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(54) **INTUITIVE CONTROL OF PORTABLE DATA DISPLAYS**

(75) Inventors: **Sina Fateh**, Sunnyvale, CA (US); **James F. Flack**, Los Alto Hills, CA (US); **Arthur L. Zwern**, Sunnyvale, CA (US)

(73) Assignee: **Rembrandt Portable Display Technologies, LP**, Arlington, VA (US)

(*) Notice: This patent is subject to a terminal disclaimer.

(21) Appl. No.: **12/574,607**

(22) Filed: **Oct. 6, 2009**

Related U.S. Patent Documents

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(64) Patent No.: **6,184,847**
Issued: **Feb. 6, 2001**
Appl. No.: **09/404,051**
Filed: **Sep. 22, 1999**

U.S. Applications:
(63) Continuation-in-part of application No. 09/264,799, filed on Mar. 9, 1999, now Pat. No. 6,084,556, which is a continuation of application No. 09/235,096, filed on Jan. 21, 1999, now Pat. No. 6,127,990, which is a continuation of application No. 08/563,525, filed on Nov. 28, 1995, now abandoned, said application No. 09/404,051 is a continuation-in-part of application No. 09/373,186, filed on Aug. 12, 1999, now Pat. No. 6,359,603, which is a continuation of application No. 09/235,096, which is a continuation of application No. 08/563,525.

(60) Provisional application No. 60/101,433, filed on Sep. 22, 1998.

(51) **Int. Cl.**
G09G 5/00 (2006.01)

(52) **U.S. Cl.** **345/8**; 715/863; 715/729

(58) **Field of Classification Search** 345/7–9, 345/156–158; 715/863
See application file for complete search history.

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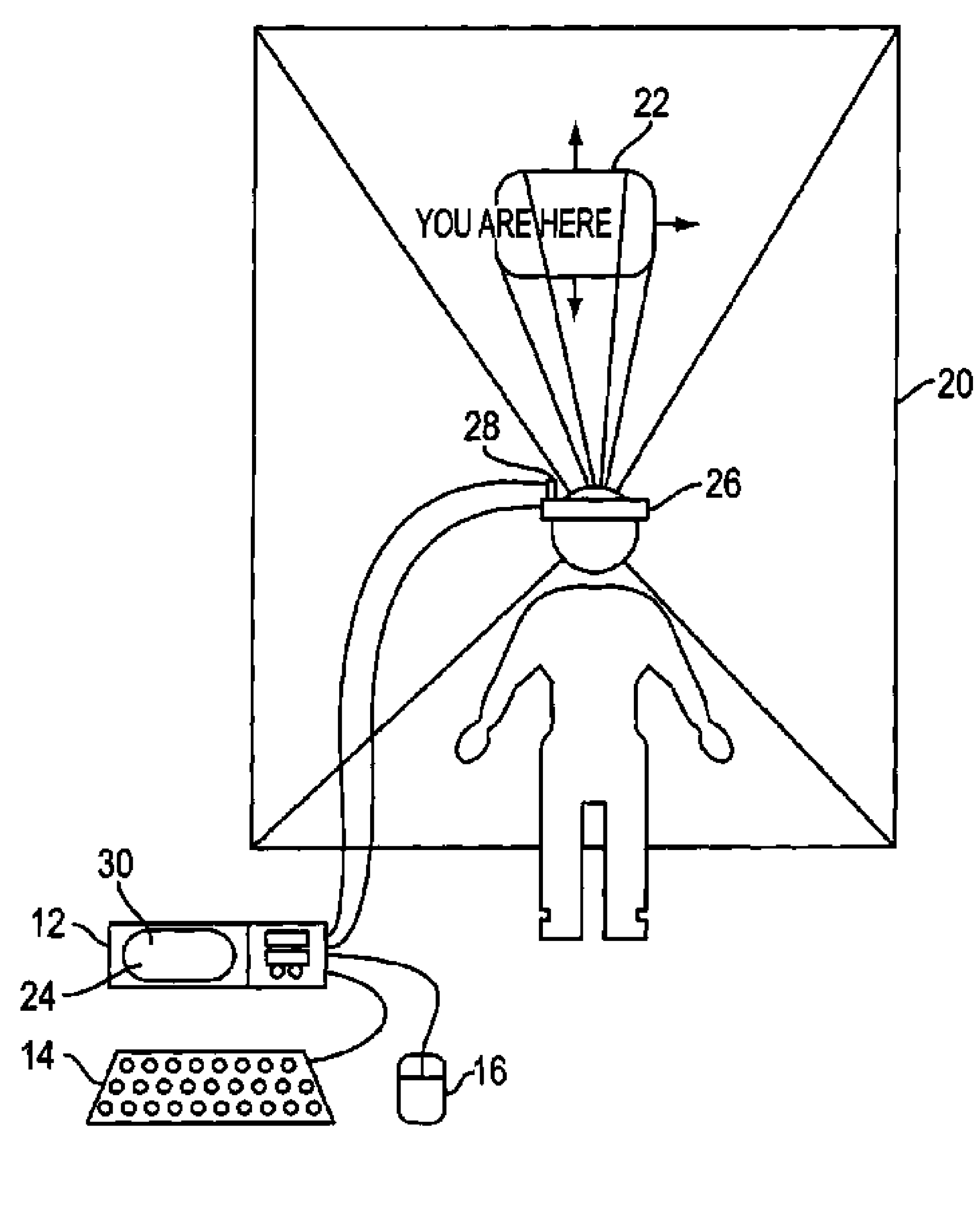
Primary Examiner — Regina Liang
(74) *Attorney, Agent, or Firm* — Schnader Harrison Segal & Lewis LLP

(57) **ABSTRACT**

A virtual computer monitor is described which enables instantaneous and intuitive visual access to large amounts of visual data by providing the user with a large display projected virtually in front of the user. The user wears a head-mounted display or holds a portable display containing a head-tracker or other motion tracker, which together allow the user to position an instantaneous viewport provided by the display at any position within the large virtual display by turning to look in the desired direction. The instantaneous viewport further includes a mouse pointer, which may be positioned by turning the user's head or moving the portable display, and which may be further positioned using a mouse or analogous control device. A particular advantage of the virtual computer monitor is intuitive access to enlarged computer output for visually-impaired individuals.

21 Claims, 11 Drawing Sheets



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(screenshots and transcription of audio associated with video are provided).

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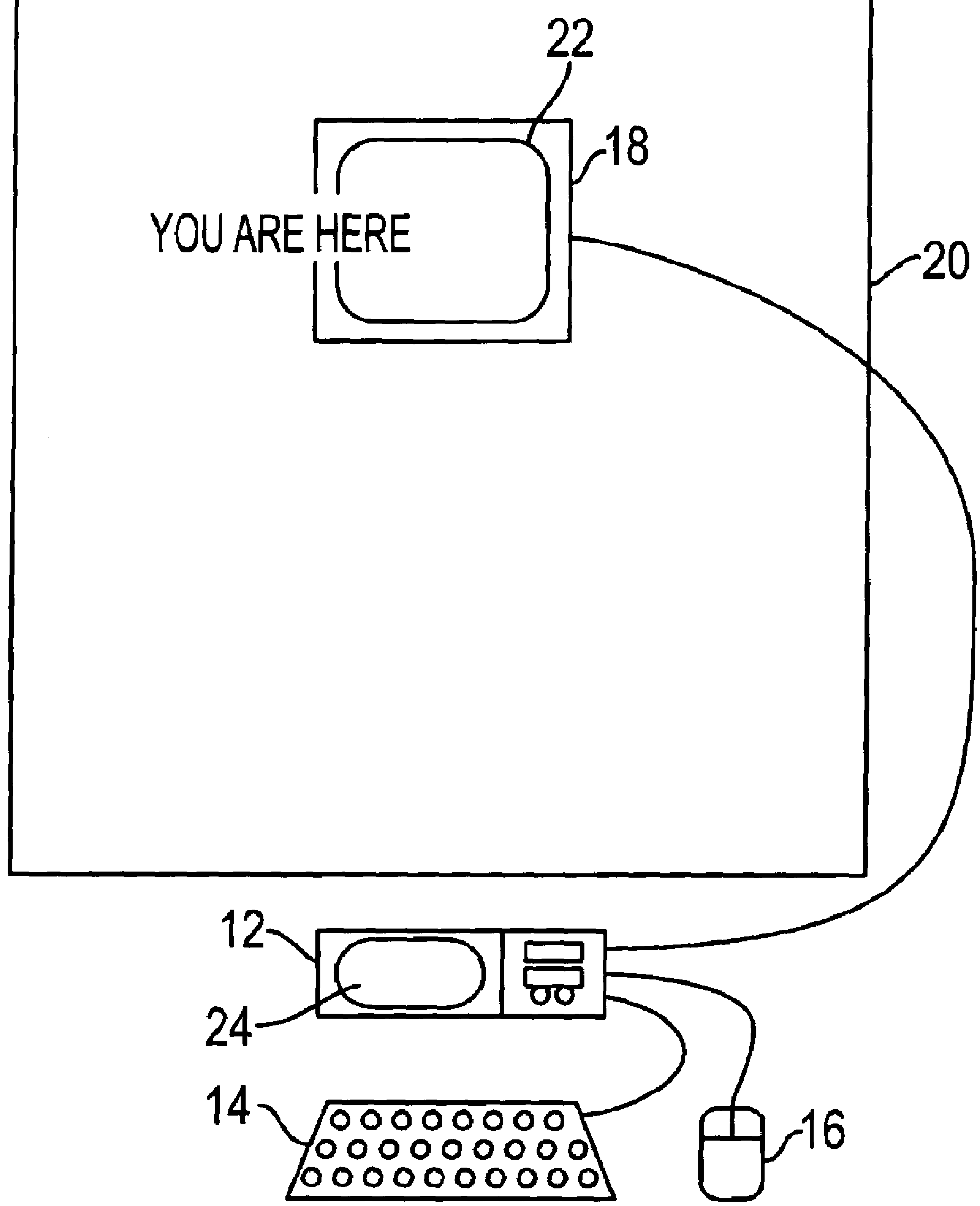


