2.2 Commercial Products

The vast majority of current commercial products are HMDs. Such displays range from high-end, expensive products such as the Cyberface 4, Datavisor, Ericsson HMD, Fakespace Simulation System, and Stereoviewer 1, which have prices around $40,000 to $55,000, to medium-price systems such as the CyberEye, MRG Head-Mounted Displays, and Private Eye, which have prices above $1,000 but less than $10,000, to quite inexpensive consumer product displays costing less than $1,000, including the i-glasses!, and VFX1. Other products described include CrystalEyes shutter glasses, the Virtual Window autostereoscopic display, and the VR -1100 and VR-2000 passive glasses projection systems. The major characteristics of many of these products are summarized in Table 1.

Before describing the commercially available products, it is useful to briefly discuss the special optical system used in most HMDs. Marketed by Leep Systems, Inc., the LEEP (Large Expanse Extra Perspective) Optical Viewer (also known as product ARV-1) is a unique set of lenses that has become a de facto standard for stereoscopic vision optics in the VE industry. It is a lens system that magnifies the images of the LCD or CRT displays of a stereoscopic viewer, so as to increase the field of view of the display. A photograph of the LEEP Optical Viewer is given in Figure 1.

The product is based on a design originally intended for use in stereoscopic photography (Howlett, 1983). At that time, stereoscopic color photography was practical only with very narrow (20° to 50°) fields of view and the LEEP invention made possible wide angle view capture for slides that must be an eye-spacing apart. The strong positive distortion needed to record a wide angle for each eye introduces an additional lateral chromatism, in which optics refract a beam of light at a different angle if it is of a different wavelength. The result of this, in the case of optics such as the LEEP, is differential magnification depending upon wavelength, which is observed as red and blue fringes at the edges of a field. The design of the LEEP lenses deliberately ignored the problem of lateral chromatism. The camera and stereoscopic viewer both used the same complementing chromatism distortion lenses for original photography and for viewing. The chromatic aberration and distortion of the image stored on the film was corrected by an inverse aberration distortion effect when the stereograph was viewed. The LEEP optics result in a wide angle "fish-eye" lens system that, as a whole, does not distort the position of objects in the image.

Photo courtesy of Leep Systems, Inc.

