Research Proposal

Building Low-Latency Wireless VR Goggles

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1. Introduction

With the emergence of digital innovation and growth of computing power, the technology of Virtual Reality, a kind of computer system allowing people to create and experience a virtual world, has been among the hottest in industry. The most common type of VR devices, VR goggles, is a kind of head-mounted display worn on the head with two optics for each eye. VR goggles popular on the market now such as Oculus Rift and HIT Vive often require connection to high energy consumption computing devices, for example, computers with graphic cards with a power of 300 watts, to get a high-resolution low-latency effect, which is the crucial factor for making the experiences lifelike. However, the goggles, as a second display monitor and a head position tracker, have to be connected to the computer via cable, using HDMI to transmit high-definition video stream and USB to transmit tracking data stream, because current remote display technologies cannot provide the low latency and high bandwidth required. The wire between VR goggles and the computer has obviously limited the mobility of the device and in turn affected the user experience. Thus, wireless transmission is an unavoidable improvement direction for VR goggles.

Simply transmitting video and tracking stream over 2.4GHz or 5GHz Wi-Fi network does not meet the *latency* requirement that the end to end latency of a typical VR system should be under 20 milliseconds [1]. If the primary latency is 10 milliseconds, an addition of 5 milliseconds will be an increase of 50%, which will make the user experience detectably worse than wired solutions. Therefore, more promising ways have been tried, including:

(1) Bypassing the problem of wireless transmission. There are two types of VR products that enhances mobility while not applying wireless transmission technology. Both can get natural low latency. One is mobile phone VR, represented by Google Cardboard [2] and Samsung Gear VR [3], which gained its popularity by low cost and convenience, as a user only need to install his mobile phone into a low-priced VR case. But the downside is also obvious: the computing power of a mobile phone is limited, compromising user experiences and the number of applications. Another type is so-called backpack VR (see Figure 1), such as MSI, HP and Zotac VR [4]. Although mobility is strengthened while screen effect is maintained, the weight (usually about 4 kilograms or so), working temperature (like carrying a heater) and battery life (usually within 2 hours) are far from satisfactory.

Figure 1

(2) Adapting low-latency high-bandwidth wireless multimedia transmission technologies. Table 1 compares the state-of-the-art wireless multimedia transmissions technologies [5][6][7].

Technology	WirelessHD	WHDI	WiGig	Wi-Fi
Industry Standard	v1.1 (Jan 2010) IEEE 802.15.3c	WHDI v1.0 (Dec 2009)	v1.1 (Jun 2011) IEEE 802.11ad, Wi-Fi compatible	IEEE 802.11n/ac
Frequency	60Ghz	5Ghz	60Ghz	2.4/5Ghz
Transmission Rate	10-28Gbps	3Gbps	7Gbps	300Mbps
Latency	<1ms	<1ms	<1ms	>15ms
Transmission Distance	⩽ 10 meters	⩽ 30 meters	> 10 meters	⩽ 10 meters
Power	<4W	5W	<4W	<2W

Table 1

Among these standards, three are expected to be used in VR systems:

a. WHDI, working at an unauthorized 5GHz band, with near zero latency. However, it has only a bandwidth of 3Gbps, which is not sufficient to transmit uncompressed full resolution 3D video. The video data must be compressed or the resolution must be reduced.

b. WirelessHD, working at an unauthorized 60GHz band, with near zero latency. Its theoretical single-channel bandwidth is up to 7Gbps, with four-channel bandwidth up to 28Gbps, which is able to transmit uncompressed 2160x1200@90fps or even 4K video stream, but due to its high frequency, the signal attenuates quickly and therefore transmission distance is limited within 10 meters. It also supports the directional transmission technology called *beamforming*, allowing the signal to avoid obstacles, but not penetrating the wall.

c. WiGig, similar to WirelessHD, with bandwidth of up to 7Gbps. It has been incorporated into the Wi-Fi standard, so the wireless protocol can switch automatically to 2.4GHz and 5GHz when roaming away from the main room [8], providing better robustness and adaptability.

