Cybersphere: The Fully Immersive Spherical Projection System

KIRAN J. FERNANDES, VINESH RAJA, AND JULIAN EYRE

The computer generated virtual environments made possible by virtual reality (VR) may be moved through and manipulated by users in real time [1], but most display methods, including computer monitors, head-mounted displays, or projection screens, have an important limitation—they do not allow users to move around the virtual environment in a natural way. Efforts to remove this limitation include the development in the U.S. of a device similar to a stationary unicycle [3], which attempts to simulate the walking motion of a person sitting upon it. But this less-than-ideal solution introduces its own restrictions on freedom of movement. By contrast, freedom of movement is not restricted with the fully immersive spherical projection system known as the Cybersphere, developed through joint research by VR Systems and the University of Warwick, both in the U.K. Users who enter this spherical system—which represents a new approach to VR visualization—can walk, run, jump, or crawl in any direction, while at the same time being able to observe an all-encompassing virtual environment. In this article we describe where the Cybersphere fits in the world of virtual reality interfaces, and discuss ways it can be applied to a cross-sectional audience, ranging from simple component visualization to highly complex military simulations.

Since the advent into VR in 1965, when Ivan Sutherland presented a paper describing the concepts of the Head Mounted Display (HMD), several systems have been developed to "perceive" physical objects. The Cybersphere, launched in October 2000, is the latest such system; others include the cathode ray tube (CRT), the head mounted display (HMD), the binocular omni-oriented monitor (BOOM), and a projection screen environment known as a CAVE. Following is a brief description of each.

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- *Cathode Ray Tube*. CRT is the most basic visual paradigm for VR, and the most common incarnation of this simple monitor is the small monoscopic display whose perspective is based on the Renaissance mythical camera model. This minimal visual interface may be enhanced for VR use with addition of stereo and viewer-centered perspective [4].
- *Head Mounted Display.* The HMD, also known as a head-coupled display system, is widely used for research purposes, and is becoming commercially popular in amusement arcades. This system consists of a pair of stereo displays, which provide the user with the visual signal received, effectively isolating the user from the external world and immersing him or her in the displayed imagery. A head-tracking device provides the location and orientation of the viewer to simulate the correct view [5], and the displayed image is adjusted according to the position of the head, creating the illusion of physical presence within the virtual environment.
- *Binocular Omni-Oriented Monitor*. Like the head-mounted display, the BOOM mounts small displays via goggles in front of the eyes. The BOOM is suspended from an articulated arm, which measures its position and orientation in space and counterbalances its mass.
- *CAVE*. The CAVE [2] is the latest incarnation of a projection-based virtual environment. These systems have been extensively used in planetariums and military flight simulators, where viewers are exposed to VR via a large hemispherical display screen. The cube-based CAVE system takes this concept a step further by back-projecting images onto the three walls of a room, and projecting from above onto the floor. An observer views the virtual environment from within the room, and is free to move within the confines of that room. As the viewer moves within the bounds of the CAVE, the correct perspective and stereo projection of the environment appear on the display screens.

The Cybersphere addresses the main limitation of all of these systems, which is that the user is unable to move around the virtual environment in a natural way. An observer is either constrained by the physical boundaries, as with the CAVE system, or by the range of the head tracking system. The cybersphere, as illustrated in Figure 1, completely encloses the user in the virtual world. This spherical projection system is comprised of a large, hollow, translucent sphere, 3.5 meters in diameter, supported by means of a low-pressure cushion of air. Walking movements of the observer cause the sphere to rotate (see Figure 1), allowing the user to navigate and explore the virtual world in a natural manner according to his or her interest in the visualized domain. The movement of the cybersphere is dictated by the walking motion of the user in all directions (unlike the unidirectional motion of a treadmill). An observer enters the sphere by means of a closable entry hatch.

Rotational movement of the large sphere is transferred to a smaller secondary sphere. This sphere is supported by a ring that contains mounted bearings, and which is mounted on a platform (see Figure 3). The smaller sphere is pushed against the large projection sphere by means of spring-loaded supports. Rotational movement of the smaller sphere is measured via rotation sensors, which are pushed against the circumference of the sphere via spring-loaded supports.

Images are projected onto segments of the outer surface of the large sphere by high power projectors, as illustrated in Figures 1 and 2. One projector is mounted on the ceiling, and four are mounted on the surrounding walls. (Two are illustrated in Figure 1; an additional two, not shown, are mounted on the front and back walls.) The plane surfaces formed by the opposite edges of each of these segments subtend a