Figure 1. LEEP Optical Viewer

Table 1. Characteristics of Commercially Available Display Devices

Technology		Product	Vendor	Resolution (in pixels)	Field of View	Weight	Price
HMD	CRT-based	Datavisor 10x/9ci	n-Vision, Inc.	1280 x 1024	80° horiz	4.2 lb	Contact vendor
		Ericsson HMD	Ericsson Microwave Systems	1280 x 960	55° horiz, 41° vert	2.3 kg	Approx. $55,000
		FS5	Virtual Research Systems, Inc.	Not applicable	55° - 76° diag	38 oz	$19,900
	LCD-based	CyberEye 100M and 100S	General Reality Company	420 x 230	22.5° horiz, 16.8° vert	14 oz	$1,995, $2,495
		CyberMaxx CM1800	VictorMaxx Technologies	320 x 400	58° horiz	14 oz	$889
		Dvisor HMD	Division, Inc.	345 x 259	105° horiz, 41° vert	8 lb	~$7,000
		i-glasses	Virtual I/O	640 x 480	30° diag	8.5 oz	$599-$799
		MRG 2.2 HMD	Liquid Image Corp.	240 x 720	84° horiz, 65° vert	4 lb	$3,495
		MRG 3c HMD	Liquid Image Corp.	768 x 556	84° horiz, 65° vert	4 lb	$5,500
		MRG 2.2 HMD	Liquid Image Corp.	480 x 234	61° horiz, 46 ° vert	2.5 lb	$2,195
		VIM 500HRpv	Kaiser Electro-Optics, Inc.	180,000 per LCD (2)	50° diag	24 oz	$3,495
		VIM 1000HRpv	Kaiser Electro-Optics, Inc.	180,000 per LCD (4)	100° horiz, 30° vert	26 oz	$7,995
		VFX1 HMD	Forte Technologies, Inc.	789 x 230	35.5° horiz, 26.4° vert	Unknown	$995
		VR4 HMD	Virtual Research Systems, Inc.	742 x 230	60° diag	31 oz	$7,900
		VR4000 HMD	Virtual Research Systems, Inc.	742 x 230	60° diag	31 oz	Contact vendor
	Unknown	VRI HMD 133	Virtual Reality, Inc.	Unknown	40° horiz, 30° vert	3 lb	Contact vendor
Shutter glasses		CrystalEyes	StereoGraphics Corp.	Not applicable	Not applicable	3.3 oz	$595
Passive glasses/ Projection system		VR-1100	VRex, Inc.	1024 x 768	Not applicable	Not applicable	$11,995
		VR-2000	VRex, Inc.	640 x 480	Not applicable	Not applicable	$8,995
Boom		BOOM 3C	Fakespace, Inc.	1280 x 1024	40° - 100° horiz	Counter-balanced	$95,000
		Cyberface 4	Leep Systems, Inc.	480 x 640	80° horiz, 60° vert	Counter-balanced	$15,750
		Fakespace Simulation System	Fakespace, Inc.	1280 x 1024	30° - 140° horiz	Counter-balanced	$95,000
		PUSH	Fakespace, Inc.	1280 x 1024	45° - 110° horiz	Not applicable	$45,000
Autostereoscopic		Virtual Window	Dimension Technologies, Inc.	680 x 480	Not applicable	Not applicable	$17,500

There is compression of the visual field that is a function of the angle from the center: the further away from the center, the more compression.

A surprising aspect of the use of LEEP optics in HMDs is that although it was designed to be provided with a deliberately distorted image, many users make no provision for correcting such distortion. Several algorithms have been published for computing the appropriate transformation, such as that by Kalawsky (1993), and product literature from LEEP suggests correcting by making the red image about 1% larger linearly than the blue image, with the green image in between. If the eyes have full range of movement, unconstrained by the HMD, the field of view possible with the LEEP optics is 140°. With most HMDs, however, the eyes are normally constrained in their movement, with an effective field of view from 110° to 130°, depending on the amount of constraints. The focal length of the LEEP optics is 41 mm, and the entrance pupil diameter 60 mm. The LEEP optics consist of three lenses per eye.

2.2.1 Datavisor Displays

Specification	
Resolution	1280 x 1024, 1.8 arc min
Field of View	80° horiz, 20° overlap
Weight	4.2 lb
Brightness	10 fL
Contrast Ratio	100:1
Pupil Diameter	12 mm
Interpupillary Distance	56-86 mm adjustable
Image Plane Focus	Infinity to 0.5 m

Figure 2. Datavisor 10x/9ci

From n-Vision, Inc., the Datavisor 10x and 9ci devices are high resolution, wide field of view, color HMDs. They use a common display system, that is, a pair of miniature CRT displays with attached field sequential shutter devices. These shutters are electronically switchable light filters that allow only one color of light (red, green, or blue) to pass at any instant. Video is provided as sequences of fields for red, green, and blue, with the appropriate shutter filter activated at the appropriate field. The following video formats are supported for field sequential display: 1280 x 1024, 1280 x 960, 1025 x 946, 875 x 808, 640 x 480. The Datavisor 10x unit also supports 24 bit, 1280 x 1024 60 Hz monochrome. Further details are given in Figure 2. Price information is available from the vendor.

The Datavisor VGA, as its name suggests, supports VGA video formats for field sequential display. It also differs from the Datavisor 10x and 9ci in resolution (640 x 480 pixels, 3.8 arc min) and field of view (50° diagonal). It supports standard 640 x 480 VESA and 640 x 480 field sequential video formats.