FIG. 1

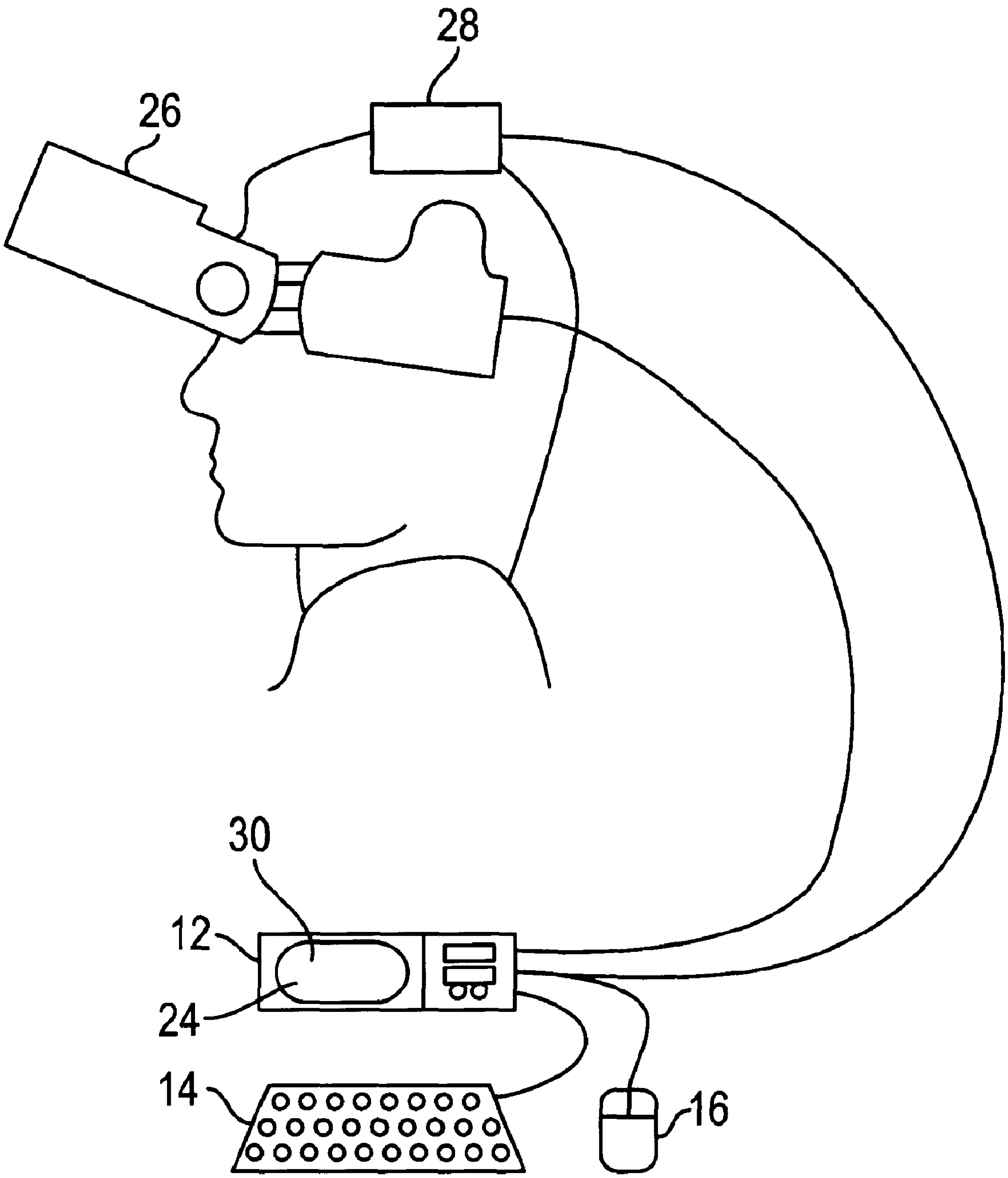


FIG. 2

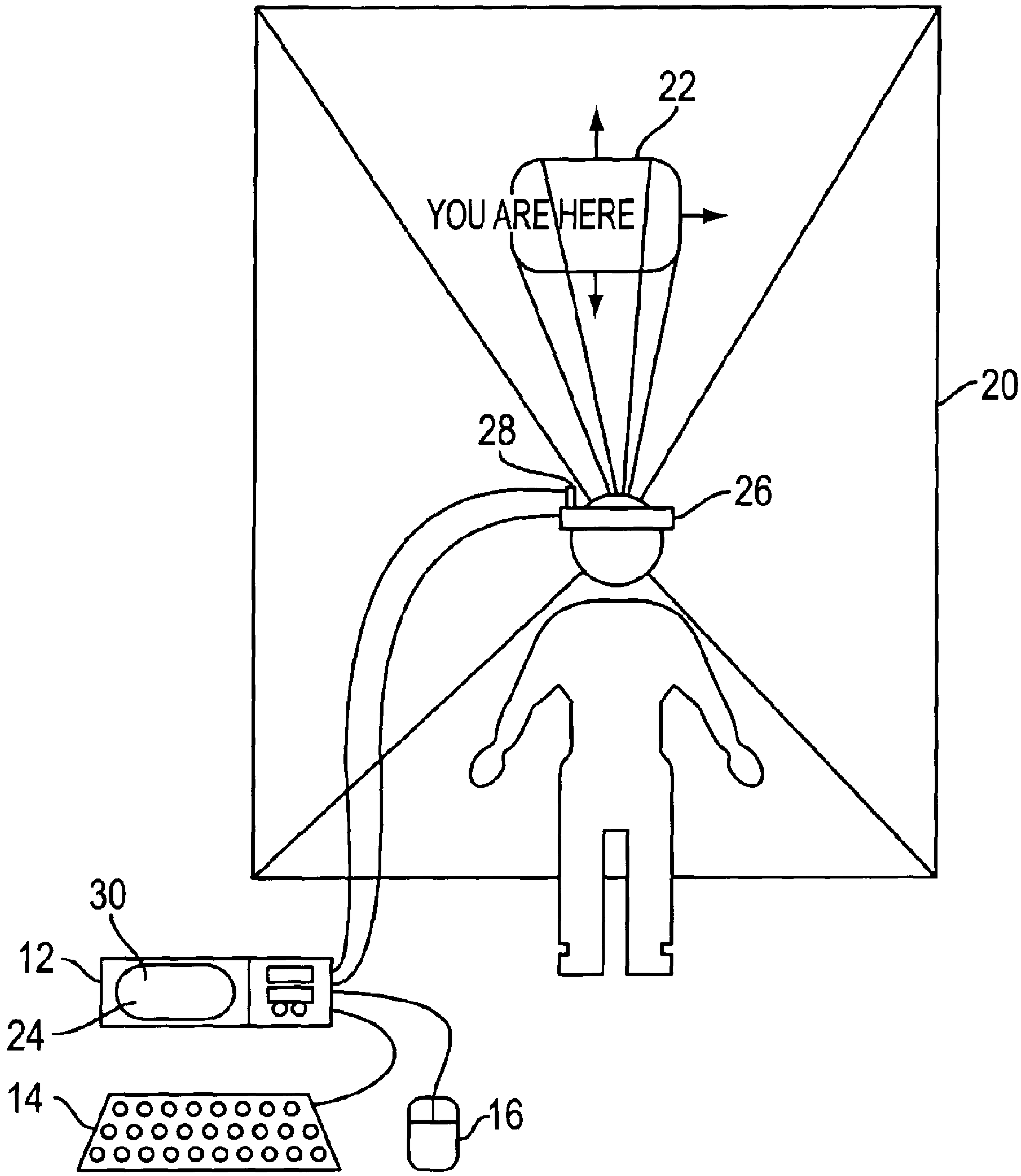
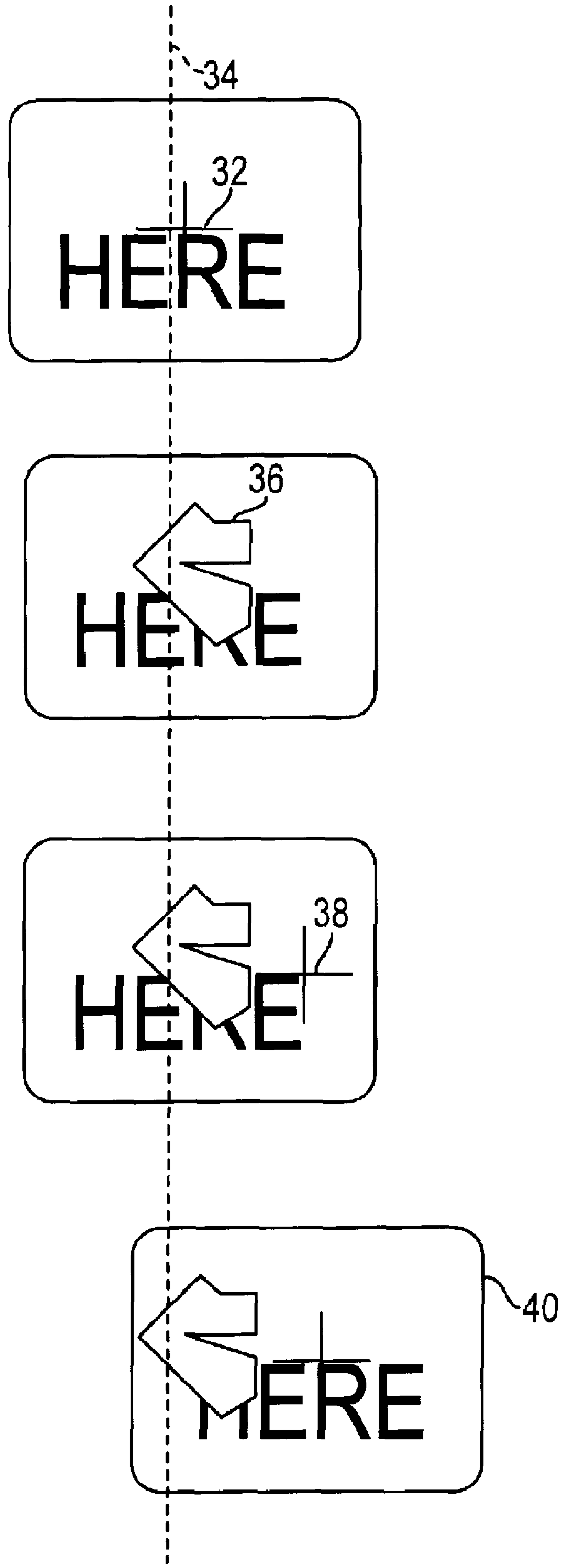


FIG. 3



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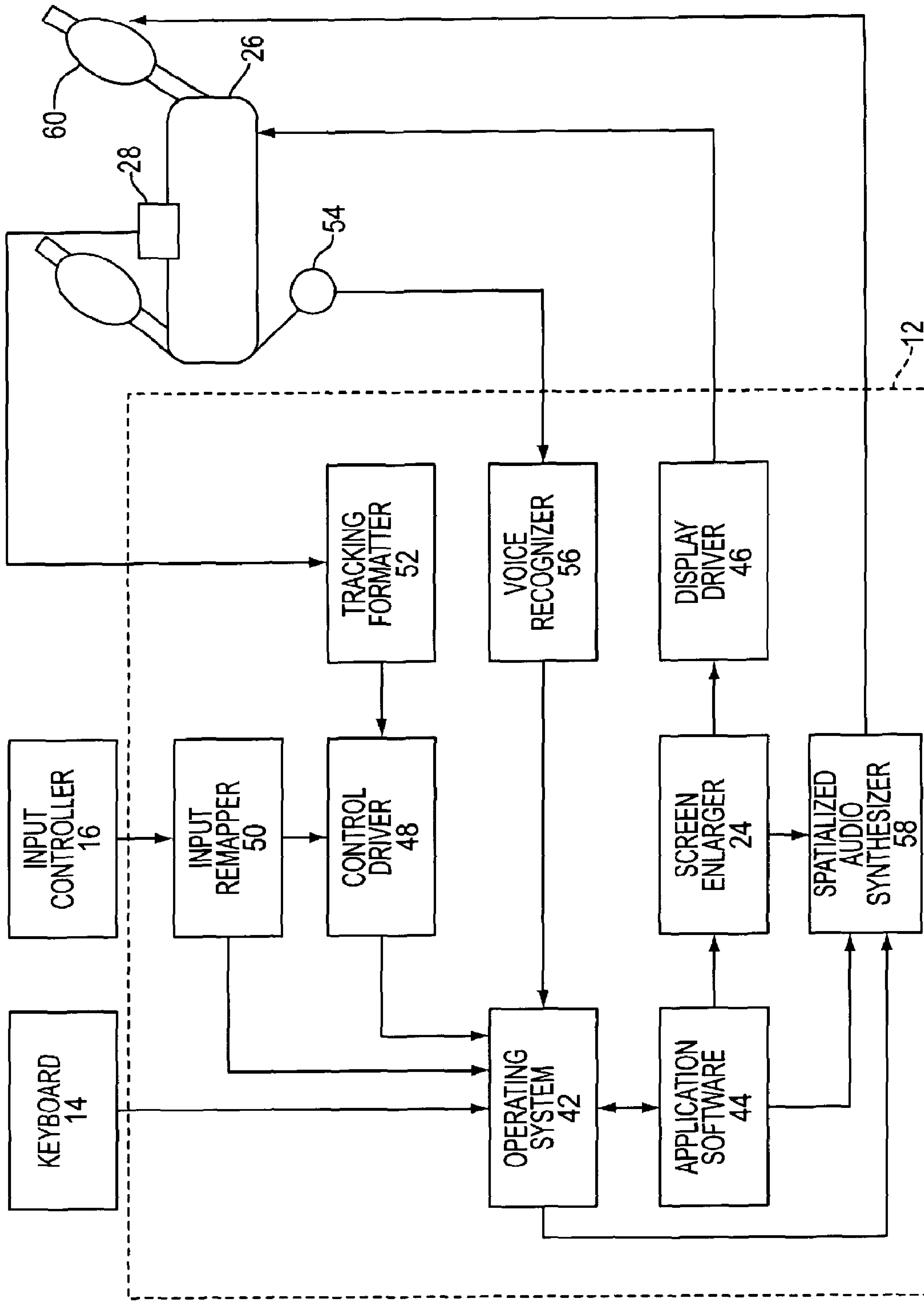
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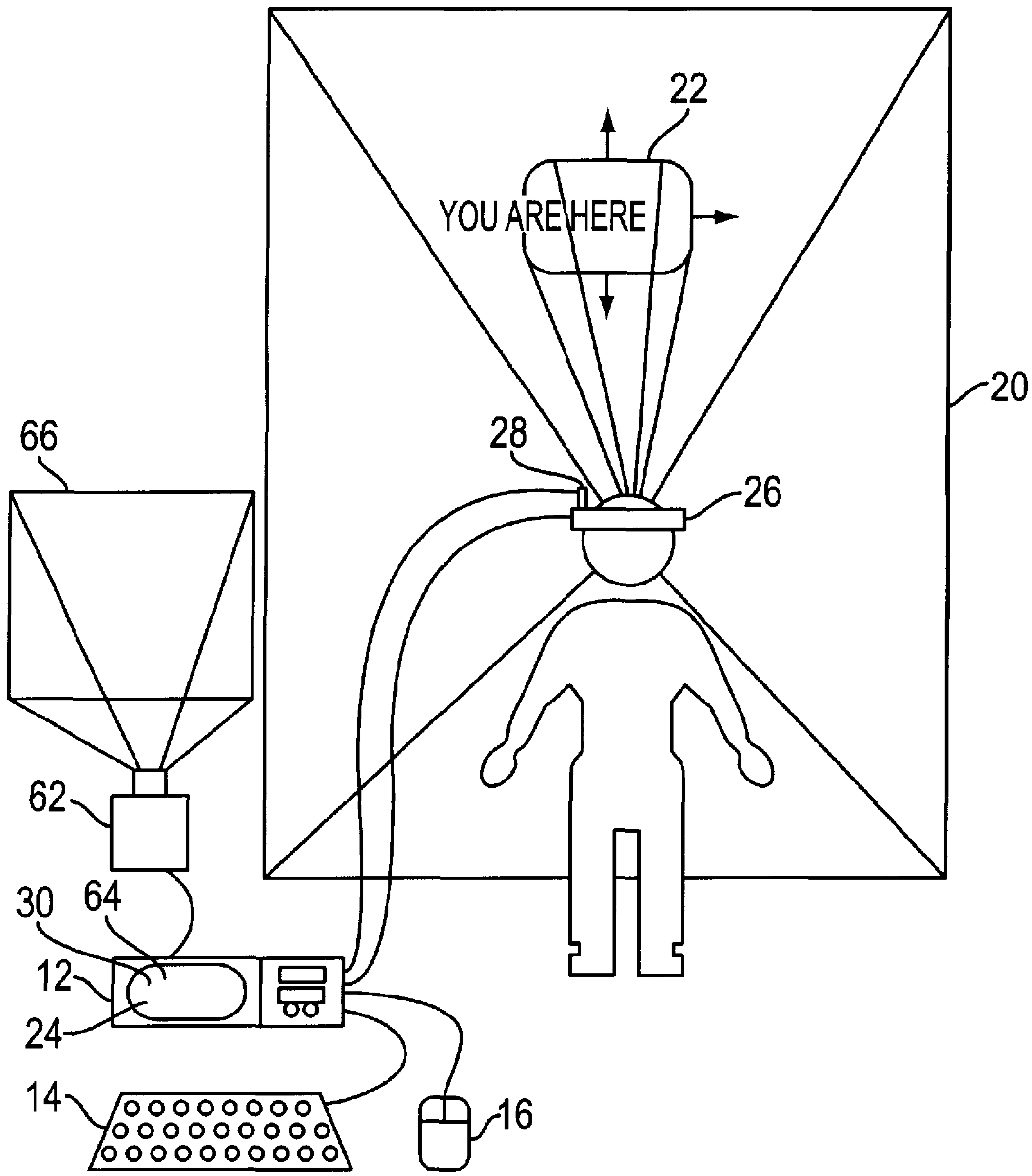
28
26
54
12
KEYBOARD 14
INPUT CONTROLLER 16
INPUT REMAPPER 50
CONTROL DRIVER 48
TRACKING FORMATTER 52
OPERATING SYSTEM 42
VOICE RECOGNIZER 56
APPLICATION SOFTWARE 44
SCREEN ENLARGER 24
DISPLAY DRIVER 46
SPATIALIZED AUDIO SYNTHESIZER 58

FIG. 5



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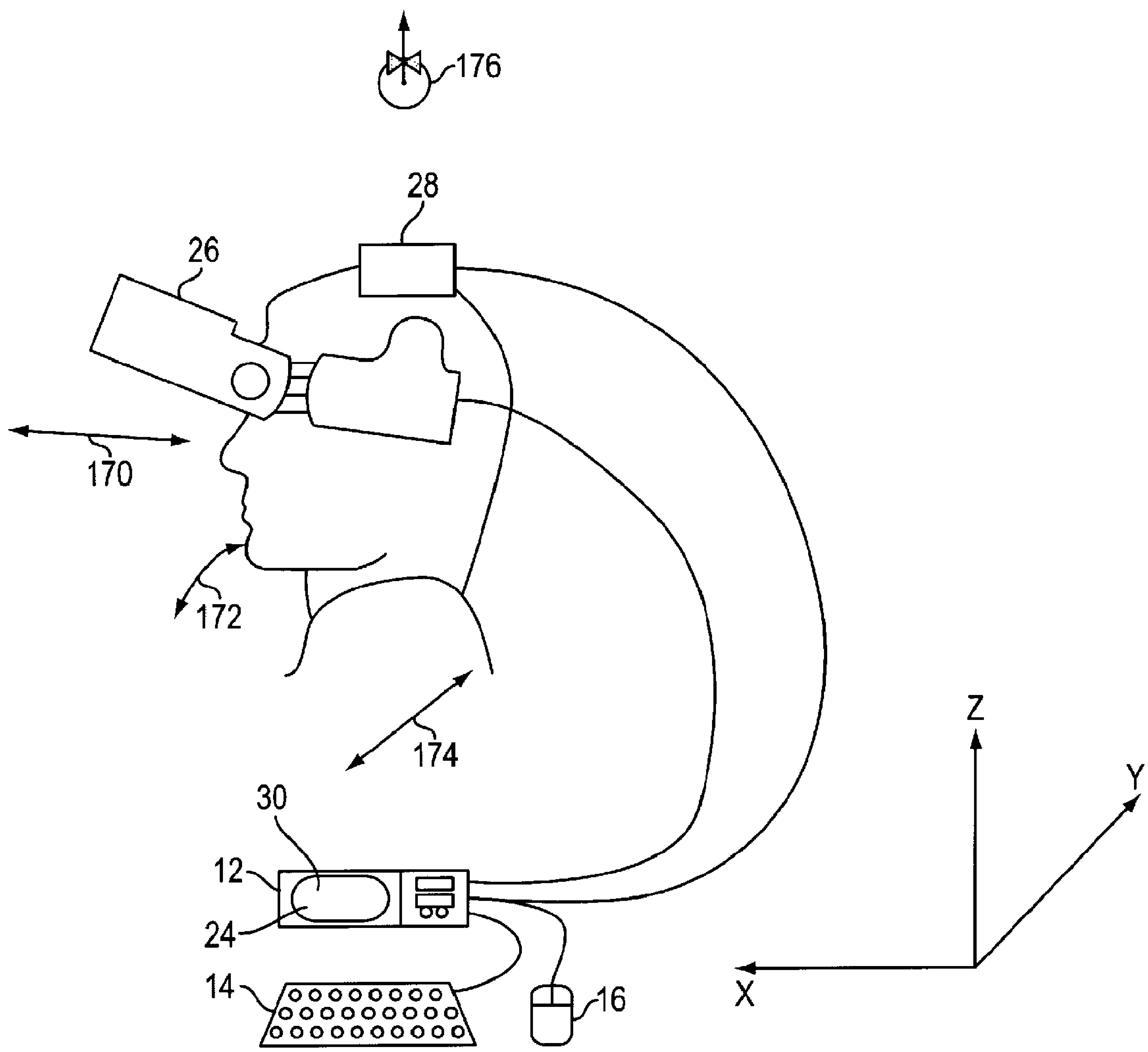

