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THE APPLICATION OF VIRTUAL WHEELCHAIR SIMULATION TO THE DETERMINATION OF ENVIRONMENTAL ACCESSIBILITY AND STANDARDS COMPLIANCE IN ARCHITECTURAL DESIGN

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ABSTRACT

In this paper we describe a system that allows a power wheelchair user to drive through a virtual architectural environment. The system allows architects and designers to visualize an environment, test the environment for handicapped accessibility, and determine whether the environment meets design standards such as the Americans with Disabilities Act of 1990. First we describe the system itself, including its hardware and software components and its user interface. Then we discuss architectural and design considerations.

KEYWORDS

Virtual environment, adaptive technology, octree, rendering, stereopsis, accessibility.

INTRODUCTION

With the passage of the Americans with Disabilities Act of 1990, the U.S. Congress opened a new world of accessibility for many people who had previously been excluded. This law prohibits barriers for disabled individuals at most public facilities. However, at the same time that the law has increased access, it has also placed a tremendous burden on architects and designers to propose environments that comply with the accessibility regulations. The Architectural and Transportation Barriers Compliance Board has helped with this dilemma by publishing the ADA Accessibility Guidelines for Buildings and Facilities (Federal Register, 1991), and organizations such as the American Institute of Architects have published guidelines dealing with accessibility issues (Packard and Kliment, 1989). Many planners and architects consider these as minimal construction and alteration guidelines, which need to be expanded to be adequate.

The true test for determining accessibility is usually post-construction, when people with disabilities actually enter the space. What is needed is a means of testing environments prior to construction to determine the level of accessibility for handicapped people, and whether the designs are in compliance with the ADA or perhaps other design standards. This paper describes our attempt to provide such a testing mechanism. Our system uses the computational power of a computer graphics workstation, together with an innovative interface, to create a virtual environment capable of representing an architectural design in which a wheelchair can be navigated and maneuvered, and in which barriers can be identified. The system consists of an instrumented, joystick-driven power wheelchair connected to a high-performance graphics workstation; it simulates the actual speed and maneuverability of the particular wheelchair within the virtual environment. The display generates realistic interiors containing multiple light sources and surface textures and

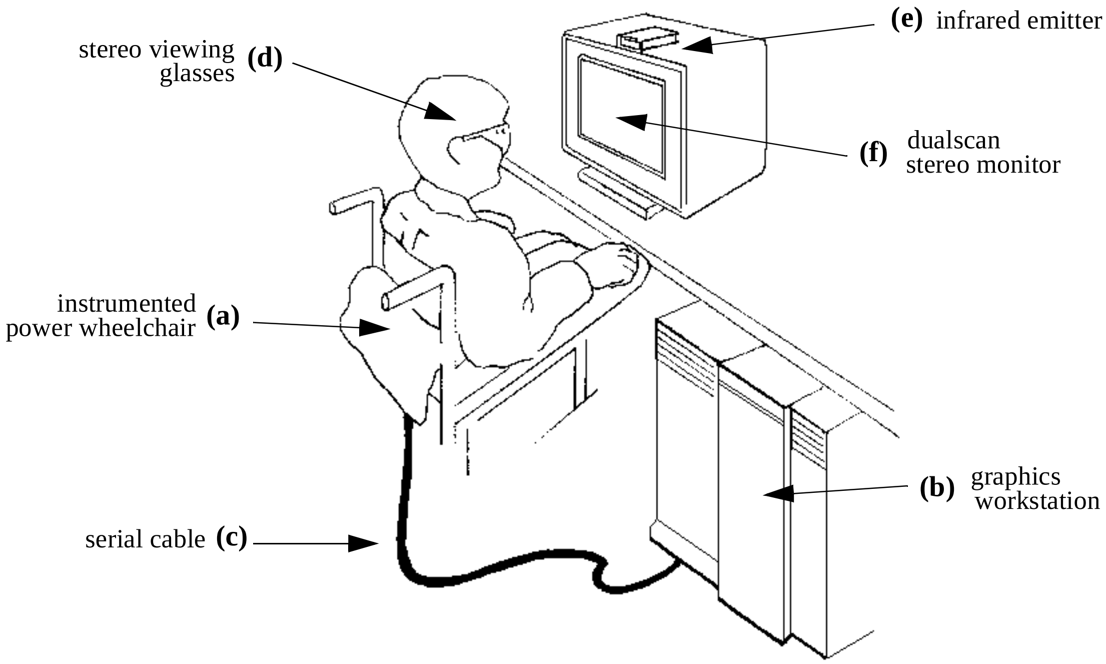

Figure 1: System configuration showing major hardware components.

is viewed in stereo through lightweight polarized glasses. The system maintains a hierarchical data structure that detects collisions between the virtual wheelchair and objects in the environment.