The Datavisor 80 device also differs from the above Datavisor products in resolution (1280 x 1024 pixels) and field of view (120° horizontal with 40° overlap). It supports the following video formats for field sequential display: 1280 x 1024, 1280 x 960, 1025 x 946, 875 x 808, 640 x 480. A final n-Vision, Inc. product is the Virtual Binoculars (VR-B), which is a full color, high resolution, wide field-of-view, hand held display system designed to emulate a wide range of commercial and military binoculars. Combining miniature full-color image sources and precision optical relay assemblies in a lightweight housing, it is designed to offer the features and performance required to exploit the improved capabilities of mid- and low-range fire arms training systems as well as high end graphics training systems at a competitive cost. The Virtual Binoculars supports standard 640 x 480 VESA and 640 x 480 field sequential video formats.

2.2.2 FS5 Head-Mounted Display

Virtual Research Systems, Inc. recently announced the FS5 HMD, a display specifically designed to lower the cost of high performance VE. This HMD uses dual black and white CRTs with color shutters, and a proprietary optical design that provides a wide field of view with adjustable overlap. A standard 100% overlap allows a 55° diagonal field of view, while reducing this to 50% overlap extends the field of view to 76°. The FS5 supports full color, with field sequential RS-170 and 180 Hz RS-170 RGB. Close-cup high fidelity Sennheiser earphones are suitable for use with 3-D spatialized audio. An optional F-Scan converter drives the HMD from any mono or stereo VGA or RS-170 video source. Further details are provided in Figure 3. The price for this product is $19,900.

Specification	
Resolution	800 lines horizontal
Field of View	55° diag. at 100% overlap, 76° diag. at 50% overlap
Weight	38 oz
Brightness	Adjustable
Contrast Ratio	100:1 adjustable
Interpupillary Distance	52 - 74 mm
Image Plane Focus	5 ft

Photo courtesy of Virtual Research Systems, Inc.

Figure 3. FS5 Head-Mounted Display

2.2.3 CyberEye 100M and 100S

Specification	
Resolution	420 x 230 pixels, 3.2 arc min.
Field of View	22.5° horiz, 16.8° vert
Weight	14 oz
Brightness	Adjustable
Contrast Ratio	100:1
Interpupillary Distance	Adjustable
Image Plane Focus	~12 ft, variable

Photo courtesy of General Reality Company

Figure 4. CyberEye 100M and 100S

General Reality Company markets two active matrix LCD CyberEye products. The CyberEye 100M is a low-cost HMD intended for extended wear, while CyberEye 100S is a stereo version of the same. Both versions support use by a single user over an extended period of time through variable focus and an adjustable interpupillary distance. Other models are available for short-duration work with multiple users or for public arcade games; these have fixed focus and locked interpupillary adjustments. The devices support

NTSC video format. A photograph of the CyberEye display and specification details common to both the CyberEye 100M and the CyberEye 100S are given in Figure 4.

The price for the product, including audio, cables, and mounting equipment, is $1,995 for the CyberEye 100M monoscopic system and $2,495 for the CyberEye 100S stereoscopic system.

2.2.4 CyberMaxx CM1800

CyberMaxx CM1800 is marketed by VictorMaxx Technologies. It is a helmet-based HMD that uses a pair of color, high resolution 0.7 inch active matrix LCD displays, one for each eye. The input is standard VGA and the unit can be used with IBM compatible PCs, Macintosh computers, and with a variety of video game players. The device has adjustable interocular distance and individual eye focus adjustments. Additional specification details are given in Figure 5.

Display Specification

Resolution	320 x 400 pixels
Field of View	58° horiz
Weight	14 oz
Brightness	Adjustable
Interpupillary Distance	Adjustable

Photo courtesy of VictorMaxx Technologies

Figure 5. CyberMaxx CM1800 Display

The HMD includes a sourceless, real-time yaw, pitch, and roll head tracker and details on this component of the product are given in Figure 6. The device also includes stereo speakers with 0.1° angular resolution, 3 DOFs (yaw, pitch, and roll), and a sampling rate of 75 samples/sec. Its price is $889.

