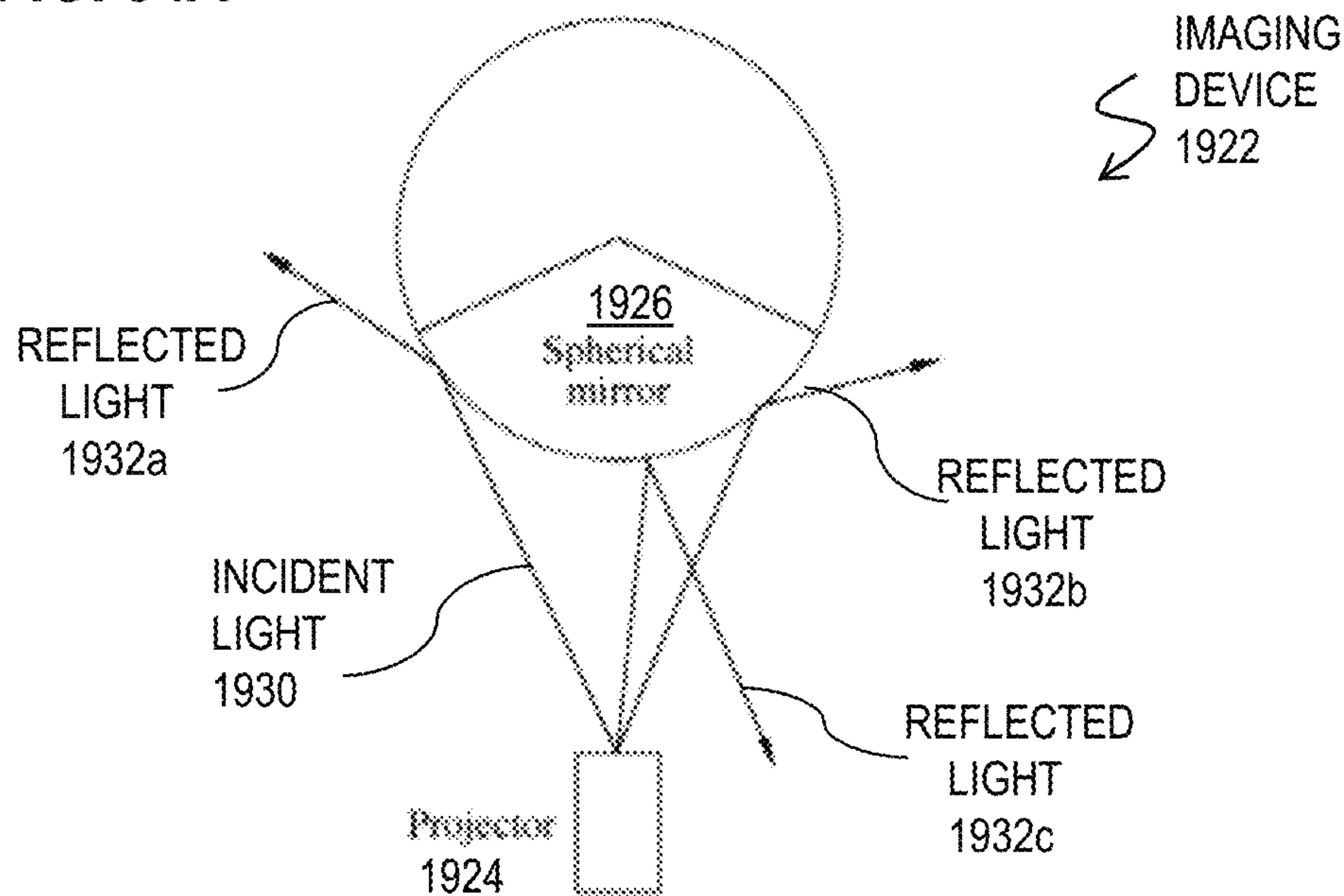


FIG. 34B

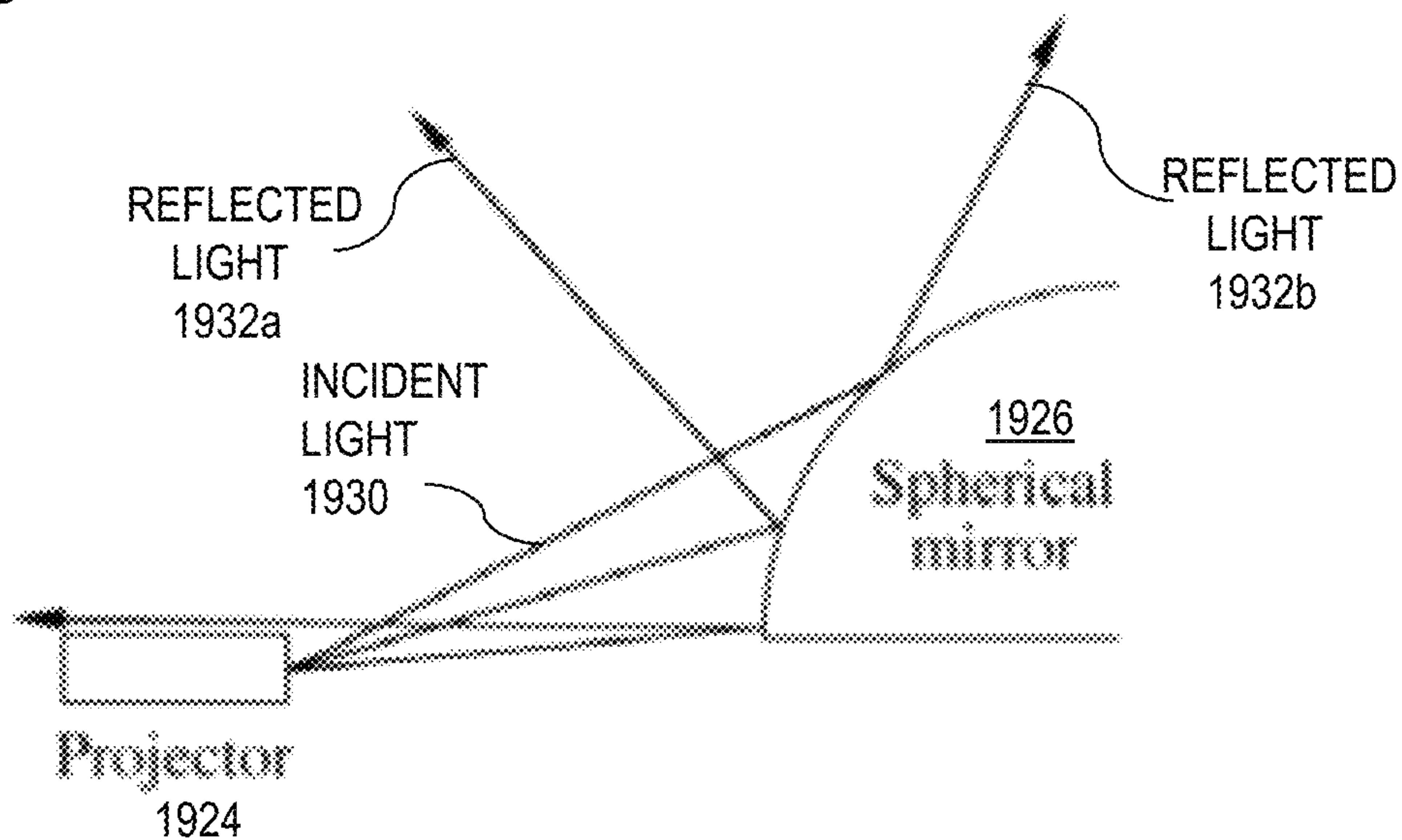


FIG. 34C

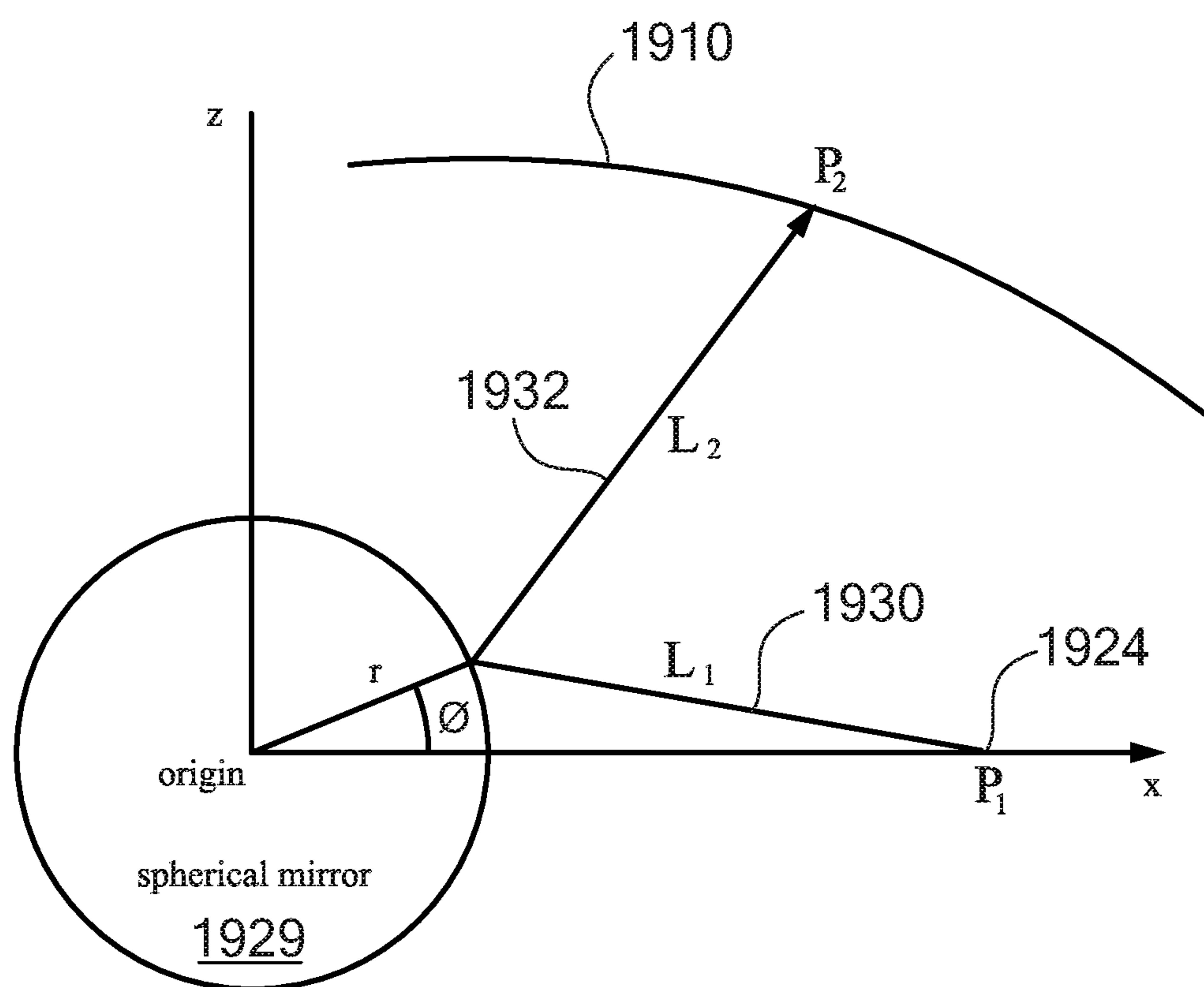


FIG. 34D

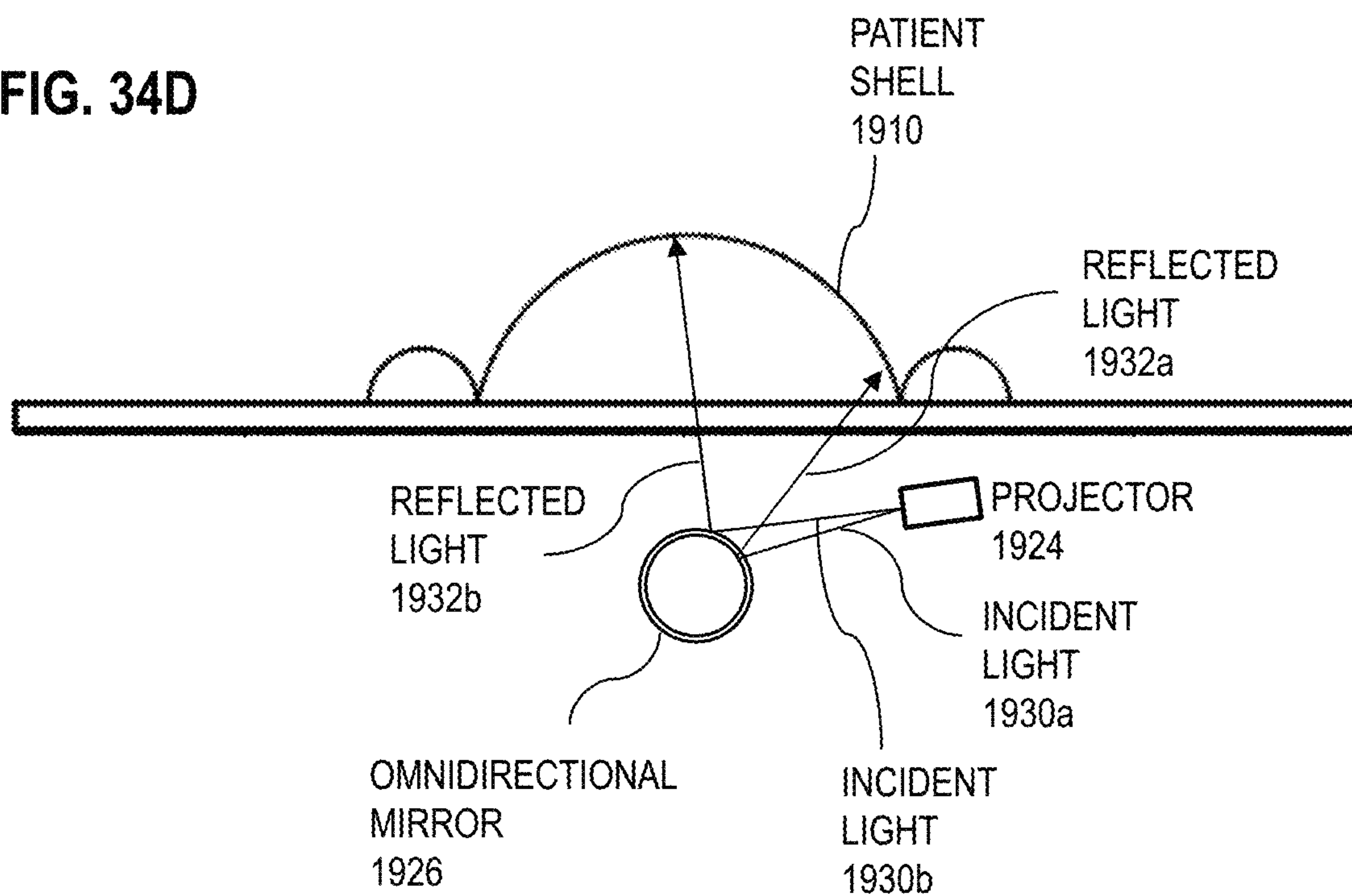


FIG. 34E

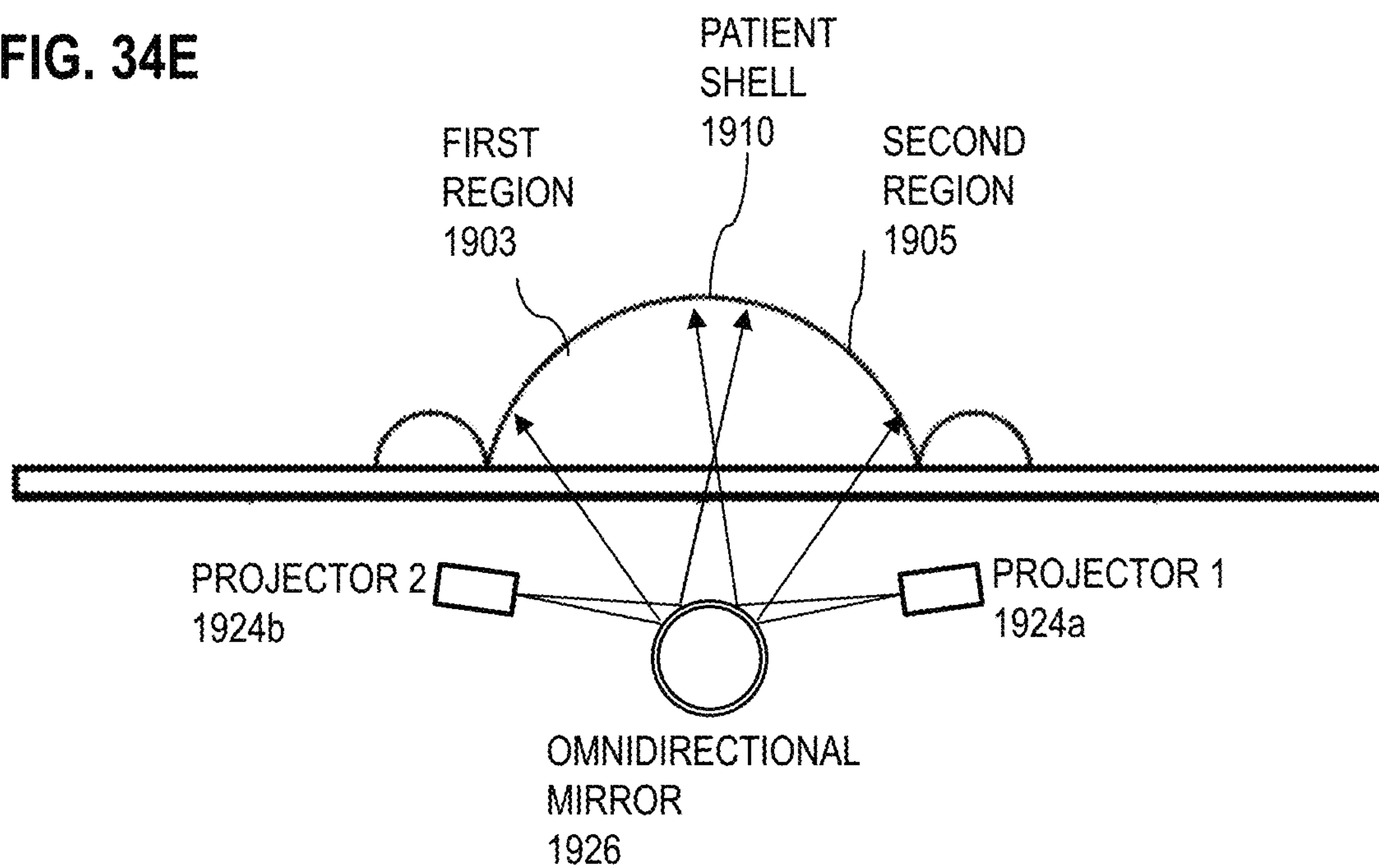


FIG. 34F

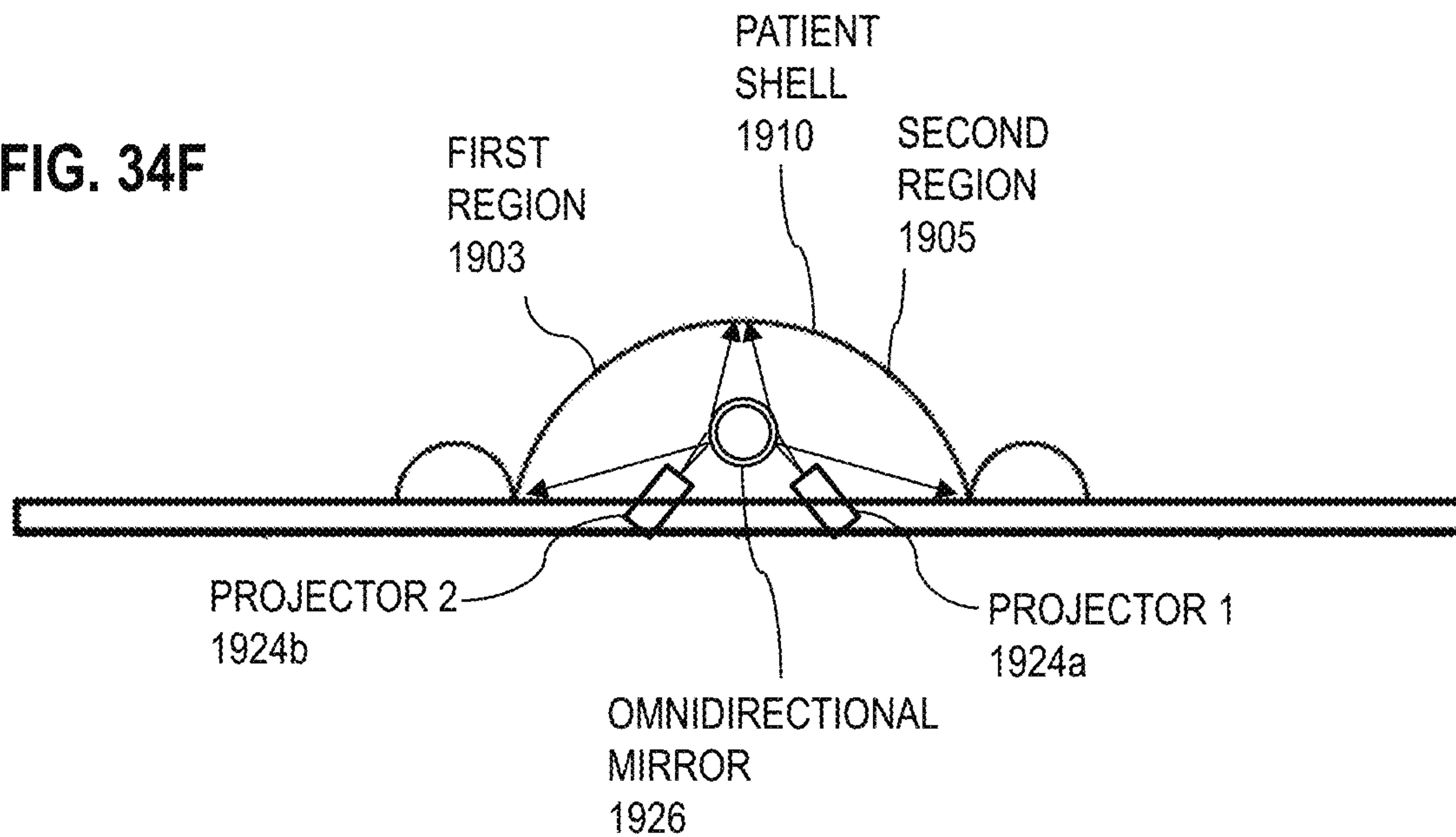


FIG. 34G

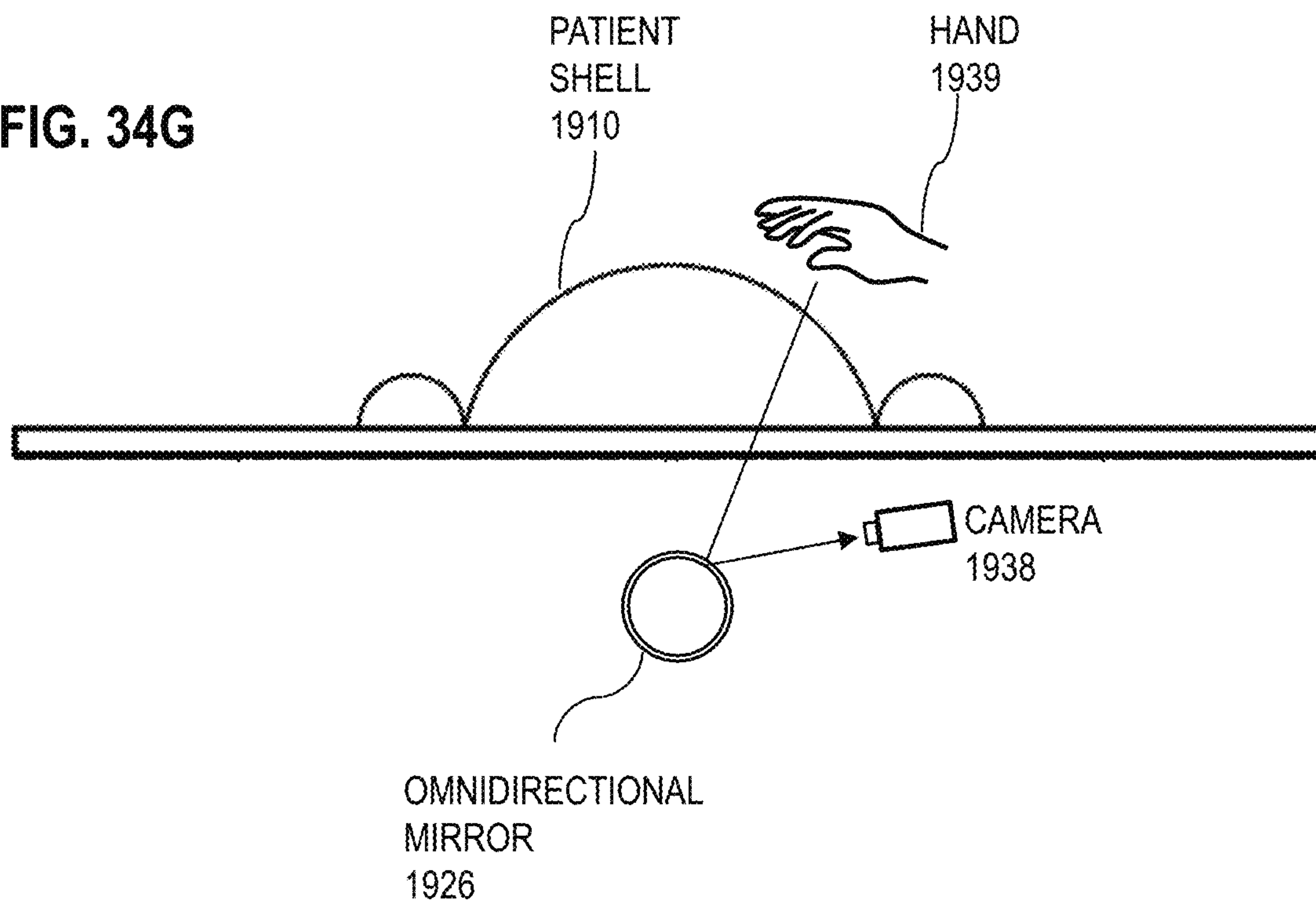


FIG. 34H

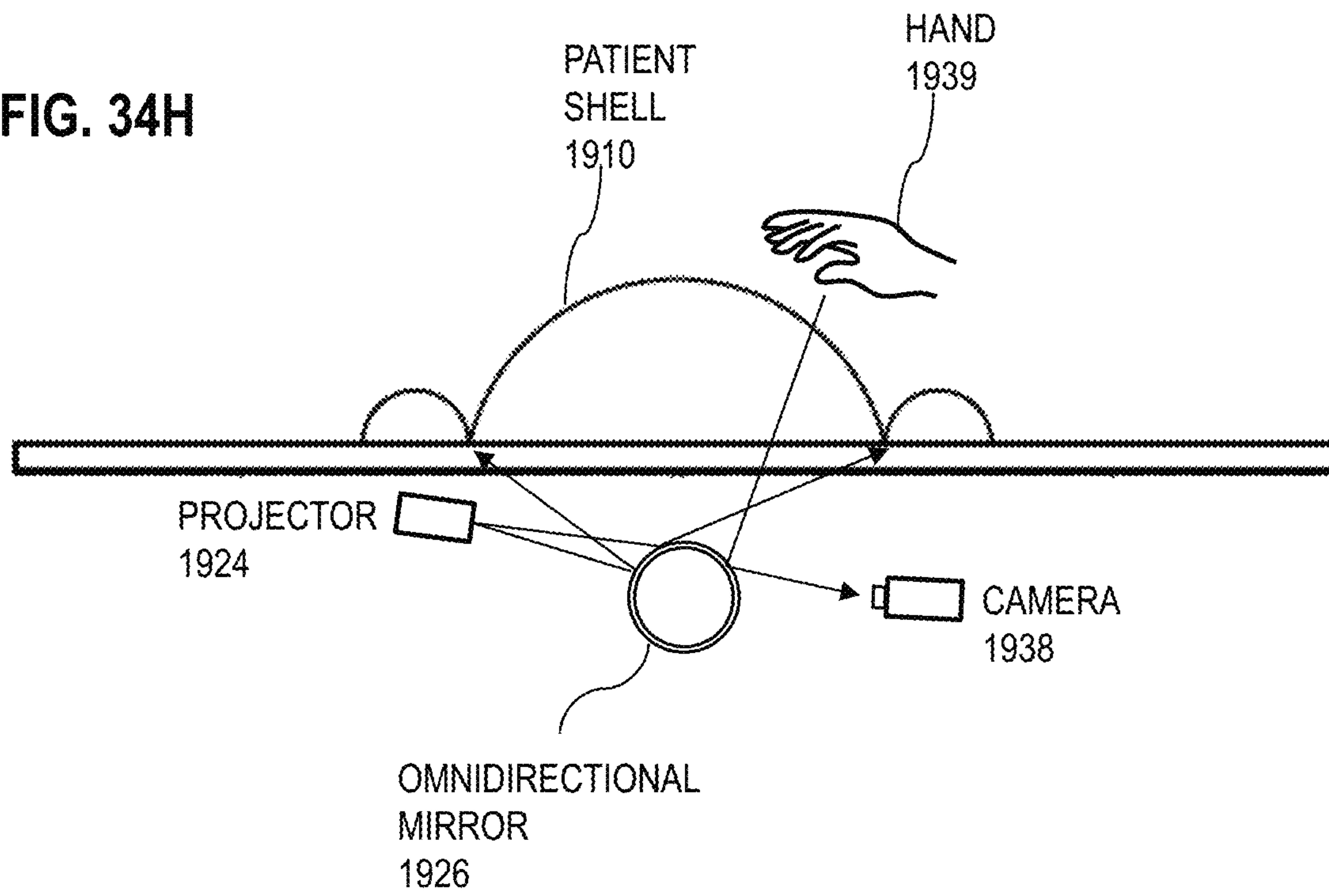
