2.4 Summary and Expectations

VEs require stereoscopic displays to allow users to perceive 3-D images. The technique used to create stereoscopy is fundamental to its advantages and limitations. The following discusses the major differences between the techniques and summarizes their relative advantages and disadvantages as of the present and as projected in the next five years. This is done for the four basic categories of displays: HMDs, shutter glasses, passive glasses, and autostereoscopic displays.

HMDs are presently the display technology of choice for most VE applications that require a full sense of immersion, primarily because they can allow a relatively wide field of view. At the present time, however, HMDs have severe limitations, primarily resulting from their weight, cumbersome design, low resolution, and limited field of view. There is a trade-off between resolution and field of view: some displays provide a wide field of view but low resolution, while others a narrow field of view with higher resolution. Poor resolution is not always the fault of the display device. In some applications the quality of rendering of complex graphical images is the major factor limiting resolution, though improved graphics hardware can be expected to change this situation in the future. Nonetheless, no HMD today provides a resolution anywhere close to that perceivable by the eye.

At the present time, there are two distinct classes of HMDs: relatively large, expensive, and heavy devices that have a wide field of view and are designed for military and other industrial applications, and the typically much less expensive devices that are small, lightweight, provide a narrow (30° or less in the horizontal plane) field of view, and are designed for the consumer market. Some of the displays intended for the consumer market, which have become available only in the last year or so, are quite inexpensive ($500 to $700), appear to be well received by users, and may challenge shutter glasses for the market in inexpensive 3-D displays. Meanwhile, researchers and manufacturers are working to meet users' demand for high resolution, wide field of view displays at low cost. Advances in component technologies are also likely to reduce some HMD problems. In particular, as LCD technology continues to develop, increases in LCD resolution will allow HMDs to achieve a wider field of view, perhaps doubling in resolution and field of view in the next five years. The weight of such HMDs should also decrease somewhat, although the weight of necessary optics is likely to remain a major limiting factor and may be a real barrier.

Will HMDs continue to be used as heavily as they are today? This is difficult to assess. Investigators have shown that a significant immersive effect can be achieved with shutter glasses and projection screens, and even with shutter glasses and a monitor (Ware, Arthur, and Booth, 1993). HMDs may play a role in the too frequent occurrence of simulator sickness, although this relationship is not well understood as yet. Moreover, initial studies have shown that many people have difficulty accommodating their eyes to the infinity position often assumed by HMDs to allow full flexibility in image projection. Such difficulties may contribute to fatigue and encourage the use of other alternative displays where this is less of a problem. As other technologies improve, the demand for HMDs may decline.

Retinal displays may solve many of the typical HMD problems of weight, cumbersome packaging, brightness, resolution, restricted field of view, cost, and accommodation. While the approach is very challenging, significant progress is being made, and a new method currently being developed may lead to commercial products that display monochrome images within a few years. Color displays are a more difficult problem because of the difficulty of generating blue and green light sources and probably cannot be expected as commercial products within the next five years.

Shutter glasses are a widely used technique for stereoscopic display, having been available for a number of years. This is due to their relative inexpensiveness, lightness, and less cumbersome design compared to HMDs. In the next five years, though, it can be expected that LCD displays used in monitors and projection displays will be widely available as products that switch sufficiently fast to be used with shutter glasses. At the present time, there are only a few manufacturers of shutter glasses, with products being very similar. Shutter glasses do suffer from problems such as crosstalk, but this problem is likely to be reduced in the future as expected advances in LCD technology lead to decreased switching time. Fast LCD displays are being developed for other purposes, including autostereoscopic displays, and a substantial reduction in crosstalk can be expected in the next five years. In addition, techniques for minimizing crosstalk by controlling brightness and timing of image display can be applied. At the present time, shutter glasses are almost always used with CRTs or projection displays, because of the slowness of LCD displays.

Passive glasses have been used very little in VEs. The new technique of using microelectronic fabrication techniques to create polarizing filters at the pixel level does make this technique practical for VEs and may lead to the increased use of passive glasses, particularly for CAVE systems in which multiple images are projected on walls. One advantage of this new passive glasses approach over shutter glasses is reduced flicker, which can be a problem even if a CRT is modified to operate at 120 Hz (resulting in a 60 Hz presentation rate to each eye). Another advantage in a CAVE system is that a single LCD projector can be used rather than multiple CRT projectors (one for each primary color), thus reducing the cost and amount of maintenance required to keep the projectors in proper alignment. While CRT and shutter glass systems presently have higher resolution than the polarization at the pixel level approach, it is expected that improved fabrication methods will allow CRT-like resolution with the latter method within the next few years.

A considerable number of different autostereoscopic display systems have been developed to the prototype stage. In particular, a significant amount of research effort is being invested in autostereoscopic technology by large Japanese display, electronics, and telecommunications companies, including Sharp, Canon, ATR, Sanyo, and Teuromo. In addition, many small start-up companies have been recently formed to develop autostereoscopic systems. As yet only one commercial product is being sold (the Virtual Window display by Dimension Technologies, Inc.) which can be expected to be used in VE applications. This is expected to change with several additional products coming to market within the next few years. Increased resolution of flat panel displays and a trend toward the display of larger numbers of perspective views simultaneously will substantially reduce the current major limitation of these systems, which is that users are limited in their lateral movement.

The relatively large amount of research and development in autostereoscopic display technology may seem surprising since there is no proven market. Different developers of autostereoscopic displays have different motivations, with some more concerned with games and military and industrial applications, and others more concerned with 3-D television. However, the high costs and the difficulty on agreeing on standardization suggest that certain applications, possibly including games, military, and industrial applications will be the initial markets, with 3-D television coming later. The use of these displays in VEs is dependent upon the (lack of) acceptance of HMDs and shutter glasses by users, as well as the type of application involved.