Tracking Specification

Sampling Rate	75 Hz
Angular Resolution	0.1° heading, 0.1° tilt
Angular Range	360° horizontal, ±45° vertical

Figure 6. CyberMaxx CM1800 Tracking

2.2.5 Dvisor Head-Mounted Display

Division, Inc., markets an active matrix LCD HMD that includes a Polhemus sensor and stereo audio. Called the Dvisor HMD, this system uses a patented depixellation technology developed by MicroSharp, that is claimed to “eliminate the pixel grid without blurring.” (The pixel grid is that matrix of pixels that is visible as individual points with low-resolution, wide field of view displays.) The optical system uses multiple aspheric lenses.

The device is described as based on an advanced, balanced ergonomic design, and designed for quick mounting and easy adjusting for any size head. Some further details are given in Figure 7. The price for this product is around $7,000. An optional five button 3-D mouse is available with the display.

Specification

Resolution	345 x 259 pixels
Field of View	105° horiz, 41° vert
Weight	8 lb
Brightness	Adjustable

Photo courtesy of Division, Inc.

Figure 7. Dvisor Head-Mounted Display

2.2.6 i-glasses!

From Virtual I/O, the "i-glasses!" is a color HMD that includes a pair of active matrix LCDs and stereo headphones. This HMD is aimed at the consumer market, with one version intended for use with video games and television, and another version that comes with a 3 DOF head tracker and an adapter that connects it to a personal computer. The device works either in a closed, immersive VE mode (with an opaque shade fitted over the outside of the headset) or a mixed-reality see-through mode. The primary difference between this HMD display and others is that the designers have chosen to sacrifice field of view for resolution. Thus, the display has only about a 30° field of view, but places the entire 640 x 480 matrix over this field. Further details are given in Figure 8. The glasses are priced at $599 by themselves, at $799 with tracking.

2.2.7 MRG Head-Mounted Displays

The Liquid Image Corporation (Canada) MRG 2.2, 3c, and 4 Head-Mounted Displays are all hybrid binocular, rugged displays that provide varying degrees of performance at a range of prices. These products all use full-color active matrix LCDs with an RGB delta pixel arrangement. The optics are large, 3 x 2 inches, and use a proprietary lens display. The devices include Sony stereo audio and optionally can be outfitted with Ascension or Polhemus tracking devices. The MRG 2.2 is the cheapest of these products, described by the manufacturer as the "industry workhorse" and provides a response time of 40 ms. The input video format is NTSC, with PAL optional. Further details for the MRG 2.2 are given in Figure 9. Its price is $3,495.

Specification	
Resolution	640 x 480 pixels, 2.3 arc min
Field of View	30° diagonal
Weight	8.5 oz
Brightness	Adjustable up to 1.45 fL
Interpupillary Distance	Fixed
Image Plane Focus	Fixed at 1.8 m

Photo courtesy of Virtual I/O.

Figure 8. i-glasses!

Specification	
Resolution	240 x 720 pixels
Field of View	84° horiz, 65° vert
Weight	4 lbs
Brightness	120 nt
Contrast Ratio	40:1
Interpupillary Distance	20 - 80 mm
Image Plane Focus	3 ft

Photo courtesy of Liquid Image Corporation

Figure 9. MRG 2.2 Head-Mounted Display

The MRG 3c is a higher performance version display, with higher resolution and a shorter response time of 15 ms. The video signal is analog RGB and either NTSC or PAL format can be used. See Figure 10 for further details. The price for this version of the MRG is $5,500.