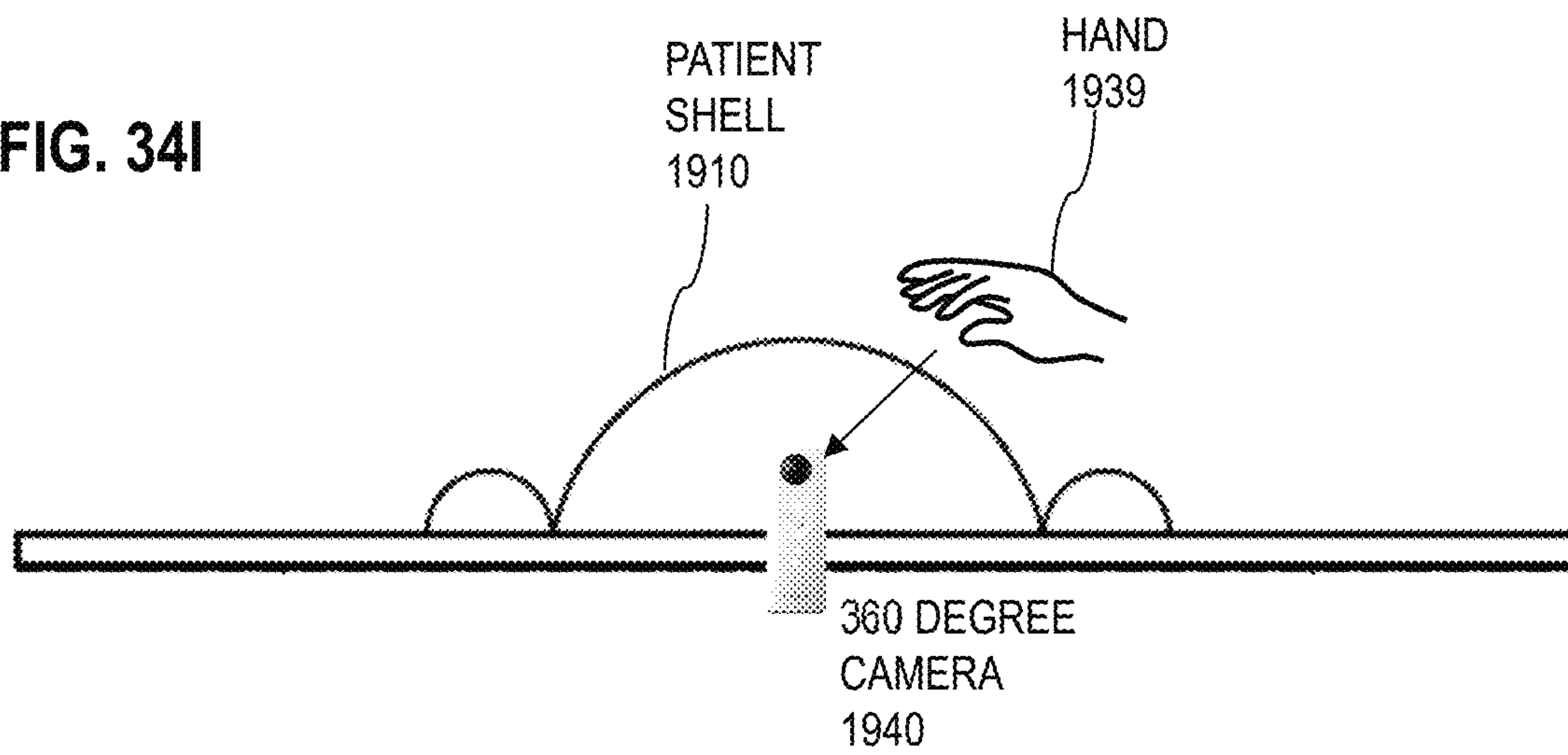
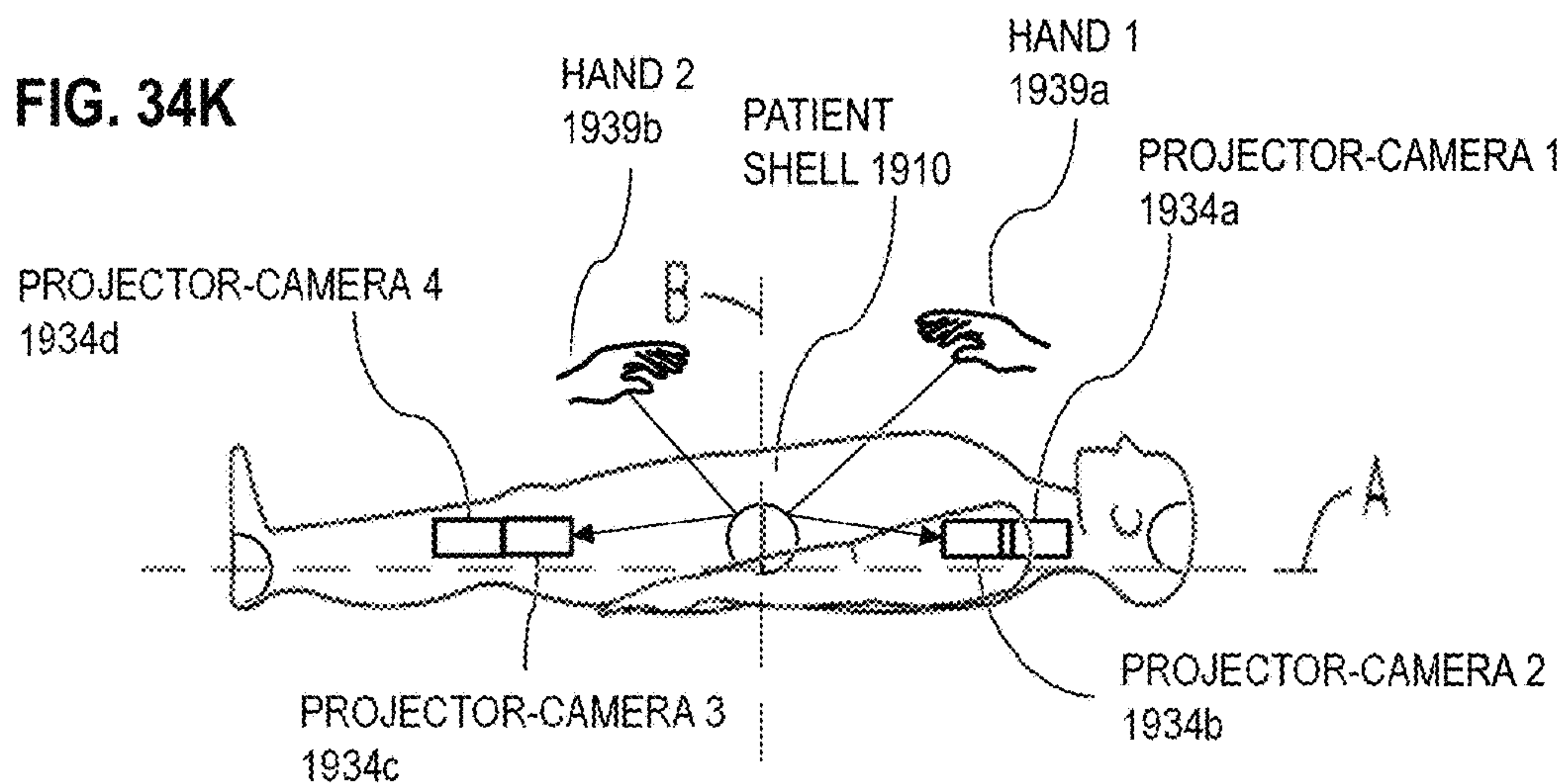
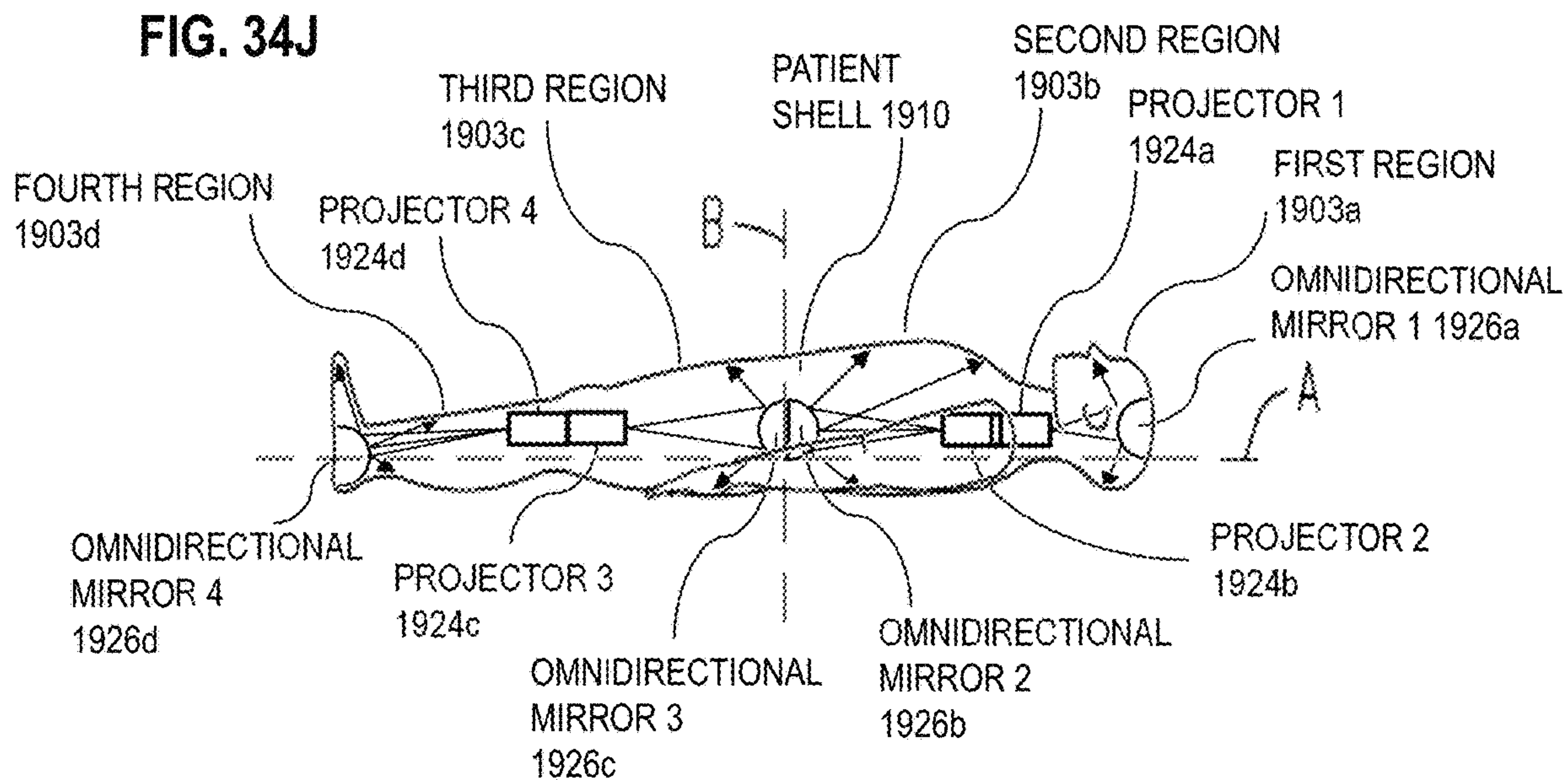


FIG. 34I





1

PHYSICAL-VIRTUAL PATIENT SYSTEM

FIELD OF THE INVENTION

This invention relates to a patient simulator system for healthcare training, and more specifically, to a realistic physical-virtual patient simulator system for healthcare training.

