Frontiers in Virtual Reality Headsets

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Introduction

Technological advances are presently transforming virtual and augmented reality from science fiction to consumer products. When widely deployed, these technologies have the potential for major impact on entertainment, culture and commerce. In this article, we provide a basics overview of what virtual (VR) and augmented (AR) realities are, some of their potential high-impact applications, discuss the effort required to achieve these technologies and drill down on an aspect of the human visuals system that presents some novel challenges for augmented and virtual reality.

What is Virtual Reality?

In short, virtual reality is any stimulation created by a computer and presented to a person that is perceivable as real. Currently virtual reality devices consist of head a mounted display, often with the addition of headphones. These devices act to completely block out a person's senses of hearing and vision (ultimately, VR technology will grow to encompass more senses) of the real world. Although it's not currently possible to display real-time virtual reality content that's indistinguishable from reality, it is already possible to produce an experience referred to in the community as "presence". Loosely defined, presence is the sense that a person has, in fact, been transported somewhere else. This transportation isn't always conscious: a person experiencing presence may logically know they're still wearing a headset, but will unconsciously have measurable reaction to virtual objects or threats, such as a fear of virtual heights.

Currently, there are a variety of companies that sell commercial head mounted displays. Several more companies, such as Sony, have announced future products and there are a wide variety of startups producing prototypes.

Going Beyond: Augmented Reality

While virtual reality aims to completely override human senses, augmented reality systems aim to combine both real world and virtual stimuli. Devices such as Microsoft's Hololens use a see-through display to overlay a virtual world onto the real world. This blending of real and virtual content has the potential to have a significant impact by augmenting everything from daily life such as virtual name-tags or line-item reviews on a restaurant menu to complex specialized tasks, such as overlaying MRI data directly onto a patient in an operating room.

Why Virtual and Augmented Reality?

Both virtual and augmented reality have a large range of potential uses. The most obvious and immediate uses are those currently commercially available: entertainment, movies, 360 video and games. However, these technologies have a wide variety of additional applications, including social and, business communication, journalism, e-commerce and education.

Virtual reality has been a futuristic technology for a long time now. Although virtual reality has been explored many times in the past, many factors suggest the technology is now ready to succeed in the main stream. Moore's law has enabled sufficiently powerful graphics hardware to render HD resolutions at frame rates sufficient for a commercially viable visual experience and the rise of smart-phones has made very high density OLED display panels and low latency accelerometers, two key components in high quality VR, inexpensive and widely available.

What does it take to make VA/AR?

Building a virtual or augmented reality system is a massive multi-disciplinary effort. At the heart of this effort are perceptual scientists whom define the requirements for matching and driving the human perceptual system, a key requirement for making VR believable, as well as preventing users from experiencing motion sickness or any other form of discomfort from the VR experience. Such requirements include audio/visual fidelity, latency limits, tracking accuracy, and many others.

Building a head mounted display requires optical, electrical and mechanical engineering, understanding of displays and tracking technology and software expertise in graphics, sound, computer vision, and user interaction. In addition, most of these components must be implemented with a great degree of care.

It is worth noting that achieving high quality in graphical and computer vision systems require extreme amounts of computing power. Virtual and augmented reality systems currently produce a rather crude representation of the world and a resolution far inferior to what humans can perceive. Achieving a virtual system that is indistinguishable from reality could consume many orders of magnitude more compute power.

A Stable Virtual World

To achieve a compelling virtual reality experience, one that minimizes the amount of motion sickness, the virtual world must appear, at all times, stable to the user. While traditional displays tend to stay in one place, VR head mounted displays are tied to a user's head and often move very quickly. This rapid display movement has the potential to cause a variety of artifacts that can at best break the sense of immersion and at worst make a user physically uncomfortable. As with most of the other requirements for VR headsets, these stability requirements are driven by the human perceptual system.

Vestibulo-Ocular Reflex

The human visual system contains one of the fastest reflexes in the human body. The vestibulo-ocular reflex (VOR) stabilizes human vision during head motion, and does with a latency of 3 neurons (about 10ms). This reflex is responsible for turning your eyes to counter the head motion and provide a stable retinal image during common head movement. Because of this reflex, the human visual system expects a stable image, crisp image during head rotation even when the screen (attached to the head) is moving at 300 degrees per second. This reflex, which stabilizes the world during normal head movement, actively destabilizes and view presented on a head-mounted display, causing it to slide across the retina and blur as VOR makes the eye-counter rotate.

Visual Artifacts from Displays: "Judder"

Judder is the blurring effect caused by the VOR and a head mounted display being used in the traditional manner of statically mounted displays. Most displays illuminate pixels for the entire duration of a frame (about 17ms at 60hz or 11ms at 90hz). When a user is turning their head at 300 degrees/second, 11ms corresponds to 3.3 degrees or about 35 pixels on an Oculus Rift and during this movement the pixel becomes smeared across that angle. To address this, VR displays use “low persistence” mode and are only on 1-2ms out of each frame, displaying black the remainder of the time. This prevents the smearing artifact, but leads to a dimmer displays and under certain conditions, a strobing effect.

Latency

In addition to judder, display latency can cause severe artifacts. Even at a more modest 100 degrees per second, a system latency of 30ms would cause the world to lag by a full 3 degrees behind a viewer’s gaze. This constant lag causes a noticeable “swimming” artifact that can be both disturbing and also lead to motion sickness. Reductions come in the form of better algorithms, better graphics hardware and careful orchestration between applications and display hardware.

Visual Artifacts from Displays: Rolling Displays

In addition to judder, displays can cause a variety of other artifacts. A rolling display is one that illuminates pixels as they arrive over the wire, rather than all at the same time. Old CRT TVs and most OLED phones are rolling: they start by illuminating the top row of the screen, then then next, and so on, until the whole screen has been illuminated. Alternatively, a “global” display is one that reads the entire frame before displaying every pixel simultaneously. Each approach has its own pros and cons. The global display adds significant latency: rather than displaying pixels immediately, all pixels wait until the last one to arrive before they begin illuminating. Alternatively, rolling displays have artifacts similar to those produced by rolling shutter cameras. If a user moves their eyes during display update, the image appears to distort or shear depending on the direction of movement. This artifact can be compensated for but the compensation requires the integration of high quality eye-tracking and achieving the latency reduction allowed by rolling displays while minimizing the artifacts they produce is an open research problem.

Conclusion

Virtual and augmented reality are still nascent technologies, but have the promise of dramatic world-wide impact. As we continue to improve displays, graphics, tracking and our understanding of the human perceptual system more applications will become realizable. A variety of companies are presently investing heavily in this space in anticipation of its potential impact. VR may have come and gone many times in the past, but this time a proper mix of technology and funding is shaping up to make for a very exciting future!