The MRG 4 is similar to the MRG 3c, but intended for VE games and provides less resolution, lower contrast ratio, and a 40 ms response time. One novel feature is an optional holographic diffuser that diffuses the sharp pixel patterns into a softer image. The manufacturer claims that the device is “the world’s best selling arcade HMD.” Additional details for the MRG 4 are given in Figure 11. Its price is $2,195.

2.2.8 VIM Personal Viewer

Kaiser Electro-Optics, Inc. market a low-cost HMD called the Vision Immersion Module (VIM) Personal Viewer. Intended for easy use by a number of users, this product has adjustable eyepieces, is suitable for use with eyeglasses, and has a removable head

Specification	
Resolution	768 x 556 pixels
Field of View	84° horiz, 65° vert
Weight	4 lb
Brightness	120 nt
Contrast Ratio	100:1
Image Plane Focus	3 ft

Photo courtesy of Liquid Image Corporation

Figure 10. MRG 3c Head-Mounted Display

Specification	
Resolution	480 x 234 pixels
Field of View	61° horiz, 46° vert
Weight	2.5 lb
Brightness	120 nt
Contrast Ratio	30:1
Interpupillary Distance	20 - 80 mm
Image Plane Focus	768 x 556 pixels

Photo courtesy of Liquid Image Corporation

Figure 11. MRG 4 Head-

mount for easy sterilization. Collimating optics mean that focusing and interpupillary distance adjustments are unnecessary for each user. The VIM 1000HRpv employs four full color 0.7 in active matrix LCDs (with 180,000 pixels per LCD) with resolution limited only by these displays and not by the optics. Input is in SVGA 800 x 600 at 56-60 Hz. The VIM 500HRpv uses two LCDs, providing a reduced field-of-view, and requires a NTSC input. Both HMDs include Sennheiser stereo headphones. A photograph of the VIM Personal Viewer 1000HRpv and further details are given in Figure 12. The price for the 500HRpv version is $2,495 and that for the 1000HRpv version is $6,495.

2.2.9 VFX1 Head-Mounted Display System

Forte Technologies, Inc.'s VFX1 is a color HMD system that uses active matrix LCDs. It includes head tracking, audio (headphones and microphone), and a Cyberpuck that is a replacement for a mouse or joystick.

Specification	
Resolution	180,000 per LCD
Field of View	100° horiz, 30° vert
Weight	26 oz
Interpupillary Distance	Not applicable

Photo courtesy of Kaiser Electro-Optics, Inc.

Figure 12. VIM Personal Viewer 1000HRpv

Specification	
Resolution	789 x 230 pixels
Field of View	35.5° horiz, 26.4° vert
Interpupillary Distance	Adjustable
Image Plane Focus	Adjustable

Figure 13. VFX1 Head-Mounted Display System

There is a large degree of software support available for the VFX1, including a CD with shareware that includes Heretic, Zephyr, Descent, Dark Forces, Magic Carpet, Quarantine, Compuserve, America Online, and 3D Ware Virtual World. It is also supported by programs such as DOOM, System Shock, SuperKarts, Flight Unlimited, and Mechwarrior2, and by vendors such as Electronic Arts, Origin, Looking Glass Technologies, and Microprose. Figure 13 provide further details about the display device. The list price is $995.

2.2.10 VR4 Head-Mounted Display

From Virtual Research Systems, Inc., the VR4 and VR4000 are lightweight HMDs with dual 1.3 inch diagonal active matrix LCDs, as shown in Figure 14. The display system offers 10-30 mm adjustable eye relief and video input can be S-video or RGB. A position tracker is not included but can be attached. The price for the VR4 is $7,900.

The VR4000 is similar to the VR4 but is intended for entertainment applications in which different users frequently take it on and off. It is hardened and has stereo earphones which are built in and fixed away from the head for quicker fitting. The VR4000 is intended to be sold in large quantities to OEMs and its price is negotiable.