BACKGROUND OF THE INVENTION

There are presently a number of patient simulator systems for training healthcare personnel, including fully screen-based simulated systems and mannequin systems, including robotic Human Patient Simulators (HPS). In the screen-based systems, a computer-based virtual patient is displayed on a screen. The visual appearance could include 2D computer graphics, 3D graphics, stereo, or head-tracked imagery. However, there is typically no physical interaction with anything resembling a real physical patient. The mannequin-based simulators are typically computer controlled/robotic and can be programmed for a range of responses that simulate a variety of healthcare symptoms and problems. They are able to simulate physical symptoms that can be checked such as heart rate, blood pressure, and simulated breathing. The available simulators range from relatively simple and inexpensive mannequins (a.k.a. “manikins”) useful for basic “part task” training, such as that disclosed in U.S. Pat. No. 6,227,864. Other available patient simulator mannequins utilize complex computer-controlled systems to provide more realistic environments, as disclosed for example in U.S. Pat. No. 6,273,728. Unfortunately, the mannequin’s visual appearance and certain behaviors are often static and unrealistic—there is typically no ability to change such things as the skin color, the skin temperature, the patient race or gender, nor the patient shape/size. Most patient simulators also have no way of sensing the touch (location and force) of the healthcare provider; hence the simulated patient is unable to react to physical contact, neither physiologically nor emotionally.

More realistic mannequins and figures are often used in amusement and theme parks to entertain guests. These devices can use, for example, a film image projected on the face to animate its expression. One technique, known as the front projection technique, involves projecting the film image directly onto the outer surface of the figure’s face from a concealed source in front of the face. A second technique, shown in U.S. Pat. Nos. 5,221,937, and 6,467,908, and published Application No. US20120285978, for example, uses back projection that involves projecting the film image, usually by one or more reflectors, onto the back of the figure’s face from a remote film source to animate the facial expression of the figure. However, these animated figures do not provide the full functionality and interactivity needed in a healthcare training situation.

Hence, there is a need for patient simulators for healthcare training that combine both physical and virtual realities in systems that are not only customizable to a large number of scenarios but also realistic to provide complete physiological simulation necessary for proper training.

The present invention is designed to address these needs.

SUMMARY OF THE INVENTION

Broadly speaking, the invention comprises an improved system, method, and computer-readable media for a patient simulator for healthcare training that combines physical and

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virtual realities, hereinafter referred to generally as a Physical-Virtual Patient (PVP) system.

The invention can be implemented in numerous ways, including as a system, a device/apparatus, a method, or a computer readable medium. Several example embodiments of the invention are discussed below.

As a system, an embodiment of the invention includes a translucent or transparent patient shell. Such shells would typically be created from a smooth rigid or semi-rigid material that allows for the formation of projected imagery on the surface, where the shell is also formed to approximate or in some way represent the shape of a real human (or other type of patient, e.g., an animal). The shell may have a fully or partially open back side to allow for illumination from behind, or might be completely closeable such that internal projection can be affected on all of the surfaces. The shell may be secured to a rigid frame or other assembly to allow the frame to be interchangeably mounted to a bed or other fixed system. Alternatively, the frame and associated components may be made to be held and moved independently of any bed or other fixed system. The shell is illuminated from below or inside by one or more image projectors adapted to render dynamic patient imagery onto the underneath or inside of the shell so that the image appears on the surface of the shell in a realistic manner. Various well-known optical components and configurations can be used to, for example, “fold,” translate, scale, spread/compress, distort/un-distort the projected imagery. Flat and what can be called “omnidirectional” (e.g., cylindrical, spherical, hemispherical, and pyramidal mirror systems) are just some examples of components used to modify the path or shape of the projected imagery. Some of those same optical components or configurations might be simultaneously or independently used for optical sensing of touch, or other optical effects or needs, as well understood by a person of ordinary skill. A person of ordinary skill in the art would also understand that it is also possible to omit independent specialized optics, and to arrange two or more imaging devices (e.g., projectors or cameras) such that they achieve an “omnidirectional” effect, e.g., physical construction with lenses placed close to each other such that the frusta meet or overlap (typically a small amount). One or more computing units including memory and a processor unit communicate with the projectors and other interactive sensing and output devices to provide the interactive simulation. Interactive sensing and output devices include, but are not limited to, optical touch sensing devices, targeted temperature feedback devices, audio-based tactile devices for creating a sensation of pulse, human/object tracking, and spatial audio components with signal processing capabilities to both recognize real speech (input) and to create a sensation of audible vital signs (output). The system further includes interchangeable human shells and parts of human shells representing body parts capable of being secured to and used with the patient system without having to change out the expensive and sensitive optical, electrical, or other components that remain fixed in the frame/assembly of the patient system. This approach is beneficial for example when the frame/assembly of the patient system is incorporated into a bed, as the human shells could be removed or replaced without disturbing sensitive components mounted inside the bed (underneath the shells).

In a specific embodiment, a patient simulation system for healthcare training is provided, comprising: a shell of a physical anatomical model of at least a portion of a patient’s body (e.g., human or animal), the shell adapted to be illuminated from behind or from within the shell to provide

one or more dynamic images viewable on the outer surface of the shell; a bed system adapted to receive the shell via a mounting system, wherein the bed system—with or without a rigid frame/assembly, has one or more image units adapted to render the one or more dynamic images viewable on the outer surface of the shell; one or more interface devices located inside, underneath, or around the patient shell to receive input and provide output associated with the patient or people/devices near the patient; and one or more computing units in communication with the image units and interface devices, the computing units adapted to provide an interactive simulation for healthcare training.

Further refinements include wherein the shell is at least in part translucent or transparent for illumination from behind by the one or more image units; wherein the shell includes one or more interchangeable human-shaped shells and interchangeable parts of patient-shaped shells (e.g., human or animal) representing body parts, adapted to be secured via the mounting system to the rigid frame, assembly, or bed system; wherein an underneath surface of the shell consists of a rear projection “screen” material (e.g., a coating such as on a projection screen) to permit better visualization of the one or more dynamic images viewable on the outer surface of the shell; wherein the shell has one or more openings on a back side thereof to allow for unobstructed rendering of the one or more dynamic images by the one or more image units; wherein the shell is an upper longitudinal slice of a prone human figure having a partially or fully open back to allow for unobstructed rendering of the one or more dynamic images by the one or more image units; and wherein the shell has one or more additional separations or flexible portions to allow for movement of the shell on an articulating PVP system.

Aspects of the invention further include wherein the one or more image units render dynamic patient imagery from behind or inside the shell onto an underneath of the shell so that the one or more images viewable on the outer surface of the shell simulate viewable conditions including one or more of skin color, medical condition, and facial expressions.

The one or more interface devices may include one or more sensory devices, interactive devices, human/object tracking devices, and output devices, such as one or more optical touch sensing devices, targeted temperature feedback devices, audio-based tactile sense of pulse devices, and spatial audio components with signal processing to simulate vital signs.

In certain embodiments, the system includes an upper assembly adapted to resemble a standard hospital bed or gurney, and a lower frame or assembly adapted to house the one or more image units, interface devices, and computing units. In other embodiments, the system includes an internal assembly, surrounded by complete enclosed human-shaped shell, where the internal assembly is adapted to support the one or more image units, interface devices, and computing units, for example. The one or more image units include one or more projectors and one or more mirrors coupled to a support in the frame or assembly and arranged with proper alignment, registration, and focus, so that a projected image will properly project onto the underneath surface of the shell and show through on the outer surface of the shell. The plurality of projectors may span the portion of the system that will be occupied by the shell so that each of the plurality of projectors are positioned to cover a different portion of the shell.

As a method, an embodiment comprises implementing one or more patient simulations using the PVP system for healthcare training. The method of the present invention

may be implemented in conjunction with a computing device and as part of a computer program product with a non-transitory computer-readable medium having code thereon. The computing device may include at least one processor, a memory coupled to the processor, and a program residing in the memory which implements the methods of the present invention.

Aspects of the invention include a method for implementing one or more patient simulations using a patient simulation system having a shell comprising a physical anatomical model of at least a portion of a patient’s body and a frame or assembly (e.g., bed or full human) adapted to receive the shell, the method including: illuminating the shell from behind to provide one or more dynamic images viewable on the outer surface of the shell via one or more image units adapted to render the one or more dynamic images viewable on the outer surface of the shell; interfacing with one or more interface devices located about or within or near the patient shell to receive input and provide output as part of the simulation; and providing an interactive simulation for healthcare training via one or more computing units in wired or wireless communication with the image units and interface devices. In some embodiments, the frame or assembly is omitted and the method includes the illuminating step.

The advantages of the invention are numerous, including cost and visual realism. In terms of cost, because of the interchangeability of the shells with the expensive components remaining fixed in a rigid frame/assembly associated with the system, the system would be flexible in terms of patient’s physical characteristics, while remaining relatively inexpensive compared to an HPS. In addition, the system provides very realistic dynamic visual appearances, including “human” patients that can turn and look at you, appear pale or flush, appear to cry, smile, etc., to provide a more realistic experience. The system may be used for a range of civilian and military healthcare training, including physicians, nurses (including, for example, nurse practitioners), healthcare technicians, emergency healthcare technicians, paramedics, administrative staff, and even hospital volunteers. The conventional HPS does not change visual appearance in any way. It cannot change skin color per certain healthcare conditions, cannot simulate wounds graphically under computer control, cannot appear to change gender or race, cannot exhibit live facial expressions (e.g., smile, frown, or look frightened), and cannot move or give the appearance of moving body parts such as heads or limbs.

Accordingly, aspects of the present invention provide an advantage for simulation of a human patient in a way that supports changing appearance (e.g., race and various healthcare symptoms), alterable size (e.g., child or adult), some physiological signals, along with apparent or actual motion of body parts.

Other aspects and advantages of the invention will become apparent from the following detailed description taken in conjunction with the accompanying drawings, illustrating, by way of example, the principles of the invention.

All patents, patent applications, provisional applications, and publications referred to or cited herein, or from which a claim for benefit of priority has been made, are incorporated herein by reference in their entirety to the extent they are not inconsistent with the explicit teachings of this specification.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the manner in which the above-recited and other advantages and objects of the invention are obtained,

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a more particular description of the invention briefly described above will be rendered by reference to specific embodiments thereof, which are illustrated in the appended drawings. Understanding that these drawings depict only typical embodiments of the invention and are not therefore to be considered to be limiting of its scope, the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIG. 1 is a block diagram of an embodiment of the invention.

FIG. 2 is an illustration of a shell of an embodiment of the invention.

FIG. 3 is an illustration of a bed system of an embodiment of the invention.

FIG. 4 shows a top-view sample layout of the placement of the projectors of the imaging system of an embodiment of the invention.

FIG. 5 shows an illustration of example torso dimensions.

FIG. 6 shows a first design example for Torso Projection having a Single Mirror Path Folding.

FIG. 7 shows a second design example for Torso Projection having a Dual Mirror Path Folding.

FIG. 8 shows a third design example for Torso Projection having a Single Mirror Crossfire Configuration.

FIG. 9 shows a first design example for Legs Projection having Single Mirror Path Folding.

FIG. 10 shows a second design example for Legs Projection having Dual Mirror Path Folding.

FIG. 11 shows a diagram of a hybrid system embodiment that includes a Physical Virtual (PV) human body shell onto which images may be projected that also has a replica arm that is suitable for practicing injections or blood removal.

FIG. 12 shows a patient simulator mannequin embodiment that has been modified to replace the head portion with a PV head shell component onto which images can be projected.

FIG. 13 shows a design example for an optical touch sensing device employing a mirror to achieve a folded optical path.

FIG. 14 shows a design example for an optical touch sensing device with a direct (not folded) optical path.

FIG. 15A is an image that illustrates an example of side view of a deformable shell, according to one embodiment;

FIG. 15B is a cross-sectional view of the outer surface of the deformable shell of FIG. 15A across multiple regions of the patient body, according to one embodiment;

FIGS. 16A-16B are images that illustrate an example of a reconfigurable or alternate configuration part (e.g., prone or seated) with identifying indicia, according to an embodiment;

FIG. 17 is an image that illustrates an example of a shell of a non-human patient, according to an embodiment;

FIG. 18A is an image that illustrates an example of an actively-illuminated finger of the shell of FIG. 5 positioned in an interactive device to measure a physiological parameter, according to an embodiment;

FIG. 18B is an image that illustrates an example of a conventional orifice in an ear of a human patient;

FIG. 19A is an image that illustrates an example of a mobile compact unit that houses the system of FIG. 3, according to an embodiment;

FIG. 19B is an example that illustrates an example of a mobile bed system assembled from the mobile compact unit of FIG. 19A, according to an embodiment;

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FIG. 20 is an image that illustrates an example of a bed system with a plurality of shock actuators to mount the bed system to a surface, according to an embodiment;

FIG. 21A is an image that illustrates an example of the shell of FIG. 2 with one or more dynamic images including a human venous system, according to an embodiment;

FIG. 21B is an image that illustrates an example of the shell of FIG. 2 with one or more dynamic images including a human skeletal system, according to an embodiment;

FIG. 22 is an image that illustrates an example of the system of FIG. 3 with a front projection device and a head mounted display worn by a user to view the dynamic images, according to an embodiment;

FIG. 23 is an image that illustrates an example of a ray diagram from an optical source to left and right eyes of a user through a parallax barrier to provide an autostereoscopic display, according to an embodiment;

FIG. 24 is an image that illustrates an example of microcapsules within the outer surface of the shell of FIG. 2 to change a reflective property of the shell, according to an embodiment;

FIG. 25 is an image that illustrates an example of a simulated layer of skin over the outer surface of the shell in FIG. 2, according to an embodiment;

FIG. 26 is an image that illustrates an example of a plurality of openings defined by the outer surface of the shell and a fluid reservoir communicatively coupled to the openings, according to an embodiment;

FIG. 27 is an image that illustrates an example of a plurality of touch sensing devices embedded in the outer surface of the shell in FIG. 2, according to an embodiment;

FIG. 28A is an image that illustrates an example of a healthcare provider with a stethoscope and a tracking device mounted to the stethoscope, according to an embodiment;

FIG. 28B is an image that illustrates an example of the bed system of FIG. 3 with a wireless transceiver communicatively coupled to the tracking device of FIG. 28A and audio sources in the shell, according to an embodiment;

FIG. 29 is a flow diagram that illustrates an example of a method for displaying dynamic images on the shell of FIG. 1, according to an embodiment;

FIG. 30 is a block diagram that illustrates a computer system upon which an embodiment of the invention may be implemented;

FIG. 31 is a block diagram that illustrates a chip set upon which an embodiment of the invention may be implemented;

FIG. 32 is a block diagram that illustrates a mobile device upon which an embodiment of the invention may be implemented.

FIG. 33A is a block diagram of one example of a system including a shell with imaging devices enclosed by the shell, according to an embodiment;

FIG. 33B is a schematic diagram that illustrates an example of a cross-sectional side view of a plurality of imaging devices enclosed by the shell of FIG. 33A, according to an embodiment;

FIG. 33C is a schematic diagram that illustrates an example of a cross-sectional end view of a plurality of imaging devices enclosed by the shell of FIG. 33A, according to an embodiment;

FIG. 34A is a schematic diagram that illustrates an example of a top view of an imaging device of FIG. 33B within the shell, according to an embodiment;

FIG. 34B is a schematic diagram that illustrates an example of a side view of an imaging device of FIG. 33B within the shell, according to an embodiment; and

FIG. 34C is a schematic diagram that illustrates an example of a ray diagram of the imaging device of FIGS. 34A-34B projecting light onto the inner surface of the shell, according to an embodiment;

FIG. 34D is a schematic diagram that illustrates an example of a cross-sectional end view of a plurality of omnidirectional imaging devices of the system of FIG. 3, according to an embodiment;

FIG. 34E is a schematic diagram that illustrates an example of a cross-sectional end view of a plurality of omnidirectional imaging devices of the system of FIG. 3, according to an embodiment;

FIG. 34F is a schematic diagram that illustrates an example of a cross-sectional end view of a plurality of omnidirectional imaging devices of the system of FIG. 33A, according to an embodiment;

FIG. 34G is a schematic diagram that illustrates an example of a cross-sectional end view of a plurality of omnidirectional interactive devices of the system of FIG. 3, according to an embodiment;

FIG. 34H is a schematic diagram that illustrates an example of a cross-sectional end view of a plurality of omnidirectional interactive devices of the system of FIG. 3, according to an embodiment;

FIG. 34I is a schematic diagram that illustrates an example of a cross-sectional end view of a plurality of omnidirectional interactive devices of the system of FIG. 33A, according to an embodiment;

FIG. 34J is a schematic diagram that illustrates an example of a cross-sectional side view of a plurality of omnidirectional imaging devices contained within the shell of the system of FIG. 33A and FIG. 34F, according to an embodiment; and

FIG. 34K is a schematic diagram that illustrates an example of a cross-sectional side view of a plurality of omnidirectional imaging devices contained within the shell of the system of FIGS. 33A and 34J, according to an embodiment.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings, the preferred embodiment of the present invention will be described.

Notwithstanding that the numerical ranges and parameters setting forth the broad scope are embodiment-specific approximations, the numerical values set forth in specific non-limiting examples are reported as precisely as possible. Any numerical value, however, inherently contains certain errors necessarily resulting from the standard deviation found in their respective testing measurements at the time of this writing. Furthermore, unless otherwise clear from the context, a numerical value presented herein has an implied precision given by the least significant digit. Thus, a value 1.1 implies a value from 1.05 to 1.15. The term “about” is used to indicate a broader range centered on the given value, and unless otherwise clear from the context implies a broader range around the least significant digit, such as “about 1.1” implies a range from 1.0 to 1.2. If the least significant digit is unclear, then the term “about” implies a factor of two, e.g., “about X” implies a value in the range from 0.5X to 2X, for example, about 100 implies a value in a range from 50 to 200. Moreover, all ranges disclosed herein are to be understood to encompass any and all sub-ranges subsumed therein. For example, a range of “less than 10” for a positive only parameter can include any and all sub-ranges between (and including) the minimum value

of zero and the maximum value of 10, that is, any and all sub-ranges having a minimum value of equal to or greater than zero and a maximum value of equal to or less than 10, e.g., 1 to 4. Finally, a person of ordinary skill would understand that different embodiments will correspond to different numerical analyses with different numerical results, all subject to at least the caveats listed above.

