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Applications drive VR interface selection

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Based on the general press and Hollywood's interpretations of virtual reality, it would be easy to form the impression that head-mounted goggles and flex-sensing gloves are the sole means of accessing and manipulating computer-generated worlds. Actually, a wide range of alternative technologies are available, allowing developers and end users to configure systems ideally suited for specific applications. While each of these technologies is a variation of the basic goggle-and-glove concept, each is also tailored for specific application requirements and computer platforms. Since these targets range from home gaming devices to parallel supercomputers, variations can be extreme, with each device having certain advantages and limitations.

Physical interfaces to virtual environments fall into two broad categories:

- devices for navigation and physical interaction, such as deskbound and flying "mice," gestural devices, and navigation controls built into viewing devices.
- viewing devices, such as head-mounted displays, counterbalanced displays, shutter glasses, and a new class of immersive "desktop" viewers.

This survey will describe the range of available devices (see Table 1) and discuss how application considerations affect the selection of components when configuring a VR system. Immersive displays are a logical point to begin our survey, since the visual image is so critical to creating an effective virtual experience.

Immersive display systems

A recent article in *VR News*[1] noted that the trade-off among high-quality, color resolution, and the field of view required to create an immersive display is the major challenge faced in viewing devices. We believe that the 60,000-color pixel density of LCD-based approaches, representing just five percent of the color density of graphics workstations, does not achieve the necessary illusion. For this discussion, we define immersive viewing as an 80-degree or greater field of view, with a resolution of at least one million pixels per eye (graphics workstation displays typically support 1.3 million color pixels, or triads, per eye). As we shall see, effective weight and mass are also issues for many applications.

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At first glance, stereo shutter glasses represent the least costly technology for immersive viewing. The 3D image is created by alternately occluding one eye view in synchronization with a 2D display that creates alternate, offset views of an image, but the field of view is limited to the width of the 2D display screen. When cost and physical size are not a concern, a truly immersive experience can be achieved with a "cave" environment, based on large-screen wraparound monitors to achieve a wide field of view.

A key design criterion for immersive displays is that they must be able to accommodate human variations in interocular spacing and head size. In the realm of head-mounted displays, systems designed for military applications, such as flight or battlefield operations training address this problem with custom mounting systems that provide adjustments for different users.[2] Training applications take place in controlled environments, with the goal often being full immersion without the intrusion of real-world stimuli. Human trainees, who have a vested interest in completing the experience, are more likely to tolerate head-mounts weighing four or more pounds.

In consumer entertainment applications, where a large number of headset solutions are offered, virtual experiences are usually of short duration. So far, it appears that VR gaming customers accept head-mounts. For longer immersions—such as for scientific and commercial research or concurrent engineering and design projects—discussions with end users indicate that there is resistance to viewing devices that must be worn. Additionally, motion-tracking systems in head-mounts are usually electromag-

Table 1. Application design requirements and issues.

Application domain	Domain requirements	Display considerations	Navigation considerations
Consumer:			
Gaming systems	Low-cost PC or dedicated platforms Mid- to high-cost: "Arcades" and VR parlors	A,B,C (low cost) E,G (high cost)	1,2,3
Location-based entertainment	Large audiences, shared experience	A,C,F (high throughput) B,E,G (low throughput)	1,3,5
Education/ edutainment	Multiuser, shared experience Throughput may be important	A,C,F (high throughput) B,E,G (low throughput)	1,3,5
Commercial/research:			
Scientific visualization	Degree of immersion is variable Entry/exit can be an issue	A (low immersion, except "caves") D, F (high immersion)	1,2,3,4
Training	Entry/exit not an issue	E,G	1,4,5
Virtual prototyping	Entry/exit an issue Ergonomics evaluation requires "hands free"	D G (hands-free)	2,4,5
Concurrent engineering	Team approach requires flexibility	D,F	2,3,4,5
VR software development	Entry/exit issues	A,C,D,G	1,2,5

A. Stereo glasses (Lightweight; degree of immersion based on cubic area of 2D screen)
B. Head-mounted, LCD-based (Relatively lightweight; low resolution, mono- or bichromatic)
C. Fixed, noninteractive (Immersive experience; 3rd-party control; high or low resolution affects cost)
D. Haptic-coupled desktop device (Immersive; individual control; usable in small areas)
E. Head-mounted, CRT-based (High weight and mass; supports high resolution and color; relatively fragile; requires adjustment for each user)
F. Counterbalanced CRT, hands-on (Practically weightless; supports high resolution and color; inherently rugged; no individual adjustment)
G. Counterbalanced CRT, hands-free (Practically weightless; inherently rugged; no individual adjustment)

1. Flying devices (Intuitive use; point-and-click-control; six DOF costs $1,000 or more, two-DOF joysticks around $100)
2. Desk-bound devices (Tricky to use at first; cost range: $300-$2,000)
3. Attached devices (Single axis movement; integrated with counter-balanced or fixed viewers, small added cost)
4. Gesture devices—flex (Complex, requires frequent adjustment for kinematic accuracy; cost range: $500-$12,000)
5. Gesture devices—pinch (Intuitive use, flexible control system; easily integrated into system; cost: $2,000 for system, $100 for gloves)

netic in nature. This makes them subject to interference from both radio and CRT emissions, limiting their usefulness outside of controlled environments. The alternative tracking technology for head-mounts, ultrasound, is subject to line-of-sight limitations.

