

Characteristics of Professional HMDs

An analysis of current and best practices in professional displays

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Introduction

As of July 2009, the perfect head mounted display (HMD) – the one providing exceptional immersion, superb image quality, a wireless and featherweight design for a ridiculously low price – does not exist. However, many users might find that a ‘good enough’ HMD can be found for their particular application. This document discusses the key attributes for HMDs, explains why they might be important, and offers some selection guidelines.

Primary Characteristics

HMDs are used when there is a need for a personal, portable display system that provides a high degree of user immersion. In contrast, a simple computer monitor is not immersive, and projection screen (and 'CAVE' systems) are not personal or portable¹.

The three most important HMD attributes are field of view (FOV), resolution and weight, and we will start our discussion with those aspects.

1. Field of view

The impact of field of view on the degree of immersion cannot be underestimated. The human visual field is approximately 200° wide (about 150° for each eye) and 90° tall. The binocular overlap (portion of the visual field that is visible to both eyes) is about 100°. This wide field of view offers immersion and situational awareness. Systems that offer a limited FOV – sometimes called "tunnel vision" – eliminate peripheral vision, prevent users from feeling visually immersed, and reduce situational awareness while increasing the prevalence of “simulator sicknesses.”

1.1. *Horizontal field of view*

In our experience, a minimum of 100° horizontal field of view is required to achieve good immersion and situational awareness. Moreover, limited FOV forces users to use head movements in situations where eye movements normally suffices. The excessive eye movement triggered by narrow FOV systems is a source of discomfort, and thus lowers the ability to use the HMD for extended periods of time.

¹ See the 2007 and 2008 HMD market surveys (<http://sensics.com/support/Downloads.php>) for user input on the most important HMD attributes and ‘good enough’ values for them.

1.2. Vertical field of view

For many applications, 45° to 50° field of view is sufficient. However, how much vertical field of view is required truly depends on the particular application. For instance, driving simulators typically require only a narrow vertical field of view because the ‘out of window’ view in most cars is limited in the vertical direction. At the same time, scientific research into motion and balance often needs taller vertical field of view so that a test subject can see the ground, their feet, and so on.

One should also pay attention to whether the afforded field of view is symmetrical vertically or not. The visual field of a typical human is not symmetrical: we have greater downwards-gazing field of view than upward-gazing field of view. Perhaps the Homo sapiens evolved to being more concerned about stones on the ground than dinosaurs sweeping from the sky. The same logic often applies to head-mounted displays. In a 45-degree vertical field of view, for instance, it is typically better to have a +15° / -30° field of view than a ±22.5°

1.3. The Marketing of FOV

Just like television sizes are marketed with a diagonal measure (e.g. 24” television), HMD manufacturers often refer to the diagonal FOV measure. This can be misleading. A 60° diagonal FOV is usually 49° horizontal x 33° vertical, less than half of the recommended horizontal FOV and about 2/3 of the recommended vertical FOV.

1.4. Binocular overlap

Larger stereoscopic overlap (the area seen by both eyes) enhances perception of depth and simplifies exploration and manipulation of near-field items. Our sense of depth is the result of seeing slightly different images in the left and right eye. Greater binocular overlap allows a stronger sense of depth. However, if you consider an HMD as having two independent ‘eyes’, then for a given horizontal field of view in one eye, the binocular overlap can be conceptually increased at the expense of lower total horizontal (binocular) field of view. Alternatively, the total binocular horizontal FOV can be increased by trading off binocular overlap.

Different vendors report their binocular overlap differently. Some report it in percent of the horizontal field of view. Some report it in actual degrees. For instance, a vendor with 40° horizontal field of view might claim 100% overlap, which means that the binocular overlap is 100% of 40°, thus 40°. In contrast, another vendor might report 55° of overlap, which is clearly better than 100% of 40°. Wide field of view systems typically do not have 100% overlap.

One advantage of systems with 100% overlap is the ability to operate in non-stereo mode. This is done simply by presenting the same image to both eyes. In contrast, systems where overlap is less than 100% require some processing (in the HMD hardware or in the computer software) to adapt a non-3D image (e.g. a movie) for optimal viewing on the HMD.

2. Resolution

Everyone wants high resolution. Higher resolution throughout the visual field brings out fine detail in a scene – such as the ability to read text on a car’s dashboard - makes images look more realistic and increases the amount of information that can be displayed.

The characteristics of a computer monitor are often specified as a size measure (e.g. 21”) and as input resolution (e.g. 1920x1200). Consequently, users are sometimes tempted to look at the input resolution as a key parameter for HMDs. “I want a 1280x1024 HMD” or “I want an HD 1080 HMD”. While the input resolution is useful – for instance in determining compatibility with a particular image generator – **pixel density** is at least as important in determining visual quality. Consider the image quality a 1280x1024 image on a 13” monitor as compared to the same 1280x1024 image on a 32” monitor. It’s the pixel density that matters.