FIG. 1 shows a block diagram of a patient simulator 5 for healthcare training hereinafter referred to as the Physical-Virtual Patient (PVP) system. The PVP system 5 includes a translucent or transparent patient shell 10 secured to a housing 12. The shell 10 is illuminated from below by one or more image projectors 20 in the housing 12 adapted to render dynamic patient imagery onto the underneath of the shell 10 so that the image appears on the surface of the shell 10 in a realistic manner. One or more computing units 16 including memory and a processor unit communicate with the projectors 20 and other sensory devices 22 and interactive devices 24 to provide the interactive simulation. In some embodiments, the computing unit 16 includes a module 17 that includes one or more instructions for the computing unit 16 to perform one or more operations discussed herein and/or one or more steps of a method 1500 depicted in the flowchart of FIG. 29. In some embodiments, the computing unit 16 is a computer system 1600 as discussed below with respect to FIG. 30 and/or a chip set 1700 as discussed below with respect to FIG. 31 and/or a mobile device 1800 as discussed below with respect to FIG. 32.

Sensory devices 22 and interactive devices 24 include, but are not limited to, optical touch sensing devices, targeted temperature feedback devices, audio-based tactile sense of pulse devices, and spatial audio components with signal processing device to simulate vital signs. The PVP system 5 further includes interchangeable human shells 10 and parts of human shells representing body parts capable of being secured via a mounting device 14 to the housing 12 without having to change out the expensive and sensitive components (20, 22, 24) that remain fixed in the housing 12.

The patient simulator 5 combines physical (e.g., patient shell) and virtual (e.g., imaging, sensory) realities. In some embodiments, the PVP system 5 the housing 12 may take the form of a real (or realistic) hospital bed, modified to include a prone human-shaped mannequin in the form of a shell 10, such as a vacuform (vacuum formed material) patient “shell” that is illuminated from below by one or more image projectors 20 (e.g. digital projectors) that render dynamic patient imagery onto the rear (underneath) of the shell 10. The effect is that nearby humans (e.g., nurses in training, students) can see a dynamic physical-virtual “patient” lying in bed, where the imaging system provides for the patient to exhibit lifelike facial expressions (while talking, etc.), lifelike skin color (e.g., to convey race or symptoms), realistic wounds, etc. FIG. 25 is an image that illustrates an example of a simulated layer of skin 1104 over the outer surface 1102 of the shell 1100 in FIG. 2, according to one embodiment. In some embodiments, the simulated layer of skin 1104 and the outer surface 1102 of the shell collectively display the dynamic images from the image units 20. This might be the case, for example, in embodiments that use projected imagery, and both the outer surface and the simulated skin are semi-translucent/opaque. In another embodiment the outer surface of the shell might emitting light (imagery) such as from a deformable display technology, and the simulated skin would be transparent. In other embodiments, the simulated layer of skin 1104 displays the dynamic images from the image units 20 separate from the outer surface 1102 of the shell 1100 (e.g. the skin layer 1104 is placed in a region

corresponding to an opening in the shell **1100**, or the shell **1100** is totally transparent (not semi-transparent). In still other embodiments, the sensor devices **22** (e.g. touch sensing devices, temperature sensing devices, etc.) are operatively coupled to the simulated layer of skin **1104**. In still other embodiments, the simulated layer of skin **1104** has one or more of a temperature, texture and softness corresponding to a respective temperature, texture and softness of real skin (e.g. the simulated layer of skin **1104** is constantly heated and temperature is held fixed at human body temperature, etc.). In further embodiments, the simulated layer of skin **1104** defines one or more openings **1105** that simulate a wound. In an example embodiment, during the interactive simulated for medical training, the user of the system **5** is instructed to repair the wound opening **1105** (e.g. using a suture, etc.). In some embodiments, the computing unit **16** transmits a signal to an interactive device **24** (e.g. audio device) to audibly instruct the user, such as a guide, to repair the wound opening **1105** with certain medical equipment that is provided and/or may provide verbal instructions and/or feedback.

Projectors **20**, when mounted as a rear projection system, allow for materials such as blankets, clothing-like coverings, and various healthcare components or devices to be placed over the physical-virtual patient in the bed **12** and to not interfere with the projected images. The same would be true for the use of emissive deformable displays.

To add to the interactivity and enhance healthcare training simulation, further embodiments of the PVP system also include touch sensing (e.g., from hands or medical devices) via a sensor system **22** for the “skin” (e.g., via various optical approaches), and skin temperature control (e.g., via temperature-controlled air streams directed to the underside of the shell) via interactive devices **24**. Further interactive devices **24**, such as audio or other active sources (e.g., via speakers under the bed, pointing up toward the shell) may be used to add audible or tactile signals such as a heartbeat or pulse. FIG. **27** is an image that illustrates an example of a plurality of touch sensing devices **1302** embedded in the outer surface of the shell **10** in FIG. **2**, according to an embodiment. In an embodiment, the interface devices include the sensory devices **22** such as the touch sensing devices **1302**. In one embodiment, the touch sensing devices **1302** generate one or more first signals upon receiving input from an environment of the system (e.g. when a user touches the outer surface of the shell **10** adjacent to the touch sensing device **1302**). In this embodiment, the computing unit **16** receives the one or more first signals from the touch sensing devices **1302** and subsequently transmits one or more second signals to the image units **20**, where the second signal is based on the received one or more first signals. In one example embodiment, the image units **20** are configured to vary the one or more dynamic images viewable on the shell **10** based on the one or more second signals received from the computing unit **16**. In some embodiments, the image units **20** are configured to vary the one or more dynamic images on the shell **10** such that a part of the patient’s body (e.g. a virtual part based on a dynamic image) moves from a first position to a second position. In an example embodiment, the part of the patient’s body is the eyes and the image units **20** cause the eyes to move from a first direction **1304** (FIG. **27**) to a second direction **1306** (e.g. in a direction of the location where the touch occurred). In yet another example embodiment, the part of the patient’s body is the mouth and the image units **20** cause the mouth to move from a first position (e.g. closed, open) to a second position (e.g. open, closed), etc. In yet another example embodiment, the

part of the patient’s body is a physical part of the body (e.g. not a virtual part based on a dynamic image from the image unit **20**) and the control unit **16** is configured to transmit the one or more second signal to an interactive device **24** (e.g. motor) to cause the part of the patient’s body to move from a first position to a second position (e.g. a tongue in a mouth from a first position inside the mouth to a second position outside the mouth; a joint of the body to move from a first position to a second position, such as an arm to move from a first position to a second position or a leg to kick outward when a user taps the knee, etc.). In such an embodiment the projectors or displays in general could be adapted to move with the moving body part, or the system could track the changing relationship between the projector/display and the moving body part and render the imagery in a “pre-distorted” way that appears correct.

In still other embodiments, an audio output device **1308** (FIG. **27**) such as an audio speaker is configured to receive the second signal from the computing unit **16** and is configured to transmit an audio sound (e.g. pain shriek, laugh, cry, etc.) based on the received second signal from the computing unit **16**. In an example embodiment, the transmitted audio sound is based on the second signal from the computing unit **16** and the second signal is based on a value of a measured parameter (e.g. pressure) and/or a location of a measured parameter (e.g. weighted more for sensitive areas). In some embodiments, a user can input a desired trainee skill level (e.g. using an input device **1612** in FIG. **30**, such as a keyboard, mouse, etc.) where the desired skill level is based on a number of the patient’s body parts that are responsive to the touching sensing devices **1302**. In still other embodiments, touch sensing devices **1302** can be provided to detect other visual responses (e.g. capillary refill, tug lips, tug eyelids, pupil dilations), and non-touch sensing devices can be used to similarly detect physiology responses (e.g. change of heart rate, pulse, breathing).

The interactive devices **24**, such as targeted temperature feedback devices, audio-based tactile sense of pulse devices, and spatial audio components with signal processing device may be provided to simulate vital signs. In some embodiments, the shell defines a plurality of slots which separate a plurality of joints in the patient’s body (e.g. slots that define a plurality of fingers in FIG. **5** and similarly define a plurality of toes). In one embodiment, the interactive devices **24** include a sensor (e.g. pulse oximeter, blood pressure cuff, etc.) to measure a value of a physiological parameter (e.g. pulse, oxygen level, heart rate, blood pressure, etc.) and the joints are configured to operatively connect with the sensor. In some embodiments, the joints do not transmit a signal that is measurable by the sensor. In other embodiments, the joints do transmit a signal that is measurable by the sensor. FIG. **18A** is an image that illustrates an example of a finger **502** of the shell of FIG. **5** positioned in a sensor (e.g. pulse oximeter **500**) to measure a physiological parameter, according to an embodiment. As appreciated by one skilled in the art, the pulse oximeter **500** includes a pair of red and IR LEDs **504** that transmit radiation and a photodiode **506** to detect an intensity of the radiation transmitted through a finger to measure the pulse and oxygen level in the blood. In this embodiment, the finger **502** includes an internal photodiode/LED **503** which collectively detect and transmit radiation to the photodiode **506** with the appropriate intensity and direction so that the pulse oximeter **500** registers a pulse and oxygen level of a desired value (e.g. normal range). In some embodiments, the internal photodiode/LED **503** transmit radiation so that the pulse oximeter **500** registers an abnormal pulse and/or oxygen level, for purposes of medical

training. In other embodiments, other parts of the shell (e.g. arm) can be provided with similar internal components to transmit a signal to a measuring sensor (e.g. blood pressure cuff) to register values of physiological parameters that are within or not within normal range, for example. For example, U.S. Pat. No. 3,868,844A to Klein teaches a dynamic arterial blood pressure simulator comprising a pressure chamber, a flexible member in the wall of the chamber, a cam having a shape proportionate to at least one hypothetical arterial blood pressure cycle, and means for driving the cam to displace the flexible member producing a variable pressure within the chamber. In an example embodiment, the internal components to stimulate the blood pressure signal include a pneumatic air-based system or a servo based mechanical deformation.

In another embodiment, the shell **10** defines at least one orifice that receives a virtual overlay representing a natural membrane (e.g. ear drum) and/or attach equipment within the at least one orifice in the interactive simulation. FIG. **18B** is an image that illustrates an example of a conventional orifice (ear canal **554**) in an ear **550** of a human patient. In some embodiments, the shell **10** includes an orifice corresponding to the ear canal **554** and a virtual overlay corresponding to the natural ear drum **556**. In an example embodiment, the material used to simulate the ear drum includes transparent opaque material such as Ear Model Soft Silicone provided by Soundlink® (Model number 8541766604). In another example embodiment, U.S. Publication Number 20180315348A1 discloses material that can be used to simulate the ear drum and is incorporated by reference herein. In another example embodiment, the size of the material used to simulate the ear drum would mimic that of a human eardrum which would vary on the size of the patient. In another example embodiment, the size of the material used to simulate the human eardrum would be used in simulated training for assessment and diagnosis of disease processes related to the ear (e.g. otitis media, etc.)

The targeted temperature feedback over the surface of the body provides numerous advantages. The temperature-controlled forced air in select areas of a rear-projection surface, e.g., a human body, uniquely conveys temperature information to users. From a healthcare standpoint (as an example) skin temperature, when combined with visual appearance and behavior, can be an important symptom of shock or fever. The audio-based tactile sense of pulse uniquely uses multiple surface-mounted acoustic emitters (speakers or similar transducers) and associated signal processing to provide a tactile sense of movement at a “phantom” location (a location other than the emitters). This method may be used to simulate the feeling of a pulse in the wrist or neck, for example, without the need for transducers mounted at the exact point of the tactile sense. The separately-mounted spatial audio components and signal processing are uniquely used to provide a sense of a sound emanating from “within” a rear-projection surface, when sensed on the surface. This feature may be used, for example, to simulate a heartbeat and breathing emanating from within the body, heard through a stethoscope placed on the surface of the body (the rear-projection human form/shell). The technique may be used to simulate anomalies such as labored breathing, pneumonia, or heart anomalies (e.g., a valve prolapse).

FIG. **28A** is an image that illustrates an example of a healthcare provider **1400** with a stethoscope **1402** and a tracking device **1404** mounted to the stethoscope, according to an embodiment. FIG. **28B** is an image that illustrates an example of the bed system **12** of FIG. **3** with a wireless transceiver **1410** communicatively coupled to the tracking

device **1404** of FIG. **28A** and audio sources **1406**, **1408** in the shell, according to an embodiment. In these embodiments, the interactive devices **24** of the system **5** include the tracking device **1404** and/or the wireless transceiver **1410** and/or the audio sources **1406**, **1408**. In an embodiment, the wireless transceiver **1410** is communicatively coupled to the tracking device **1404** to receive a first signal indicating a location of the stethoscope (e.g. diaphragm **1404**) and further communicatively coupled to the one or more audio sources **1406**, **1408** to transmit a second signal to a respective audio source **1406**, **1408** to cause the respective audio source to transmit an audio signal. In an example embodiment, the audio signal is configured to be detected by the medical equipment (e.g. stethoscope **1402**) and indicate a normal or abnormal condition in the patient’s body. In an example embodiment, the audio source **1406** positioned at the first location (e.g. abdomen) is configured to transmit an audio signal when the stethoscope **1404** is positioned at the first location (e.g. placed on the abdomen) and/or the audio source **108** positioned at the second location (e.g. chest) is configured to transmit an audio signal when the stethoscope is positioned at the second location (e.g. placed on the chest). In still other embodiments, multiple audio sources may be positioned in the same area (e.g. multiple audio sources for multiple regions of the chest or abdomen, etc.). In still other embodiments the audio signal transmitted by the audio source **1406** is different than the audio source **1408** (e.g. configured to simulate audio sounds of abdomen (bowel, stomach) and chest, respectively, detected by the stethoscope). Although the stethoscope is discussed in this embodiment, in other embodiments other medical equipment may be used (e.g. pulse oximeter, blood pressure cuff, etc.) and non-audio signals may be transmitted to non-audio sources (e.g. IR sources, haptic sources, etc.) so that the medical equipment detect the signal from the source as within or not within normal range (e.g. depending on the training parameters).

The shell **10** may be comprised of variations of shapes of humans, or non-human shapes, to accommodate “synthetic animatronics”—the use of computer graphics to convey the appearance of multiple and/or changing postures such as head (e.g., turning the head), or limbs (e.g., rotating the hand/arm). Because the image projectors **20** are located in the bed system **12** underneath the shell **10**, a variety of shells **10** may be provided to allow for a wide range of patient simulators **5** without the increased cost and complexity of having imaging projectors **20** and electronics (e.g., sensor system **22**, interactive devices **24**, CPU **16**) in each simulator. To that end, a variety of such patient shells **10** may be substituted/exchanged on the bed system **12**, to allow, for example, different sized humans (e.g., thin or heavy, adult or child) or missing limbs (e.g., from an accident or amputation). This substitution may be accomplished, for example, by mounting via a suitable mounting device **14** the patient shells **10** in uniformly sized rigid frames that can be locked into place in the bed **12**. Other suitable mounting devices **14** are also contemplated herein, such as brackets, fasteners, coupling members that allow for securely mounting and interchanging the patient shells **10**. The rear-projection human form uniquely employs interchangeable human bodies and body parts. This feature will accommodate different genders, ages, and healthcare conditions. Examples include a child (small body), an obese person, and an amputee. Among other advantages, this approach offers a lightweight and simple (no attached electronics) approach to rapidly changing the simulated physical-virtual patient. The human shell forms themselves can be relatively inexpensive and

robust. The expensive and sensitive components remain fixed under the bed system. FIG. 17 is an image that illustrates an example of a shell 400 of a non-human patient (e.g. dog) used with the bed system of FIG. 3, according to an embodiment. In some embodiments, the shell 400 comprises the physical anatomical model of a portion of a non-human patient's body (e.g. body of an animal), the shell adapted to be illuminated to provide one or more dynamic images on the outer surface of the shell. In an example embodiment, the non-human patient is an animal and the computing unit 16 is adapted to provide the interactive simulation for veterinary training (e.g. transmits one or more signals to the image units 20 to project dynamic images corresponding to the anatomy of the animals, where the dynamic images are sized so to project over an area corresponding to the size of the animal's body, etc.).

Other combinations/variations of imaging systems and techniques, used in lieu of or in addition to the imaging system 20 include the use of Shader Lamps—front (top) projection onto a static mannequin, the use of flexible displays (e.g., OLED), and the like, especially in retrofit situations. For example, front/top projection onto a robotic Human Patient Simulator (HPS) would add to the complete physiological simulation afforded by typical HPS units. Other retrofit techniques may be used to support synthetic animatronics, skin temperature changes, or touch sensing. FIG. 22 is an image that illustrates an example of the bed system of FIG. 3 with a front projection device 902 (projecting downward) and a head mounted display 906 worn by a user 904 to view the dynamic images, according to an embodiment. In an embodiment, the image units 20 include at least one front projection device 902 that is mounted above the shell 10 and is configured to render the one or more dynamic images viewable on the shell from above downward onto the shell. In another embodiment, the head mounted display 906 is communicatively coupled to the one or more computing units 16 and/or the image units 20 and/or the interface devices so that the head mounted display 906 is configured to display one or more of the shell 10 and the one or more dynamic images viewable on the shell. In an embodiment, the head mounted display 906 is an augmented reality (AR) headset which projects one or more virtual dynamic images on the real outer surface of the shell 10 in a frame of reference viewable by the user 904 through the head mounted display 906. In an example embodiment, the AR headset 906 projects some of the dynamic images (e.g. organs 803 in FIG. 21A) onto the outer surface of the shell 10 and the image units 20 in the lower assembly 12a project other dynamic images (e.g. venous system 802 in FIG. 21A) onto the outer surface of the shell 10. In an example embodiment, if occlusion between physical and virtual body parts or devices is the dominant factor, images would be preferred to come from the image units 20 in the lower assembly 12a since it preserves natural line of sight. In another example embodiment, the AR headset 906 is used for anything requiring virtual 3D imagery that could be “detached” from the patient's body, e.g., blood on the patient/wound imaged with the image units 20, but for blood dripping on the floor, images from the AR headset 906. In another example embodiment, front projection from the front projection device 902 can have superior image quality in some cases. On the flip side, front projection makes touch sensing more difficult. In an embodiment, the front projector is used to project different appearances onto opaque parts of the patient simulator (like painted wounds), otherwise the underneath projector is used. In still other embodiments, the one or more dynamic images are displayed by the head

mounted display 906 based on a display characteristic assigned to a part of the patient's body. In an example embodiment, the display characteristic indicates that the one or more interface devices (e.g. sensory devices 22) provide output from the part of the patient's body. In another example embodiment, the display characteristic indicates whether the part of the patient's body is a real part viewable in real space or a virtual part only viewable in the frame of reference viewable by the user through the head mounted display 906.

In another embodiment, the AR headset 906 is configured to project the one or more virtual dynamic images of the virtual part such that the virtual part is shifted within the frame of reference to align with the shell 10 comprising the physical anatomical model of the portion of the patient's body. In this embodiment, the module 17 of the computing unit 16 features one or more instructions so that the virtual images are shifted within the frame of reference of the headset 906 so to align with the shell 10. In an example embodiment, optical marker tracking (e.g. c3aresys) is one example of such a method.