2.2.11 VRI HMD 133

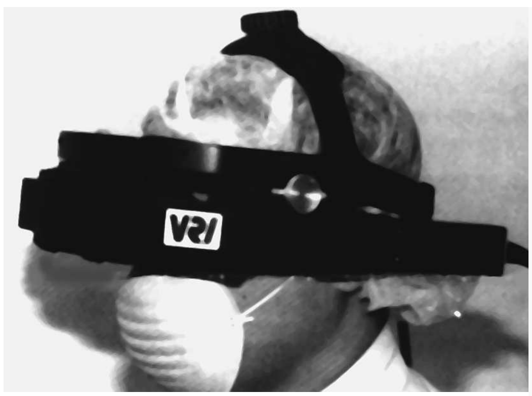
From Virtual Reality, Inc., the VRI HMD 133 is a lightweight, high resolution, color HMD that is intended for a variety of applications but particularly surgery. The unit is mounted on a headband that has ratchet adjustments on the back and top of the head. It is available in both see-through and opaque configurations, and can be easily switched between the two configurations. The video format is 1280 x 1024. Figure 15 provides additional details.

Specification

Resolution	742 x 230 pixels
Field of View	60° diagonal
Weight	31 oz
Interpupillary Distance	52 mm to 74 mm

Photo courtesy of Virtual Research Systems, Inc.

Figure 14. VR4 and VR4000 Head-Mounted Displays



Specification

Resolution	1000 pixels per inch
Field of View	40° horiz, 30° vert
Eye Relief	28 mm
Brightness	14 fL
Weight	3 lbs
Interpupillary Distance	62-75 mm
Image Plane Focus	Adjustable

Photo courtesy of Virtual Reality, Inc.

Figure 15. VRI HMD 133

2.2.12 CrystalEyes Shutter Glasses

CrystalEyes stereo-viewing technology, from StereoGraphics Corporation, employs electronically-switched liquid crystal lenses mounted in lightweight eyewear. The lenses shutter, either passing or blocking light, in synchrony with the left and right views of a stereoscopic image displayed sequentially on a computer or projection screen. These left and right views, called a stereo pair, are written on the screen at a high rate. When the left image of a stereo pair is displayed on screen, the switching circuit onboard the eyewear is instructed through an infrared link to cause the left lens to switch to a transmitting or clear mode. The right lens remains turned off, or in a blocking mode. Thus, the left image on screen is seen only by the left eye. During the next half cycle, the right image is displayed on screen, the right lens is switched clear and the left lens turned off. The right eye, then, sees the right image, and the left eye is blocked. The infrared link provides the synchronization signal, indicating whether a left or a right image is written on the screen, to an infrared receiver in the eyewear.

The on-screen image and the shutters switch between the left and right eye views so rapidly that the user cannot detect the shutters opening and closing. Instead, the user sees a constant image with two perspectives and the brain fuses the two images to make one 3-D image. Specification details for the CrystalEyes Shutter Glasses, and a photograph of the device, are given in Figure 16. A photograph of the glasses is shown in Figure 16, together with some specification details. The price is $595 for each pair of shutter glasses and $200 for the infrared emitter (which can synchronize multiple pairs of glasses).

Specification	
Weight	3.3 oz
Dynamic Range	1000:1
Shutter Close Time	0.2 ms
Shutter Open Time	2.8 ms
Field Rate	61-160 fields per sec

Photo courtesy of StereoGraphics Corporation

Figure 16. CrystalEyes Shutter Glasses

2.2.13 VR-1100 and VR-2000 Stereoscopic Projection Systems

The VRex, Inc. VR-1100 stereoscopic projection system is a device for projecting 3-D stereoscopic displays on a screen and users wear passive polarized glasses to view the projected image. While the primary purpose of the device is 3-D stereoscopic display to large audiences, it also can be used as a projection display in VE systems and has been used in this way in CAVE systems, see Section 2.3.12.