Although human vision is analog, not digital, a reasonable estimate of the visual acuity for a person with 20/20 vision is 60 pixels/degree. This means that to match human visual quality, an HMD with a field of view of 40°x30° (HxV) would need to present 2400x1800 pixels.

Pixel densities are sometimes expressed in arcmin/pixel, which has an inverse relationship with pixels/degree: 20 pixels/degree is approx 3 arcmin/pixel, whereas 60 pixels/degree is approx 1 arcmin/pixel.

Some HMDs present a certain low pixel density in the center of the visual field and an even lower pixel density outside the center of the field. At first blush, this is an elegant solution since human visual acuity is also lower outside the central vision area. However, when considering eye rotations we realize that a person might be looking with his central vision at an area that is not the center of the HMD display, and thus this method has a severe drawback.

Professional HMDs typically offer from 1280x1024 to 1920x1200 pixels per eye (mostly with 15-20 pixels/degree).

3. Weight

Only a few people take well to having a large weight on their head for extended periods of time. A lightweight HMD helps users feel comfortable. It also allows greater freedom of movement, unlike heavy HMDs that introduce inertia into head rotations. Balance is just as important as is weight. If an HMD is front-heavy, neck strain will usually result, so much that counter weights (additional weight on the back of the HMD) are sometimes installed. Another way to battle HMD weight is to install some boom mechanism that suspends the HMD from the top, though this will typically restrict movement and making the system more cumbersome.

There is a dramatic range in the weights of offered HMDs. Professional HMDs can be as light as 350 grams (12 oz) or as heavy as 2 Kg (4.5 lbs). Some HMDs are so front-heavy that counter-weights are required. While clever head-mounts are sometimes offered, a heavy HMD is still heavy no matter how it is attached to your head.

Secondary Characteristics

Primary characteristics such as FOV, weight and resolution are important to most users. Secondary characteristics described below are important to some users, depending on the particular need and application.

4. Underlying Display Technology

When users talk about their recent experience with head-mounted displays, they often refer to image quality. "The colors were great", "the image was very bright" and so forth. Indeed, image quality (lack of smear, brightness, contrast, color gamut) scores very high on HMD requirement surveys, right next to high resolution and wide field of view.

It turns out that the micro-display technology used inside the HMD can critically impact the user experience, often more than other design decisions for a particular HMD.

Many HMDs today using LCOS (liquid crystal on silicon), which has similarities to LCD technology, with the exception that LCD is transmissive - that is, the light source is behind the display, where LCOS is reflective - which means the light source needs to project on the front of the display. LCOS displays are a common choice because they come in higher resolution than comparable single-chip OLED (Organic LED) display, and are available from multiple vendors. Unfortunately, LCOS-based designs have some disadvantages:

- They require a light source which reduces the display contrast (the light is on even when a black picture is displayed) as well as substantially increases power consumption.
- They often have limited temperature range, or require somewhat exotic solutions like local LCOS heaters to warm up the display before initial use.
- They typically exhibit motion blur and smear, just like many of us experienced with LCD monitors. This is particularly relevant in HMDs since images inside an HMD constantly change to track user head movements.
- Depending on the specific design, users may experience color flashes or other artifacts during head movement.

OLEDs are also used in several HMDs. OLEDs are self-emitting, meaning that they do not require independent lighting. OLEDs, such as those available from eMagin², typically offer a larger color gamut, higher brightness, higher contrast and lower power consumption. OLEDs are also faster than LCOS and thus are free of LCOS artifacts. However, OLEDs typically come in lower resolutions than LCOS displays and are available from fewer vendors.

So... look inside! Next time you look at an HMD, inquire what display technology is inside the display. Specifically, consider:

² See http://emagin.com/technology/why_OLED.php for a comparison of OLED to other displays

4.1. Brightness

Brightness is sometimes measured in fL (foot Lamberts) or cd/m^2 (candela/meter²). Higher brightness is desirable. Typical values for LCOS displays are 15 fL whereas OLED displays can have brightness in excess of 100 fL

4.2. Contrast

Contrast is often expressed as contrast ratio which is the ratio of the luminance of the brightest color (white) to that of the darkest color (black) that the HMD is capable of producing. Higher contrast ratios are desirable. LCOS systems typically offer 100:1 contrast ratio whereas OLED systems can provide contrast in excess of 750:1 because they do not require back light.