Additionally, in an embodiment, FIG. 22 depicts a flexible display (OLED 908) positioned on the outer surface of the shell 10, wrapped around corresponding to the shape of the shell (body part). The emissive display would provide an alternate means to achieve imagery on the surface of the shell. Additionally, a flexible display could also be embedded into the surface of the shell, again formed in a manner such that it corresponds to the shape of the shell (body part). Furthermore, autostereoscopic mechanisms could provide the effect of stereo imagery seen by nearby viewers. FIG. 23 is an image that illustrates an example of a ray diagram from an optical source (e.g. OLED 908) to left and right eyes of a user 904 through a parallax barrier 910 to provide such an autostereoscopic display (ASD), according to an embodiment. In an embodiment, the user 904 is positioned at a fixed separation 912 from the parallax barrier 910 and thus in an example embodiment, the parallax barrier 910 provides the ASD for a number of pre-computed fixed spots (e.g. with fixed separation 912) next to the bed system 12. In an example embodiment, stereoscopy is employed (e.g., shuttering, anaglyphic) with or without head tracking. As would be understood by a person of ordinary skill, these and other stereo vision approaches would allow a user, wearing the appropriate glasses, to see virtual imagery appearing above or below the outer surface 1102 of the shell. In a further example embodiment, the outer surface of the shell 10 is actuated to match the simulated 3D movement (e.g. movement/deformation). In an example embodiment, there is various advantages and disadvantages for using the OLED or autostereoscopic as opposed to the augmented AR. Specifically, using the OLED requires no glasses, provides mono imagery, permits multiple users, has no occlusions, provides a physical object to touch but as disadvantages adds additional expense and increases the complexity of the shell. Similarly, the autostereoscopic provides advantages of not requiring glasses, providing stereo imagery, but includes disadvantages of limited eye movement and limited multiple users.

In an example embodiment, the shell 10 is made to serve as a rear projection screen in the form of a 3D figure of a human. The shell 10 may be molded from a translucent moldable material, such as plastic. In accordance with an embodiment, shell 10 comprises vacuformable material. A number of suitable vacuformable materials may be chosen such as acrylic, butyrate, and PETG (glycol-modified polyethylene terephthalate) which is a copolyester that may be a

clear amorphous thermoplastic. The underneath surface **10b** of the shell **10** may be coated with a rear projection screen material to permit better visualization of the image through to the top surface **10a** projected by imaging system **20**, and/or better optical sensing of touch through to the top surface **10a** via the sensor system **22**.

One or more openings may be provided on the back **10c** of the shell **10** to allow for better projection of images by the imaging system **20** in the bed system **12** onto the underneath surface **10b**. Alternatively, part, most, or the entire back side **10c** of the shell **10** may be removed, such that the shell **10** comprises an upper longitudinal slice (e.g., approximately 1/2) of a prone human figure having a partially or fully open back **10c**. The edge of the open back **10c** of the shell **10** may be secured to a frame **18** or other rigid support device, so that the frame **18** can then be easily, securely, and interchangeably mounted to a corresponding mounting device **14** of the bed system **12**.

For example, a human shaped vacuform “shell” **10** can be obtained from a provider who produces special effects for theme parks, museums, trade shows and special events (e.g., PeopleVisionFX of Roselle, NJ). In order to better provide for imaging and interactivity, the vacuform “shell” **10** may be sliced from head to toe longitudinally (line A of FIG. 2) opening the back side **10c** to allow projection of the images through the opening, as shown in FIG. 2. It may also be separated at the waist (line B of FIG. 2) to allow for movement (e.g., bending at the waist) or other separations may be provided for movement of other body parts. The shell **10** with the cut-away back side **10c** may then be mounted on a frame **18** or similar device that can be secured into place on the bed system **12**. Proper mounting and placement of the shell **10** with respect to the bed system **12** and imaging system **20** comprise proper alignment, registration, and focus of the projected image onto the underneath surface **10b** of the shell **10**. Alignment and registration marks may be provided on the shell or as part of the frame **18** and/or mounting system **14**.

The projectors **20** (e.g., digital projectors) that render dynamic patient imagery onto the underneath **10b** of the shell **10** are designed and properly placed to project through the open back **10c** of the shell **10**. The projectors **20** may be placed in respective/corresponding openings **26** in the upper **12a** and lower **12b** bed mattress support areas. The sliced shell **10** may be mounted rigidly to a rectangular or similarly shaped frame **18** that that will mate with (attach to) a corresponding mounting device (e.g., frame) **14** on the bed system **12**. The frame **14** may include a rigid “fill” material (e.g., plastic) that extends from the frame **14** to the shell **10**.

In an example embodiment (see FIG. 3), the bed system **12** includes an upper assembly **12a** and a lower assembly **12b**. The upper assembly **12a** may resemble a standard hospital bed or gurney. The lower assembly houses the electronics (e.g., imaging system **20**, sensor system **22**, and interactive devices **24**). It may be specifically manufactured or retrofitted from a standard hospital bed (e.g., a POCKET NURSE® Full Electric Hospital Bed, of Monaca, PA). In certain embodiments, the hospital bed can be modified to allow only one point of articulation at/across the “waist” or knee, for example, with all other articulation restricted mechanically. Height adjustment may be maintained/allowed. When retrofitting, the mattress support area in the upper assembly **12a** is cut/modified to provide one or more openings **26** through which the imaging system **20** can project imagery from below onto the underside **10b** of the shell **10**. Opening(s) **26** are placed and sized to properly project the imagery from the imaging system **20** through the

mounting device **14** onto the underneath **10b** of the shell **10**. The opening(s) **26** cut in support area may be placed and sized to mate with the frame **18** of the shell **10** using a corresponding frame or similar mount **14**. FIG. 19A is an image that illustrates an example of a mobile compact unit **600** that houses the bed system of FIG. 3, according to an embodiment. FIG. 19B is an example that illustrates an example of a mobile bed system **5** assembled from the mobile compact unit **600** of FIG. 19A, according to an embodiment. In an embodiment, the system **5** is configured to be converted from a mobile compact unit **600** to a bed system **5** positioned on wheels **602a**, **602b** that are configured to move over a surface **604** (e.g. floor of a hospital or medical unit or training area to perform the medical training). In another embodiment, the unit **600** encloses the shell **10** and the image system **20** and interface devices **20**, **22**, **24** positioned below the shell **10** in the bed system **5**. In still other embodiments, the mobile unit **600** can be converted not only into the bed system **5** but into a room with a plurality of interior surfaces that are free-standing or linked together for support, and together represent walls that define the room that holds the bed system **5**. These walls can serve as projection surfaces to allow the rendering of realistic environmental artifacts, different scene locations, a caregiver/parent, etc. surrounding the bed systems **5**. Thereby, making a portable CAVE-like structure. (See [4] C. Cruz-Neira, D. J. Sandin, T. A. DeFanti, R. V. Kenyon, and J. C. Hart. The CAVE: audio visual experience automatic virtual environment. Commun. ACM, 35(6):64-72, June 1992, which is incorporated by reference herein.) In this embodiment, the system further comprises a plurality of interior surfaces defining an enclosure (e.g. room or portable) to position the bed system **5**. The plurality of interior surfaces and the bed system **5** are enclosed within the mobile compact unit **600**. In this embodiment, the mobile compact unit **600** is configured to be converted into the enclosure and the bed system positioned within the unit **600**. A person of ordinary skill would understand that the same mobile compact unit **600** could be used to contain a PVP that is not in a bed, is an animal, etc.

The lower assembly **12b** is designed to support and house the electronics (e.g., imaging system **20**, sensor system **22**, interactive devices **24**, CPU **16**). In an embodiment, a platform such as a strong horizontal “shelf” or other mounting structure may be rigidly affixed to the upper and lower bed portions, mounted to the underside of the bed. The chosen support arrangement may allow for lateral, horizontal and vertical adjustments of the electronics. For flexibility and customization, the platform may be in the form of an “optical breadboard” (metal “pegboard”) such as those manufactured by Thorlabs Inc. of Newton, New Jersey, that will permit repositioning of electronics, projectors, cameras, mirrors, etc. Rigid, passive, or active vibration damping may also be provided. FIG. 20 is an image that illustrates an example of a bed system with a plurality of shock actuators **702a**, **702b** made from rubber or other materials with elastic effect to mount the bed system **5** to a surface **704**, according to an embodiment. In an embodiment, the system **5** is mounted to a surface (e.g. interior surface of an airplane) by a shock absorber **702a**, **702b** configured to absorb at least a portion of an induced force from the surface in a direction of the system (e.g. turbulence during the flight for in-flight nurse training). In yet another embodiment, the system **5** is mounted to a surface by a shock inducer **702a**, **702b** configured to induce a force in a direction from the surface to the system **5** to simulate an induced force from a moving surface (e.g. to simulate turbulence experience in an air-

plane, etc.). This advantageously permits the medical training to incorporate realistic scenarios such as air travel conditions (e.g. medical transport training). In an example embodiment, the shocker actuator **702a**, **702b** includes any shock inducer appreciated by one of ordinary skill in the art such as a monotube gas shock absorber. The design may accommodate folded optics arrangement with projectors and cameras below so they can be mounted horizontally on the optical breadboard, and the imagery can be reflected to the underside of the vacuform shell **10**, as well as omnidirectional cameras and projectors.

Alternatively, the design may include “sleds” (mounting units) for projectors, cameras, and mirrors so that they can be moved around on the optical breadboard, and clamped down when in place. Sleds for projectors may provide a mechanism to mount wide angle adapters for projectors (such as wide-angle conversion lens that fit in front of the projector’s standard lens allowing a projection image that is 50% larger than the projector’s standard lens at the same distance (e.g., the SSC065 Mini ScreenStar Wide Angle Converter (0.65x) by Navitar, Inc. Rochester, New York). Adjustability of the optical sleds (mirrors, cameras, projectors) may include one or more of the following: translate in 2D on the optical breadboard, rotate about an axis coming out of the breadboard perpendicular, tilt up and down out of the plane of the breadboard. sleds/mounts may be used for mirrors.

The imaging system **20** provides the virtual effects for a more realistic experience. A wide variety of projectors may be used to obtain these effects. The imaging may be aligned, registered, stabilized, and controlled using image processing software (e.g. module **17** in computing unit **16**) in a controller or CPU **16** in communication with the imaging system **20**. Computer generated graphics may be used to create one or more images for projection. A media controller (separate from or part of CPU **16**) may be operable to control media supplied to the imaging system **20** via communication means (e.g., wired/wireless) and therefore, projection of a particular image/image stream. Media may be retrieved from a plurality of stored and/or dynamically generated media, suitable for the particular training exercise.

The imaging system **20** comprises one or more projectors coupled to a support platform (via breadboard) in the lower assembly **12b**. The platform provides a rigid support such that once the shell **10** and projector(s) of the imaging system **20** are arranged with proper alignment, registration, and focus, and the optical components are sufficiently calibrated (e.g., the geometric and photometric parameters), the projected image will properly project onto the underneath surface **10b** of the shell **10** and show through on to the top surface **10a** of the shell **10**. An example projector includes the AAXA M2 micro projector from AAXA Technologies of Tustin, CA, which can be used with an adapter (e.g., a Vivitar adapter) for WFOV (Wide Field Of View). LED projectors may be chosen for reliability, consistency, short throw, non-critical resolution, lighting, etc. Since the human shell **10** can have different images projected on different parts thereof, a plurality of projectors may be used. The projectors can be arranged to have projector overlap on the “shell” surface (which may be minimal).

For the purpose of touch sensing for the simulator, the sensor system **22** may provide for camera-based optical touch technology, such as optical touch sensing device **32**, to detect the presence of a touching object, including traditional infrared, waveguide infrared, vision-based, LCD In-cell Optical, or the like (see FIGS. **13** and **14**). In an embodiment, the interface devices includes one or more

sensors **32** to detect a presence of an object (e.g. hand) within a proximate distance of the outer surface of the shell **10**. In one embodiment, the sensor **32** is an optical touch sensing device configured to detect one of a hand of a user within the proximate distance of the outer surface of the shell and a gesture of the hand of the user. In an example embodiment, the sensor **32** is configured to detect hovering and associated mid-air gestures (e.g., 3D pinch, tap, grasp). In yet another example embodiment, the sensor **32** is a pressure sensor that is configured to detect and/or measure a level of pressure during touch (e.g., using optical IR touch sensing or Velostat-like materials). The term “camera” **30** is used in optical touch to designate an assembly that typically includes a housing, image sensor, cable, lens, and IR filter. Depending on the system architecture, a camera **30** may also include an IR light source (for retro-reflective systems) and an image processor. Advantages of certain features include this body-specific optical touch sensing over the entire human body form and its unusual topology. Specifically, the system employs novel multiple overlapping infrared light sources and image forming cameras to cover and decode touch over a non-parametric surface, with shape discontinuities and occlusions, such as occurs with a touch surface in the shape of the human body.

In other embodiments, the sensor device **22** and/or optical touch sensing device **32** includes omnidirectional optical devices, as defined below. FIG. **34G** is a schematic diagram that illustrates an example of a cross-sectional end view of a plurality of omnidirectional interactive devices of the system of FIG. **3**, according to an embodiment. In an embodiment, FIG. **34G** depicts an optical touch sensing device where an omnidirectional mirror **1926** is positioned to reflect light received from a hand **1939** moved in close proximity to the shell **1910** and the reflected light is subsequently directed into a camera **1938**. In this embodiment, the camera **1938** subsequently processes the omnidirectional image of the hand **1939** to detect a presence of the hand **1939**. Although a hand **1939** is depicted, the sensor device **22** can be utilized to detect the presence of any object. FIG. **34H** is a schematic diagram that illustrates an example of a cross-sectional end view of a plurality of omnidirectional interactive devices of the system of FIG. **3**, according to an embodiment. The arrangement of FIG. **34H** is similar to the arrangement of FIG. **34G**, with the exception that an omnidirectional projector **1924** is included in the arrangement of FIG. **34H** to direct light on the omnidirectional mirror **1926** which is subsequently reflected by the hand **1939** back to the omnidirectional mirror **1926** and into the camera **1938** after which the hand **1939** is detected.

Although FIGS. **34G-34H** depict an optical touch sensing device with omnidirectional imaging devices, in other embodiments, such an optical touch sensing device can be positioned within the patient shell **1910**. FIG. **34I** is a schematic diagram that illustrates an example of a cross-sectional end view of a plurality of omnidirectional interactive devices of the system of FIG. **33A**, according to an embodiment. In an embodiment, a 360 degree camera **1940** is mounted within the shell **1910** and is configured to capture omnidirectional images that indicate a presence of the hand **1939** within a proximate distance of the shell **1939**.

For example, in an embodiment, the camera units may be mounted in the bed system **12**, with distinct optical paths from the projectors (e.g., folded optical paths). Each camera unit may comprise a pair of cameras arranged with a cold mirror such that IR light only is passed to one camera (e.g., used for touch sensing), and visible light (only) is passed to the other camera (e.g., used for calibration of the visible

projector imagery), where the latter may use an IR cut filter on the camera. Mirrors may be used for folding projector and (if desired) camera unit optical paths. The camera arrangement may use mirror units that already mate with the optical breadboard, and accommodate different sized mirrors. The underside of the bed may include a form of IR illumination source to illuminate (IR) the underneath **10a** of the human shell **10** for the purpose of touch sensing of the sensor system **22**. An example of touch sensing using a spherical display prototype that has touch-sensing capabilities with an infrared camera that shares the optical path with the projector without shadowing or occlusion problems is described in “Sphere: A Multi-Touch Interactive Spherical Display” by Benko, Wilson and Balakrishnan (See research.microsoft.com), incorporated herein by reference. The IR light **28** would preferably emanate from near the cameras **30** (or a comparable optical path, so that reflected light returns to the camera), cover the area imaged by the camera, and be sufficiently bright to illuminate close objects on the opposite side—the outside/top/upper part **10a** of the shell **10**. For example, IR ring lights may be used provided the distance/range is sufficient (see FIGS. **11-12**).

The invention provides a novel overall systems/methods for training healthcare professionals that combines the visual and physical shape to afford dynamic visual patient appearance (e.g., behavior, emotion, symptoms or pathology); body-specific optical touch sensing over the entire human body form and its unusual topology; interchangeable human bodies and body parts to accommodate, for example, different genders, ages, and healthcare conditions; targeted temperature feedback over the surface of the body; a tactile sense of pulse; and aural senses of a heartbeat and breathing (including anomalies for both).

The following is an example PVP system **5**, with reference to FIGS. **4-10**. The dimensions used herein are examples only. The actual dimensions would be adjusted to accommodate the actual components and shell size.

Example Projector Specifications: Aaxa M2 Projector. Measurements (W×D×H): 132×125×47 mm. At 68.5" distance, image was 34" wide and 26" tall (without conversion lens). At 68.5" distance, image was 50" wide and 38" tall (with conversion lens). Throw Ratio:

$$R - \frac{d}{w} - \frac{1}{2 \tan\left(\frac{\alpha}{2}\right)} \quad R - \frac{d}{w} - \frac{1}{2 \tan\left(\frac{\alpha}{2}\right)}$$

where α is the horizontal/vertical projection angle, d is the distance from the projector to the surface, and w is the width or height. There can be a vertical offset, so the bottom of the projected images lines up with center of lens.

Example Camera Specifications: Basler Ace acA2000-50gc. Measurements (W×D×H): 29×42×29 mm. 2048×1088 pixel @ 50 fps. Gigabit Ethernet interface with PoE. Interchangeable C-mount lenses should support a variety of mounting distances.

Example Projector Placement and Configuration: FIG. **4** shows a rough layout, in the top-view, of the proposed placement. In this example, seven projectors (**P1** to **P7**) span the portion of the bed surface that will be occupied by the patient “shell” **10**. Specifically, **P1** covers the head, **P2** through **P5** cover the torso, and **P6**, **P7** cover the legs. Since the bed ‘articulates,’ projectors **P1** through **P5** are mounted accordingly so they remain ‘static’ with respect to the articulated top half of the bed. In order to achieve the above-mentioned design, two different configurations are

contemplated. The design is divided into ‘Torso’ and ‘Legs’ for convenience. The ‘head’ design is not highlighted herein, but may be very similar to those proposed for legs or torso.

Example Torso with Average Human Measurements: (See FIG. **5**) Shoulder width: approximately 18"=457.2 mm; Chest height (above mattress): approximately 4.5"=114.3 mm; Torso height: approximately 30"=762 mm. For a design with **4** projectors covering the complete torso, horizontal image width at the torso is approximately 15"=381 mm; vertical image height is approximately 11.28"=286.5 mm.