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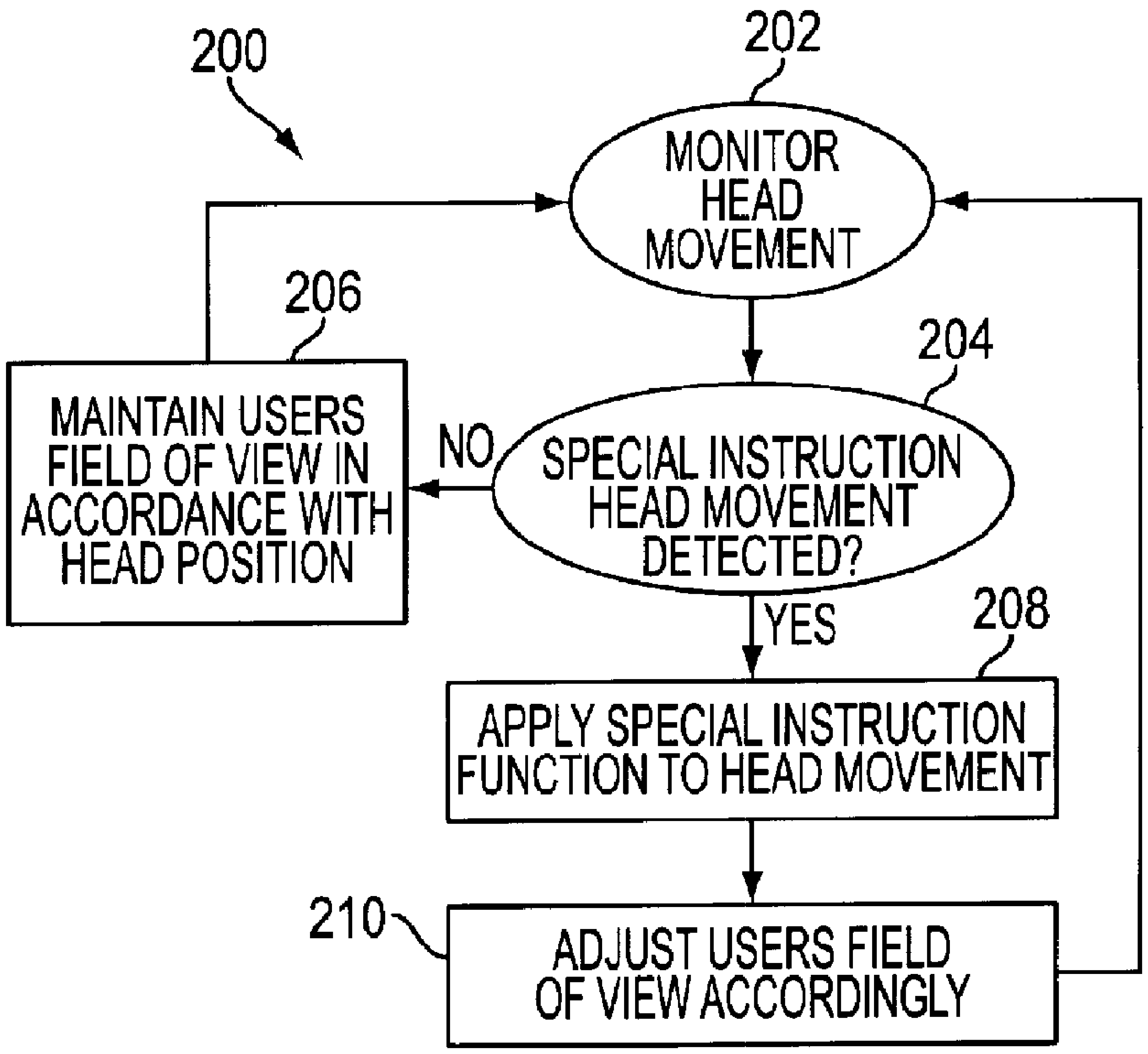
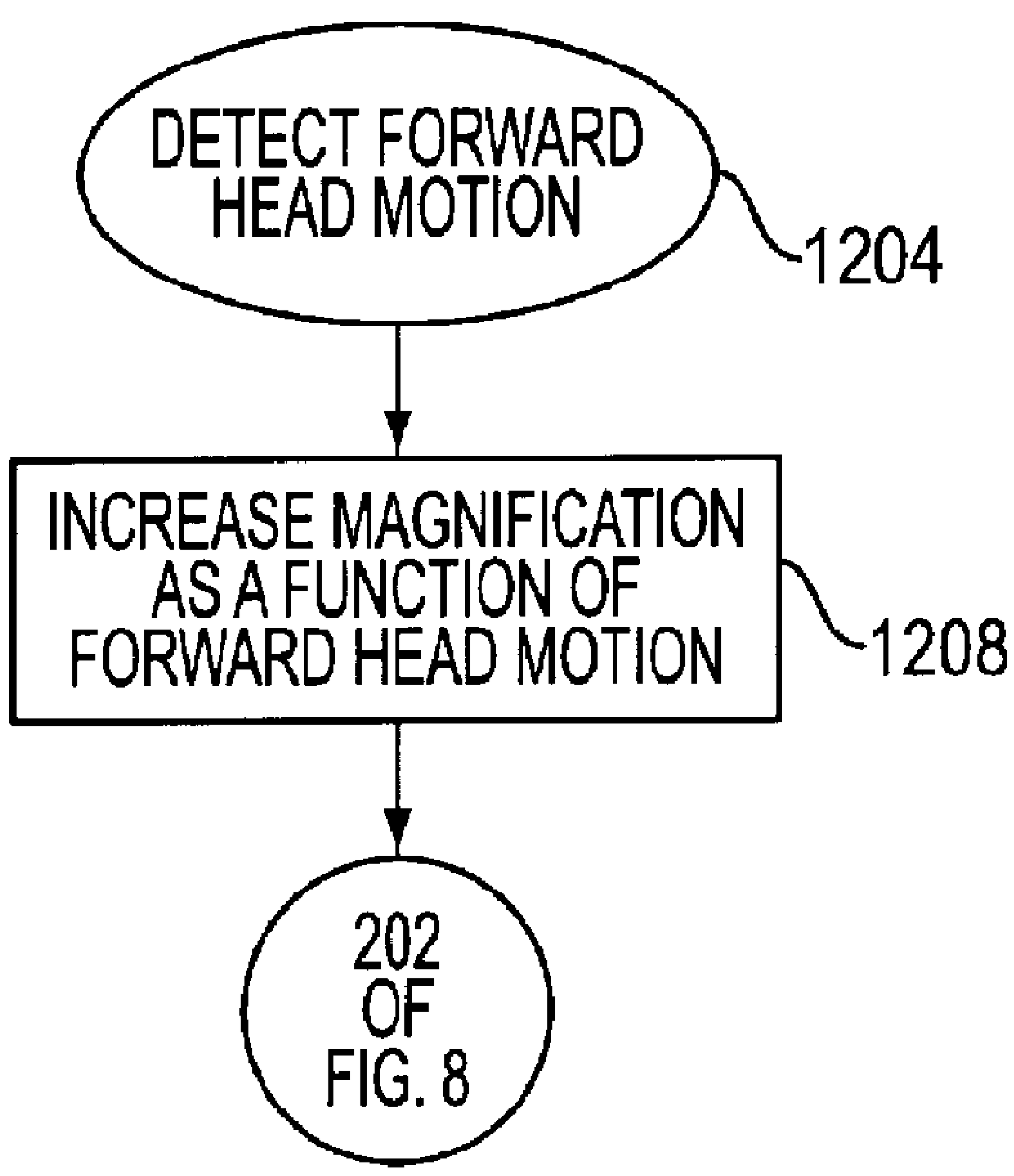


FIG. 8



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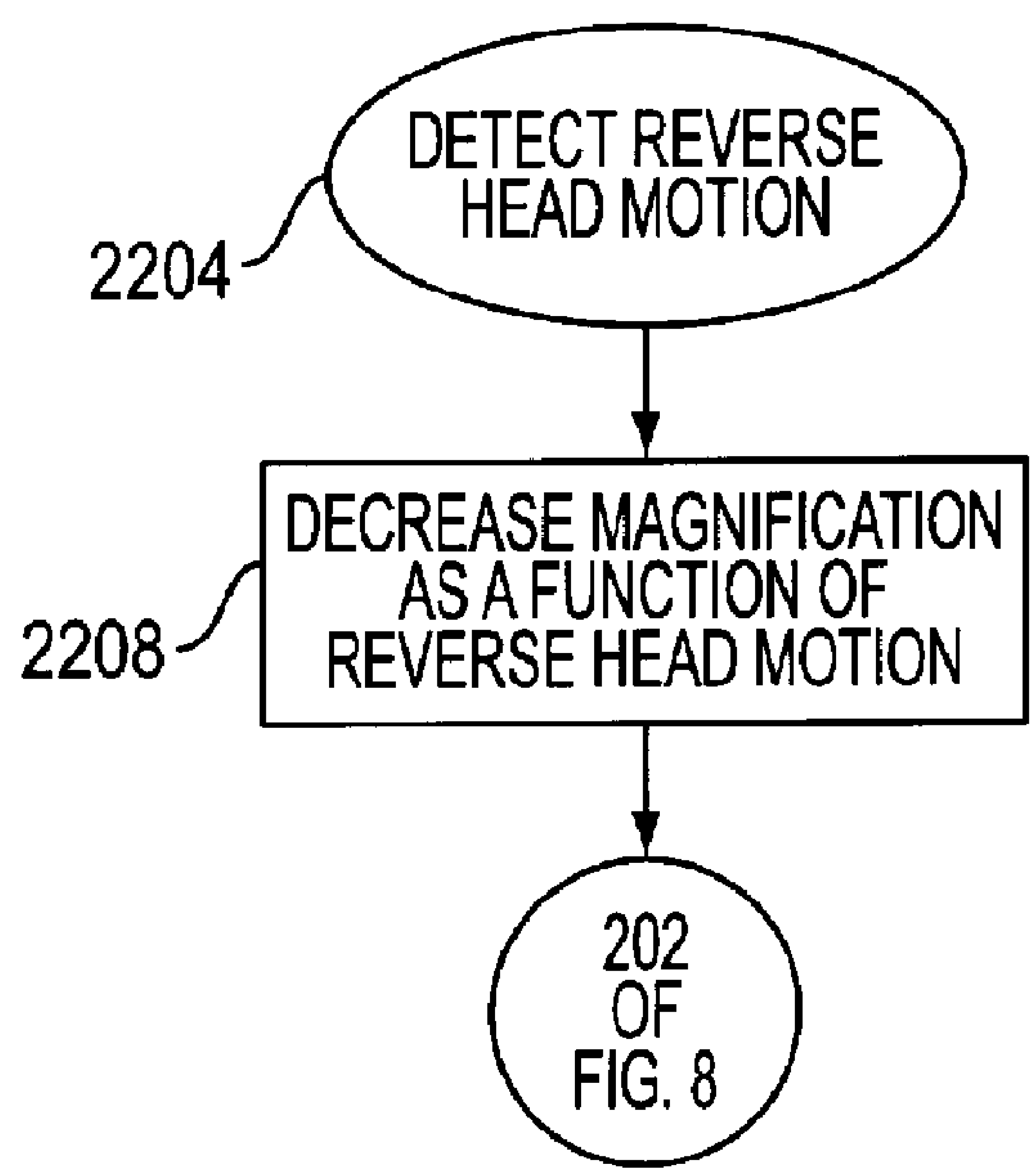