The theoretical power of these technologies is only below 5 watts, so a 10,000 mA·h mobile phone power bank weighting only a few hundred grams can support up to 5 hours' consecutive working [1]. The biggest difficulty, as mentioned earlier, is reduce latency. [9] achieved the wireless transmission for Oculus Rift DK1 on 5GHz 802.11n Wi-Fi network. It adopted H.264 encoding for video compression, and USB/IP virtual connection for tracking data stream transmission. The average delay of this system is 94.1 milliseconds, which is about twice that of the original wired Oculus DK1. Sensics zSight [1], a professional head-mounted display, claims to have achieved HD1080p video wireless transmission with a latency of about 1 millisecond and a distance of 30 meters tolerating obstacles. It uses WHDI for wireless transmission of both video stream and tracking stream. WHDI supports a bi-directional data link, in which the video stream is upstream from PC to the goggles, and the tracking data is downstream from the goggles to PC. The downside is update rate: WHDI transmits downstream data during blank periods between upstream video frames, which is sometimes not interactive enough.

2. Objectives and goals

We therefore propose to design and implement a wireless VR system that allows mainstream VR goggles such as Oculus Rift which is connected to PC by wire to be in a wireless way, without compromising the user experience. A prototype will be made to demonstrate its effects.

Four main research questions need to be addressed in this work.

Low latency high definition video transmission. Current wireless display solutions mostly support only video of 1080p@60fps. This is designed for household entertainment such as movies and PC games, which is not directly compatible to the required resolution and framerate of VR displays.

Tracking data transmission and power supply. The USB cord which transmits tracking data and supplies power should also be cut for wireless transmission. A way need to be found for replacement.

Multi-channel transmission. Dual displays require dual video signals; multiple players sharing one virtual space also require multiple links to support.

Avoiding obstacles and extending transmission distances. Although high frequency transmission like 60GHz provides sufficiently low latency and large bandwidth, a drawback is that it cannot travel through obstacles, and the transmission distance is short. It may keep users from moving around freely.

3. Methodology

3.1 Low latency high definition video transmission

The latency we often refer to in VR is actually motion to photon latency, i.e. the total time from user motion to the corresponding screen display reaction. Figure 2 shows the key steps in this process. [10]

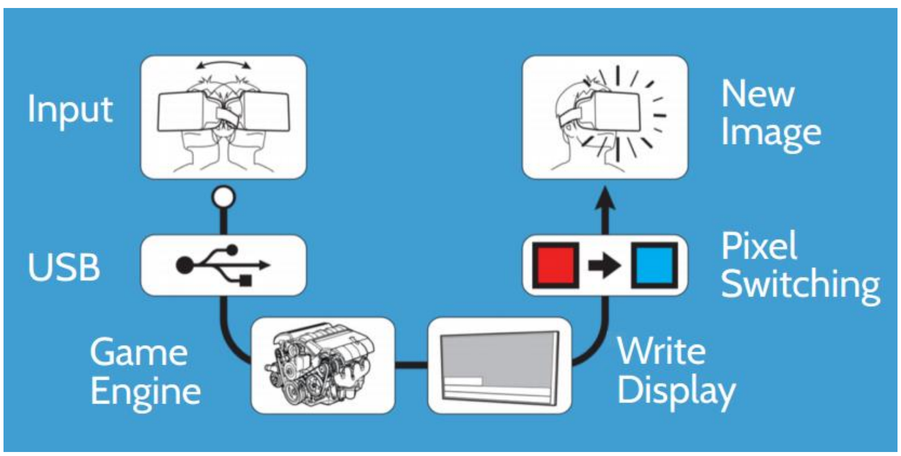

Figure 2

To reduce the latency, we must seek four levels of optimization: hardware level, such as increasing the refresh rate and using OLED; driver level, such as Timewarp Async technology and Front Buffer Rendering [10]; graphics engine level, on which system level optimization including parallelizing the compressing and decompressing algorithms and moving the operations into OS kernel space to reduce the time for mode switch; and network level, which may require simplifying the protocol stack of 60GHz or 5GHz wireless transportation to remove the unnecessary packing and unpacking of data.