FIG. **6** shows a first design example design for Torso Projection having a Single Mirror Path Folding (Design 1). The throw ratio of the projectors makes it difficult to achieve a direct projection without dropping them well beneath the surface of the bed. As a result, it was decided to use mirrors to fold the path of the projection, thereby allowing us to mount the projectors closer to the bed surface. FIG. **6** shows an example ‘to-scale’ version of the projection. The projectors are mounted horizontally facing inward under the outer edges of the bed, with mirrors on the inside to achieve the desired projection as shown. The measurements are shown in the following table:

TABLE 1

Single Mirror Path Folding (Design 1)				
Projector Pair	Projector height (from base of bed surface)	Mirror Distance (from projector)	Mirror Dimension (length)	Mirror Angle
1 (P4, P5)	420.5 mm (16.5")	250 mm (9.84")	217.7 mm (8.54")	56°
2 (P2, P3)	420.5 mm (16.5")	250 mm (9.84")	210.5 mm (8.28")	-56°

FIG. **7** shows a second design example design for Torso Projection having a Dual Mirror Path Folding. This design involves the use of two mirrors to fold the path of the projection, thereby allowing mounting of the projectors even closer to the bed surface. FIG. **7** shows an example ‘to-scale’ version of the projection. The projectors are vertically facing upward mounted under the outer-edges of the bed, with mirrors as shown to achieve the desired projection as shown. The measurements are shown in the following table:

TABLE 2

Dual Mirror Path Folding (Design 2)				
Projector Pair	Projector height (from base of bed surface)	Mirror Distance (from projector)	Mirror Dimensions (length)	Mirror Angle
1 (P4, P5)	282.5 mm (11.1")	M1: 76 mm (2.99")	M1: 112.5 mm (4.42") M2: 223.5 mm (8.79")	M1: 16° M2: 16°
2 (P2, P3)	282.5 mm (11.1")	M3: 76 mm (2.99")	M3: 112.5 mm (4.42") M4: 215.9 mm (8.5")	M3: -16° M4: -16°

FIG. **8** shows a third design example for Torso Projection having a Single Mirror Crossfire Configuration. This design uses the projectors in a “cross-fire” configuration, i.e. each projector illuminates the torso side that is laterally opposite to the projector’s mounting position. FIG. **8** shows an example ‘to-scale’ version of the projection. This placement leaves a greater buffer zone from the projectors to the edge of the bed, potentially allowing a future placement of the

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patient shell closer to one side of the bed. The measurements are shown in the following table:

TABLE 3

Single Mirror Crossfire Configuration (Design 3)				
Projector Pair	Projector height (from base of bed surface)	Mirror Distance (from projector)	Mirror Dimensions (length)	Mirror Angle
1 (P4, P5)	284.8 mm (11.21")	163 mm (6.42")	137.1 mm (5.4")	14°
2 (P2, P3)	284.8 mm (11.21")	163 mm (6.42")	133 mm (5.24")	-14°

FIG. 9 shows a first design example for Legs Projection having Single Mirror Path Folding. FIG. 10 shows a second design example for Legs Projection having Dual Mirror Path Folding. Two projectors may be used to cover the legs. The vertical image width at the torso may be about 12"~300 mm; the horizontal image height may be about 15"~392 mm. The same designs as those used for the torso can be used here.

Example Camera Unit and IR Illumination Placement and Configuration: The exact placement of the cameras (camera units) and associated cold mirrors, IR illumination, etc. may be determined based on the chosen shell and projector configuration. The following are two possibilities in regard to camera placement: (1) Placing them in-line with the projectors, looking into the mirrors at the projected image. This would use 7 cameras. (2) Mount them between the mirrors looking upwards. The placement of the mirrors may take the desired camera positions into account in order to not obstruct their view. Generally, the whole body could be covered by 3 cameras. To quantify the required lens focal lengths, the best and worst case can be considered for covering the complete torso with one upward-facing camera (possibility 2). Smaller focal lengths of the lens will increase the magnitude of non-linear distortions towards the edges of the image. This may result in a reduced peripheral resolution and more complicated calibration procedures. The following table lists the focal lengths for the lenses and possible models that fulfill these requirements

TABLE 4

Camera Unit Placement:			
Mounting Distance	Desired image width/height at distance	Required Lens Focal Length	Lens Model
282.5 mm (11.02")	762 × 457.2 mm	3.24 mm	Fujinon FE185C086HA 2.7 mm F/1.8
420.3 mm (16.55")	762 × 457.2 mm	4.85 mm	Pentax C30405KP 4.8 mm F/1.8

In an embodiment, omnidirectional imaging devices can be utilized instead of the imaging devices of FIGS. 6-9. FIG. 34D is a schematic diagram that illustrates an example of a cross-sectional end view of a plurality of omnidirectional imaging devices of the system 5 of FIG. 3, according to an embodiment. In FIGS. 34D/34E/34G/34H the omnidirectional imaging devices are shown outside the shell, as variations of FIGS. 6-9 and FIGS. 13-14. In an embodiment, a projector 1924 is provided that outputs incident light 1930a, 1930b which is reflected off an omnidirectional mirror 1926 into a cone of reflected light 1932a, 1932b to

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project an image onto the shell 1910. Unlike the arrangements of FIGS. 6-9, the imaging devices (projector 1924, omnidirectional mirror 1926) are omnidirectional imaging devices, as defined below. FIG. 34E is a schematic diagram that illustrates an example of a cross-sectional end view of a plurality of omnidirectional imaging devices of the system 5 of FIG. 3, according to an embodiment. The arrangement of FIG. 34E is similar to the arrangement of FIG. 34D with the exception that the arrangement of FIG. 34E includes two projectors 1924a, 1924b mounted on opposite sides of the omnidirectional mirror 1926. In an embodiment, incident light 1930 from the first projector 1924a is reflected off the omnidirectional mirror 1926 to project an image in a second region 1905 of the shell 1910, whereas incident light 1930 from the second projector 1924b is reflected off the omnidirectional mirror 1926 to project an image in a first region 1903 of the shell 1910 that is distinct from the second region 1905. A person of ordinary skill in the art will be familiar with the possibility of, and methods for correcting, nonlinear imagery distortions on the regions of 1903 and 1905, resulting from the omnidirectional mirror. A person of ordinary skill in the art will also be familiar with methods for blending such distorted imagery in regions of overlapping projected imagery.

In some embodiments, one or more of the imaging devices 20, sensor devices 22 and/or interactive devices 24 of FIG. 1 are positioned within or enclosed by the shell 10. In these embodiments, the frame 18 and/or mounting device 14 and/or housing 12 of the system 5 are omitted. FIG. 33A is a block diagram of one example of a system 1900 including a shell 1910 with imaging devices 1920 enclosed by the shell 1910, according to an embodiment. In one embodiment, the system 1900 is self-contained (e.g. contained within the patient shell 1910). In still other embodiments, the shell 1910 has sensor devices 1922 enclosed by the shell 1910 and/or interactive devices 1924 enclosed by the shell 1910. The respective imaging devices 1920, sensor devices 1922 and/or interactive devices 1924 are similar to the imaging devices 20, sensor devices 22 and interactive devices 24, with the exception of the differences discussed herein. Additionally, the shell 1910 is similar to the shell 10 discussed previously, with the exception of the differences discussed herein. In one embodiment, the shell 1910 features one or more aspects of the shell discussed with respect to FIGS. 15-32 to the extent those features are not mutually exclusive with the shell 1910 that encloses one or more of the imaging devices 1920, sensor devices 1922 and/or interactive devices 1924.

FIG. 33B is a schematic diagram that illustrates an example of a cross-sectional side view of a plurality of imaging devices 1922a, 1922b enclosed by the shell 1910 of FIG. 33A, according to an embodiment. In one embodiment, a first imaging device 1922a projects an image on a first region 1902 (e.g. abdomen region) of the shell 1910 (e.g. projects the image on an inner surface of the shell 1910 so that the image is viewable by a user from the outer surface of the shell 1910). In another embodiment, a second imaging device 1922b projects an image on a second region 1904 (e.g. chest region) that is different from the first region 1902. Although the shell 1910 of an adult subject is depicted in FIG. 33B, in other embodiments, the shell of an infant (e.g. baby) is provided with internal imaging devices. One advantage of the embodiment of FIGS. 33A-33B is that no frame or mounting device is required to the project the image that is viewable from the outer surface of the shell 1910. This permits a greater flexibility in terms of the usage of the shell in different contexts of scenarios.

FIG. 33C is a schematic diagram that illustrates an example of a cross-sectional end view of a plurality of imaging devices **1922a**, **1922b** enclosed by the shell **1910** of FIG. 33A, according to an embodiment. In the embodiment of FIG. 33C the first imaging device **1922a** projects an image on a first region **1903** (e.g. left side) of the shell **1910** whereas the second imaging device **1922b** projects an image on a second region **1905** (e.g. right side) of the shell **1910**. In some embodiments, a combination of the imaging devices of FIG. 33B and FIG. 33C can be utilized so that images can be projected on the inner surface of the shell **1910** in both a left and right region of the shell **1910** (FIG. 33C) and two regions along a length of the subject **1910** (FIG. 33B).

In one embodiment, the imaging devices include an “omnidirectional” imaging device, which includes one or more characteristics are discussed herein. In one embodiment, a person of ordinary skill in the art would understand the concept of “omnidirectional” imaging devices (e.g. cameras or projectors) that are typically achieved by the addition of wide field-of-view optics (e.g. lenses or mirrors) to conventional imaging devices, or by mechanically locating the optical components of the imaging devices near each other such that they capture (or project) from approximately the same location, while “looking out” in different directions. When multiple individual cameras are used in a single imaging device, the (multiple) single-camera images are typically aligned with each other and “stitched together” into a single omnidirectional image. A person of ordinary skill in the art would further understand that because the omnidirectional imagery is composed from one or more conventional cameras, the resulting omnidirectional images would resemble those of conventional cameras, e.g., they would typically be rectangular, even though the angular mapping of image pixels to rays emanating from the omnidirectional device (e.g., each specified as azimuth/yaw and elevation/pitch angles) is typically not regular. For example, an omnidirectional image might be organized and represented in a rectangular fashion (e.g., having rows and columns) and yet comprise some pixels that were imaged near the top or “pole” of a hemispherical mirror and are angularly dense (e.g. the pole is very small), and some pixels that were imaged near the “equator” and angularly sparse (e.g. the equator is relatively large). In an example embodiment, the omnidirectional images are transmitted and received from the imaging devices **1920** and the CPU **1916** and/or the CPU **1916** is configured to process the omnidirectional images as discussed herein. As such, in one embodiment, omnidirectional images—once assembled (e.g. if created from multiple cameras) would be handled (e.g. by the CPU **1916**—captured, recorded, transferred, etc.) the same as conventional images. Omnidirectional projectors could be used to project dynamic imagery all around a point inside an enclosed shell **1910**, for example, and multiple overlapping omnidirectional cameras might be used to cover the entire interior of the shell—much like multiple overlapping conventional projectors can be used. Just as with conventional projectors, omnidirectional projectors could be used for calibration of the cameras or other optical components, and for presenting the appearance of the patient on (all over) the shell. Omnidirectional cameras could be used to capture dynamic imagery of the shell all around a point inside an enclosed shell, for example, and multiple overlapping omnidirectional cameras might be used to cover the entire interior of the shell—much like multiple overlapping conventional cameras can be used. Just as with conventional cameras,

omnidirectional cameras could be used for calibration of the projectors or other optical components, and for touch sensing on the shell.

A person of ordinary skill in the art will be familiar with the design and support of various omnidirectional camera approaches, from at least as early as 1996 when Vic Nalawa at Bell Laboratories wrote a technical report on the subject. (see [5], V. Nalwa. A true omnidirectional viewer. Technical report, Bell Laboratories, Holmdel, NJ 07733, February 1996 which is incorporated by reference herein.) In one embodiment, plexiglass or other hard and clear plastic can be used to support a camera above an omnidirectional mirror. In an embodiment, the camera itself will be seen in the middle of the image (e.g., a small artifact). In some embodiments, a human-shaped frame (e.g., metal frame) could be used to join two or more shell pieces to create a complete human (or other) body as in FIG. 34J and FIG. 34K. In an embodiment, projectors, cameras, and/or omnidirectional components could be affixed to the frame. A person of ordinary skill in the art will understand that as long as power can be achieved inside such a complete human shell, there are a variety of ways to generate and acquire imagery using the internal projectors and cameras (e.g. through the use of wireless technology, where the CPU **1916** is in wireless communication with the imaging devices **1920**). In still other embodiments, the CPU **1916** can be in wired communication with the imaging devices **1920** (e.g. cable directed through small openings in the shell **1910** between the CPU **1916** and respective omnidirectional components). In another embodiment, a person of ordinary skill in the art would also appreciate that the unit could be powered by internal rechargeable batteries that are recharged through a variety of means, including possibly inductive methods.

In one example embodiment, the imaging device **1922** is made omnidirectional by including a spherical mirror and a projector, as disclosed in [1] and [2], which are both incorporated by reference herein. FIG. 34A is a schematic diagram that illustrates an example of a top view of an imaging device **1922** of FIG. 33B within the shell **1910**, according to an embodiment. In an embodiment, the imaging device **1922** includes an optical source that generates an optical signal and one or more optics (e.g. lens, mirror) that are reflective and/or refractive that direct the optical signal over the appropriate region (e.g. first region or second region as depicted in FIGS. 33B, 33C). In some embodiments, the optical source is a projector **1924** that is similar to the projector disclosed in [1] and [2] with the exception that the size of the projector is scaled so to fit within the shell **1910**. In another example embodiment, the optic includes an omnidirectional mirror **1926** that is similar to the spherical mirror disclosed in [1] and [2] except scaled to be used within the shell **1910**. The transmission and redirection of the light from the projector **1924** to the omnidirectional mirror **1926** and to the inner surface of the shell **1910** is similar to the transmission and redirection discussed in [1] and [2] for hemispherical domes, with the exception that the scale is adjusted based on the interior of the shell **1910**. As depicted in FIG. 34A incident light **1930** from the projector **1924** is reflected by the spherical mirror **1930** as reflected light **1932a**, **1932b**, **1932c** in various directions so that the collective reflected light **1932** projects the image to the region **1902** or **1904** (FIG. 33B) or the region **1903** or **1905** (FIG. 33C). FIG. 34B is a schematic diagram that illustrates an example of a side view of an imaging device **1922** of FIG. 33B within the shell **1910**, according to an embodiment. FIG. 34C is a schematic diagram that illustrates an example

of a ray diagram of the imaging device 1922 of FIGS. 34A-34B reflecting light 1932 onto the inner surface of the shell 1910, according to an embodiment. The ray diagram of FIG. 34C depicts the projector 1924 (P1) that transmits the incident light 1930 (along line L1) and is reflected as reflected light 1932 (along line L2) to generate the image (at point P2) on the inner surface of the shell 1910 (which is subsequently viewable from the outer surface of the shell 1910).

FIG. 34F is a schematic diagram that illustrates an example of a cross-sectional end view of a plurality of omnidirectional imaging devices of the system of FIG. 33A, according to an embodiment. In an embodiment, the arrangement of FIG. 34F includes an omnidirectional mirror 1926 mounted within the shell 1910 (e.g. using any means appreciated by one skilled in the art) and a pair of projectors 1924a, 1924b mounted within the shell 1910 (e.g. using any means appreciated by one skilled in the art). In one embodiment, incident light 1930 from the projector 1924b is reflected off the omnidirectional mirror 1926 and projects an image along the shell 1910 in a first region 1903. In another embodiment, incident light 1930 from the projector 1924a is reflected off the omnidirectional mirror 1926 and projects an image along the shell 1910 in a second region 1905 that is adjacent and/or different than the first region 1903. A person of ordinary skill in the art will be familiar with the possibility of, and methods for correcting, nonlinear imagery distortions on the regions of 1903, resulting from the omnidirectional mirror. A person of ordinary skill in the art will also be familiar with methods for blending such distorted imagery in regions of overlapping projected imagery.

FIG. 34J is a schematic diagram that illustrates an example of a cross-sectional side view of a plurality of omnidirectional imaging devices enclosed within the shell of the system of FIG. 33A and FIG. 33B, according to an embodiment. In an embodiment, the arrangement of FIG. 34J includes four omnidirectional mirrors 1926a, 1926b, 1926c, and 1926d mounted within the shell 1910 (e.g. using any means appreciated by one skilled in the art) and four projectors 1924a, 1924b, 1924c, and 1924d mounted completely within a surrounding shell 1910, possibly comprised from multiple shell pieces arranged and supported to form a complete surrounding shell (e.g., using any means appreciated by one skilled in the art). In one embodiment, a first pair of omnidirectional projectors 1924a, 1924b are positioned in a first region (e.g. upper region) of the shell 1910, where the projectors 1924a, 1924b are configured to direct light in opposite directions. In one example embodiment, the projectors 1924a, 1924b are connected (e.g. rear end of projector 1924a connected to rear end of projectors 1924b). In another embodiment, a second pair of omnidirectional projectors 1924c, 1924d are positioned in a second region (e.g. lower region) of the shell 1910, where each projector 1924c, 1924d are configured to direct light in opposite directions. In another embodiment, a first pair of omnidirectional mirrors 1926a, 1926b are provided in the first region (e.g. upper region) and are spaced apart so that the first pair of projectors 1924a, 1924b are positioned between the spaced apart omnidirectional mirrors 1926a, 1926b and/or are configured to direct light at the respective omnidirectional mirrors 1926a, 1926b. In another embodiment, a second pair of omnidirectional mirrors 1926a, 1926b are provided in the second region (e.g. lower region) and are spaced apart so that the second pair of projectors 1924c, 1924d are positioned between the spaced apart omnidirectional mirrors 1926c, 1926d and/or are configured to direct light at the respective omnidirectional mirrors 1926c, 1926d. Although

four omnidirectional mirrors and four projectors are mounted within the shell 1910 in FIG. 34J, in other embodiments less or more than four omnidirectional mirrors and/or less or more than four projectors can be mounted within the shell 1910. In one embodiment, incident light from a first projector 1924a (e.g. positioned within a neck of the shell 1910) is reflected off a first omnidirectional mirror 1926a (e.g. positioned within a head of the shell 1910) and projects an image along the shell 1910 in a first region 1903a (e.g. one or more images of facial features of the shell 1910 or features along the top or back of the head). In another embodiment, incident light from a second projector 1924b (e.g. positioned within an upper torso region or chest region of the shell 1910) is reflected off a second omnidirectional mirror 1926b (e.g. positioned in a central region such as an abdomen region of the shell 1910) and projects an image along the shell 1910 in a second region 1903b (e.g. chest and/or back region of the shell 1910) that is adjacent and/or different than, but might overlap, the first region 1903a. In another embodiment, incident light from a third projector 1924c (e.g. positioned within a lower region such as adjacent a knee region of the shell 1910) is reflected off a third omnidirectional mirror 1926c (e.g. positioned within the central region of the shell 1910) and projects an image along the shell 1910 in a third region 1903c (e.g. thigh and/or buttock region of the shell 1910) that is adjacent and/or different than, but might overlap, the second region 1903b. In another embodiment, incident light from a fourth projector 1924d (e.g. positioned within the lower region) is reflected off a fourth omnidirectional mirror 1926d (e.g. positioned within a foot region of the shell 1910) and projects an image along the shell 1910 in a fourth region 1903d (e.g. leg region and/or foot region of the shell 1910) that is adjacent and/or different than, but might overlap, the third region 1903d.

A person of ordinary skill in the art will be familiar with the concept of projector-camera systems (“procam systems”) as the practice of pairing a projector with a camera that is either mounted proximal to the projector, or possibly mounted inside the projector. A person of ordinary skill in the art will appreciate that in the latter instance, the camera and projector can share some portion of a collinear optical path to the omnidirectional mirror, as described and prototyped for example by John Underkoffler in his Luminous Room. (See [6] J. Underkoffler. A View From the Luminous Room. Personal Technologies, 1(2):49-59, June 1997, which is incorporated by reference herein) In an embodiment related to that depicted in FIG. 34J, the arrangement of FIG. 34K includes four projector-camera units 1934a, 1934b, 1934c, and 1934d, each paired with an omnidirectional mirror as depicted in the arrangement of FIG. 34J. A person of ordinary skill in the art will appreciate that the projectors and cameras can be used simultaneously for rendering imagery onto the shell regions 1903a, 1903b, 1903c, and 1903d as depicted in FIG. 34J, and sensing touch as described herein. Additionally, in another embodiment, the omnidirectional mirrors 1926b, 1926c of FIGS. 34J-34K can be used to detect the presence of nearby objects (e.g. hand 1939a and/or hand 1939b) based on reflection of incident light from the nearby objects which is directed to the projector-cameras 1934a, 1934b, 1934c, 1934d.

In other example embodiments, the imaging device 1922 is an omnidirectional degree (e.g. 360 degree) camera, that operates using technology similar to Fullview® cameras (www.fullview.com) and/or Insta360® cameras (<http://www.instal360.com>) and/or Viar360® cameras (viar360.com) and/or Ozo® cameras (www.ozo.nokia.com).