FIG. 10

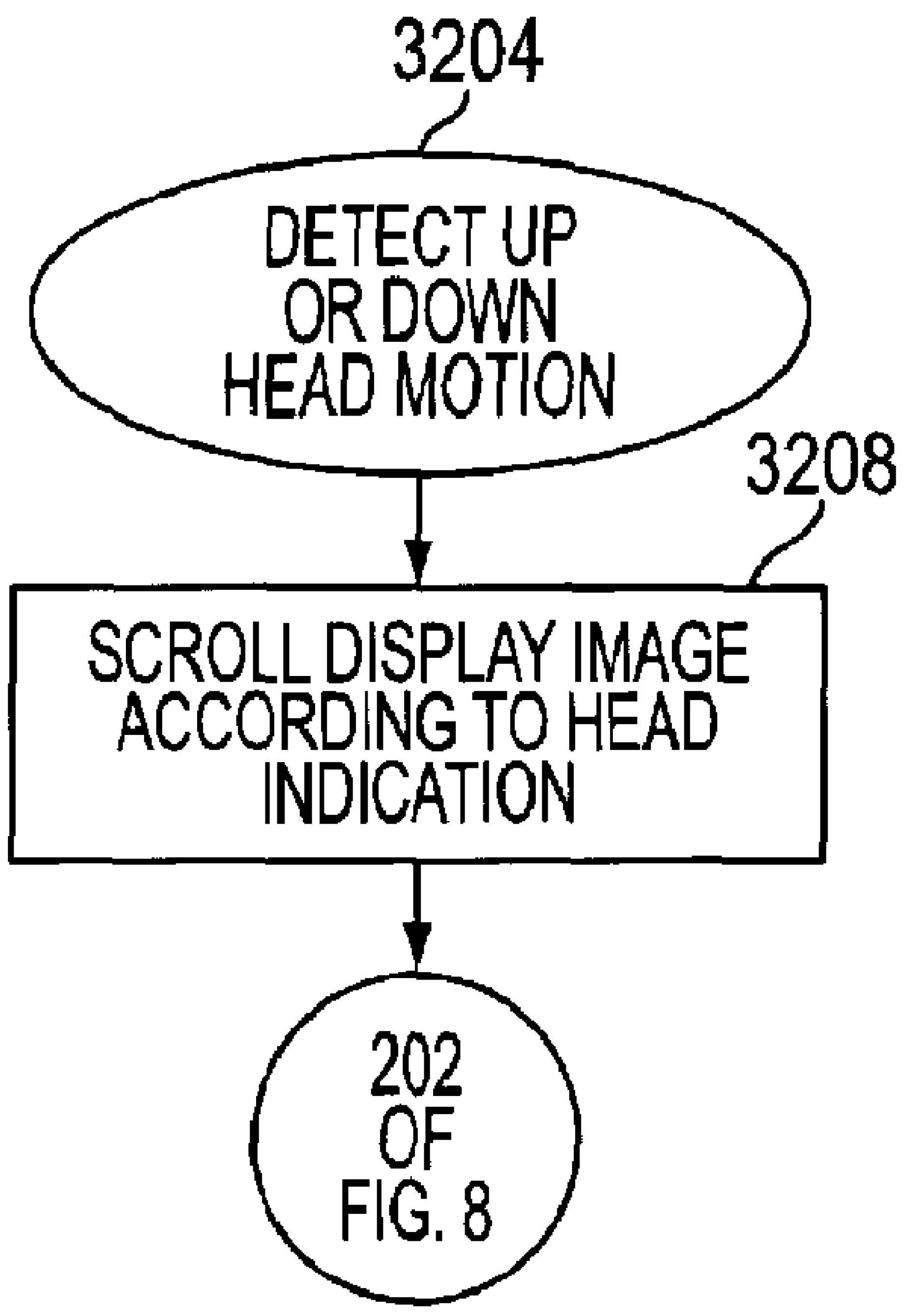

3204
DETECT UP OR DOWN HEAD MOTION
3208
SCROLL DISPLAY IMAGE ACCORDING TO HEAD INDICATION
202 OF FIG. 8

FIG. 11

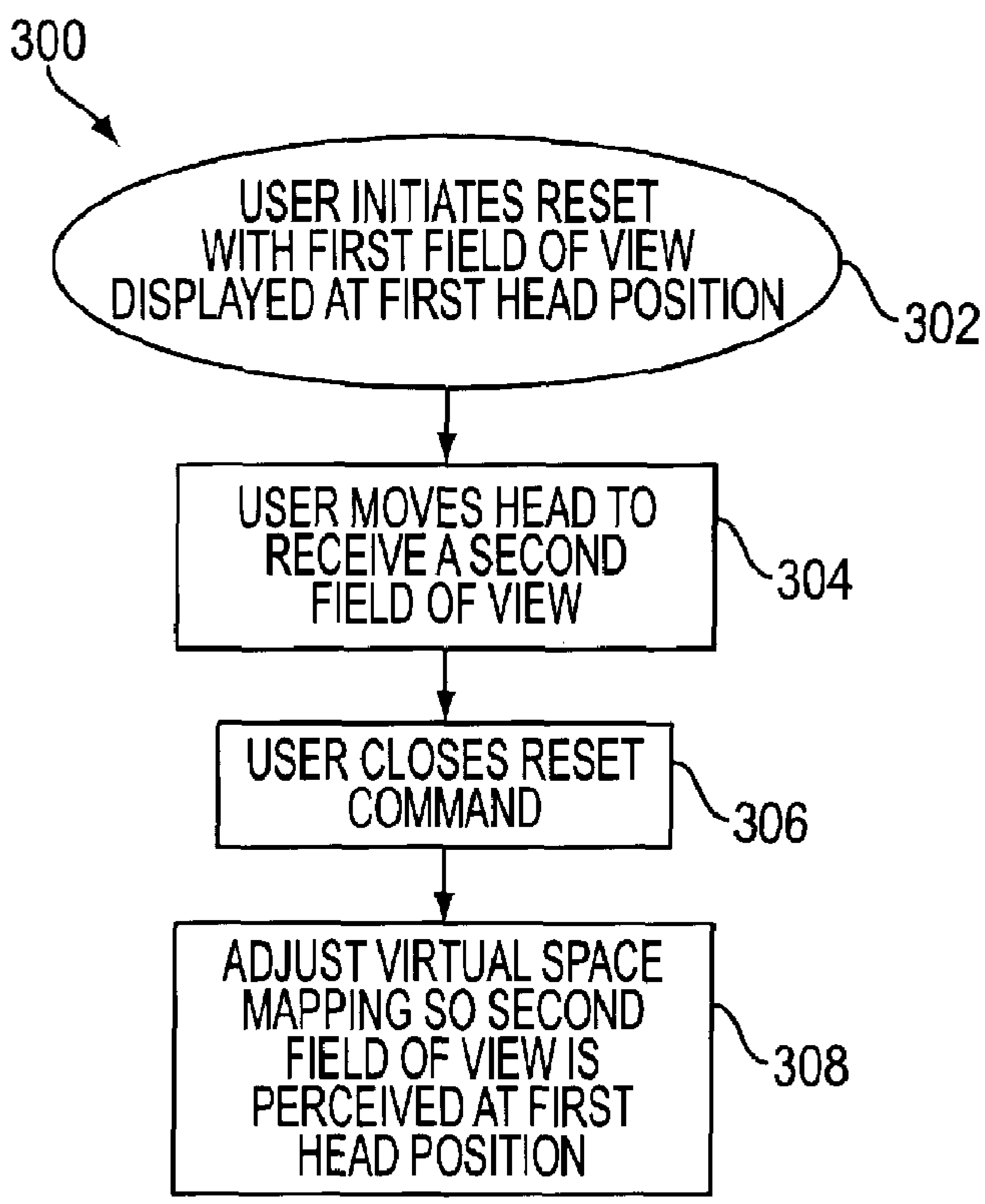
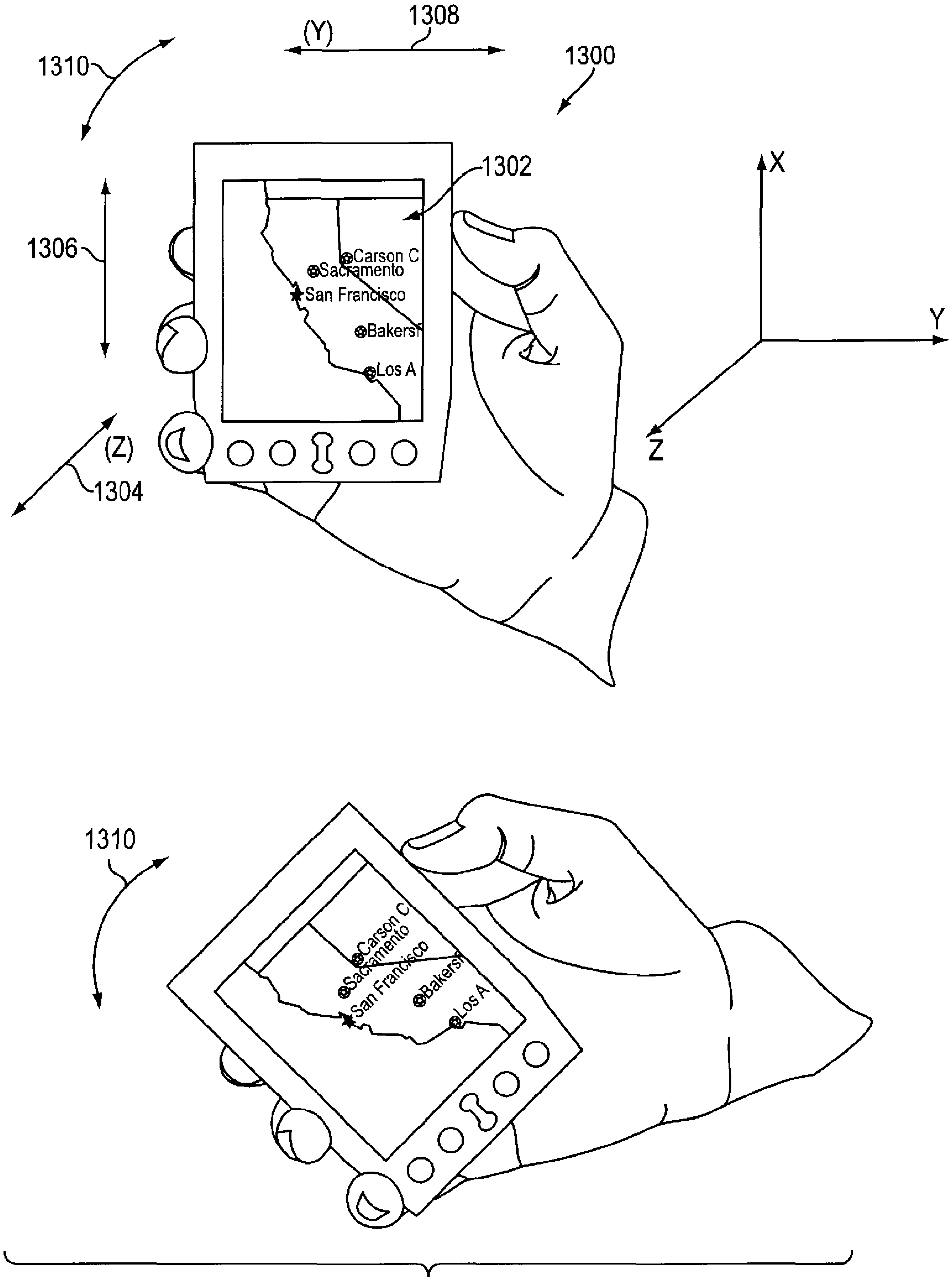

300
USER INITIATES RESET WITH FIRST FIELD OF VIEW DISPLAYED AT FIRST HEAD POSITION
302
USER MOVES HEAD TO RECEIVE A SECOND FIELD OF VIEW
304
USER CLOSES RESET COMMAND
306
ADJUST VIRTUAL SPACE MAPPING SO SECOND FIELD OF VIEW IS PERCEIVED AT FIRST HEAD POSITION
308