The device projects via a rear-screen technique using a LCD projection active matrix display based on an 10.4 inch active matrix thin film transistor full-color LCD panel. It is designed for use with a high-end workstation, such as the Sun Sparc, but can be driven by standard NTSC/PAL and SECAM video sources. Response time is 25 ms and the display provides a resolution of 1024 x 768 pixels.

The VR-1100 projector uses a unique technology, known as spatial multiplex imaging, in which left and right eye images are combined in a checkerboard pattern. Half the pixels in the left and right eye images are thrown away, with the combining process resulting in alternative pixels that are from the left and right eye images. These pixels are polarized with a particular orientation and then viewed by ordinary passive glasses, in which one eye has a plastic sheet with a horizontal polarization and the other a sheet with vertical polarization, matching the polarization of the pixels. The advantage of the approach lies in its avoidance of the more costly and cumbersome shutter glasses, as well as reduced flicker. (The passive glasses cost about a dollar apiece.) The primary disadvantage of the technique is the loss of resolution that results from throwing away alternate pixels. The same technology is used in 3-D LCD projector panels (used with viewgraph projectors), lower resolution projectors, and in 3-D LCD displays in laptop computers, manufactured by the same company. A photograph of the projection system is given in Figure 17. Its price is $11,995.

Photo courtesy of VRex, Inc.

Figure 17. VR-1100 Stereoscopic Projection System

A second, related product, the VR-2000, is an integrated system that includes stereo audio. Details are given in Figure 18. Its price is $8,995.

VRex, Inc. also markets a system known as the VR Cove, in which three VR-2000 projectors project on three screens surrounding a user.

Specification

Resolution	640 x 480 pixels
Brightness	110 lumens
Contrast Ratio	100:1

Photo courtesy of VRex, Inc.

Figure 18. VR-2000 Stereoscopic Projection System

2.2.14 BOOM 3C

The BOOM 3C from Fakespace, Inc. is a boom-mounted visual display that consists of dual CRT displays, one for each eye, optics, and an opto-mechanical tracking system. The approach of placing a display on a boom allows the weight of the display to be counterbalanced. It provides a relatively unconstraining and comfortable interface, and one that is particularly useful with groups since it is easy to pass the display around to members of a group for viewing one at a time. The BOOM 3C uses interchangeable modules to provide a flexible display, allowing variation from 40° to 110° in the horizontal field of view. The resolution of the display is 1280 x 1024 pixels per eye, though use of standard video will reduce this to 1280 x 960 for interlaced video and 640 x 480 non-interlaced. Video input is RGB field sequential stereo or mono. Further details on the visual display are given in Figure 19.

Specification	
Resolution	1280 x 1024 pixels
Field of View	40 -110° horiz
Weight	Counter-balanced

Photo Courtesy of Fakespace, Inc.

Figure 19. BOOM 3C Visual Display

The mechanical arm, or boom, has position sensors at six joints and the articulated support structure has 6 degrees-of-freedom (DOF) motion, to produce a global 3-D tracker for head motion. Raw analog data from the arm sensors is converted into floating point angles. Using known direct-kinematics equations, it then is possible to obtain the position and orientation of the end of the arm that supports the CRT viewer. These parameters are sent to the graphics workstation which renders the images for the two eyes so that images appropriate for the current head position can be generated. Specification details for the tracking element of the BOOM 3C are given in Figure 20.

Tracking Specification	
Sampling Rate	>70 Hz
Latency	200 ms
Accuracy	0.16 in
Resolution	0.1°
Working Volume	6 ft diameter circle, 2.5 ft vertical
Field of View	140°

Figure 20. BOOM 3C Tracking

This device costs $95,000, including both the tracking and visual display elements. Custom versions of the BOOM 3C are available. MedView, for example, is a custom version of the BOOM 3C that Fakespace, Inc. developed for medical purposes.