The following groups of people can use the system: 1) *Architects and designers* can use the system to improve the handicapped accessibility of building designs and help evaluate a design for ADA compliance; 2) *power wheelchair users* can use the system as a training simulator; and 3) *health care professionals* can use the system as an instrument for assessing user performance and to determine the best power wheelchair control mechanism for a particular patient. In this paper we focus on the system's implications for architects and designers.

HARDWARE CONFIGURATION

The hardware components of the system are displayed in Figure 1. The system consists of a) an instrumented power wheelchair, b) a graphics workstation, c) a serial cable, d) a pair of stereo viewing glasses, e) an infrared emitter (which synchronizes the stereo viewing glasses), and f) a dualscan stereo monitor (which alternately displays the scene from the viewpoint of each eye). We are currently using an Action™ joystick-driven wheelchair supplied by Invacare Corporation, a leading manufacturer of assistive devices. This model is instrumented with a computer interface that communicates through a standard serial cable. Our workstation is a Silicon Graphics IRIS Crimson VGXT™, with a 150 MHz CPU and 16 MB of internal memory. The monitor provides stereo vision through a pair of CrystalEyes™ polarized stereo viewing glasses, manufactured by Stereo Graphics.

USER INTERFACE

From the handicapped user's point of view, the system's user interface is very simple. The user dons polarized stereo viewing glasses, selects an architectural scenario, and drives through the virtual environment. The system accurately simulates the dynamics of the particular wheelchair in the particular environ-

Figure 2: Photograph of a user with the system.

ment: the chair moves with the same speed and turning radius as it would in the physical world. The scene can be any architectural space, either the interior of a building or an outdoor setting. Figure 2 shows a 16-year-old with Cerebral Palsy using the system.

The system easily supports chairs with different control mechanisms. The Action Power™ line of wheelchairs are fitted with a variety of controls that support users with different levels of disability. Among the controls produced by Invacare are a hand-operated *joystick*, a head-operated *chin control*, a *chest muscle actuator*, which detects flexing and relaxing of the operator's chest muscles, a *halo*, which detects the tilt of the operator's head, and a *sip & puff device*, which consists of a hollow tube that detects positive or negative air pressure from the operator's mouth. When connected to a computer, the wheelchair interface does two things: 1) it turns off the motors, so the chair does not actually move while connected to the system, and 2) it supplies the system with the speed and direction of rotation of each wheelchair wheel. Since the system always receives the same information regardless of a particular wheelchair's control mechanism, it can be used interchangeably with any properly instrumented power wheelchair. All the Action Power™ wheelchairs come equipped with a similar serial computer interface.

The system uses stereo viewing glasses and display hardware to provide stereo viewing. Stereopsis is an important perceptual attribute of any virtual environment; perceptual scientists have long known that stereopsis is important in navigation (Gordon, 1989). By capitalizing on human stereopsis, we can improve the dimensional quality of images that employ only monocular depth cues such as occlusion, texture gradients, and shadows. The rendering hardware produces stereo viewing by alternately rendering the scene from the viewpoint of each of the observer's eyes. As the screen displays the scene from one eye, the glasses darken over the opposite eye. An infrared emitter on top of the monitor keeps the glasses in sync with the display hardware (Figure 1e). Since the glasses are battery-powered, they require no tether to the system, and thus the interface is lightweight and unencumbering.

SOFTWARE DESCRIPTION

The software component of the system is implemented on top of X Windows™ and Motif™ for the user interface, and SGI's IRIS™ Performer for rendering and scene database management. The software processing occurs in two phases: the *initialization phase* and the *wheelchair data processing phase.*

In the *initialization phase*, the user selects the particular architectural scenario and wheelchair model that will be used. Next, the system establishes communication with the wheelchair through the serial port. It then loads the scene data into an octree data structure, which provides intersection testing (described below). Next, the system loads the scene data into the workstation's hardware display list. Finally, the system configures the hardware rendering loop to return control to the software system 10 times a second, which matches the rate at which the wheelchair transmits messages to the host computer.