FIG. 12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Bakersf
Los A

FIG. 13

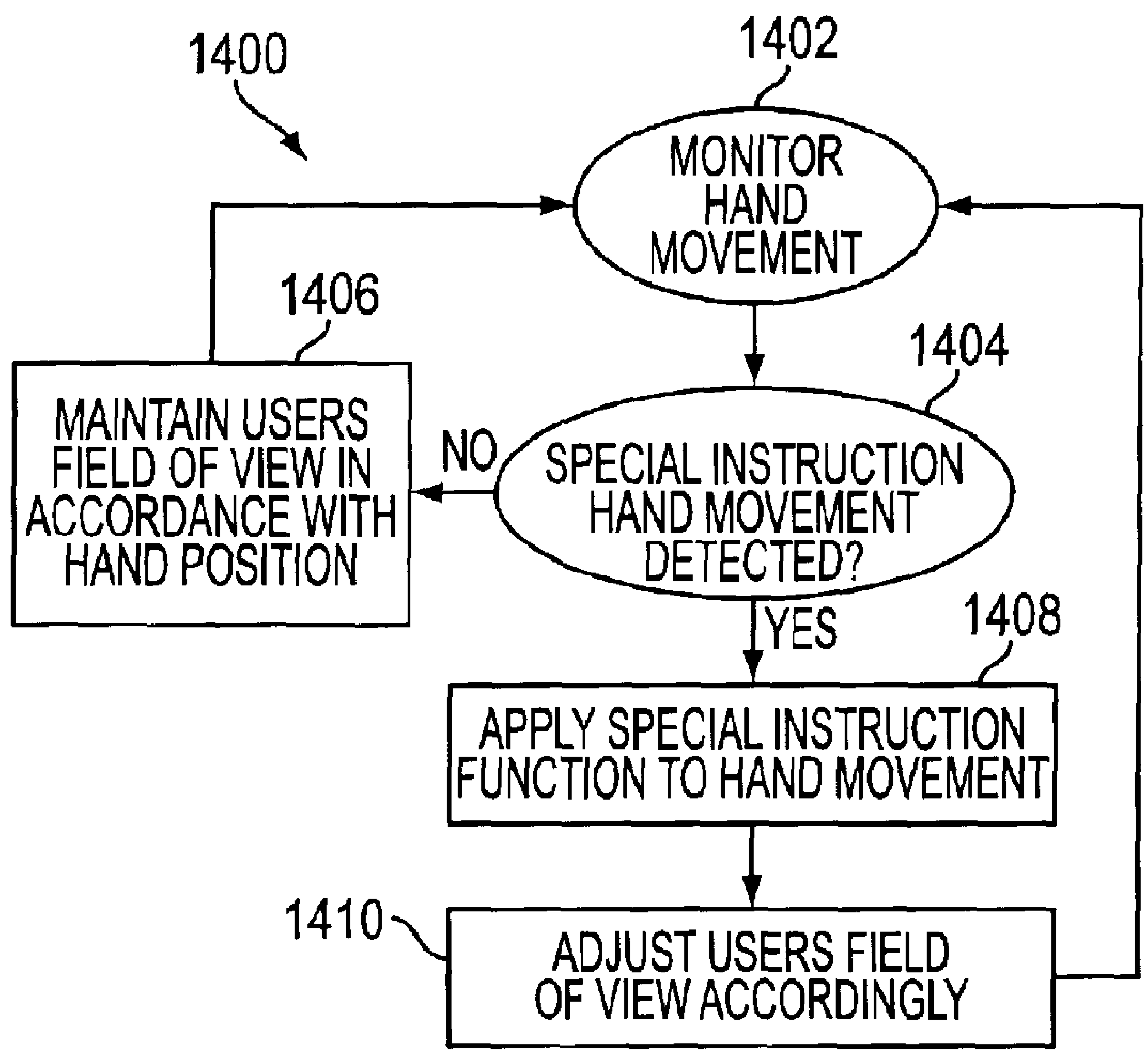

FIG. 14

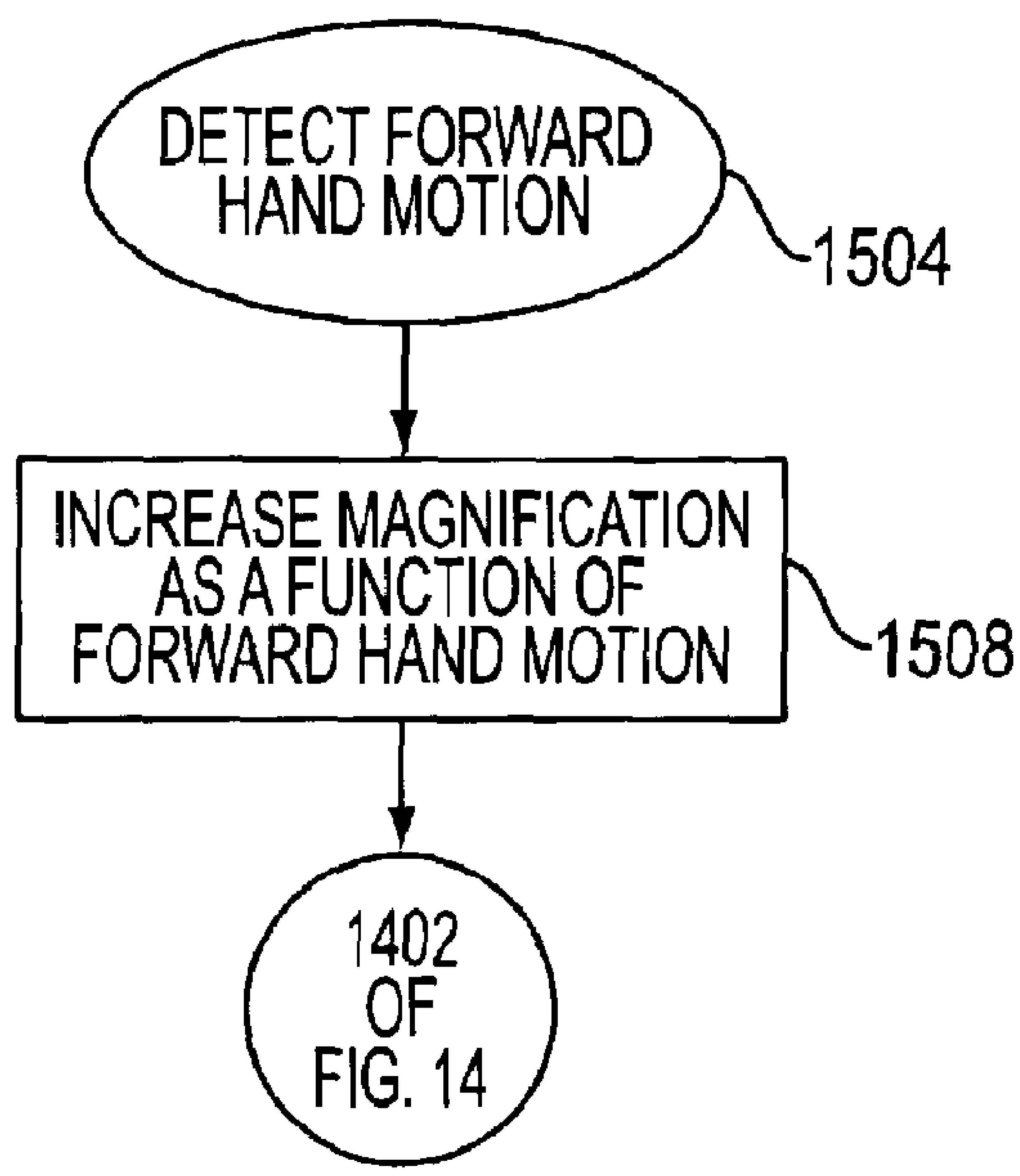

FIG. 15

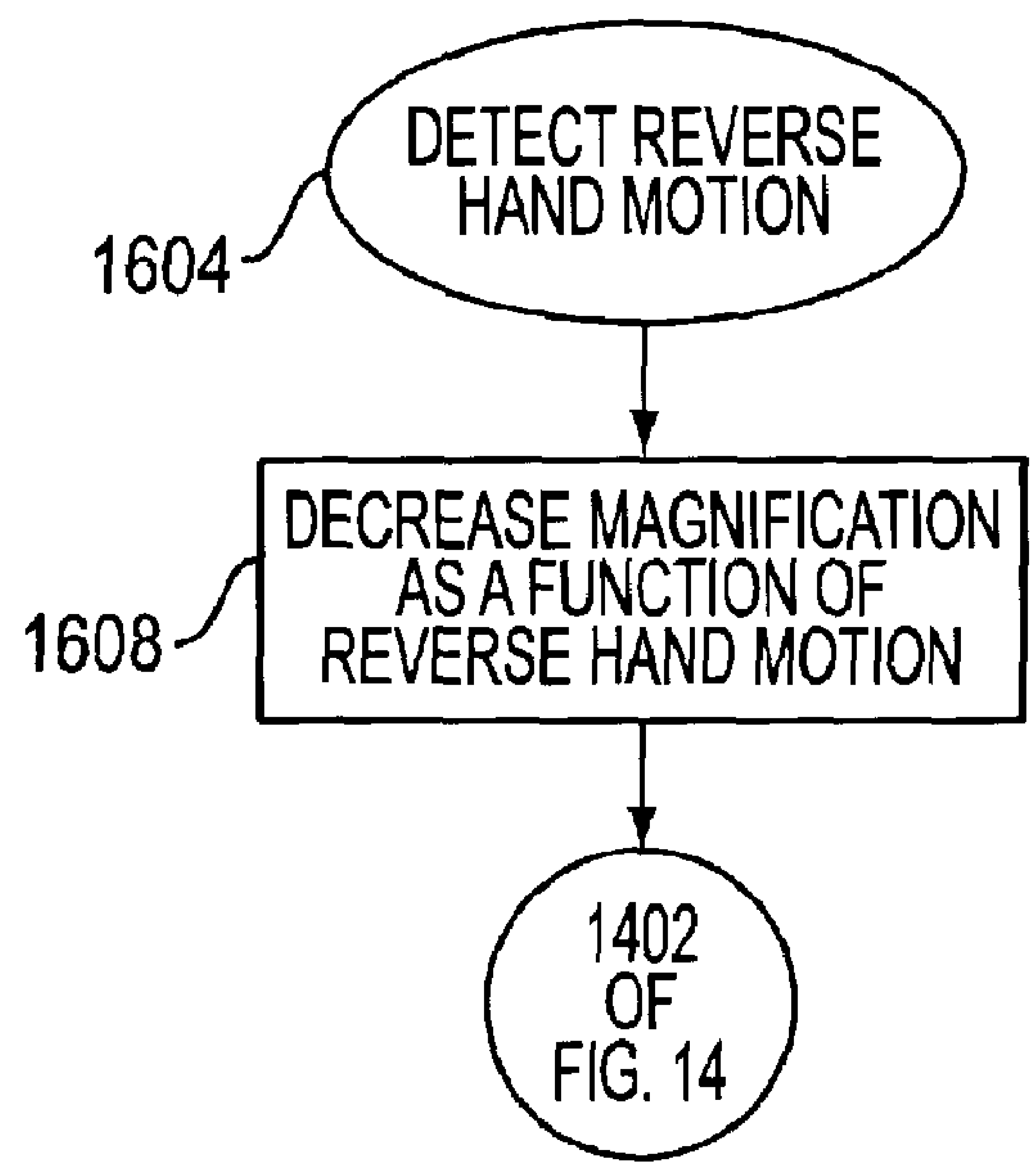

FIG. 16

INTUITIVE CONTROL OF PORTABLE DATA DISPLAYS

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

This application claims *the* benefit of [provisional application] *priority to U.S. Provisional Application* No. 60/101,433, filed Sep. 22, 1998*, and is a continuation-in-part of U.S. patent application Ser. No. 09/264,799, filed on Mar. 9, 1999, which issued as U.S. Pat. No. 6,084,556 on Jul. 4, 2000, which is a continuation of U.S. patent application Ser. No. 09/235,096, filed Jan. 21, 1999, which issued as U.S. Pat. No. 6,127,990 on Oct. 3, 2000, which is a continuation of U.S. patent application Ser. No. 08/563,525, filed Nov. 28, 1995, now abandoned. This application also is a continuation-in-part of U.S. patent application Ser. No. 09/373,186, filed Aug. 12, 1999, which issued as U.S. Pat. No. 6,359,603 on Mar. 19, 2002, which is a continuation of U.S. patent application Ser. No. 09/235,096, filed Jan. 21, 1999, which issued as U.S. Pat. No. 6,127,990 on Oct. 3, 2000, which is a continuation of U.S. patent application Ser. 08/563,525, filed Nov. 28, 1995, now abandoned*.

FIELD OF THE INVENTION

The invention relates to human/computer interfaces to visual data and more particularly to systems that must display a larger amount of visual data than may be conveniently displayed in a single conventional computer monitor. The present invention uses virtual reality techniques to provide instantaneous and intuitive access to large fields of visual data, and to provide visually-impaired users with enhanced access to enlarged visual data.

DESCRIPTION OF PRIOR ART

Among the visually-impaired population, the most common approach to computer access is specialized software and/or hardware that enlarges the image displayed on the computer monitor. This is because simpler solutions such as moving closer to the monitor, using a larger monitor, adding an optical screen magnifier, or using a spectacle-mounted telescopic system provide either limited magnification or a very limited viewing field. Examples of commercially-available screen enlargers include LP-DOS by Optelec (Westford, Mass.), Zoomtext by Ai Squared (Manchester Center, Vt.), MAGic by Microsystems Software (Framingham, Mass.), and Magnum by Arctic Technologies (Troy, Mich.). In addition, simplistic screen enlargement modules are included in both the Microsoft Windows and Apple Macintosh operating systems.

These conventional computer display magnification solutions operate by magnifying the original image of a software application's output to a "virtual page" whose size is much larger than the physical monitor. For example, with a magnification of 10, a standard 8.5"×11" page would be approximately 7 feet wide by 9 feet tall. The visually-impaired user then operates the computer by using a mouse, joystick, or cursor keys to control which portion of the virtual page is shown on the monitor at any given point in time. Since the monitor is fixed, the user is in essence moving the virtual page across the monitor, in a manner analogous to that used in closed-circuit television (CCTV) systems for magnifying book pages.

In most cases, conventional screen magnification is performed completely in software running on the host computer's central processing unit (CPU). While this provides a very low-cost solution, the data to be shown on the display must be rendered in its entirety whenever the user pans to a new location within the enlarged image. This can result in lags between commanding the computer to pan and seeing the new image. To overcome this problem, the entire virtual image can be rendered and stored in a video display buffer. Then, as the user selects a portion of the image for viewing, the required portion of the data can be quickly read out of the display buffer and sent to the display device. An example of such a hardware-accelerated screen magnifier is the Vista by Telesensory, Inc. (Mountain View, Calif.). This technique is a form of hardware acceleration known as image deflection.

Unfortunately, there are two basic shortcomings to the conventional approach, even with hardware acceleration. The first problem is spatial orientation, in that it is difficult to determine where on the page one's view is directed at any given time. This occurs because the monitor does not move, and there are no other visual cues to indicate where on the virtual page one's line of sight is facing. This spatial orientation problem is exacerbated for high magnifications and for portable systems employing small display monitors. For example, one study (Goodrich, et. al.) found mean magnifications of 15.48× for nearly 100 experienced users of closed-circuit television devices. At 15×, a 15" monitor can only display about 1% of a standard 8.5"×11" page, making most computer work essentially impossible for such users. The problem is further exacerbated by the emergence of graphically-intensive computing regimes such as Microsoft Windows and the Internet World Wide Web, where individual graphic elements may be magnified to become larger than an instantaneous viewing window, or may be automatically generated outside of the user's instantaneous viewing window without the user's awareness.

The second fundamental problem in the conventional approach is dynamic control, in that all of the various control schemes for navigating about the page are cumbersome, confusing, and slow. This is because the navigation methods are unintuitive, relying on such logic as "use joystick to move cursor around screen, and when cursor reaches the edge of the screen, the next portion of document in that direction will be displayed." Alternatively, some screen enlargers maintain the cursor at the center of the screen, and require the user to position a desired insertion point over the cursor by moving the entire virtual page with a mouse or joystick. In all cases, dynamic control is not only unintuitive, but requires use of at least one hand, which negatively impacts productivity, and may make use by physically-impaired users difficult or impossible.

Together, these spatial orientation and dynamic control problems were termed the "field navigation" problem in the National Advisory Eye Council's 1994-98 National Plan (Legge, et. al.), in which the Low Vision and its Rehabilitation Panel identified this area as a particularly promising opportunity for new technologies.

One promising new technology that is now maturing is virtual reality, which is typically defined as a computer-generated three-dimensional environment providing the ability to navigate about the environment, turn one's head to look around the environment, and interact with simulated objects in the environment using a control peripheral.

In a virtual reality system, the user is "immersed" in a synthetic environment, in which virtual objects can be located anywhere in the user's physical space. The user views these objects by wearing a head-mounted display (HMD), which uses an optical system to cause a tiny display source such as a cathode ray tube or liquid crystal display to appear as a large display screen several feet in front of the user. Since the display source (or sources in the case of two eyes) is fixed to the user's head, the display is viewable regardless of where the user points his line-of-sight. The user also wears a head-tracker, which senses the direction the user is facing, and sends this information to the host computer. The computer uses this data to generate graphics corresponding to the user's line of sight in the virtual environment. This approach to human/computer interfaces was first conceived by Ivan Sutherland in 1966 for use in military simulators, and was first commercialized in the form of the Eyephone head-mounted display by VPL Research in the late 1980s.

Prior art in this area includes a wide range of relevant patents describing low-vision aids, improved virtual reality systems and components such as HMDs and head-trackers, but none which embody or anticipate the present invention.

In the field of low-vision aids, U.S. Pat. No. 4,227,209 issued Oct. 10, 1980 discloses an electronic sensory aid for visually-impaired users including an image sensor and a display array, wherein the degree of magnification provided in the display array may be adjusted by changing the number of display elements corresponding to each sensor array element. For use in electronic sensory aid applications requiring a large depth of focus, an improved image capture approach is disclosed in U.S. Pat. No. 5,325,123 issued Jun. 28, 1994, in which the imaging camera includes an opaque stop with a small aperture, thus allowing the magnification to be adjusted by moving the camera towards or away from the object to be magnified. A non-electronic sensory aid is disclosed in U.S. Pat. No. 4,548,485 issued Oct. 22, 1985, in which an XY stage is used to move textual material across an optical viewing system that captures a portion of the textual material for enlargement.

In U.S. Pat. No. 5,125,046 issued Jun. 23, 1992, and U.S. Pat. No. 5,267,331 issued Nov. 30, 1993, an improved imaging enhancer for visually-impaired users is disclosed in which an image is captured, digitized, and electronically enhanced to increase contrast before displaying the imagery. An improvement to this approach using a head-mounted display is disclosed in U.S. Pat. No. 5,359,675, issued Oct. 25, 1994.

In the field of virtual reality systems, U.S. Pat. No. 5,367,614 issued Nov. 22, 1994 to Bisey discloses a three-dimensional computer image display system using an ultrasonic transceiver head-tracking system to control a three-dimensional display to cause the image to change its perspective in response to head movements. In addition, U.S. Pat. No. 5,442,734 issued Aug. 15, 1995 to Murakami discloses a virtual reality system incorporating a head-mounted display, head-tracker, and image processing system in which predictive tracking algorithms are used to differentially update portions of the display field to provide more rapid updating of those portions of the display field corresponding to the center of the user's visual field. In U.S. patent application Ser. No. 07/621,446 (pending) filed by VPL Research, Inc., a virtual reality system is disclosed in which spatialized audio cues are generated to provide real-time feedback to users upon successful completion of manual tasks such as grasping virtual objects using a sensor-laden glove input device.

In the head-mounted display field, U.S. Pat. No. 5,003,300 issued Mar. 26, 1991 to Wells discloses a raster-based head-mounted display that may be used to display an image to either eye. U.S. Pat. No. 5,151,722 issued Sep. 29, 1992 to Massof discloses a video-based head-mounted display featuring a unique folding optic configuration so that the device may be worn like a pair of glasses. U.S. Pat. No. 5,281,957 issued Jan. 25, 1994 to Schoolman discloses a portable computer system incorporating a head-mounted display that may be hinge-mounted to an eyeglass frame so that the display may be folded up out of the way for viewing the physical environment. A wide variety of additional patents in the area of specific design improvements for head-mounted display devices exists, however, the specific head-mounted display design approach employed to effect the present invention is not critical, so long as image quality, brightness, contrast, and comfort are maintained at high levels.

In recent years, there have been several attempts made to apply head-mounted displays to the problems of enhancing imagery for visually-impaired users. One such effort has resulted in the Low-Vision Enhancement System (LVES) developed by Johns Hopkins University and marketed commercially by Visionics (Minneapolis, Minn.). The LVES device incorporates a head-mounted display with integrated cameras and an image processing system. The cameras generate an image of whatever is positioned directly in front of the user, and the image processing system enlarges the image and performs enhancement functions such as contrast enhancement. While the LVES device can provide magnified imagery of real-world objects to some visually-impaired users, it suffers from several shortcomings compared to the present invention. First, the LVES does not incorporate a head-tracker to provide a hands-free means for navigating within computer data. Further, the LVES suffers from a jitter problem exactly analogous to that experienced by users of binoculars or telescopes. In simple terms, any jitter in the user's line-of-sight is magnified by the same factor as the imagery, which causes the image provided to the user to appear unsteady.

U.S. Pat. No. 5,109,282 issued Apr. 28, 1992 to Peli discloses a novel image processing method for converting continuous grey tone images into high resolution halftone images, and describes an embodiment of the method applicable to presentation of enlarged imagery to visually-impaired users via a head-mounted display. In this device, the imagery is generated by a conventional camera manually scanned across printed text as is common in closed-circuit television systems for the visually-impaired. The head-mounted display is a Private Eye by Reflection Technologies (Waltham, Mass.), which employs a linear array of light-emitting diodes converted to the impression of a rectangular array by means of a scanning mirror. In the disclosed device, benefits of using a head-mounted display for low-vision access to printed material in portable situations are discussed, including the larger visual field, higher visual contrast, lighter weight, and smaller physical size provided by an HMD compared to a portable conventional television monitor. However, no connection to a computer for viewing computer-generated imagery is disclosed or anticipated, and no incorporation of a head-tracking device is disclosed or anticipated.

In the tracker art, a variety of tracking approaches and applications have been conceived and constructed. U.S. Pat. No. 5,373,857 issued Dec. 12, 1994 to Travers, discloses a head-tracking approach for the yaw degree of freedom in virtual reality applications consisting of a magnetic sensor disposed on a headset to produce a displacement signal relative to angular displacement of the head set with respect to the earth's magnetic field. A more sophisticated approach has been developed by the Massachusetts Institute of Technology (MIT), in which an analogous magnetic sensor is used to correct drift in a much faster differential sensor such as an accelerometer, which sensors together provide extremely rapid response and high accuracy within a single package. The MIT approach, believed to be patent-pending, additionally incorporates differential sensors to detect changes in the pitch and roll degrees of freedom, which sensors may also be corrected using slower absolute sensors such as liquid-filled capacitive tilt sensors.

Also within the tracker art, a number of devices have been disclosed which sense head movement for purposes of controlling positioning of a cursor or mouse pointer within the viewable portion of a conventional display monitor. U.S. Pat. No. 4,209,255 issued Jun. 24, 1980 to Heynau discloses a system for pilots employing a light-emitting diode mounted on the pilot's head, with photodiodes located on the display to sense the tapered energy field from the light-emitting diode for purposes of determining the pilot's aim-point within the display.

U.S. Pat. No. 4,565,999 issued Jan. 21, 1986 to King discloses a cursor control system for use with a data terminal wherein a radiation source and a radiation sensor are used to determine changes in a user's head position for purposes of controlling cursor position on the screen.

U.S. Pat. No. 4,567,479 issued Jan. 28, 1986 to Boyd discloses a directional controller for video or computer input by physically-impaired users consisting of a series of mercury switches disposed in proximity to a user's head, wherein movements of the user's head are sensed and converted into cursor control commands. This device also employs a pressure switch activated by the user's mouth which can provide a further control signal such as that generated by clicking a mouse button.

U.S. Pat. No. 4,682,159 issued Jul. 27, 1987 to Davison discloses an apparatus and method for controlling a cursor on a computer display that consists of a headset worn by the user, and a stationary ultrasonic transmitter for emitting sound waves which are picked up by receivers in the headset. These sound waves are compared for phase changes, which are converted into positional change data for controlling the cursor.

U.S. Pat. No. 5,367,315 issued Nov. 22, 1994 to Pan discloses an infrared-light based system that indicates head and eye position in real time, so as to enable a computer user to control cursor movement on a display by moving his or her eyes or head. The device is intended to emulate a standard mouse, thereby allowing use of the presently available software and hardware.

While the above examples demonstrate a well-developed art for controlling computer cursors via head movement, none disclose or anticipate application of head-controlled cursor movement within a head-mounted display, and none anticipate an approach such as the present invention wherein the cursor remains fixed at a particular position within the display while the displayed data is moved instead of the cursor. Movement of displayed data within a head-mounted display in response to head movement has heretofore been used only within virtual reality systems designed for simulating sensory immersion within three-dimensional computer simulations. In such applications, cursors or mouse pointers are not controlled by head movement, but are generated when required through the use of a separate hand-controlled input device.

While virtual reality is still a developmental technology involving exotic graphics hardware, specialized software, and long integration cycles, the concept of closing a control loop between head-tracker data and HMD imagery can be implemented analogously for viewing arbitrary computer data instead of specially-constructed virtual environments. For normally sighted individuals, this could be beneficial by providing a large virtual computer desktop surrounding the user, which can provide simultaneous access to a larger amount of visual data than is possible using the small virtual desktops currently provided on common computing platforms such as Macintosh and Windows. For visually-impaired individuals, head-tracked HMD display techniques can be used to conveniently access a magnified virtual page, and thus enable productive computer use by nearly 1,000,000 new users.

SUMMARY OF THE INVENTION

It is therefore an object of the current invention to solve the field navigation problem by combining virtual reality display techniques originally developed for military flight simulators with screen magnification techniques, in order to create a novel and intuitive display interface for visually impaired users.

