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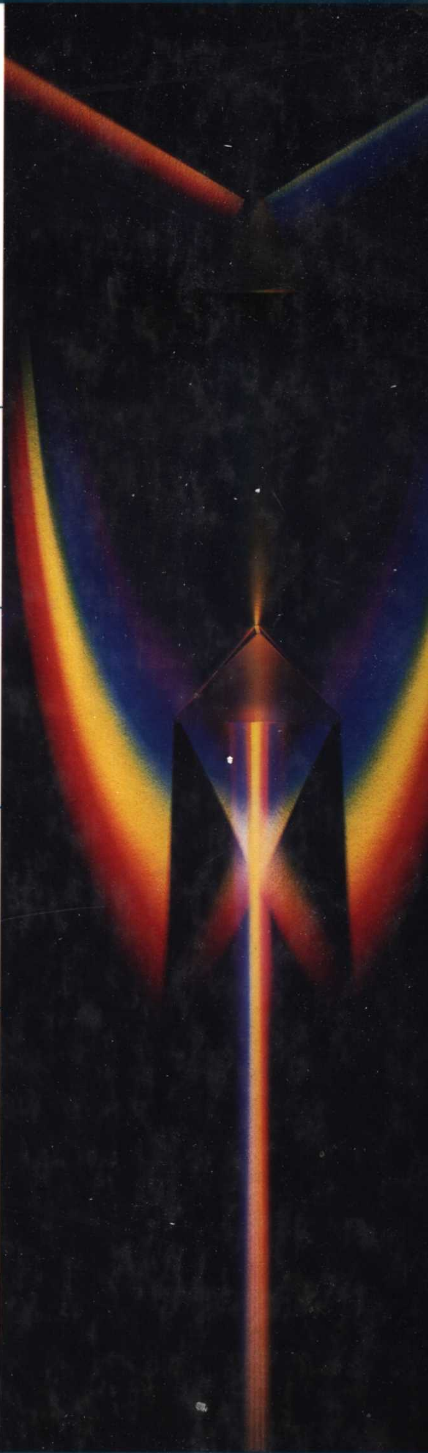
James E. Melzer
& Kirk Moffitt

HEAD MOUNTED DISPLAYS

Designing for the User



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SERIES EDITORS

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James E. Melzer
Kirk Moffitt

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Preface

One of our early experiences with a commercial head-mounted display (HMD) was at an evening reception following a virtual reality conference. Although we had been building military HMDs for several years, this was going to be a new experience. After fortifying ourselves with wine and cheese, it was our turn to view the HMD. We were disappointed. It was front-heavy and uncomfortable. It had a fuzzy appearance, and it did not allow for eyeglasses. When we mentioned this, the man demonstrating the device assured us that it was not the wine and that it would not have made any difference if we *had* worn eyeglasses.

At the same show we had the opportunity to try on a headset that was billed as *the VR HMD.* One of us has a rather large head, and this device did not fit over it. After a quick modification by the vendor, we managed a tight fit, but it was not worth the effort. The imagery was so badly misaligned that viewing it for more than a few moments was painful.

Another experience was a series of meetings we were having with a group of Army flight-safety officers. We wanted them to fly one of our company's HMDs in their helicopter, but first we needed approval from their safety committee. The process took quite some time, because of what we perceived as incessant questions about the most minute details of our design. After a particularly grueling face-to-face session, the meeting broke up and we left with our flight-safety approval. As we were walking out of the building, one of the flight surgeons took us aside. He told us not to take the interrogations personally, because the people we were talking with were the ones responsible for investigating accidents—an unpleasant task, considering how a helicopter crashes.

These three examples show why in designing or buying an HMD we need to understand who the user is, how the user will interact with the display, and what the environment will be like. The first two examples show the results of a lack of this understanding—poorly aligned displays that don't fit. The third shows the results of having that understanding. The flight surgeons learned about the delicate balance between the HMD *as display* and the HMD *as life-support* through their experiences.

An HMD is something you wear *and* something you view. It is a personal device that can provide you with information, train you to do a job by simulating what it would really be like, or entertain you by transporting you to a fantasy world. At the center of these experiences is the human who wears and views the HMD. Properly designed, an HMD can suspend belief sufficiently to train a pilot to fly an airplane or a surgeon to perform a new operation, or transport you to the surface of Mars. Improperly designed, the HMD can be uncomfortable to wear, difficult to use, and even painful to view.