For example, in other example embodiments, the imaging device **1922** is a hemispherical projector (e.g. a specific form of an omnidirectional projector), that operates using technology similar to Newtonian® 3 projector manufactured by Go Dome of Houston Texas (www.go-dome.com/dome-products/newtonian-projection-system-2/) and/or Go-Vex® projector manufactured by Go Dome of Houston Texas (www.go-dome.com/dome-products/newtonian-projection-system-2/go-vex/) and/or Go-Frame® projector manufactured by Go Dome of Houston Texas (www.go-dome.com/dome-products/newtonian-projection-system-2/go-frame/) and/or a fisheye lens or spherical lens as disclosed by [3] which is incorporated by reference herein. As indicated above, the imagery for such an omnidirectional projector would be much the same as a conventional projector, except that the angular mapping of pixels would be irregular, with the angular density varying along the surface of the sphere as discussed above. A person of ordinary skill in the art would understand that this mapping is just a variation of the normal mapping.

An exemplary system for implementing the invention includes a computing device or a network of computing devices. In a basic configuration, computing device may include any type of stationary computing device or a mobile computing device, including but not limited to the computer system as discussed below in reference to FIG. **30** and/or the chip set as discussed below with reference to FIG. **31** and/or the mobile device as discussed below with reference to FIG. **32**. Computing device typically includes at least one processing unit and system memory. Computing device may also have input device(s) such as a keyboard, mouse, pen, voice input device, touch input device, etc. Output device(s) such as a display, speakers, printer, etc. may also be included. A computing device also contains communication connection(s) that allow the device to communicate with other computing devices and the PVP system, for example over a network or a wireless network.

A number of different configurations of the described embodiments exist. For example, the core elements of the disclosed PVP system (device/apparatus, method, computer readable medium) can be realized in other physical configurations or arrangements beyond that associated with a bed. For example, the same elements could be used in chair-like (seated patient), standing, or other postural embodiments appropriate for the training application. In yet another example, the same elements could be used to flip the shell on its front side so that the back side (e.g. back area, back of head, back of legs, etc) can be viewed. This could support more realistic simulations of such scenarios as preliminary exams and even blood tests, where a patient is typically sitting upright; testicular or other exams where the patient is typically standing; or prostate exams where a patient might be bending over, or on their side for example. Other configurations are contemplated herein that would be evident to a person of ordinary skill in the art.

In another example, hybrid combinations of the described embodiments with elements of other training body parts may be provided. The elements of the disclosed PVP system (device/apparatus, method, computer readable medium) can be combined with other training-related human body elements in a hybrid fashion. For example, a portion of the human body shell corresponding to the upper arm could be replaced with a replica arm designed for practicing the insertion and removal of intravenous lines. Examples of such arms include the “Multi-Venous IV Training Arm” and the “Arterial Arm Stick Kit” offered by Laerdal Medical. Similarly, the entire projected torso of the disclosed embodi-

ments could be replaced by a training torso such as the “Laerdal IV Torso” (also offered by Laerdal Medical). Such hybrid configurations would result in systems that can be used to train medical tasks that are specific to a particular body part (e.g., insertion and removal of intravenous lines) while the remainder of the patient is illuminated with computer graphics depicting other symptoms, patient behavior, emotion, etc. as described herein. In one embodiment **111** shown in FIG. **11**, a hybrid system is shown comprising a PV human body shell **115** onto which images may be projected that also has a replica arm **112**, that is suitable for practicing injections or blood removal. FIG. **26** is an image that illustrates an example of a plurality of openings **1204** defined by the outer surface of the shell **1200** and a fluid reservoir **1206** communicatively coupled to the openings, according to an embodiment. In an embodiment, the outer surface **1202** of the shell **1200** defines a plurality of openings **1204** and the interface devices includes a fluid reservoir **1206** that is communicatively coupled to the plurality of openings with a respective plurality of conduits **1207**. The fluid reservoir **1206** is configured to transmit fluid (e.g. liquid, gas, etc.) through the plurality of openings **1204** in the outer surface based on a signal received from the computing unit **16**. In an embodiment, the fluid reservoir **1206** is a reservoir of simulated blood that is configured to transmit simulated blood through the conduits **1207** and through the plurality of openings **1204** based on the signal received from the computing unit **16**. In another embodiment, the fluid reservoir **1206** is a reservoir of gas that simulates a biological process (e.g. decaying flesh, sweat, body odor, urination and/or flatulence, etc.) involving the human body. The fluid reservoir **1206** is configured to transmit the gas through the conduits **1207** and the plurality of openings **1204** based on the signal received from the computing unit **16**. In an example embodiment, specific training simulations are provided that determine an output of the fluids, e.g. to simulate a patient that is hypotensive, a decreased urine output is simulated. In yet another example embodiment, a drop in blood pressure can be calculated based on the amount of virtual blood that is output through the openings **1204**. In a further example embodiment, a standard wound diagnostic task is provided that simulates how “wound rot” smells like. In still other embodiments, larger sized holes may be provided over the outer surface of the shell **10** (e.g. arteries) to simulate the spurting of blood from these regions of the patient’s body.

Alternatively, other training-related human forms could be combined with core body elements of the disclosed PVP system in a hybrid fashion. For example, the head of a Laerdal patient simulator (also known as a “mannequin” or “manikin”) could be removed and replaced by a PVP head element to simulate a combination of body physiology from the mannequin body with facial expressions, temperature, and touch sensing (for example) from the PVP head. Similarly, a real human patient actor (e.g., a “standardized patient”) could hide their arm behind their body to allow it to, in effect, be replaced by a PVP arm, allowing their arm to exhibit dynamic visual and temperature symptoms, for example. Such hybrid configurations would result in systems that can be used to train full-body medical tasks that would benefit from the complex simulation of conventional mannequins while the head of the patient is illuminated with computer graphics to depict speaking, facial expressions, emotion, visual/temperature symptoms related to the face as described herein. In one embodiment **120**, as shown in FIG. **12**, a patient simulator mannequin **121** has been modified to replace the head portion with a PV head shell component

122, onto which images can be projected. In an embodiment, as depicted in FIGS. 11-12, the shell is a patient virtual overlay adapted for overlaying a replica or real body part (e.g. PV head shell component 122). In an example embodiment, real body parts from a cadaver can be integrated into the PVP (e.g., with front projection). In still other embodiments, as depicted in FIGS. 11-12, the system includes a mannequin 121 replicating a patient body including the shell of at least one body part (e.g. replica arm 112). In one example embodiment, the system can be used for “reverse” body part modularity (e.g. use PV for part of an existing/modular manikin/simulator). FIGS. 16A-16B are images that illustrate an example of an interchangeable part (e.g. replica arm 121) with identifying indicia used in the shell 10 of the bed system 5 of FIG. 3 according to an embodiment. In one embodiment, the shell 10 includes one or more interchangeable parts and each interchangeable part has identifying indicia such that one or more interface devices are configured to read the identifying indicia when the interchangeable part is connected to the shell 10. In some embodiments, an input sensor detects when a part is connected to a shell. In one embodiment, the input sensor triggers the RFID reader 304. In another embodiment, the RFID reader 304 is constantly scanning to detect for a signal from the input sensor indicating that the part is connected to the shell. In another embodiment, the interface device is further configured to transmit a signal to the computing unit 16 with the read identifying indicia. In an example embodiment, the identifying indicia is one of an optical tag or RFID tag (Radio Frequency Identification) tag 302 and the interface device is a reader 304 of the optical tag and RFID tag 302. In another example embodiment, automatic detection or identification of hybrid parts and/or pieces can be used for integrated behavior, appearance, etc.

The above embodiments are merely a few examples wherein many similar hybrid combinations could be realized and are contemplated herein. Similarly, there are many application areas that are contemplated herein, including for example breast exams (e.g., a PVP incorporating a physical breast replica with pressure sensors such as disclosed by Kotranza, Lind, and Lok) being able to detect nodules, lumps, tumors and/or masses; abdominal exams; testicular exams; gynecological exams; prostate exams; catheter insertions; and treatment associated with severed or amputated/missing limbs.

In a further example embodiment, Physical-Virtual Overlay Shells for Humans or Mannequins may be provided. Herein, the core elements of the disclosed Physical-Virtual Patient (PVP) system (device/apparatus, method, computer readable medium) can be realized in relatively thin PV structures that are formed (roughly or precisely) to conform over or around a body part of a real human or a physical patient simulator (also known as a “mannequin” or “manikin”), resembling for example a shin pad or knee pad. For example, the embodiment of 120 also comprises a PV overlay shell 123 over the shin of the mannequin 121. Such PV overlay shells could be worn or placed over (e.g., on top of) a corresponding body part such as an arm, hand leg, foot, torso, or head. The visual aspects of such PV overlay shells could be realized in various ways, for example using projectors in a “front projection” configuration or flexible emissive displays, e.g., flexible OLED displays. The temperature effects and touch sensing could also be realized in various mechanisms including, for example, heating/cooling pipes and light pipes. Microphones, surface-mount slim speakers, and other miniature audio components could provide sound input and output, and tactile feedback. Such PV

overlay shells would support the combination of sophisticated mannequins (e.g., from Laerdal Medical) or real humans with PV effects, without otherwise requiring modification of the patient simulator or uncomfortable body contortions of the human. There are many such approaches to realizing display and sensing overlay structures that are contemplated herein.

In a further example embodiment, herein the core elements of the disclosed Physical-Virtual Patient (PVP) system (device/apparatus, method, computer readable medium) can be realized in combination with actuated body components such as limbs (e.g., arms/hands or legs/feet), where the actuation is designed to simulate more realistic and challenging patient movement, both voluntary and involuntary, for scenarios such as gynecological exams or urinary catheter insertions. In a further example embodiment, the system can simulate the body being positioned in a lithotomy position for gynecological exams (e.g. the AR headset being attached to the speculum (be able to see the cervix)). This can be achieved using actively actuated joints (i.e. via motors/pneumatics or other such powered actuators) or passively actuated joints (i.e. unpowered via coupling/transmission/using passive elements) (including hybrid combinations of both) whose responses can be tuned to follow complex position-force relationships (variable stiffness/impedance/admittance). The actuation could be applied to PV elements (e.g., a PV head), physical elements (e.g., rubber legs or arms), PV overlay shells, or hybrid combinations. There are many such approaches to adding actuation to the core elements that are contemplated herein.

In a further example embodiment, a Mobile Physical-Virtual Patient Systems is provided. Any of the previously described embodiments, configurations, or hybrid combinations of PV, physical, or real simulated patients could be mounted on a mobile platform, or equipped with actuated legs, to allow realistic movement (e.g., translation, rotation, or walking) around the scenario space. This would support, for example, the simulation of a patient who is pacing, or moving in an agitated manner. There are many such approaches to adding mobility to the core elements of the invention that are contemplated herein.

In addition, other embodiments of the PVBP system are configured for veterinary applications. Accordingly, the body components of the system are configured to resemble that of animals, such as dogs, cats, horses, cows, etc.

FIG. 15A is an image that illustrates an example of side view of a deformable shell 200 used in the bed system 5 of FIG. 3, according to one embodiment. FIG. 15B is a cross-sectional view of the outer surface of the deformable shell 200 of FIG. 15A across multiple regions 202, 204 of the patient body, according to one embodiment. In one embodiment, the shell 200 is deformable with a first region 202 having a first level of deformity over a first portion (e.g. torso) of the patient’s body and a second region 204 having a second level of deformity over a second portion (e.g. stomach) of the patient’s body. In an example embodiment, the first region 202 is a torso region of the shell 200 with a lower level of deformity (harder shell) than the second region 204 that is a stomach region of the shell 200 with a higher level of deformity (softer shell). In an example embodiment, FIG. 15B depicts in one embodiment that the first region 202 includes hard shell 206 material whereas the second region 204 includes soft shell 208 material (e.g. in a gap 207 in the hard shell 206 material of the deformable shell 200 and/or adjacent the second region 204). In other embodiments, the shell 200 is a deformable hybrid shell where the hard shell can have more than one gap (e.g. gap

207) allowing for a mix between hard and soft shells. In still other embodiments, the interactive devices in the lower assembly **12b** include an air blower that directs air on the soft shell **208** material and/or through a gap to deform the soft shell **208** material and simulate a breathing torso. In some embodiments, gaps are provided in the hard shell **206**. In other embodiments, the soft materials **208** could also be mixed with the hard shell **206** material in certain regions of the shell **200**. In still other embodiments, some materials of the shell **20** are configured to turn from hard shell **206** material to soft shell **208** material, depending on factors (e.g. heat and/or low currents applied to the shell **200**).

FIG. **21A** is an image that illustrates an example of the shell **800** of FIG. **2** with one or more dynamic images including a human venous system **802**, according to an embodiment. FIG. **21B** is an image that illustrates an example of the shell **800** of FIG. **2** with one or more dynamic images including a human skeletal system **804**, according to an embodiment. In an embodiment, the imaging devices **20** are configured to render the one or more dynamic images including the underlying venous system **802** and/or underlying organ **803** structures of the patient's body and/or one or more underlying bone structures (e.g. skeletal system **804**) of the patient's body. In still other embodiments, one or more of color tone and/or ability to change and add different gradients could also be displayed with the dynamic images. Although FIGS. **21A-21B** depict human venous system and/or human skeletal system, the embodiments of the invention are not limited to this particular embodiment and can depict non-human venous system, non-human skeletal systems, etc. In yet another embodiment, the computing unit **16** and imaging unit **20** are configured to project the underlying venous system and/or skeletal system based on one or more parameters (e.g. length, width, thickness, etc) of the shell **10** and thus, the projected venous system and/or skeletal system are sized based on the size of the shell **10**.

FIG. **24** is an image that illustrates an example of microcapsules **1006** within the outer surface **1002** of the shell **1000** of FIG. **2** to change a reflective property of the shell, according to an embodiment. In one embodiment, an example of the effect achieved by the microcapsules **1006** is disclosed in U.S. Pat. No. 10,321,107, which is incorporated by reference herein. In some embodiments, the microcapsules **1006** are embedded in the outer surface **1002** (or inner surface, see embodiments discussed below with respect to FIGS. **33-34**) of the shell **1000**. The microcapsules **1006** are configured to change a reflective property of the outer surface **1002** (or inner surface, see embodiments discussed below with respect to FIGS. **33-34**). of the shell **1000** based on a signal received from the computing unit **16**. In an example embodiment, the microcapsules **1006** operate similar to an E-ink system (e.g. Kindle®) and based on the signal received from the computing **16**, vary the reflective property (e.g. brightness or color) of the outer surface **1002** to create one or more dynamic images. In one example embodiment, the microcapsules **1006** create the dynamic images with or without assistance of the imaging devices **20**. In one embodiment, some of the dynamic images on the outer surface of the shell **1000** are provided by the microcapsules **1006** and other dynamic images on the outer surface of the shell **1000** are provided by the imaging devices **20**. In an example embodiment, the described system depends on added light (using the projectors) but does not leverage the light that is already there in the environment. Consequently, in this embodiment, it may need a dark room which may cause the dynamic images to "glow" compared to the environment. In one embodiment, the microcapsules **1006**

embedded in the surface changes the reflective properties of the surface without emitting any light. In an example embodiment, for the patient bed, the projectors could still act as a backlight if needed, but that the surface reflectance parameters would be controlled by the computer unit **16** and microcapsules **1006**. This could be tuned to realistic reflectance properties of the surface to match the material properties of the simulated patient (e.g., skin, wounds, clothes). In yet another embodiment, this could extend to more than just RGB light reflectance but include sub-surface scattering, realistic 3D wound layers, visible blood capillaries underneath the outer skin layers, etc.

Although steps are depicted in FIG. **29**, in other embodiments, one or more steps, or portions thereof, are performed in a different order, or overlapping in time, in series or in parallel, or are omitted, or one or more additional steps are added, or the method is changed in some combination of ways. In step **1501**, the shell **10** is illuminated with the image units **20** to provide dynamic images viewable on the outer surface of the shell **10**. In one embodiment, in step **1501** a user provides user input through one or more input devices to activate the interactive simulation for medical training (e.g. selecting a difficulty level, AI level of the patient, etc.). In another embodiment, in step **1501** the computing unit **16** transmits one or more signals to the imaging devices **20** based on the module **17**, so that the imaging devices **20** transmit the dynamic images to the shell **10** and/or to the outer surface of the shell **10** (e.g. at different time increments). In an example embodiment, in step **1501** the computing unit **16** transmits the signal to the imaging devices **20** to transmit the dynamic image to the shell **10** based on any of the embodiments and/or examples discussed herein. In other embodiments, in step **1501** the computing unit **16** transmits one or more signals to output devices other than the imaging device **20** to provide output other than visual output (e.g. tactile display, aural/audio output devices, fluid reservoir **1206**, etc.)

In step **1502**, after the dynamic images are projected by the imaging devices **20** onto the shell **10** and/or outer surface of the shell **10**, the interface devices (e.g. sensor devices **22**, interactive devices **24**) receive data. In one embodiment, in step **1502** the interface devices receive data based on input from a user (e.g. touching the shell or skin, hovering within a proximal distance of the shell or skin, contacting a part of the body with medical equipment such as the stethoscope on the stomach/chest or the pulse oximeter on the finger, etc.). In an example embodiment, after step **1502** a physiological model of the patient is checked against the received data in step **1502** (e.g. pulse rate is checked with a pulse rate from a physiological model, SpO2 measured level is checked with a level from a physiological model, etc.) and based on this step the dynamic image on the shell **10** is modified (e.g. if the temperature of the patient is above a normal temperature in the physiological mode, the dynamic image on the shell **10** is modified to indicate a fever by changing the color of the skin, etc.).

In step **1504**, the computing unit **16** receives the data from the interactive devices in step **1502** and compares the received data with threshold data to indicate a change in the dynamic image and/or a change in movement of a physical part of the patient's body and/or a change in some parameter of the system. In one embodiment in step **1504**, the computing unit **16** determines whether a detected pressure from a sensor device **22** exceeds a pressure threshold indicating a change in the dynamic image (e.g. move eyes of patient, open mouth of patient, etc). In another embodiment, in step **1504**, the computing unit **16** determines whether medical

equipment (e.g. stethoscope) has engaged a certain region (e.g. chest) of the patient body so to change a parameter of the system (e.g. transmit a signal to the audio source adjacent the chest so that the stethoscope can detect an audio sound from the audio source). In one embodiment in step 5 **1504**, the computing unit **16** determines whether a detected pressure from a sensor device **22** exceeds a pressure threshold indicating that a part of the patient's body should be moved (e.g. transmit a signal to a motor to move the right arm from a first position to a second position to manifest 10 detection of the pressure). Other embodiments of step **1504** can be performed based on the teachings in other embodiments discussed herein. In an example embodiment, after step **1504** a behavioral model of the patient is checked against the received data in step **1504** (e.g. detected pressure 15 from pressure sensor **22** is compared with the behavioral model that provides the pressure threshold that indicates a certain action of the patient such as opening of the eyes, opening of mouth, etc.) and based on this step the dynamic image on the shell **10** is modified (e.g. if the pressure is 20 above the pressure threshold of the behavioral model, the dynamic image on the shell **10** is modified to open the mouth of the patient and/or open the eyes of the patient, etc.).

In step **1506**, it is determined whether to change the dynamic image and/or the movement of a physical part of 25 the patient's body and/or a parameter of the system, based on step **1504**. If the determination in step **1506** is affirmative, the method **1500** proceeds back to step **1501** and the dynamic image is changed and/or the physical part of the patient body is moved and/or the parameter of the system is 30 modified, as determined in step **1504**. If the determination in step **1506** is negative, the method **1500** proceeds to step **1508** and it is determined whether the system is still activated. If this determination is affirmative then the method **1500** proceeds back to step **1502** and if the determination is 35 negative the method **1500** ends at block **1510**.

FIG. **30** is a block diagram that illustrates a computer system **1600** upon which an embodiment of the invention may be implemented. Computer system **1600** includes a communication mechanism such as a bus **1610** for passing 40 information between other internal and external components of the computer system **1600**. Information is represented as physical signals of a measurable phenomenon, typically electric voltages, but including, in other embodiments, such phenomena as magnetic, electromagnetic, pressure, chemical, molecular atomic and quantum interactions. Computer system **1600**, or a portion thereof, constitutes a means for performing one or more steps of one or more methods 45 described herein.