It is another object of the current invention to provide an intuitive computer display interface allowing the user to automatically achieve proper spatial orientation by directly coupling the user's head orientation to the displayed portion of a magnified virtual page.

It is a further object of the current invention to provide an intuitive computer display interface allowing the user to automatically control the position of a cursor or mouse pointer on a computer-generated virtual page by directly coupling the user's head movements to movements of a cursor across the virtual page, thus freeing the user's hands for other tasks.

It is an additional object of the present invention to provide hands-free instantaneous selection from between many concurrently active computer applications by changing one's line-of-sight from one application window's virtual location to another.

It is yet another object of the present invention to provide and maintain a cursor at a user-selectable position within the user's field-of-view, in order to support use of the virtual computer display by users with arbitrary, non-central preferred retinal loci.

It is still another object of the present invention to alert the user to events occurring outside of the user's instantaneous field-of-view through the use of spatialized audio alerts perceived to originate from the direction of the event, thus causing the user to turn and look in the direction of the event.

It is yet a further object of the present invention to provide effective operation at magnifications much greater than those possible using fixed monitors, by using a novel technique known as spatial compression.

It is still another object of the present invention to provide improved scrolling of imagery across the user's field-of-view, through application of smoothing, thresholding, prediction, and drift compensation algorithms to improve response to raw data representing the user's instantaneous line of sight.

It is still a further object of the present invention to provide a computer display for visually-impaired users that is convenient, lightweight, low-cost, minimally power hungry, and capable of portable operation without degraded performance.

It is another object of the present invention to provide a means for visually-impaired users to view enlarged video imagery in real time over an expanded field-of-regard, thus reducing jitter compared to head-mounted closed-circuit television systems.

In accordance with the present invention, there has been devised a "virtual computer monitor" (VCM) which is broadly comprised of a head-mounted display means worn by the user, a head-orientation sensing means worn by the user, and software means for interfacing these devices to a host computer such that the user's head orientation data is processed to determine which portion of an arbitrary software application's output imagery to display. By properly matching the angle of head rotation to the extent of scrolling across the magnified image, the image can be made to appear fixed in space. The particular location of the portion of the virtual image which is actually being seen by the user is dependent upon the direction in which the user looks. As the user looks to the right, the portion of the virtual image being seen by the user is to the right of the portion of the virtual image previously being seen by the user. Similarly, as the user looks up, the portion of the virtual image being seen by the user is above the portion of the virtual image previously seen by the user. Upon initialization of the VCM device, the user triggers calibration between the user's straight-ahead line of sight and the center of the virtual page. From then on, the user can rotate her head left, right, up, and down to visually scan across the page in corresponding directions. The overall impression is analogous to a normally sighted person scanning across a newspaper page.

As applied to a computer interface device for the visually-impaired, the VCM software provides a magnification adjustment to allow each user to achieve adequate visual resolution without needlessly reducing his instantaneous viewing field. The software also provides a cursor, which nominally remains positioned at the center of the HMD physical field regardless of head movements so that the cursor can be positioned anywhere upon the virtual page by turning to face that location. A further adjustment allows setting the fixed cursor location to any arbitrary position in the HMD device's physical field, so that users with unusable portions of their visual fields can select an alternative preferred retinal loci instead of the center. A software selection also provides an overview display, which shows a reduced-magnification image of the entire virtual page, with a bold black box highlighting the outline of the instantaneous field within the entire field.

An additional important feature is the ability to temporarily adjust the cursor position in real-time using a controller peripheral such as a joystick or mouse. This feature allows fine positioning of the cursor within the field by temporarily locking the head-tracking system to freeze a portion of the virtual page on the physical display, while the controller is used to move the cursor in small increments.

An additional important feature is the ability to display image components in addition to the cursor at fixed points in the physical display, which allows menus or other icons to remain in the user's instantaneous viewing field at all times while scrolling across image content.

An additional important feature resides in the ability to reduce the lag between a head motion and display of the new direction's image by using image deflection, thresholding, smoothing, prediction, and a novel drift compensation technique to reduce display "swimming", which is caused whenever imperfect head orientation sensing causes the displayed image to not appear fixed in real-space.

An additional important feature resides in the ability to magnify images by extremely large factors using spatial field compression, where the displayed image is scrolled across the physical display at a faster rate than the head is turned. This enables use by individuals with limited head motion, and allows magnification to levels that would otherwise require turning completely around to view edges of the image.

An additional important feature resides in the use of a partially immersive HMD, which avoids simulation sickness by allowing the user to maintain a constant frame of reference in the physical world since real objects can be seen around one or more edges of the display.

It is therefore an advantage of the current invention that it solves the field navigation problem by combining virtual reality display techniques originally developed for military flight simulators with screen magnification techniques, in order to provide a novel and intuitive display interface for visually impaired users.

It is another advantage of the current invention that it provides an intuitive computer display interface allowing the user to automatically achieve proper spatial orientation by directly coupling the user's head orientation to the displayed portion of a magnified virtual page.

It is a further advantage of the current invention that it provides an intuitive computer display interface allowing the user to automatically control the position of a cursor or mouse pointer on a computer-generated virtual page by directly coupling the user's head movements to movements of a cursor across the virtual page, thus freeing the user's hands for other tasks.

It is an additional advantage of the present invention that it provides hands-free instantaneous selection from between many concurrently active computer applications by changing one's line-of-sight from one application window's virtual location to another.

It is yet another advantage of the present invention that it provides and maintains a cursor at a user-selectable position within the user's field-of-view, in order to support use of the virtual computer display by users with arbitrary, non-central preferred retinal loci.

It is still another advantage of the present invention that it alerts the user to events occurring outside of the user's instantaneous field-of-view through the use of spatialized audio alerts perceived to originate from the direction of the event, thus causing the user to turn and look in the direction of the event.

It is yet a further advantage of the present invention that it provides effective operation at magnifications much greater than those possible using fixed monitors, by using a novel technique known as spatial compression.

It is still another advantage of the present invention that it provides improved scrolling of imagery across the user's field-of-view, through application of smoothing, thresholding, prediction, and drift compensation algorithms to improve response to raw data representing the user's instantaneous line of sight.

It is still a further advantage of the present invention that it provides a computer display for visually-impaired users that is convenient, lightweight, low-cost, minimally power hungry, and capable of portable operation without degraded performance.

It is another advantage of the present invention that it provides a means for visually-impaired users to view enlarged video imagery in real time over an expanded field-of-regard, thus reducing jitter compared to head-mounted closed-circuit television systems.

The above and other objects, features, and advantages of the present invention will become more readily understood and appreciated from a consideration of the following detailed description of the preferred embodiment when taken together with the accompanying drawings, which, however, should not be taken as limitative to the present invention but for elucidation and explanation only.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a conceptual sketch illustrating operation of a conventional screen enlarger;

FIG. **2** is a block diagram of the hardware components of the virtual computer monitor;

FIG. **3** is a conceptual sketch illustrating operation of a virtual computer monitor, and intuitive field navigation via head rotation;

FIG. **4** illustrates various means for configuring the virtual computer monitor display, including A) typical configuration, B) typical configuration in combination with a blockage of the user's foveal vision, C) mouse pointer/cursor offset to a non-central preferred retinal locus, and D) Entire display field offset to be centered about a non-central preferred retinal locus;

FIG. **5** is a block diagram of the logical flow of data processing in an advanced embodiment of the virtual computer monitor;

FIG. **6** is a pictorial illustration showing the present invention applied to magnification of real-time imagery;

FIG. **7** is a pictorial illustration showing several intuitive head gestures that correspond to special discrete functions;

FIG. **8** is a flow chart illustrating one computer implemented method for controlling a computer system with a head-mounted display device;

FIGS. **9-11** are flow charts illustrating methods for performing magnification and scrolling commands with intuitive head gestures;

FIG. **12** is a flow chart illustrating one method for controlling the correspondence between the displayed field of view and the user's head position;

FIG. **13** is an illustration showing a PDA operable by intuitive body gestures, in accordance with an embodiment of the present invention;

FIG. **14** is a flowchart showing a computer implemented method for responding to a user's hand movement;

FIG. **15** is a flowchart showing a method for discrete magnification in accordance with one aspect of the present invention; and

FIG. **16** is a flowchart showing a method for discrete demagnification in accordance with another aspect of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

The system of this invention **10** concerns a computer **12** controlled by a user through conventional means such as a keyboard **14** and input controller **16**, and whose output is viewed on a display monitor **18**. Referring to FIG. **1**, the invention **10** is specifically intended for use in applications where the total amount of data to be viewed can be configured as a virtual display **20**, which is significantly greater in extent than the amount of data that can be conveniently viewed within an instantaneous viewport **22** provided by the display monitor **18**. An example of such an application is when the virtual display **20** consists of a large computer desktop running several application windows, while the amount of data that can be visually resolved within the instantaneous viewport **22** consists of a single application window. Another example of such an application is when the virtual display **20** consists of a word-processing document magnified for a visually-impaired user by a screen enlarger **24**, which may consist of software or a combination of software and hardware. In either case, conventional control means such as a keyboard **14** or input controller **16** may be used to select which portion of the virtual display **20** is shown within the display monitor **18** at any given moment, as described in the prior art.

Referring to FIG. **2**, the most basic embodiment of the invention **10** is achieved by implementing the display monitor as a head-mounted display **26**, wherein tiny display sources such as LCDs are held within close proximity to the user's eyes, and optically coupled to the eyes with a lensing system such that the image of the computer display appears to float in space several feet in front of the user. Such devices are well known in the art, and are commercially available from sources including General Reality Company (San Jose, Calif.), Optics 1 (Westlake, Calif.), and Virtual I/O (Seattle, Wash.). In addition to the head-mounted display, the user wears a head-tracker **28**, which senses changes in orientation of the user's head and reports them to the computer **12** to result in the perception of scrolling the instantaneous viewport **22** across the virtual display **20**. Head-trackers are also well-known in the art, and a variety of different devices are available from sources including General Reality Company, Precision Navigation (Mountain View, Calif.), and Polhemus Inc. (Colchester, Vt.).

With respect to the present invention, a wide variety of different head-mounted displays **26** and head-trackers **28** may be used without affecting the fundamental operating concepts embodied therein, and many suitable devices are commercially available. For the head-mounted display **26**, it is important to provide adequate field-of-view to ensure that a significant portion of the user's visual field is addressed, and to provide a sufficient number of picture elements, or pixels, so that small text can be resolved. Useful minimums are twenty degree field-of-view and 100,000 pixels per eye, although these figures are subjective. In addition, visual contrast must be high (100 to 1 or greater) for visually-impaired users. For some visually-impaired users, maximizing contrast can become sufficiently critical that a color display **[**can not**]** *cannot* be used, and a black and white unit must be used instead. In general, parameters such as field-of-view, pixel count, contrast, size/weight, cost, and other factors such as apparent image distance well-known in the art of head-mounted display design may be traded-off to provide a best compromise over a varied population of users, or may be traded-off to optimize performance for a single user.

The simplest embodiment of the invention **10** uses a CyberTrack™ model head-tracker **28** from General Reality Company. This model provides an output signal emulating that of a mouse, which can be read directly by a standard Microsoft mouse driver **30** for purposes of controlling the manner in which the instantaneous viewport **22** is selected from within the virtual display **20**. In alternative embodiments using a different head-tracker **28** which can not so emulate a mouse, an additional software module can be used to interpret the output of the head-tracker **28** and convert the output into "mickeys" that emulate mouse output, or an additional software module can adapt the output of the head-tracker **28** for directly controlling scrolling of the instantaneous viewport **22** without use of an intervening mouse driver. All told, a wide variety of alternative means for converting head-tracker output into scrolling of the instantaneous viewport have been conceived, so the approach selected for the present embodiments should not be considered limitative of the invention.

Referring to FIG. **3**, the result of the invention **10** is to provide the user with the perception that the virtual display **20** is fixed in space in front of the user, and that the user can position the instantaneous viewport **22** provided by the head-mounted display **26** at any point within the virtual display **20** merely by rotating his or her head to look in the desired direction. Because the user's nervous system provides proprioceptive feedback which constantly provides the user with a sense of direction, and because turning to look in a particular direction is a natural and intuitive means for viewing objects in that direction, the invention **10** provides a solution for both the spatial orientation and dynamic control aspects of the field navigation problem.

Referring to FIG. **4**, further detail of the instantaneous viewport is shown. Specifically, a mouse pointer **32** is shown. The mouse pointer **32** is typically maintained in the center of the instantaneous viewport **22** as the viewport is scrolled, and is used to allow selection of particular data items by the user. Such selection may be performed by clicking a button on the input controller **16**. In the present invention **10**, the mouse pointer may also be adjusted to remain at a non-central position **34** within the instantaneous viewport **22** while the viewport is scrolled. Such a non-central position **34** may be used in a case where the user suffers from a visual impairment such as macular degeneration, which can cause the foveal (central) portion of the user's visual field to be blocked, as illustrated by the visual blockage **36**. An alternative approach in the event of a visual blockage is to physically rotate the head-mounted display **26** with respect to the user's line-of-sight, so that the instantaneous viewport **22** is no longer centered around the user's line-of-sight, but is instead skewed into an offset position **38**.

In any of these embodiments, an improvement to the simple scrolling of the instantaneous viewport **22** can be achieved using hardware or software logic that enables scrolling using a combination of data generated by the head-tracker **28** and the input controller **16**. Specifically, when the mouse is not active, head-tracker **28** output is used to perform large-magnitude positioning of the instantaneous viewport **22** with respect to the virtual display **20**. Once the instantaneous viewport **22** is positioned at the approximate desired position using head movements, the input controller **16** can then be used to perform fine positioning of the instantaneous viewport. The input controller **16** can also be used to select data items, or click and drag to select multiple data items, as is common within the art. Whenever such actions are taken with the mouse, the instantaneous viewport is moved appropriately, maintaining the mouse pointer **32** at its selected location within the instantaneous viewport. In a preferred embodiment, the input controller **16** and head-tracker **28** can operate simultaneously, which allows "click & drag" functions such as holding down the mouse button to anchor one corner of a selection box, then scrolling the head until an opposing corner is reached, and releasing the mouse button to select all of the items within the resulting selection box.

The present invention has been implemented in two alternative prototype embodiments, with additional embodiments contemplated. The first embodiment is constructed using an Apple Macintosh Duo 230 portable computer **12**, a General Reality CyberEye Model 100 head-mounted display **26**, and InLARGE screen magnifier software by Berkeley Systems (Berkeley, Calif.). In this embodiment, the head-tracker **28** is an experimental device utilizing Gyrostar ENC-05E solid-state gyroscopes by Murata Manufacturing Company (Kyoto, Japan, and US location at Smyrna, Ga.). Two gyroscopes are used, one each for the head's pitch (elevation) and yaw (direction) degrees of freedom. The output of each gyroscope consists of a differential voltage, with the difference voltage directly proportional to the angular velocity of the sensor. These outputs are fed to the Macintosh computer **12** via the Apple Desktop Bus (ADB) Port, which is used on all Macintosh computers for accepting input from keyboards, mice, and other input control devices. Because the gyroscopes output differential data representing an angular velocity, the data is digitized using a simple analog-to-digital converter integrated circuit, and then used directly for scrolling the imagery, with only a linear scaling factor applied. This scaling factor is dependent on the magnification factor applied to the imagery, and serves to maintain the enlarged image at a fixed position in space as perceived by the user. In the case of an absolute orientation tracker such as a magnetometer, the data must first be converted from orientation to rate of change in orientation by taking the mathematical derivative of the data with respect to time.

In this first embodiment and most conceivable alternative embodiments which utilize differential head tracking devices such as gyroscopes and accelerometers, various tracking errors are introduced by the lack of a stable reference. These errors include drift, temperature instability, hysteresis, cross-axis coupling, and limited dynamic range.

Drift is evidenced by slow motions in the imagery which occur in the absence of any true head motion, and is corrected by incorporating a low-frequency cut-off filter in the tracking data output. Such low-frequency cut-off filters are well-known in the tracking art, and do not affect perceived performance.

Temperature instability is evidenced by drift that occurs following rapid changes in the ambient temperature in which the tracker is used. Some such instability is removed with software which acts like a low-frequency cut-off filter by ignoring D.C. drift, while some is unavoidable and requires a waiting period for temperature of the system hardware to stabilize. This software ignores any D.C. signal component from the head tracker **28** and allows a scaling factor to be input to the system to control the magnitude of the shift in the virtual image as a function of the amount of rotation of the user's head.