4.3. Motion Blur

This is related to the response time of the display, the amount of time a pixel takes to go from black to white and back to black again. It becomes especially important in rapidly-changing images such as an action movie or when there are rapid head movements. Response time is measured in milliseconds (ms). Lower numbers mean faster transitions and therefore fewer visible image artifacts. Response time is not often reported by HMD vendors. However, LCOS displays typically have a response time of 5-10 milliseconds whereas OLED displays have a much faster response time that is a few microseconds.

4.4. Color gamut

The color gamut is that portion of the color space that can be represented, or reproduced. In general, a larger color gamut means the ability to reproduce a scene more accurately. Make sure the HMD you choose can faithfully display the colors you care about.

4.5. Display Artifacts

Various approaches to HMD design bring about potential artifacts that may become a distraction for some users or a disadvantage for some applications. Some of these artifacts could include:

- Geometrical distortion such as ‘barrel’ or ‘pincushion’ distortion would cause a straight-line grid to appear warped. This is particularly noticeable in displays that use high-magnification lenses to try and achieve relatively wide field of view with a single display element. Such distortion may be distracting, but in the case of augmented reality applications it might also cause misalignment between the physical world and the world displayed inside the HMD.
- ‘Screen door’ effects. Depending on the display technology, electronic artifacts that have to do with shuttering polarizer or other structural elements may become a significant distraction during tracked head movement.

- Tiling. Some HMDs use multiple displays to achieve both high resolution and wide field of view. With these designs, it is sometimes possible to notice the transition from one display to the other. Although the brain learns to ignore these transition artifacts within a couple of minutes (just like a hockey or football player quickly ignores the gridiron bars in the helmets), they might impact the initial impression of a user.
- Color mismatch between the eyes. Just like two monitors of the same model from the same manufacturer may appear to display different colors, the micro-displays inside an HMD potentially suffer from the same problem. Care should be exercised on the manufacturer side to match the colors of the display. Optionally, such a utility might be provided to the user.

5. Packaging

Aside from the weight and balance characteristics discussed above, there are additional packaging considerations:

5.1. *Cable management*

Most HMDs today are tethered. Thus, one should consider various attributes of the cables provided with the HMD. Particularly:

- Do the cables add a significant weight to the product?
- Are the cables flexible enough to accommodate the desired movement with the HMD?
- How long can the cables be? Standard cables are typically 2-5 meters in length, but some applications require much larger distances between the control units and the HMDs. Are 10 meter cables available? 30 meter? 100 meter?
- Are the cables rugged enough to withstand the operating conditions? If the cable is on the floor in a lab, what happens if it is accidentally stepped on?
- Is there signal degradation when using longer cables?

5.2. *Suitability to Operating Environment*

Some HMDs are operated in a lab, whereas others are operated in harsher conditions (outside, or operated by kids). One must make sure the HMD is suitable for the operating environment. Specifically:

- Is there substantial moisture or water in the environment? Is the HMD water tight?
- Is the HMD expected to take occasional hits or drops?
- What is the storage and operating temperature range? LCOS displays sometimes need a gradual 'warm up' period if they are stored in a low temperature.

5.3. *Ease of Integrating Peripherals*

HMDs are often used together with additional peripheral devices such as motion trackers, eye trackers and cameras (for augmented reality applications – see below). One should consider the desired devices and explore whether the HMD supports a convenient physical integration, and good cable management. Specifically:

- When integrating motion trackers, it is preferred that the motion tracker is in a known position relative to the display and center of rotation. Such knowledge facilitates accurate high-quality trackers. HMDs that provide fixed ‘mounting holes’ into the HMD frame are preferred over those that allow improvisational attachments using Velcro.
- Eye trackers are important in various cognitive studies as well as innovating human-machine interface. HMDs that support eye trackers should have adequate space to install and adjust the eye tracker, and allow eye tracker positioning that is in line with the manufacturer’s specifications (e.g. distance and angle to the eye) in order to achieve optimal tracking performance.
- Cameras can be used in vision enhancement applications or in augmented reality to integrate live video with computer-generated graphics. Ideally, cameras need to have a rigid mount that is as close as possible to the actual human eye spacing and location. If cameras are mounted too high, for instance, video that is being fed into the HMD will be from a different perspective than that of the user.
- Some applications require the attachment of other instrumentation or rigid markers. One should investigate whether the HMD frame allows for such attachments.

5.4. *Contact Points and Hygiene*

Depending on the application, the location and number of contact points between the HMD and the head may be of interest. For instance, if the use of external earphones is desired, an HMD frame that does not cover the ears is advantageous. For medical purposes, the number of contact points might need to be minimal.