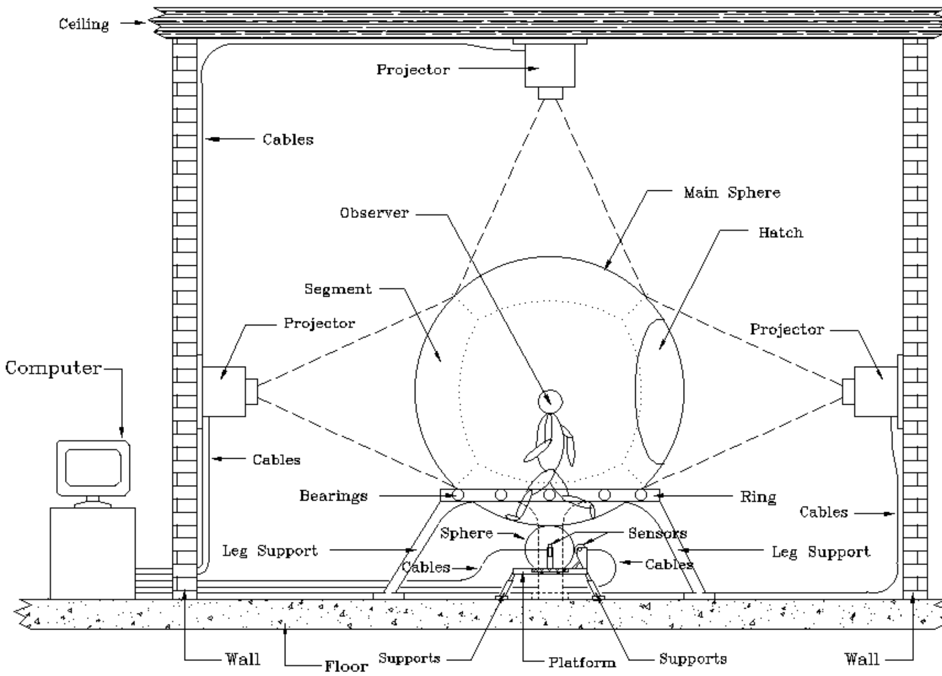

Figure 1. Schematic of the Cybersphere.

right angle at the center of the sphere. The combination of the images from each projector provides a fully immersive visual experience for the observer.

Signals provided by the rotation sensors, fed to the computer via cables, are used by the computer to update the projected images, giving the observer the illusion of walking freely through the computer generated environment. Following are more detailed descriptions of the four primary components of the Cybersphere: the primary projection sphere, the secondary rotation sensing sphere, the supporting structures, and the projection equipment.

- *The primary projection sphere.* This sphere has a diameter of 3.5 meters, designed to coincide with the eye-line of the average male adult. It weighs approximately 270Kg and is fashioned of polycarbonate, chosen due to its strength and optical properties. Research using finite element analysis tools [6] helped us device a method of sphere fabrication, using two interconnected 3mm polycarbonate layers. This technique involves the subdivision of the sphere into 30 identical interlocking diamond-shaped segments, as shown in Figure 2. To ensure a smooth finish on the inner and outer surfaces of the sphere, the layers are affixed to each other by countersunk screws and tapped holes in the inner polycarbonate layer. The relative position of each layer is offset to enable rigidity. Sandblasting (with a suitably fine medium) the inner surface of the polycarbonate layer solved the problem of preparing the polycarbonate surface for back-projection of images. This technique also eliminated the potential problem of internal reflections within the sphere.
- *The secondary rotation sensing sphere*. The secondary rotation sensing sphere arrangement, shown schematically in Figure 3, consists of a spring-loaded sup-

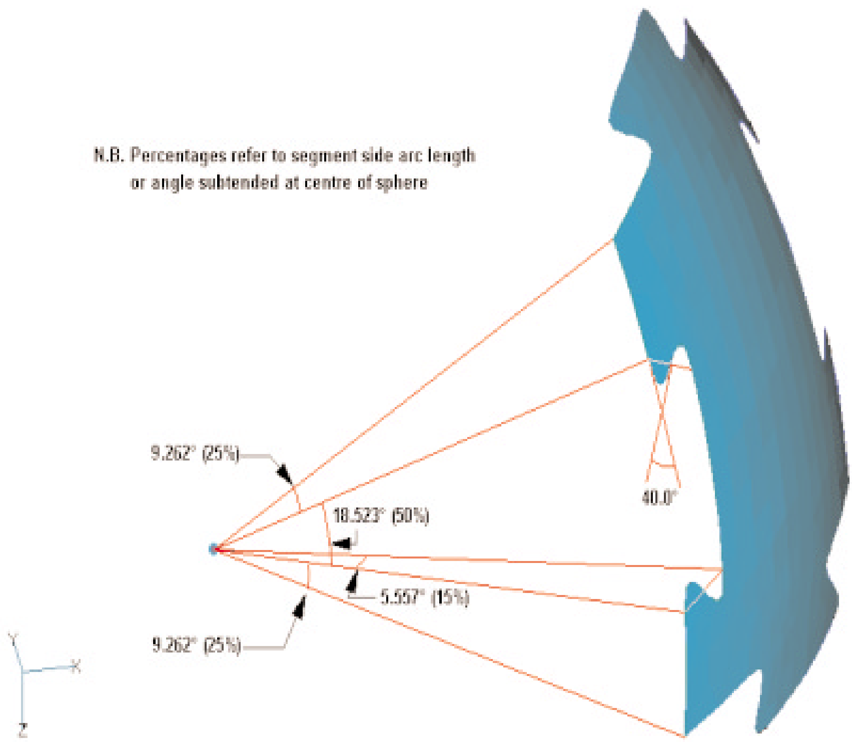

Figure 2. Interlocking segments of the Cybersphere.