Hysteresis is evidenced by sensitivity differences between motion in one direction and motion in a direction 180 degrees opposite. This artifact can be addressed by using a different scaling factor depending upon the tracker's direction of travel. The magnitude of this sealing factor can be determined experimentally, depending upon the magnitude and direction of the hysteresis.

Cross-axis coupling is evidenced by the displayed image moving a small amount in one axis when all of the head motion is along an orthogonal axis. This artifact is also controlled by the software which acts like a low-frequency cut-off filter, and may be further controlled by disabling one axis whenever the orthogonal axis rate of motion is greater than an empirically-determined threshold.

Finally, dynamic range limitations result in upper and lower limits to the rate at which the head may be turned while still maintaining the perception that the image is fixed in space. The lower limit is nominally determined by the electronic noise floor of the sensor devices, although it is raised by addition of the low-frequency cut-off filter. The upper limit is determined by the maximum rate of change measurable by the sensor. If this rate of change is exceeded by overly rapid turning of the user's head, the imagery will appear to move in the same direction as the head is turning. This last artifact has not been solved, but may be addressed in a future embodiment through the use of an absolute position tracker.

In this first embodiment, the Apple Macintosh ADB port allows simultaneous operation of multiple input control peripherals. Because of this feature, either the input controller **16** or a variety of secondary controllers may be used in conjunction with the head-tracker **28** to perform navigation within the imagery. Such controllers include joysticks, trackballs, light pens, simple switches, or any other control device which is ADB port compatible.

The second embodiment of the invention has been implemented for the Intel/Microsoft personal computer architecture. In this embodiment, the computer **12** is a 90 Mhz Pentium host computer, the head-mounted display **26** is a CyberEye Model 100, and the head-tracker **28** is a 3-axis magnetometer, available as the Model TCM-2 from Precision Navigation, Inc. (Mountain View, Calif.) or the Cyber-Track™ from General Reality Company (San Jose, Calif.). This embodiment has been made functional using LP-DOS from Optelec (Westford, Mass.) as the screen enlarger **24**, although alternative commercially available screen enlargers may be used without modifying the remaining components of the system.

In this second embodiment, the selected head-tracker **28** is an absolute orientation sensor, although any alternative head-tracking device may be used. The specific 3-axis magnetometer used as the head-tracker **28** in this embodiment connects to the serial port of the computer **12**, and provides an internal conversion from absolute position to differential data in the form of mouse "mickeys" compatible with the Intel/Microsoft personal computer architecture. Because of this feature, the output of the head-tracker **28** can be read directly by a standard Microsoft mouse driver, which provides a menu for setting the scaling factor required for maintaining a fixed image as perceived by the user.

In this second embodiment, the Intel/Microsoft personal computer architecture does not make use of the Apple ADB bus, but instead uses RS-232 serial communication ports to connect to control devices such as the head-tracker **28** and the input controller **16**. This complicates the system design because the standard Microsoft mouse driver can only access one serial port (and therefore one control device) at any particular moment. Since proper operation of the invention **10** requires simultaneous response to the head-tracker **28** and the input controller **16**, hardware or software is required to access two control devices simultaneously.

In the most common case of a conventional computer mouse employed as the input controller **16**, this may be accomplished in one of at least five ways. First, an existing mouse driver that includes dual-port capability such as the original Borland mouse driver may be used. Second, the source code for the standard Microsoft mouse driver may be modified to support simultaneous access to two serial ports. Third, a device such as the "WhyMouse" by P.I. Engineering (Williamston, Mich.) may be used. This device serves as a "Y" adapter to connect two mouse-type pointing devices into one serial port. Circuitry internal to the WhyMouse automatically routes one or the other device's data to the serial port based on a priority scheme, wherein the first device to emit data gains control of the input. Fourth, a custom solution can be implemented in the form of a unique software driver, or fifth, in the form of a software module running on an intelligent input/output controller such as the Rocketport32 card from Industrial Computer Source (San Diego, Calif.). Such intelligent input/output controllers are available from several commercial sources in the form of a circuit board that may be inserted in an expansion slot within the computer **12**. These circuit boards include two or more serial ports, as well as an on-board processor that can manipulate the inputs from the serial ports prior to delivering the tracking data to the computer's internal bus.

Of the four potential approaches to dual input device operation, the preferred embodiment exploits the fourth approach. This is because a custom software module avoids hardware costs, while providing the greatest flexibility in terms of application optimization and user convenience. For example, a custom software module allows the user to select whether the input controller **16** and head-tracker **28** can operate simultaneously in the manner preferred by the inventor, or whether the input controller **16** and head-tracker **28** operate in a priority scheme as provided in the WhyMouse product. In addition, a custom software approach can provide optional use of a variety of alternative devices as the input controller **16**. For example, some users may prefer a hand-operated joystick to a mouse, while physically-impaired users may require a finger-operated joystick or head-operated directional switches with a puff & suck switch for activating the mouse clicking function.

Referring to FIG. **5**, a block diagram of an advanced embodiment of the invention **10** is shown. In FIG. **5**, the computer **12**, keyboard **14**, input controller **16**, screen enlarger **24**, head-mounted display **26**, and head-tracker **28** are illustrated as previously defined, while a standard computer operating system such as Microsoft Windows is conceptually shown as **42**, a typical computer application such as Microsoft Word is shown as **44**, and a typical display driver such as a VGA graphics board is shown as **46**. The software module used for combining the inputs of the input controller **16** and head-tracker **28** is shown as the control driver **48**. An additional software module called the input remapper **50** is also shown interposed between the input controller **16** and the control driver **48**. This input remapper **50** is a program that converts inputs from a variety of potential devices that may be used as the input controller **16** into a single convenient data format such as mouse mickeys. For example, the output of a joystick used as the input controller **16** can be remapped by the input remapper **50** so that pressing the joystick trigger button results in a mouse click signal being sent to the control driver **48**, moving the joystick to the left results in emulation of sliding the mouse to the left, etc. By separating the input control software into a control driver **48** and an input remapper **50**, the control driver **48** can be made standard, with only the input remapper **50** modified whenever it is desirable to support a new type of input controller **16** within the invention **10**. The use of an input remapper **50** is a common approach in CD-ROM personal computer games, where the user can select between the mouse, joystick, keyboard, or other devices for purposes of controlling game play.

FIG. **5** also illustrates use of a tracking formatter **52**, which is a software module interposed between the head-tracker **28** and the control driver **48**. The tracking formatter **52** performs various functions depending upon the particular sensing means employed within the head-tracker **28**. These functions can be separated into three categories.

The first category of functions performed by the tracking formatter **52** is conversion of the data stream emanating from the head-tracker **28** into a format readable by the control driver **48**. This conversion is tracking sensor-dependent. In the case of a magnetometer-based tracker with mouse emulation as used in the Intel/Microsoft embodiment, no conversion is required. In the case of a magnetometer without mouse emulation, the tracking output would consist of rapidly-updated azimuth and elevation position figures, in which event the tracking formatter **52** would subtract the prior position sample from the present sample and then convert the format to mouse mickeys to provide the control driver **48** with emulated mouse output consisting of changes in position. In the case of a gyroscopic tracker with output converted to digital form such as that used in the Apple Macintosh embodiment, the output of the head-tracker **28** consists of angular velocity figures. In this event, the angular velocity samples are simply multiplied by the time period of each sample to yield a change in position, with each positional change then converted into mouse mickeys by the tracking formatter **52**.

The second category of functions performed by the tracking formatter **52** consists of error correction functions such as those previously described for the Apple Macintosh embodiment of the invention **10**. In that embodiment, the tracking formatter **52** performs low-frequency cut-off filtering, applies a directionally-dependent scaling factor, and disables one axis of travel when the orthogonal axis velocity rises above a threshold. These functions could also be performed in hardware such as an application-specific integrated circuit or a field-programmable gate array if higher-performance at high-volume production is desirable.

The third category of functions performed by the tracking formatter **52** consists of enhancement functions such as orientation prediction. This function addresses the pipeline delay between the instant in time when the head is turned, and the time when the displayed image is updated to display the new user line-of-sight. This delay can be calculated to be the sum of the tracker sensing time, tracker to computer communication time, tracker formatter processing time, control driver processing time, operating system and application software processing time, screen enlarger processing time, and display refresh time. In a typical embodiment, the sum of these delays can become bothersome, causing a perception of the display "swimming" with respect to the user's line of sight changes. This swimming causes perceptual mismatches between the user's internal proprioceptive cues and external visual cues, which in severe cases can cause disorientation and nausea effects known in the virtual reality field as simulator sickness. To avoid such effects, the current position and velocity of the head in each degree of freedom can be used to predict the future position, in the manner of So and Griffin or Azuma and Bishop. By doing so, the predicted future position can be used as the input to the processing pipeline instead of the current actual position, thus decreasing the average mismatch between the proprioceptive and visual cues.

FIG. **5** also illustrates the use of a voice recognition system as a means for inputting control commands and application data into the invention **10**. The voice recognition system consists of a microphone **54** disposed near the user's mouth, such as by mounting onto or within the head-mounted display. The output of the microphone is input to the computer's audio input port, which digitizes the audio data. The digital data is then analyzed by a voice recognizer **56**, which may consist of hardware, software, or a combination of the two. For example, a typical embodiment of the voice recognizer **56** for an Intel/Microsoft architecture would consist of Dragon Dictate software by Dragon Systems (Newton, Mass.), running on a SoundBlaster audio board by Creative Laboratories (Milpitas, Calif.). Regardless of the particular embodiment of the voice recognizer **56**, the output is sent to the operating system in the form of digital data interpreted as either commands or content depending upon the state of the operating system.

The incorporation of the voice recognizer **56** enables use of convenience-enhancing commands for purposes such as positioning the virtual display with respect to the user's line-of-sight, selecting enlargement factors, controlling tracking, selecting between system operating modes, and controlling individual computer applications. For example, position commands include "center me" to center the user's instantaneous viewport **22** within the virtual display **20**, "top right" to move the instantaneous viewport **22** to the top right, etc. Enlargement commands include absolute commands such as "Mag 8" to set the screen enlarger **24** to a magnification of 8 to 1, and relative commands such as "zoom double" to temporarily increase the magnification by a factor of two. Tracking control commands include "lock vertical" to lock-out response to the elevation tracking function, which simplifies scrolling horizontally across text. Selecting between system operating modes includes a complete set of commands for operating the screen enlarger **24**, such as "scroll text" to enter the enlarger's text scrolling mode. Finally, application control commands are application-dependent and available commercially as libraries, which typically include most or all mouse-accessible functions such as "page down", "font: Times", "edit: cut", etc.

FIG. **5** additionally illustrates a spatialized audio generator **58**, which is used to alert the user to computer-generated events occurring outside the user's instantaneous viewport **22**. This is done by providing the user with slightly different signals in each ear via a pair of loudspeakers or stereo headphones **60**, with the differences calculated to simulate directionality via slight delays between the nearer ear's signal and the farther ear's signal, slight reduction in high-frequency content in the farther ear's signal, and other spatial processing as is commonly known in the art. The spatialized audio generator **58** can be constructed from commercially-available components such as a SoundBlaster audio board from Creative Laboratories (Milpitas, Calif.), which includes audio spatialization software as a standard feature. The input to the spatialized audio generator **58** is provided by the operating system **42** for simple alerts such as "beeps" signifying an error or other message window, and may be provided by the application software **44** or the screen enlarger **24** for more advanced messages such as synthesized voice messages or text-to-speech conversion.

In FIG. **5**, it is noted that the control driver **48** contains a scaling factor used to adjust the amount by which the instantaneous viewport **22** moves across the virtual display **20** per degree of head rotation. In most instances, this scaling factor is set so that the virtual display **20** appears fixed in space while the instantaneous viewport is scanned across it. However, for extremely high magnification factors, fixing the virtual display can be problematic, as the user's head may be required to rotate more than is comfortable to scan from one edge of the virtual display to the opposing edge. Under such conditions, the present invention **10** may be configured by the user with a different scaling factor, which increases the amount by which the instantaneous viewport **22** moves across the virtual display **20** for each degree of head rotation. When viewed by the user, this results in the virtual display appearing to move across the user's instantaneous viewport **22** in a direction directly opposite to that in which the user is scanning. *Because the instantaneous viewport **22** and the virtual display are both moving in opposite directions, scrolling appears to be faster, but the user can scan from one edge of the virtual display **20** to the opposing edge with a smaller total head rotation. This approach to utilizing the present invention is deemed spatial field compression.

It is also noted in FIG. **5** that a snap-back function may be included within the control driver **48**, wherein data from the input controller **16** is used only for temporary repositioning of the mouse pointer **32** and instantaneous viewport **22** within the virtual display **20**. Specifically, this function records activity of the input controller **16** while such activity is being used to control the displayed imagery. Once such activity ceases, the inverse of the recorded activity is fed to the operating system **42**, which snaps-back the image displayed in the instantaneous viewport **22** to that which would be viewed in the absence of the input controller **16**. The result of this snap-back function is that the virtual display **20** is maintained at a fixed location in space, which may be temporarily modified by use of the input controller **16**, but is returned to following use of the input controller **16**.

It is also noted in FIG. **5** that additional image processing may be performed by the screen enlarger **24** or elsewhere in the processing pipeline to incorporate additional functions which may be desirable for visually-impaired users or other applications. For example, a common feature in commercial screen enlargers consists of contrast reversal, where instead of displaying black text on a white background, white text can be displayed on a black background. This improves text readability for some users. Another potentially useful feature is image enhancement, wherein the imagery is digitally enhanced to strengthen edges, which improves resolution ability for some users.

Finally, in FIG. **5** it is noted that if the screen enlarger **24** is set to an enlargement factor of one-to-one or omitted entirely, and a display driver **46** providing a virtual desktop function such as the MGA Millenium by Matrox (Dorval, QC, Canada) is used, then the present invention **10** can be used in an identical fashion by a non-visually-impaired user for purposes of accessing large areas of a virtual desktop, which enhances tasks such as simultaneous use of many individual computer applications.

A further embodiment of the present invention **10** is illustrated in FIG. **6**, which shows the invention **10** applied to magnification of real-time imagery. In this embodiment, a video camera **62** and a video frame grabber board **64** are added to any of the previously described embodiments. The video camera is then mounted in a stationary position and aimed at an image to be enlarged **66**.

This image to be enlarged **66** may be a small object to be magnified such as text in a book, or may be a distant object to be resolved such as a blackboard in a classroom lecture. Each frame of video captured by the video grabber board **64** is output to the system bus as application output data by software included commercially with the video frame grabber board **64**, and fed to the screen enlarger **24**. The screen enlarger **24** magnifies the imagery, creating a virtual display **20** of the image to be enlarged **66** that occupies a larger angular extent as seen by the user than does the image to be enlarged **66**. The head-mounted display **26**, head-tracker **28**, tracking formatter **52**, and control driver **48** are then used as previously described to provide an instantaneous viewport **22**, which may be positioned at any convenient point within the virtual display **20** by turning one's head. In this embodiment, improvement is made upon earlier closed-circuit television inventions for the visually-impaired in that the camera captures the entire image to be enlarged **66** at all times, instead of moving with the user's head or hand and capturing just the amount of imagery that can be displayed within the instantaneous viewport **22**. By doing this, spatial awareness is maintained, but jitter in camera motion is not magnified to become disruptive to the user. In addition, by interposing a computer within such a closed-circuit television loop, any image may be instantly saved to permanent memory with a single keystroke for later review, editing, or printout.

As will be appreciated, the present invention is useful in a wide range of applications such as text processing and virtual map navigation. To enhance the user's control of the computer system, the present invention teaches entry of computer control commands through intuitive head gestures. In other words, in addition to adjusting the user's field of view by tracking head motion, we define specific head gestures and correspond these specific head gestures in an intuitive manner with "special discrete commands." FIG. **7** illustrates some possible head gestures that may be useful. A two-tailed motion arrow **170** illustrates forward or backward head motion and such gestures may correspond to increasing or decreasing display magnification. A two-tailed motion arrow **172** illustrates head-nodding motion, which could control document scrolling. For example, the user could begin nodding with a downward or upward motion to initiate downward or upward scrolling, respectively. Another two-tailed motion arrow **174** indicates side-to-side head motion. This side-to-side motion could bring about a panning action. The last two-tailed motion arrow **176** illustrates brisk or abrupt head shaking motion, which could cause erasure or screen clearing.