2.2.15 Cyberface 4

The Cyberface 4, from Leep Systems, Inc., is an active matrix LCD boom-mounted display, and is an extension of a previous product by LEEP systems known as the Cyberface 3, which is available now only on a custom-order basis. The display uses high resolution 12-bit VGA (RGB) active-matrix LCDs to provide relatively high resolution over a wide field of view. The pixel pitch is 6.2 arc minutes, while the pixel structure is vertical stripe. Further details are given in Figure 21. (Note that the figures given for brightness and contrast are preliminary.) The price is $15,750.

Another product, the Cyberface 5, is expected to be available in 1996. This will be a more sophisticated product using two LCD displays for each eye, one that has high resolution for the fovea and another that provides low resolution with a very wide field of view. The images from the two displays are optically added together. The display weight is expected to be 26 ounces, and the estimated price is $45,000.

Specification	
Resolution	480 x 640 pixels, 6.2 arc min.
Field of View	80° horiz, 60° vert
Weight	Counter-balanced
Brightness	~3 fL
Contrast Ratio	≥80:1
Pupil Diameter	70 mm
Interpupillary Distance	64 mm
Image Plane Focus	42 mm effective focal length

Figure 21. Cyberface 4

2.2.16 Fakespace Simulation System

Another Fakespace, Inc. product, the Fakespace Simulation System (FS2), is a counter-balanced boom-mounted immersive display that uses dual CRT displays. The electronics, optics, and mechanics of the device are similar to the Fakespace BOOM 3C, but the FS2 is designed for immersive rather than pass-around viewing. Like the BOOM 3C, this device has 6 DOF movement and optics with user interchangeable modules that allow a horizontal field of view ranging from 30° to 140°. Video input is RGB field sequential color and the video resolution is 1280 x 1024 interlaced or 640 x 480 non-interlaced. A photograph of the device is given in Figure 22, together with some specification details. The product is priced at $95,000.

Specification	
Resolution	1280 x 1024 pixels
Field of View	30 - 140° horiz
Weight	counter-balanced

Photo courtesy of Fakespace, Inc.

Figure 22. Fakespace Simulation System

2.2.17 PUSH

The Fakespace, Inc. Personal Use Stereoscopic Haptic (PUSH) display provides an immersive display for individual use. The device uses one CRT display for each eye and an opto-mechanical tracking system. Based on the BOOM 3C technology, also manufactured by Fakespace, Inc., PUSH is built on an 18 inch, 3 DOF desktop support structure, providing full 6 DOF control. PUSH features an easily mastered, intuitive method of controlling movement in the VE by simply pushing or rotating the device in the desired direction. A photograph and specification details are given in Figure 23. The PUSH is designed for OEM application developers and costs $45,000.

Specification	
Resolution	1280 x 1024 pixels
Field of View	45, 60, or 110° horiz
Weight	Not applicable

Photo courtesy of Fakespace, Inc.

Figure 23. PUSH

2.2.18 Virtual Window

Dimension Technologies, Inc.'s Virtual Window is an LCD backlit display using an autostereoscopic technique. The device is based on the parallax barrier approach, in which a mechanical or optical arrangement is used so that a given pixel is only seen by one eye. The Dimension Technologies approach is unusual in that instead of using lenses or vertical bars in front of the display surface to prevent more than one eye from seeing a pixel, it uses a unique backlighting arrangement that accomplishes the same goal. Rather than having an even backlit illumination, the device uses a backlight consisting of a large number of narrow vertical lines equally spaced, with one vertical line for every two columns of pixels in the display in front. The effect of this is that a given pixel can be seen only by one eye, and not the other, like parallax barrier systems, but without the reduction in brightness that results from cutting off part of the light.

This display is claimed to be the only autostereoscopic display device currently on the market. The device is full color, with 6 million colors, and advertised to have brightness 1.6 times that of a standard CRT. It can be used in either a 3-D mode or a 2-D mode. The display size is a little over 11 inches diagonal. Further details are given in Figure 1. The price for Virtual Window is $17,500.