This is not surprising, as it seems to be the fate of many new technologies when first introduced. One example is the early DOS-based computers. To perform a routine task like saving a file to disk, the user had to enter a string of seemingly unrelated and unintelligible characters. This turned off some people, confused others, and convinced still more that the personal computer was not a solution for everyday tasks.

Early HMDs took a similar path. It was thought that a display on the head was simply that—glass and electronics mounted in front of the eyes, with no serious regard given to what was really needed by the user. Early designers were rushing toward a vision of virtual and interactive imagery, and they placed their emphasis on the technology, not on the user. The result was displays that were uncomfortable to wear and difficult to use. HMDs have received a lot of publicity recently—some good as a result of excellent new applications, and some bad as a result of poor designs that were poorly implemented.

It is for all of these reasons that we decided to focus this book on the fundamental needs of the user. We know that the technology will improve over the next few years—we have seen it change just during the writing of this book—but the human who wears the HMD will not appreciably change over the next several millenia. If we understand what these fundamental needs are, we can take the developments in technology, implement them in our designs, and provide an HMD that will benefit the user. There will still be trade-offs to be made as technology improves, but understanding the user's essential needs will help us make intelligent decisions.

This book is a compilation of the many subjects that relate to the design of HMDs. It is by its nature a multidisciplinary discussion, because to adequately address the needs of the user, we must cross numerous behavioral, psychological, performance, and anthropometric boundaries. The authors of the chapters are experts in their fields with academic, commercial, and military backgrounds and we thank them for their fine work. We hope that this book will benefit both users and designers of HMDs.

We would like to extend our thanks to Kaiser Electronics for support during Kirk Moffitt's tenure with the company, and to Kaiser Electro-Optics for continued support of Jim Melzer. Finally, we would like to thank Warren Smith for his support and guidance during the preparation of this book.

Contents

Chapter

1

HMD Design— Putting the User First

James E. Melzer

Kirk Moffitt

The head-mounted display (HMD) is a critical link in virtual-environment and visually coupled systems. HMD users can experience immersion in computer-generated virtual environments, privately view a movie, perform a delicate endoscopic surgical procedure, or fly an attack helicopter nap-of-the-earth in darkness. The success of these tasks depends on the design of the HMD system. Given the intimate interface to the human, the user should be the central focus of the design process. An HMD will be successful only if full consideration is given to the characteristics and tasks of the user.

1.1 The Richness of an HMD

The head-mounted display (HMD) provides the user with a set of capabilities that conventional displays cannot duplicate. An HMD can be personal, interactive, expansive, *and* virtual. Handheld televisions and video games, personal computer monitors, panoramic theater screens, and head-up displays share one or two of these attributes at most. Only an HMD provides the user with an intimate display that can be reactive to head and body movement and surround him or her with a virtual environment that extends far beyond the confines of the miniature image source.

Unlike televisions, computer monitors, and movie screens, which usually vary only in size, HMDs come in many types that accommodate a wide range of uses. An HMD can be any of the following:

- A simple reticle projector that a pilot uses to designate an enemy aircraft
- A more thorough symbology display that gives the pilot orientation and status information
- A small offset display that a technician can glance at for reference data
- A private view of a selected movie by an airline passenger
- Stereo imagery relayed from head-steered cameras located on a remote vehicle
- A computer-generated, panoramic world that can be navigated with simple movements and gestures

This wealth of applications makes a book on HMD design worthwhile. It is not our intent to provide a formula for building each variation, but rather to engage the reader in a discussion of fundamental HMD design concepts that center on the characteristics and capabilities of the user. The chapters in this book cover topics as diverse as fitting HMDs to human heads, perceptual requirements of HMDs, and incorporating brain-actuated control into HMDs. The common thread is the need to put the user at the center of the design process.