Turning to FIG. **8**, one computer implemented method **200** for responding to a user's head movement will now be described. A first step **202** represents monitoring the user's head movement. Hence at step **202**, the user is supplied a head-mounted display device which provides at least visual feedback. The computer system, through the display device e.g., has the capability to track the user's head movement. Such a computer system is described above in more detail. Note that in preferred embodiments, the user's head movement will be monitored in what may be considered for present purposes a continuous manner. In a next step **204**, the computer system responds to sensed user head movement by determining whether a special discrete command has been entered. If not, control is passed to a step **206**, which updates the virtual space such that the user's field of view is maintained in accordance with the head position.

In step **204**, the computer system must distinguish special discrete commands from other head movement simply intended to adjust the user's field of view. This can be accomplished in step **206** through a variety of mechanisms. In some embodiments, certain head gestures could be mapped to corresponding special discrete commands. For specific examples, see the descriptions of FIG. **7** above, and FIGS. **9-11** below. These head motions ought to if possible be distinct from motions a user might be required to make to use the head-mounted display. In other embodiments, a first head gesture (e.g., a very abrupt nod or such) could indicate to the computer system that the next head motion is (or is not) a special discrete character. Thus the first head gesture would operate like a control character, with subsequent head gestures being special discrete commands.

In any event, when the computer system has ascertained in step **204** that a special discrete instruction has occurred, control is passed to a step **208**. In step **208**, the computer system applies a function associated with the special discrete command to the sensed head motion. These functions can be based on head position and all related derivatives (velocity, acceleration, etc.). These functions may also be piecewise, with discrete portions having varying response characteristics. Once such a function has been applied, control is passed to a step **210** wherein the user's display is adjusted accordingly. Once the display is adjusted, control is passed back to monitor head movement step **202**.

With reference to FIGS. **9-11** several example head gestures and their corresponding special discrete commands will now be described. FIG. **9** illustrates the implementation of a discrete magnification instruction in accordance with one embodiment of the present invention. In a step **1204** (a specific case of step **204** of FIG. **8**), the computer system detects a forward head motion intended to cause magnification. Control is thus passed to a step **1208** (a specific case of step **208** of FIG. **9**) where the magnification function is implemented. This function may increase magnification as a function of the change in user's head position, the speed of the user's head gesture, and/or the acceleration of the user's head gesture. After the magnification has been adjusted, control is passed back to step **202** of FIG. **8**. Steps **2204** and **2208** of FIG. **10** implement a process similar to that of FIG. **9**, the difference being that the method of FIG. **10** applies to reverse head motion and a corresponding decrease in magnification. FIG. **11** illustrates a method for scrolling through the virtual display space. In a step **3204**, the computer system detects either up or down head motion defined as corresponding to special discrete scrolling commands. In response, in a step **3208**, the computer system scrolls through the virtual display space accordingly. When finished, control is passed back to step **202**.

So far the described special discrete commands have been well-known commands such as scrolling, page down, erase, etc. However, it is contemplated that robust control of a computer system through a head mounted display device requires commands specific to such a computing environment. In particular, there should be a mechanism by which a user can adjust the correspondence between the displayed field of view and the user's head position. For instance, a user may wish to reset his "neutral" field of view display. Imagine a user, initially looking straight ahead at a first display, moving his head **30** or **40** in order to examine or work within this second field of view. It may sometimes make sense to examine this second field of view with the head cocked this way, but often it would be preferable to reset the field of view so that the user may perceive the second field of view while looking straight ahead. The present invention covers all mechanisms that would accomplish this reset feature.

With reference to FIG. **12**, a method **300** for controlling the correspondence between the displayed field of view and the user's head position will now be described. In a first step **302**, the user initiates a correspondence reset command. When this reset is initiated, the user will be in a first field of view with the user's head in a first head position. The computer preserves this information. In a next step **304**, the user moves his head to a second position in order to perceive a second field of view. In a step **306**, the user closes the reset command. In a final step **308**, the computer system resets the virtual space mapping so that the second field of view is perceived at the user's first head position.

Note that the reset command may be initiated and closed by specific head gesture(s). Alternatively, the field of view could be coupled to the viewer's head position with a "weak force." For example, the "weak force" could operate such that above a certain threshold speed, the displayed field of view would change in accordance with the user's head position. In contrast, when head movement was slower than the certain threshold speed, the field of view would remain constant but the user's head position would change.

The above discussion focused on head-mounted display devices. However, the present invention contemplates a variety of portable display devices operable to control a computer system through intuitive body gestures and natural movements. For example, a wrist worn display could be controlled by hand, wrist, and arm movements. This would allow functions such as pan, zoom, and scroll to be effected upon the wrist worn display. The wrist worn display could be coupled remotely with a central computer system controlled by the user through the wrist worn display. Alternatively, the wrist worn display itself could house a computer system controlled by the intuitive gestures. Additionally, the gesture tracking device could be separate from the wearable display device, allowing the user to attach the gesture tracking device and manipulate it as desired. Still further, the user may be provided multiple wearable control devices for controlling the computer system through intuitive body gestures.

A further portable device operable to control a computer system through intuitive body gestures and natural movements is a Personal Digital Assistant (PDA). FIG. **13** is an illustration showing a PDA **1300** operable by intuitive body gestures, in accordance with an embodiment of the present invention. The PDA **1300** includes a display **1302**, and is quite small, light weight, and relatively inexpensive.

As with the head wearable display, we define specific hand gestures that correspond in an intuitive manner with "special discrete commands." FIG. **13** illustrates some possible hand gestures that may be useful. A two-tailed motion arrow **1304** illustrates forward or backward hand motion along the z-axis and may correspond to increasing or decreasing display magnification. A two-tailed motion arrow **1306** illustrates up and down hand motion along the x-axis, which could control document scrolling. For example, the user could begin rotating with a downward or upward motion to initiate downward or upward scrolling, respectively. Another two-tailed motion arrow **1308** indicates side-to-side hand motion along the y-axis. This side-to-side motion could bring about a panning action. The last two-tailed motion arrow **1310** illustrates brisk or abrupt **[**head**]** *hand* shaking motion, which could cause erasure or screen clearing.

Turning to FIG. **14**, one computer implemented method **1400** for responding to a user's hand movement will now be described. A first step **1402** represents monitoring the user's hand movement. Hence at step **1402**, the user is supplied a hand-portable display device which provides at least visual feedback. The computer system, through the display device, gyros and/or accelerometers has the capability to track the user's hand movement. Such a computer system is described above in more detail. Note that in preferred embodiments, the user's hand movement will be monitored in what may be considered for present purposes a continuous manner. In a next step **1404**, the computer system responds to sensed user hand movement by determining whether a special discrete command has been entered. If not, control is passed to a step **1406**, which updates the virtual space such that the user's field of view is maintained in accordance with the hand position.

In step **1404**, the computer system must distinguish special discrete commands from other hand movement simply not intended to adjust the user's field of view, such as small natural movements caused by the user's environment. This can be accomplished in step **1406** through a variety of mechanisms. In some embodiments, certain hand gestures could be mapped to corresponding special discrete commands. For specific examples, see the descriptions of FIG. **13** above, and FIGS. **14** and **15** below. These hand motions preferably are distinct from motions a user might be required to make to use the hand-mounted display. In other embodiments, a first hand gesture (e.g., a very abrupt rotation) could indicate to the computer system that the next hand motion is (or is not) a special discrete character. Thus the first hand gesture would operate like a control character, with subsequent hand gestures being special discrete commands.

In any event, when the computer system has ascertained in step **1404** that a special discrete instruction has occurred, control is passed to a step **1408**. In step **1408**, the computer system applies a function associated with the special discrete command to the sensed hand motion. These functions can be based on hand position and all related derivatives (velocity, acceleration, etc.). These functions may also be piecewise, with discrete portions having varying response characteristics. Once such a function has been applied, control is passed to a step **1410** wherein the user's display is adjusted accordingly. Once the display is adjusted, control is passed back to monitor hand movement step **1402**.

With reference to FIGS. **15** and **16** several example hand gestures and their corresponding special discrete commands will now be described. FIG. **15** illustrates the implementation of a discrete magnification instruction in accordance with one embodiment of the present invention. In a step **1504** (a specific case of step **1404** of FIG. **14**), the computer system detects a forward hand motion intended to cause magnification. Control is thus passed to a step **1508** (a specific case of step **1408** of FIG. **14**) where the magnification function is implemented. This function may increase magnification as a function of the change in user's hand position, the speed of the user's hand gesture, and/or the acceleration of the user's hand gesture. After the magnification has been adjusted, control is passed back to step **1402** of FIG. **14**. Steps **1604** and **1608** of FIG. **16** implement a process similar to that of FIG. **15**, the difference being that the method of FIG. **16** applies to reverse hand motion and a corresponding decrease in magnification. When finished, control is passed back to step **1402**.

While the present invention has been described in **[**tenns**]** *terms* of several preferred embodiments, there are many alterations, permutations, and equivalents which may fall within the scope of this invention. It should also be noted that there are many alternative ways of implementing the methods and apparatuses of the present invention. It is therefore intended that the following appended claims be interpreted as including all such alterations, permutations, and equivalents as fall within the true spirit and scope of the present invention.

What is claimed is:

1. A computer implemented method for assisting a user in the control and operation of a computer system having a display screen coupled with the computer system, the computer implemented method comprising the steps of:

equipping the user with a portable display device coupled to the computer system;

mapping visual feedback generated by the computer system and intended for display upon a display screen into a virtual desktop suitable for display by the portable display device;

continually displaying a certain portion of the virtual desktop within the portable display device such that the user can view the certain portion of the virtual desktop;

tracking motion of the portable display device including discrete motion gestures initiated by the user; **[**and**]**

when the tracked motion corresponds to a request for a special discrete command, performing the special discrete command*;*

wherein the virtual desktop represents a text document; and

wherein the tracked motion is a shaking motion of the portable device and the special discrete command is an erase command.

[2. A computer implemented method as recited in claim **1** wherein the detected motion is a forward motion and the special discrete command is an increase in magnification of the displayed certain portion of the virtual desktop.**]**

[3. A computer implemented method as recited in claim **2** wherein the degree of increase in magnification is a function of the acceleration of the detected motion.**]**

[4. A computer implemented method as recited in claim **1** wherein the detected motion is backward motion and the special discrete command is an decrease in magnification of the displayed certain portion of the virtual desktop.**]**

[5. A computer implemented method as recited in claim **4** wherein the degree of decrease in magnification is a function of the acceleration of the detected motion.**]**

[6. A computer implemented method as recited in claim **1** wherein the virtual display space represents a text document.**]**

[7. A computer implemented method as recited in claim **6** wherein the detected motion is an abrupt downward motion and the special discrete command is a scroll display down command.**]**

[8. A computer implemented method as recited in claim **6** wherein the detected motion is a rotating motion and the special discrete command is a page down function.**]**

[9. A computer implemented method as recited in claim **6** wherein the detected motion is a shaking motion of the portable device and the special discrete command is an erase command.**]**

10. A computer implemented method as recited in claim **1** wherein the neutral display position is the image presented when the device is not in motion, and the special discrete command includes a step of setting the current field of view to the neutral position.

11. A computer implemented method for assisting a vision-impaired user in the control and operation of a computer system, the computer system being display driven in that a primary source of feedback for interacting with the computer system is visual feedback generated by the computer system, the visual feedback intended for display upon a display screen coupled with the computer system, the computer implemented method comprising the steps of:

equipping the vision-impaired user with a portable display device coupled to the computer system;

mapping the visual feedback generated by the computer system and intended for display upon a display screen into a virtual desktop suitable for display by the portable display device;

continually displaying a certain portion of the virtual desktop within the portable display device such that the vision-impaired user can view the certain portion of the virtual desktop, the certain portion of the virtual desktop corresponding to that portion of the virtual desktop which is located within the line of sight of the vision-impaired user;

adjusting a magnification of the virtual desktop in accordance with input from the visually-impaired user, whereby the certain portion is correspondingly adjusted such that the certain portion displayed within the portable device is a larger or a smaller percentage of the virtual desktop depending upon the vision-impaired user's magnification adjustment, the adjust magnification input being a function of the portable display;

tracking changes in the vision-impaired user's line of sight; and

updating the portable display device such that the certain portion displayed maintains the correspondence with that portion of the virtual desktop which is located within the line of sight of the vision-impaired user,

whereby the visually-impaired user can adjust the magnification of the visual feedback provided by the computer system to a magnification level improving comprehension of the visual feedback, and, even when the magnification level precludes simultaneous display of all the visual feedback within the portable display device, the visually-impaired user may still access all the visual feedback by adjusting his or her line of sight.

12. A computer implemented method as recited in claim **11** further comprising the step of displaying a pointer within the certain portion of the virtual desktop, the pointer having a fixed relation with the vision-impaired user's line of sight.

13. A computer implemented method as recited in claim **12** further comprising the steps of:

receiving a request to adjust the fixed relation between the pointer and the vision-impaired user's line of sight; and

adjusting the fixed relation in accordance with the received request.

14. A computer implemented method as recited in claim **12** further comprising the step of providing the vision-impaired user a pointer control input device for controlling operation of the pointer, the pointer control input device coupled to the computer system.

15. A computer implemented method as recited in claim **14** further comprising the steps of:

receiving a create selection box command via the pointer control input device;

anchoring a first **[**comer**]** *corner* of a selection box at a first point where the pointer is disposed within the certain portion displayed upon receipt of the create selection box command;

sizing the selection box in conjunction with movement of the vision-impaired user's line of sight;

receiving a close selection box command via the pointer control input device;

defining the selection box by anchoring a second **[**comer**]** *corner* of the selection box, the second **[**comer**]** *corner* opposing the first **[**comer**]** *corner*, the second **[**comer**]** *corner* anchored at a second point where the pointer is disposed within the certain portion displayed upon receipt of the close selection box command; and

marking as selected that portion of the virtual desktop, which is bounded by the selection box.

16. A computer implemented method as recited in claim **15** wherein the create selection box command corresponds to the depression of a button located on the pointer control input device and the close selection box command corresponds to the release of the button located on the pointer control input device.

17. A computer implemented method as recited in claim **11** further comprising the step of redefining the orientation of the certain portion displayed within the virtual desktop such that, without adjusting the vision-impaired user's line of sight, the certain portion displayed within the head-mounted display device changes.

18. A computer implemented method as recited in claim **17** wherein the orientation of the certain portion displayed is redefined in response to a request by the vision-impaired user.

19. A computer implemented method as recited in claim **11** wherein the step of mapping the visual feedback into the virtual desktop includes the substep of performing spatial field compression to reduce the total display orientation change required for redirecting the vision-impaired user's line of sight from one location within the virtual desktop to another location within the virtual desktop.

20. A computer implemented method as recited in claim **11** wherein the visual feedback generated by the computer system and intended for display upon a display screen includes multiple application windows.

21. A computer implemented method as recited in claim **20** wherein a first window of the multiple application windows corresponds to a first application executing upon the computer system.

22. A computer implemented method as recited in claim **20** further comprising the steps of:

monitoring a real scene in real space and time;

capturing images of the real scene; and

displaying within a first window of the multiple application windows the captured images of the real scene.

23. A computer implemented method as recited in claim **22** wherein a second window of the multiple application windows corresponds to an application program executing upon the computer system.

24. A computer implemented method for assisting a user in the control and operation of a computer system having a display screen coupled with the computer system, the computer implemented method comprising the steps of:

equipping the user with a portable display device coupled to the computer system;

equipping the user with a wearable control device operable to monitor movement and gestures made by the user with the portable control device, the computer system storing a map corresponding certain gestures and movements to certain computer operating instructions;

mapping visual feedback generated by the computer system and intended for display upon a display screen into a virtual desktop suitable for display by the portable display device;

continually displaying a certain portion of the virtual desktop within the portable display device such that the user can view the certain portion of the virtual desktop;

tracking motion of the portable control device;

determining that a user implemented gesture with the portable control device corresponds to a specific computer operating instruction; and

executing the specific computer operating instruction.

25. A computer implemented method as recited in claim **24** wherein the portable display device and the portable control device are formed as a single unit.

26. A computer implemented method as recited in claim **24** wherein the portable display device and the portable control device are separate devices.

27. A computer implemented method as recited in claim **24** wherein the computer system is housed within *the* portable display device.

28. A computer implemented method as recited in claim **24** wherein the computer system is housed within the portable control device.

29. A computer implemented method as recited in claim **24** wherein the computer system is remote from the portable display device.

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