The issue of hygiene might be just as important. The ability to clean or sanitize the HMD between uses may be of value. This could imply that the HMD design incorporate closed-cell surfaces that could be wiped clean, or have disposable pads that can be replaced as needed.

5.5. *Size and Height*

The physical size of the HMD may be of importance for several reasons:

- The farther the HMD is from the head, the more inertia is going to be noticeable upon head rotation or rapid movement.
- A low-profile HMD (e.g. one that does not have parts above the skull cap) is useful when operating in low-clearance spaces such as when doing simulations inside the cab of a car and training in low-clearance spaces

- The size of overall bounding box of an HMD may be important when transporting the HMD from one location to the next.

6. Electronic Interface

The electronic and software interface to the HMD matters in determining the performance that can be expected of the display, and the supporting hardware that is required. Key parameters are described below:

6.1. Supported Input Resolutions

Just like a computer monitor may have an optimal or ‘native’ display resolution yet supports other input resolutions, some HMDs support a wide range of input resolutions. This is particularly important when legacy applications or existing graphics hardware dictate a specific input resolution. This may also be important in ‘compatibility mode’ where a newer HMD is used to replace a broken or outdated existing HMD. Last, this may be important to preserve square pixels to match the aspect ratio of the HMD with the aspect ratio of the input signal. We have seen HMDs that support a wide range of resolutions from 640x480 all the way to 1920x1200. Check to see which resolutions you need to have supported.

6.2. Supported Display Modes

Depending on the application, various modes of providing video to each of the two eyes in an HMD may be of use. Common modes include:

- One input per eye. This is often the highest-performance mode and allocates a video input (and thus usually a video port on a PC) to each eye. True 3D stereo can be delivered this way
- Split screen (top/bottom split or left/right split). This allows providing true 3D stereo while using just a single PC output. This mode might be useful if output ports are limited (for instance, when using a notebook computer)
- Temporal multiplexing (frame sequential or field sequential). This mode alternates left and right frame in time. In frame sequential a full frame is sent to the left eye followed by a full frame to the right eye. In field sequential, an interlaced frame (two interlaced fields) is used, and one field is provided to each eye.
- Single input. This mode is particularly useful when one wishes to display a non-3D input signal (such as a video camera or a movie) inside the HMD. Note that some wide field of view HMDs that don’t have 100% binocular overlap have special hardware that allows them to stretch a single input across both eyes in what is sometimes called a ‘movie mode’.

6.3. Power Consumption

Power consumption is important in two ways:

Overall power consumption might be important when planning the power budget of a system. For instance, a user might want to drive an HMD from a DC power supply in the field, and thus overall power consumption is important.

Power consumption in the head-mounted unit is especially important as this power turns into heat near the users' head, potentially causing discomfort and sweat during longer sessions. This problem is particularly acute for HMDs that use back-lighting technology or reflective displays. Some HMD vendors added fans in the head unit to dissipate heat, but these add undesirable noise and vibration

6.4. Latency

Latency refers to the amount of time (measured in milliseconds or frames) from the time a video signal is available at the output of a graphics card to when it is displayed inside the HMD. Latency is important because interactive closed-loop applications such as those using head-trackers to update the image are sensitive to delay. Larger latency makes an application appear less responsive and adds to user discomfort. Some vendors add a delay of one or two frames en route to the display.

7. Other Unique Capabilities

Now we will discuss a few capabilities that are fairly rare in HMDs. They appear for completeness and in case such capability is important to the user.

7.1. Color management and gamma correction

It is sometimes useful to be able to control the color values displays in the HMD. One might wish to emphasize a color group (e.g. reds), to equalize the color histogram or to perform other color manipulations. One common manipulation is 'gamma correction' which creates an exponential relationship between input and output color values. Some professional HMDs provide the ability to do real-time color and gamma correction, and this may be of value to some users.

7.2. Geometrical and other image manipulations

Real-time geometrical and image manipulations can provide interesting and useful capabilities for some projects, such as:

- Correct optical distortion from a sensor
- Introduce optical distortion to simulate a certain visual condition (e.g. astigmatism)
- Zoom into one part of the image
- Sharpen, blur or otherwise change the image

Some HMD vendors provide this real-time capability as part of the built-in control electronics of their HMDs. If such capabilities might be helpful for your project, ask your HMD vendor if they can be supported.

7.3. Upgradeability

The ability to upgrade an HMD refers to exchanging an existing HMD to one of higher performance (e.g. wider or taller field of view, higher resolution) while maintaining all other characteristics. Users of HMDs that can not cost-effectively upgrade to wider field models risk finding themselves in a “technology dead end” once they realize that wider field of view is required or once needs change.

This White Paper is Presented to you by Sensics, Inc.

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