A sequence of binary digits constitutes digital data that is 50 used to represent a number or code for a character. A bus **1610** includes many parallel conductors of information so that information is transferred quickly among devices coupled to the bus **1610**. One or more processors **1602** for processing information are coupled with the bus **1610**. A processor **1602** performs a set of operations on information. 55 The set of operations include bringing information in from the bus **1610** and placing information on the bus **1610**. The set of operations also typically include comparing two or more units of information, shifting positions of units of information, and combining two or more units of information, such as by addition or multiplication. A sequence of operations to be executed by the processor **1602** constitutes 60 computer instructions.

Computer system **1600** also includes a memory **1604** 65 coupled to bus **1610**. The memory **1604**, such as a random access memory (RAM) or other dynamic storage device,

stores information including computer instructions. Dynamic memory allows information stored therein to be changed by the computer system **1600**. RAM allows a unit of information stored at a location called a memory address to be stored and retrieved independently of information at neighboring addresses. The memory **1604** is also used by the processor **1602** to store temporary values during execution of computer instructions. The computer system **1600** also includes a read only memory (ROM) **1606** or other static storage device coupled to the bus **1610** for storing static information, including instructions, that is not changed by the computer system **1600**. Also coupled to bus **1610** is a non-volatile (persistent) storage device **1608**, such as a magnetic disk or optical disk, for storing information, including instructions, that persists even when the computer system **1600** is turned off or otherwise loses power.

Information, including instructions, is provided to the bus **1610** for use by the processor from an external input device **1612**, such as a keyboard containing alphanumeric keys 20 operated by a human user, or a sensor. A sensor detects conditions in its vicinity and transforms those detections into signals compatible with the signals used to represent information in computer system **1600**. Other external devices coupled to bus **1610**, used primarily for interacting with humans, include a display device **1614**, such as a cathode ray tube (CRT) or a liquid crystal display (LCD), for presenting images, and a pointing device **1616**, such as a mouse or a trackball or cursor direction keys, for controlling a position of a small cursor image presented on the display **1614** and 30 issuing commands associated with graphical elements presented on the display **1614**.

In the illustrated embodiment, special purpose hardware, such as an application specific integrated circuit (IC) **1620**, is coupled to bus **1610**. The special purpose hardware is configured to perform operations not performed by processor **1602** quickly enough for special purposes. Examples of application specific ICs include graphics accelerator cards for generating images for display **1614**, cryptographic boards for encrypting and decrypting messages sent over a network, speech recognition, and interfaces to special external devices, such as robotic arms and medical scanning equipment that repeatedly perform some complex sequence of operations that are more efficiently implemented in hardware. 45

Computer system **1600** also includes one or more instances of a communications interface **1670** coupled to bus **1610**. Communication interface **1670** provides a two-way communication coupling to a variety of external devices that operate with their own processors, such as printers, scanners and external disks. In general, the coupling is with a network link **1678** that is connected to a local network **1680** to which a variety of external devices with their own processors are connected. For example, communication interface **1670** may be a parallel port or a serial port or a universal serial bus (USB) port on a personal computer. In some embodiments, 55 communications interface **1670** is an integrated service digital network (ISDN) card or a digital subscriber line (DSL) card or a telephone modem that provides an information communication connection to a corresponding type of telephone line. In some embodiments, a communication interface **1670** is a cable modem that converts signals on bus **1610** into signals for a communication connection over a coaxial cable or into optical signals for a communication connection over a fiber optic cable. As another example, communications interface **1670** may be a local area network (LAN) card to provide a data communication connection to a compatible LAN, such as Ethernet. Wireless links may

also be implemented. Carrier waves, such as acoustic waves and electromagnetic waves, including radio, optical and infrared waves travel through space without wires or cables. Signals include man-made variations in amplitude, frequency, phase, polarization or other physical properties of carrier waves. For wireless links, the communications interface **1670** sends and receives electrical, acoustic or electromagnetic signals, including infrared and optical signals, that carry information streams, such as digital data.

The term computer-readable medium is used herein to refer to any medium that participates in providing information to processor **1602**, including instructions for execution. Such a medium may take many forms, including, but not limited to, non-volatile media, volatile media and transmission media. Non-volatile media include, for example, optical or magnetic disks, such as storage device **1608**. Volatile media include, for example, dynamic memory **1604**. Transmission media include, for example, coaxial cables, copper wire, fiber optic cables, and waves that travel through space without wires or cables, such as acoustic waves and electromagnetic waves, including radio, optical and infrared waves. The term computer-readable storage medium is used herein to refer to any medium that participates in providing information to processor **1602**, except for transmission media.

Common forms of computer-readable media include, for example, a floppy disk, a flexible disk, a hard disk, a magnetic tape, or any other magnetic medium, a compact disk ROM (CD-ROM), a digital video disk (DVD) or any other optical medium, punch cards, paper tape, or any other physical medium with patterns of holes, a RAM, a programmable ROM (PROM), an erasable PROM (EPROM), a FLASH-EPROM, or any other memory chip or cartridge, a carrier wave, or any other medium from which a computer can read. The term non-transitory computer-readable storage medium is used herein to refer to any medium that participates in providing information to processor **1602**, except for carrier waves and other signals.

Logic encoded in one or more tangible media includes one or both of processor instructions on a computer-readable storage media and special purpose hardware, such as ASIC* **1620**.

Network link **1678** typically provides information communication (e.g. wired or wireless using different protocols, such as WI-FI®, BLUETOOTH®, BLE®, IOT®, 5G®, etc.) through one or more networks to other devices that use or process the information. For example, network link **1678** may provide a connection through local network **1680** to a host computer **1682** or to equipment **1684** operated by an Internet Service Provider (ISP). ISP equipment **1684** in turn provides data communication services through the public, world-wide packet-switching communication network of networks now commonly referred to as the Internet **1690**. A computer called a server **1692** connected to the Internet provides a service in response to information received over the Internet. For example, server **1692** provides information representing video data for presentation at display **1614**.

The invention is related to the use of computer system **1600** for implementing the techniques described herein. According to one embodiment of the invention, those techniques are performed by computer system **1600** in response to processor **1602** executing one or more sequences of one or more instructions contained in memory **1604**. Such instructions, also called software and program code, may be read into memory **1604** from another computer-readable medium such as storage device **1608**. Execution of the sequences of instructions contained in memory **1604** causes

processor **1602** to perform the method steps described herein. In alternative embodiments, hardware, such as application specific integrated circuit **1620**, may be used in place of or in combination with software to implement the invention. Thus, embodiments of the invention are not limited to any specific combination of hardware and software.

The signals transmitted over network link **1678** and other networks through communications interface **1670**, carry information to and from computer system **1600**. Computer system **1600** can send and receive information, including program code, through the networks **1680**, **1690** among others, through network link **1678** and communications interface **1670**. In an example using the Internet **1690**, a server **1692** transmits program code for a particular application, requested by a message sent from computer **1600**, through Internet **1690**, ISP equipment **1684**, local network **1680** and communications interface **1670**. The received code may be executed by processor **1602** as it is received, or may be stored in storage device **1608** or other non-volatile storage for later execution, or both. In this manner, computer system **1600** may obtain application program code in the form of a signal on a carrier wave.

Various forms of computer readable media may be involved in carrying one or more sequence of instructions or data or both to processor **1602** for execution. For example, instructions and data may initially be carried on a magnetic disk of a remote computer such as host **1682**. The remote computer loads the instructions and data into its dynamic memory and sends the instructions and data over a telephone line using a modem. A modem local to the computer system **1600** receives the instructions and data on a telephone line and uses an infra-red transmitter to convert the instructions and data to a signal on an infra-red carrier wave serving as the network link **1678**. An infrared detector serving as communications interface **1670** receives the instructions and data carried in the infrared signal and places information representing the instructions and data onto bus **1610**. Bus **1610** carries the information to memory **1604** from which processor **1602** retrieves and executes the instructions using some of the data sent with the instructions. The instructions and data received in memory **1604** may optionally be stored on storage device **1608**, either before or after execution by the processor **1602**.

FIG. **31** illustrates a chip set **1700** upon which an embodiment of the invention may be implemented. Chip set **1700** is programmed to perform one or more steps of a method described herein and includes, for instance, the processor and memory components described with respect to FIG. **16** incorporated in one or more physical packages (e.g., chips). By way of example, a physical package includes an arrangement of one or more materials, components, and/or wires on a structural assembly (e.g., a baseboard) to provide one or more characteristics such as physical strength, conservation of size, and/or limitation of electrical interaction. It is contemplated that in certain embodiments the chip set can be implemented in a single chip. Chip set **1700**, or a portion thereof, constitutes a means for performing one or more steps of a method described herein.

In one embodiment, the chip set **1700** includes a communication mechanism such as a bus **1701** for passing information among the components of the chip set **1700**. A processor **1703** has connectivity to the bus **1701** to execute instructions and process information stored in, for example, a memory **1705**. The processor **1703** may include one or more processing cores with each core configured to perform independently. A multi-core processor enables multiprocessing within a single physical package. Examples of a multi-

core processor include two, four, eight, or greater numbers of processing cores. Alternatively or in addition, the processor **1703** may include one or more microprocessors configured in tandem via the bus **1701** to enable independent execution of instructions, pipelining, and multithreading. The processor **1703** may also be accompanied with one or more specialized components to perform certain processing functions and tasks such as one or more digital signal processors (DSP) **1707**, or one or more application-specific integrated circuits (ASIC) **1709**. A DSP **1707** typically is configured to process real-world signals (e.g., sound) in real time independently of the processor **1703**. Similarly, an ASIC **1709** can be configured to performed specialized functions not easily performed by a general purposed processor. Other specialized components to aid in performing the inventive functions described herein include one or more field programmable gate arrays (FPGA) (not shown), one or more controllers (not shown), or one or more other special-purpose computer chips.

The processor **1703** and accompanying components have connectivity to the memory **1705** via the bus **1701**. The memory **1705** includes both dynamic memory (e.g., RAM, magnetic disk, writable optical disk, etc.) and static memory (e.g., ROM, CD-ROM, etc.) for storing executable instructions that when executed perform one or more steps of a method described herein. The memory **1705** also stores the data associated with or generated by the execution of one or more steps of the methods described herein.

FIG. **32** is a diagram of exemplary components of a mobile device **1800** (e.g., cell phone handset) for communications, which is capable of operating in the system of FIG. **2C**, according to one embodiment. In some embodiments, mobile device **1801**, or a portion thereof, constitutes a means for performing one or more steps described herein. Generally, a radio receiver is often defined in terms of front-end and back-end characteristics. The front-end of the receiver encompasses all of the Radio Frequency (RF) circuitry whereas the back-end encompasses all of the base-band processing circuitry. As used in this application, the term “circuitry” refers to both: (1) hardware-only implementations (such as implementations in only analog and/or digital circuitry), and (2) to combinations of circuitry and software (and/or firmware) (such as, if applicable to the particular context, to a combination of processor(s), including digital signal processor(s), software, and memory(ies) that work together to cause an apparatus, such as a mobile phone or server, to perform various functions). This definition of “circuitry” applies to all uses of this term in this application, including in any claims. As a further example, as used in this application and if applicable to the particular context, the term “circuitry” would also cover an implementation of merely a processor (or multiple processors) and its (or their) accompanying software/or firmware. The term “circuitry” would also cover if applicable to the particular context, for example, a baseband integrated circuit or applications processor integrated circuit in a mobile phone or a similar integrated circuit in a cellular network device or other network devices.

Pertinent internal components of the telephone include a Main Control Unit (MCU) **1803**, a Digital Signal Processor (DSP) **1805**, and a receiver/transmitter unit including a microphone gain control unit and a speaker gain control unit. A main display unit **1807** provides a display to the user in support of various applications and mobile device functions that perform or support the steps as described herein. The display **1807** includes display circuitry configured to display at least a portion of a user interface of the mobile device

(e.g., mobile telephone). Additionally, the display **1807** and display circuitry are configured to facilitate user control of at least some functions of the mobile device. An audio function circuitry **1809** includes a microphone **1811** and microphone amplifier that amplifies the speech signal output from the microphone **1811**. The amplified speech signal output from the microphone **1811** is fed to a coder/decoder (CODEC) **1813**.

A radio section **1815** amplifies power and converts frequency in order to communicate with a base station, which is included in a mobile communication system, via antenna **1817**. The power amplifier (PA) **1819** and the transmitter/modulation circuitry are operationally responsive to the MCU **1803**, with an output from the PA **1819** coupled to the duplexer **1821** or circulator or antenna switch, as known in the art. The PA **1819** also couples to a battery interface and power control unit **1820**.

In use, a user of mobile device **1801** speaks into the microphone **1811** and his or her voice along with any detected background noise is converted into an analog voltage. The analog voltage is then converted into a digital signal through the Analog to Digital Converter (ADC) **1823**. The control unit **1803** routes the digital signal into the DSP **1805** for processing therein, such as speech encoding, channel encoding, encrypting, and interleaving. In one embodiment, the processed voice signals are encoded, by units not separately shown, using a cellular transmission protocol such as enhanced data rates for global evolution (EDGE), general packet radio service (GPRS), global system for mobile communications (GSM), Internet protocol multimedia subsystem (IMS), universal mobile telecommunications system (UMTS), etc., as well as any other suitable wireless medium, e.g., microwave access (WiMAX), Long Term Evolution (LTE) networks, code division multiple access (CDMA), wideband code division multiple access (WCDMA), wireless fidelity (WiFi), satellite, and the like, or any combination thereof.

The encoded signals are then routed to an equalizer **1825** for compensation of any frequency-dependent impairments that occur during transmission through the air such as phase and amplitude distortion. After equalizing the bit stream, the modulator **1827** combines the signal with a RF signal generated in the RF interface **1829**. The modulator **1827** generates a sine wave by way of frequency or phase modulation. In order to prepare the signal for transmission, an up-converter **1831** combines the sine wave output from the modulator **1827** with another sine wave generated by a synthesizer **1833** to achieve the desired frequency of transmission. The signal is then sent through a PA **1819** to increase the signal to an appropriate power level. In practical systems, the PA **1819** acts as a variable gain amplifier whose gain is controlled by the DSP **1805** from information received from a network base station. The signal is then filtered within the duplexer **1821** and optionally sent to an antenna coupler **1835** to match impedances to provide maximum power transfer. Finally, the signal is transmitted via antenna **1817** to a local base station. An automatic gain control (AGC) can be supplied to control the gain of the final stages of the receiver. The signals may be forwarded from there to a remote telephone which may be another cellular telephone, any other mobile phone or a land-line connected to a Public Switched Telephone Network (PSTN), or other telephony networks.

Voice signals transmitted to the mobile device **1801** are received via antenna **1817** and immediately amplified by a low noise amplifier (LNA) **1837**. A down-converter **1839** lowers the carrier frequency while the demodulator **1841**

strips away the RF leaving only a digital bit stream. The signal then goes through the equalizer **1825** and is processed by the DSP **1805**. A Digital to Analog Converter (DAC) **1843** converts the signal and the resulting output is transmitted to the user through the speaker **1845**, all under control of a Main Control Unit (MCU) **1803** which can be implemented as a Central Processing Unit (CPU) (not shown).

The MCU **1803** receives various signals including input signals from the keyboard **1847**. The keyboard **1847** and/or the MCU **1803** in combination with other user input components (e.g., the microphone **1811**) comprise a user interface circuitry for managing user input. The MCU **1803** runs a user interface software to facilitate user control of at least some functions of the mobile device **1801** as described herein. The MCU **1803** also delivers a display command and a switch command to the display **1807** and to the speech output switching controller, respectively. Further, the MCU **1803** exchanges information with the DSP **1805** and can access an optionally incorporated SIM card **1849** and a memory **1851**. In addition, the MCU **1803** executes various control functions required of the mobile device. The DSP **1805** may, depending upon the implementation, perform any of a variety of conventional digital processing functions on the voice signals. Additionally, DSP **1805** determines the background noise level of the local environment from the signals detected by microphone **1811** and sets the gain of microphone **1811** to a level selected to compensate for the natural tendency of the user of the mobile device **1801**.

The CODEC **1813** includes the ADC **1823** and DAC **1843**. The memory **1851** stores various data including call incoming tone data and is capable of storing other data including music data received via, e.g., the global Internet. The software module could reside in RAM memory, flash memory, registers, or any other form of writable storage medium known in the art. The memory device **1851** may be, but not limited to, a single memory, CD, DVD, ROM, RAM, EEPROM, optical storage, magnetic disk storage, flash memory storage, or any other non-volatile storage medium capable of storing digital data.

An optionally incorporated SIM card **1849** carries, for instance, important information, such as the cellular phone number, the carrier supplying service, subscription details, and security information. The SIM card **1849** serves primarily to identify the mobile device **1801** on a radio network. The card **1849** also contains a memory for storing a personal telephone number registry, text messages, and user specific mobile device settings.

In some embodiments, the mobile device **1801** includes a digital camera comprising an array of optical detectors, such as charge coupled device (CCD) array **1865**. The output of the array is image data that is transferred to the MCU for further processing or storage in the memory **1851** or both. In the illustrated embodiment, the light impinges on the optical array through a lens **1863**, such as a pin-hole lens or a material lens made of an optical grade glass or plastic material. In the illustrated embodiment, the mobile device **1801** includes a light source **1861**, such as a LED to illuminate a subject for capture by the optical array, e.g., CCD **1865**. The light source is powered by the battery interface and power control module **1820** and controlled by the MCU **1803** based on instructions stored or loaded into the MCU **1803**.

It should be understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application.

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What is claimed is:

1. A patient simulation system for medical training, comprising:

a shell comprising a physical anatomical model of at least a portion of an exterior surface of a patient's body, the shell adapted to be illuminated to provide one or more dynamic images viewable on an outer surface of the shell;

an image system comprising one or more image units adapted to render the one or more dynamic images viewable on the shell;

one or more interface devices located about the patient system to receive input and/or provide output; and one or more computing units in communication with the one or more image units and the one or more interface devices, the computing units adapted to provide an interactive simulation for medical training;

wherein

a simulated layer of skin is placed over the outer surface of the shell, wherein the simulated layer of skin has one or more of a temperature, a texture and a softness corresponding to a respective temperature, a respective texture, and a respective softness of real skin and wherein the simulated layer of skin is semi-transparent or opaque such that the simulated layer of skin is configured to display the dynamic images from the one or more image units.

2. The patient simulation system of claim 1, wherein the shell is deformable with a first region having a first level of deformity over a first portion of the patient's body and a second region having a second level of deformity over the second portion of the patient's body.

3. The patient simulation system of claim 2, wherein the first level of deformity is based on a hard shell material in the first region and the second level of deformity is based on a soft shell material in the second region.

4. The patient simulation system of claim 3, wherein the shell comprises the hard shell material and defines one or more gaps adjacent the second region to position the soft shell material and wherein the interface device comprises an air blower configured to direct air into the one or more gaps to deform the soft shell material and simulate a breathing patient on an undersurface of the second region of the shell to provide the second level of deformity.

5. The patient system of claim 1, wherein the shell is a patient virtual overlay adapted for overlaying a replica or real body part.

6. The patient system of claim 5, wherein the system comprises a mannequin replicating a patient body comprising a shell of at least one body part.

7. The patient system of claim 1, wherein the shell comprises one or more interchangeable parts and wherein each interchangeable part includes identifying indicia such that the one or more interface devices are configured to read the identifying indicia when the interchangeable part is connected to the shell and further configured to transmit a signal to the computing unit with the read identifying indicia.

8. The patient simulation system of claim 7, wherein the identifying indicia is one of an optical tag or RFID (Radio Frequency Identification) tag and wherein the interface device is a reader of the one of the optical tag and RFID tag.

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