Particularly for the compression and decompression level, some elementary experiments have been done to investigate the possibility of near zero latency in this process, as is shown in Figure 3. The ffplay program in ffmpeg toolkit is utilized to capture one screen and play it on another screen in real-time [11]. The latency of local loopback is tested to be about 90ms.

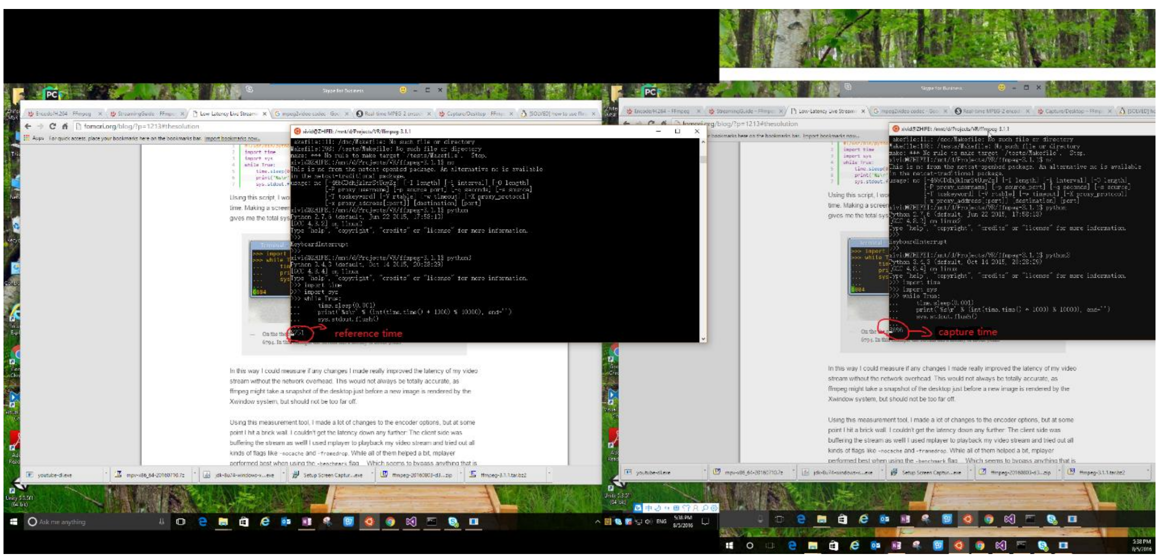

Figure 3

By employing the optimizations as described in [12], a zero latency of 60FPS video in mpeg2video encoding has been achieved. The next step to do is reducing the latency in the PC/goggles network by counting the time spent in each procedure and conduct corresponding optimization.

3.2 Tracking data transmission and power supply

Power can be supplied by connecting mobile power banks as analyzed in Section 1, while tracking data transmission can be done in two ways: one is wireless USB [13] transportation, another is to transmit the data on the same link with video stream. To tackle the update rate problem as mentioned earlier, hacking into drivers may be needed to make the two streams asynchronous. Both ways will be tried to find out a better solution.

3.3 Multi-channel transmission

Multi-channel transmission naively supported by technologies such as WirelessHD will be tested first. However, to achieve better adaptability to user numbers, scaling out the transmission devices may be a better way to guarantee the performances will not be compromised.

3.4 Avoiding obstacles and extending transmission distances

Due to the nature of high frequency transmission, although techniques such as *beamforming* to avoid obstacles and extend transmission distances will be further investigated, solutions in software systems will also be sought for, by borrowing the idea of switching among 60GHz and 5GHz as in the WiGig extended Wi-Fi standard. This again will require work in network protocols and drivers.

4. Outcomes and value

The application of wireless HMDs will accelerate the development and popularity of various VR applications, such as VR live gaming. Even when VR goggles are used in cases not requiring much freedom to move around, users would still prefer using the devices with no wires attached to their computers (Oculus VR, 2013). Therefore, all this shows the great value and large quantities of potential opportunities that can be introduced by lightweight portable wireless VR goggles.

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