For many applications that require freedom of hand motion for an effective virtual environment experience, hands-free counterbalanced displays are very effective. Disney Imagineering's Aladdin Adventure at Epcot Center uses a CRT-based stereoscopic display with an air spring and a pair of supporting cables to counterbalance most of its weight and ensure that it will not be dropped to the floor. In this prototype virtual experience, individuals use their hands to "control" flying motions that they perceive as a magic carpet ride through the simulated world. Epcot Center presents a controlled environment, so this design can accommodate magnetic trackers for position sensing. In more industrially oriented applications, such as virtual prototyping of automobile and aircraft cockpits, the Fakespace Simulation System (see Figure 1) provides hands-free viewing of environments in full color, with up to 1,280 × 1,024 interlaced resolution. In this instance, as with many other counterbalanced displays, optomechanical-based tracking is used.

While both of these hands-free, counterbalanced displays are head-mounted, they effectively weigh nothing, an important consideration in simulation systems that require immersion for long periods of time. Mass is minimized without sacrificing display quality, and inertial effects are approximately the same as those experienced in commercially available, CRT-based head-mounted displays. Counterbalanced displays are typically used for applications where immersive access to the virtual world by groups of people in succession is desirable. They are based on a design approach that addresses three common issues affecting the use of viewing hardware. First, comfort is of primary importance. Second, people frequently want to view the same scene—whether in interactive entertainment or the workplace. Finally, the need to minimize "dead time" between viewing of the immersive experience may make donning a headset impractical. This might apply in the design review stage of concurrent engineering projects or an interactive entertainment experience.[2]

One example of a short dead-time, high-throughput application is the Virtual Brewery project created by Telepresence Research and installed at Sapporo Beer Headquarters in Tokyo. In this system, an SGI Onyx computer drives a simulation viewed through one counterbalanced display and 12 fixed, stereo viewing devices slaved to the system. One patron uses the counterbalanced display to navigate and control the point of view in the environment, while 12 others "go along for the ride." This arrangement allows throughput of 1,000 people each day.

The newest provider of fixed stereo displays is Nintendo of America. The Virtual Boy system they plan to introduce in August uses two monochromatic displays mounted in a table top viewing system (Figure 2). Navigation is achieved with a hand-held game controller. Use of a lower resolution, light-emitting diode (LED) display and a narrow field of view mean that this system does not fit precisely into our definition of immersive displays. However, since it is the first immersive display product marketed by a major international company, it will certainly provide new insights into the level of acceptance this technology might gain in consumer markets.

A radically new physical interface combines the compactness of the fixed device with the ability to navigate through the virtual environment. This haptic-coupled device provides freedom of motion and position tracking based on the application of axial force (Figure 3). Early users have found that its operation is highly intuitive, and it allows for complex virtual world navigation without requiring twisting or bending by the user.

Virtual world navigation

While desktop viewers will ultimately reduce the need for peripheral navigation and manipulation devices, many applications will continue to require these devices. The basic requirement of input and control devices in virtual worlds is that they provide full and simple control over movement in three linear axes and three possible rotations.[3] *VR News* has usefully categorized available devices as gestural devices, flying devices, or deskbound devices. A fourth category, attached devices, covers the buttons or switches found on the handles of counterbalanced displays that control forward and backward movement and selection of objects in virtual environments.

While glove devices are most often pictured in popular media representations of VR, they are infrequently used navigation devices. The typical glove input device is based on the general design patented by VPL Research, which measures flex along the length of

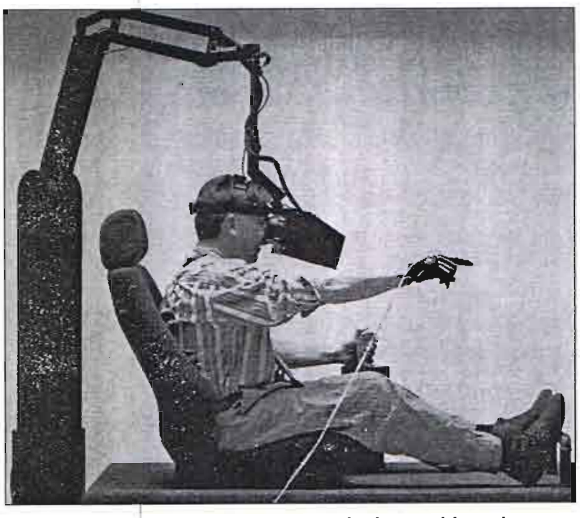

Figure 1. Counterbalanced head-mounted display leaves hands free.