The *wheelchair data processing phase* is repeatedly invoked from within the hardware rendering loop. If a new message has arrived from the chair, the system reads the speed of each wheel from the serial port buffer. It uses this data, along with the elapsed time since the arrival of the last message, to calculate a new eye point and center-of-interest for the rendered scene. Next the system tests for intersections between the wheelchair and the rest of the environment. If there are no intersections, the system updates the hardware viewing matrix with the new eye point and center-of-interest and returns control to the rendering hardware. The next time the rendering hardware traverses the display list, it renders the scene looking from the new eye point towards the new center-of-interest. If an intersection is detected, the eye point and center-of-interest are not updated; otherwise, the user would drive through the intersected object. Currently, the system issues a beep and jars the scene slightly to indicate a collision.

Each time the user's eye point and center-of-interest are updated, the system performs intersection testing between the chair and the environment. This testing prevents the user from running through walls or other objects. A naive implementation might detect an intersection by testing the chair against every polygon in the scene, yet the complexity of this operation would prevent the system from running in real time for even simple scenarios. Instead, the system uses an N-objects octree data structure to reduce the number of polygons tested and hence speed collision detection. An octree is a common data structure in computer graphics (Foley et al. 1990). An N-objects octree is a modification that recursively subdivides the scene until each octree node contains not more than N objects (Samet, 1990). Details of the subdivision and collision detection algorithm may be found in Swan (1993).

ARCHITECTURAL AND DESIGN CONSIDERATIONS

Computer visualization tools are beginning to revolutionize the way architects design environments. Traditionally, as discussed in Reynolds (1993), architects design almost exclusively through the use of 2D plans and elevations. Although axonometric views are sometimes used because of their ease of construction, these aerial views have limited relevance when people have to navigate through a building. Thus, for the most part, an architect relies on intuition to determine the spatial correctness of a building and, where this fails, design guidelines or building codes. However, it is common for both to be insufficient.

3D perspective views may be produced for client presentations, but typically this is done only after a project is finalized. Furthermore, properly drawn perspectives are time consuming and expensive to construct. Nevertheless, 3D renderings are more intuitive than 2D architectural plans, since 2D plans are readily comprehended only by those with architectural training. Thus, 3D renderings allow the involvement of both the architect and the project's clients. The usefulness of computer visualization is that it allows these 3D renderings to be set up quickly and easily. Furthermore, shaded renderings allow the study of color and texture in relation to form, space, and lights — an ability that hand-drawn perspectives lack without the investment of large amounts of time.

Design standards can assist the builder or architect in designing handicapped accessible spaces (Raschko and Boetticher, 1982; Packard and Kliment, 1989; Americans with Disabilities Act of 1990); the ADA is an example of a mandatory design standard. However, guidelines and standards refer to discrete spaces and cannot possibly account for all of the permutations a building goes through under the hands of an architect or builder (Vanier, 1993). Even when architects think they have interpreted the standards relevant to their building correctly, and the building passes inspection, handicapped persons may still have difficulty navigating through the space.

Furthermore, handicapped accessibility is often a last-minute accessory added when a structure is renovated; a common example is a seemingly cohesive building with a ramp for the handicapped tacked on the front. Because architects will now, through the ADA, be forced to deal with this problem before construction, there is the opportunity for the aesthetic integration of ramps and other accessibility structures. Some buildings, such as the Wexner Center on The Ohio State University campus (Peter Eisenman) and the Guggenheim (Frank Lloyd Wright), have ramps integrated into their designs. In both cases, the ramps provide an aesthetic and rewarding experience for all visitors (although the original intent of the these particular architects may not have been to provide handicapped accessibility).

Our visualization system addresses these and other concerns. It enables the architect to work directly with the client to develop the most effective spatial relationships. Furthermore, since the accessibility of new designs may be tested, it gives architects and designers a tool in addition to handicapped-accessible predefined organizations. Both the aesthetic value of a building as a work of art and the pragmatics of handicapped accessibility can be explored.

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