1.2 What Is an HMD?

In its simplest form, an HMD consists of an image source and collimating optics in a head mount (see Fig. 1.1). The HMD can then become more elaborate in several ways. There may be one or two display channels. These channels may display graphics and symbology with or without video overlay. They may be viewed directly and occlude external vision for a fully immersive experience, or they may use a

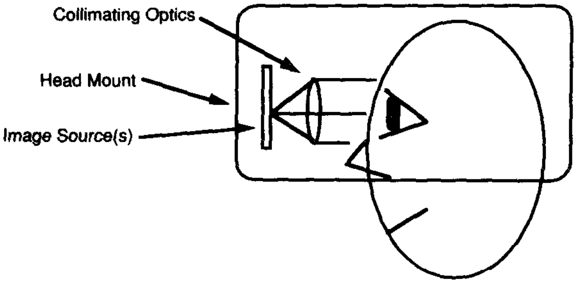

Figure 1.1 An HMD consists of an image source, collimating optics, and a head mount—providing a virtual image to the wearer.

semitransparent combiner with see-through to the outside world. In this augmented reality mode, the HMD may overlay symbology or other information on the world view.

The HMD image source may be a CRT or LCD mounted on the head, or the image may be brought up to the head through a fiberoptic bundle. An HMD may use a simple headband for mounting on the head, or the optics and the displays may be integrated into an aviator's flight helmet. This latter device is a specialized case of the head-mounted display—the *helmet-mounted display*.

The HMD is part of a larger system that can include an image generator, a head tracker, audio, and a manual input device (see Fig. 1.2). The image generator may be a sophisticated image rendering engine or a personal computer. A tracker, which communicates the orientation of the user's head to the image generator, immerses the user in a virtual environment. This immersion is often enhanced by 3D or directional audio. Input/output devices can include brain- or voice-actuated control, a joystick, and a 3D mouse or glove to manipulate virtual objects.

Properly designed, this deceptively simple arrangement of optics and electronics can fit comfortably and be worn for several hours. It can instruct you in new ideas, provide important information, or transport

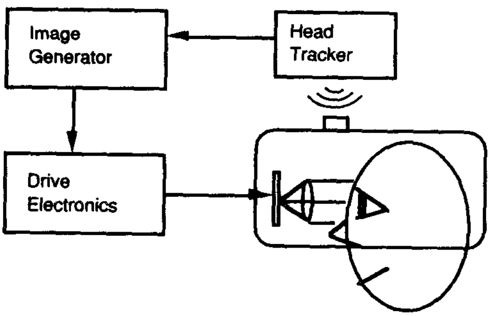

Figure 1.2 An HMD is part of a visually coupled display system consisting of an image generator, drive electronics, and a head tracker.

you to alternative realities. Improperly designed, an HMD can quickly strain your eyes, your neck, or your stomach with symptoms that can last for several hours. Why? Our evolutionary development occurred in the natural world, with the neck supporting only the head and with visual imagery being perfectly aligned and correspondent. HMDs can place a burden on the neck, can easily be misaligned, and may put the visual and vestibular systems into conflict.

These are many diverse, complex, and interdisciplinary issues that are associated with the design of an HMD. Some are subtle; some are obvious. All are centered on the needs of the users, who will be wearing the device, and the tasks they are performing. If we ignore these needs, we will produce an HMD that can have negative side effects that will not be accepted. Only by understanding the users and treating them as an integral part of the process can we assure a successful design.

1.3 Early HMDs

In the 1960s Ivan Sutherland married CRTs with focusing optics, head orientation hardware, and an early computer image generator to produce the first HMD system. Because of the weight, Sutherland suspended it from the ceiling, from which it got the name "Sword of Damocles" (Rheingold, 1991). Sutherland used this system to conduct early experiments in virtual environments and HMD-based stereovision with a wide-field-of-view binocular display.

The U.S. military briefly experimented with helmet-mounted sights in the 1970s. The Visual Target Acquisition System, or VTAS, was a simple HMD used to aim air-to-air missiles. It was a lightweight device that attached to a standard flight helmet, and it reflected light from a series of light-emitting diodes off a special visor. Unfortunately, the VTAS was abandoned because of the limitations in missile technology at that time (Dornheim, 1995b).

Improvements in HMD technology and their applications proceeded slowly until the mid 1980s, when there were four key HMD developments.

First, researchers at NASA Ames Research Center developed their Virtual Interactive Environment Work Station (VIEW), consisting of a wide-field-of-view (WFOV), head-tracked HMD with 3D virtual sound connected to a computer image generator. This HMD design, shown in Fig. 1.3, used two commercial LCD image sources with projector lenses, and it looked like an oversized scuba mask. It provided the wearer with visual and audio feedback in a WFOV immersive environment, but with low resolution. This HMD design became synonymous with the emerging technology of virtual reality, and variations of this design were sold through the mid 1990s.