Figure 2. Virtual Boy fixed stereo display. (Courtesy of Nintendo)

each finger and thumb via a proprietary, optical fiber-based bend sensor.[4] Similar flex gloves are presently available from Virtual Technologies, Fifth Dimension Technologies, Exos, and other firms. Mattel Toys also sold (but has ceased producing) a flex glove for video game use that incorporated low-cost resistive ink sensors.

One reason for the low usage of flex gloves is the need for calibration to each user and recalibration while in use. Researchers report that flex gloves can have "unintentional interdependencies among the sensors" and "the input data of two executions of the same gesture may vary widely because of the bad repetition accuracy."[5] These complications arise from attempts to use flex gloves to drive kinematic models of the human hand, creating a complete geometric representation of the hand within the virtual world. However, the primary motivation for many applications is to allow the human hand to naturally interact with a virtual world. A simpler approach, first implemented by the Institute for Simulation and Training in a program called Polyshop, uses two spatially tracked fingertip gloves to enable the rapid construction and manipulation of polygon-based geometries.[6]

If the only application requirement is to record a user's six degrees-of-freedom movement, more than a dozen variations of flying or deskbound inputs are available. Deskbound devices are primarily "forceball" approaches, although interesting hybrids of trackballs and 2D mice exist. Most of the flying devices are 3D mice, available with magnetic or ultrasonic trackers. A new class of sourceless systems, which use gyroscopic mercury switch, inertial or fixed magnetic technologies, are said to provide fewer limitations in operating areas.

Configuring VR interface systems

While technology improvements continue to drive down overall system cost, it will still be a long time before photorealistic, in-home VR experiences like those depicted in films and television are available. With this in mind, we can look at how available technologies are configured for each of the currently envisioned VR application categories. As an aid to selecting the appropriate components for a VR system configuration, Table 1 relates each viewing and navigation device to the broad class of applications. Device costs, weighed against the value or potential revenue of the application, must also be considered.

Gaming or arcade applications that combine head-mounted displays with motion platforms are delivering high quality imagery and audio at a cost of $5 to $30 for a single use experience. This arcade business model, of course, relies on high throughput of paying customers. Alternatively, the location-based entertainment or edutainment systems installed to date have been driven by corporate image goals. Movement of more than 1,000 visitors per day through the Sapporo Virtual Brewery confirms that relatively costly systems based on a combination of fixed and counterbalanced CRT displays may be readily acceptable as elements of a "virtual theme park," interactive museum, and even as teaching tools.

In commercial and research applications, planned usage is a primary consideration in system configuration. With systems intended for single users and extended duration experiences, a head-mount or hands-free counterbalanced display is suitable. For team-oriented and development work, ease of entry and exit to the virtual environment is required. Desktop use makes high-resolution, fixed devices a logical choice. In concurrent engineering and other team-oriented exercises, counterbalanced systems provide flexibility and easy access to the virtual world. Stereo glasses also may play a role in these applications. However, the multiple, large-screen monitors with separate image generation platforms required for effective "cave" environment creation turn this seemingly low-cost approach into an expensive, nontransportable alternative.

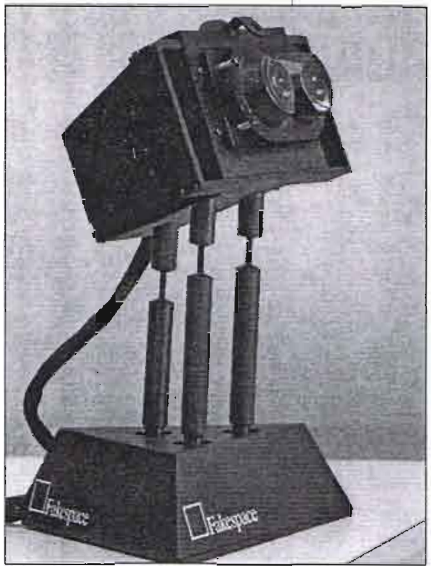

Figure 3. Haptic-coupled interface.

Clearly, the field of virtual reality is beginning to flourish, as exciting and tantalizing applications and tools become available on numerous platforms. As the science and art of designing VR experiences matures, engineers and designers must remember the constraints imposed by a specific application, but not be bound by prior assumptions regarding appropriate technology.

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