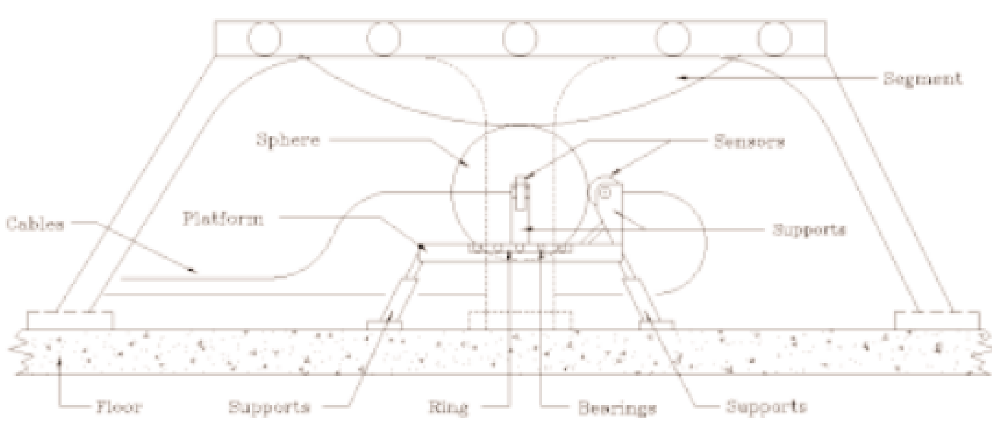

Figure 3. Secondary rotating sensing sphere.

port structure designed to keep the support platform level at all times, regardless of the amount, direction, or location of any load. This is accomplished through the use of a cross-linked support structure. The secondary sphere is supported by three thrust bearings, equally spaced around the sphere, holding it above the support platform. Investigations into the use of large low load bearing "trackballs," of the type used as a computer input device, indicated that these types of bearings would provide the optimum solution, due to their low-noise operation.

- *Support structure.* Low-pressure air supports the main projection sphere structure, as shown in Figure 1. The low-pressure air bearing provides the requisite support combined with minimal friction, seated within a circular seal. The space beneath the sphere is sealed and connected to a low-pressure, high-capacity pump. This pump provides the low pressure required to lift the sphere and the occupant. The area enclosed by the boundary of the circular seal is 4.8 square meters. To lift a weight of 400kg, the approximate combined weight of the sphere plus its occupant, requires pressure of approximately 800 Pa or 8 mbar (equivalent to 0.12 psi). Access to the sealed area below the main projection sphere exists in the form of a sealed door. The access door also has an air exit port to control the flow of air delivered by the pump. An observation window, immediately above the access door, is also incorporated into the structure. A raised platform on one side of the sphere support structure provides a means of entry into the projection sphere. Motorized support pads are incorporated into the support structure design to provide additional support for the projection sphere plus occupant when the air supply is turned off. Four of these pads are mounted onto a table, which is placed within the sealed air chamber below the sphere. Small motors, attached via a rack and pinion mechanism, are used to move the pads clear of the sphere when the air supply is switched on.
- *Projection equipment.* The projection equipment is capable of presenting imagery with suitable intensity and resolution. Presently, we are using projection equipment from BARCO, a projection equipment specialist with considerable experience of projection virtual reality systems. Details on image Distortion Correction Implementation (DCI) is beyond the scope of this article (more details on this can be obtained from the authors).

Target Market

The Cybersphere is offered as a time-rental service in the U.K., and plans are in the works to expand its use to additional areas. Also available is a design and development service for the production of virtual environments. The Cybersphere has many potential uses in a wide range of markets, including the following:

- *Civil engineering, particularly building design and construction.* The spherical projection system enables architects and designers to realistically walk through computer generated buildings to assess the suitability of their designs before construction.
- *Training and simulation.* The Cybersphere may be used to train personnel engaged in potentially dangerous activities, in the military, law enforcement, and emergency rescue arenas.
- *Real estate agents.* By using the Cybersphere to generate images of properties on the market, real estate agents could save travel time by allowing potential customers to walk through a wide range of properties within a relatively short period of time.
- *Travel agents.* By offering the Cybersphere as a decision-making tool to customers who could explore potential holiday destinations, travel agents would benefit from an increased customer base and customer loyalty.
- *The entertainment industry.* By providing an unrivalled virtual environment experience, the fully immersive spherical projection system fulfills the entertainment industry demand for bigger and more interactive player experiences.

Conclusion

The Cybersphere is a fully immersive high-resolution virtual reality interface. Its superiority over existing paradigms is demonstrated particularity in the area of movement and immersiveness.

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