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Development of a Low-Cost 3D Interactive VR System using SBS 3D Display, VR Headset and Finger Posture Motion Tracking

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***Abstract*—With 3D virtual reality (VR) technology and game design developing rapidly, a growing number of research experts are becoming involved in the study of motion sensor interactions and VR headset devices. At present, headset devices easily cost up to hundreds or even thousands of dollars. As a general gaming accessory, the price point of these devices is quite high. To reduce the cost of gaming accessories, this study combined the most current and popular headset device, with motion sensor and 3D VR technology to develop a low-cost 3D interactive VR system. This system utilized Homido VR headset to carry a smartphone, and Leap Motion, the motion sensor, was used to track hand gesture changes. Unity was used as the main 3D VR developmental environment to develop a 3D dart game system. To portray a realistic 3D environment, this system utilized Unity to develop the headset's side-by-side (SBS) 3D image for the left and right eyes. The SBS image for the left and right eyes was presented via the Homido VR headset equipped with the smartphone, allowing the user to gain a more immersive experience of the 3D dart game environment. The experiment results showed that while this system displayed SBS 3D game content to the users, they could use Leap Motion to manipulate 3D virtual objects instantaneously. Thus, this system presents users with 3D real-time interactive experience via the head-mounted device.**

Keywords-virtual reality; SBS 3D; finger posture motion tracking; VR headset;

I. INTRODUCTION

The rapid development of information technology has led to the gradual extension of virtual reality (VR) and augmented reality (AR) technology into the development of headsets [1, 2]. Industry examples including Google Glass designed by Google, Sony's Project Morpheus, Oculus VR's Oculus Rift, and Microsoft's HoloLens are summarized below.

- Google Glass: Google Glass is an optical head-mounted computer display system designed in the shape of a pair of spectacles. It was developed by Google X team, the main purpose of which was to provide the mass consumer market with a commonly applicable computer system. The device is hands-free and projects a variety of information in the lenses.
- PlayStation VR: PlayStation VR is a VR headset device designed by Sony. It was predominantly designed for Sony's PlayStation 4. The dualshock 4 controller was used as the main interactive accessory. The headset's high field of vision, six-axis motion sensing system, and 3D imaging capability have generated a new mass fervor for VR accessories.
- Oculus Rift: Oculus Rift is a VR headset display system developed by the company Oculus VR. Rift carries a 7-inch screen that greatly improves the original pixel shading, reduces latency caused by rapid movement, and addresses blurry image issues reported in its prototype. In terms of screen resolution, its field of view (FOV) is more than 90 degrees horizontal, with a resolution of 1280 × 800. In terms of interaction, Rift provides 3-axis gyros, accelerometers, and magnetometers, which enable users to interact directly with 3D content.
- Microsoft HoloLens: HoloLens is a pair of smart glasses that runs on the Windows 10 platform. HoloLens utilizes advanced sensors and high-resolution head-mounted 3D holographic display that can be used in AR applications. The users can interact with the environment via gaze, voice, and gestures. HoloLens carries a high-performance depth camera with $120^0 \times 120^0$ angle of view. It can track head movements and capture video and audio information. In addition to its high performance CPU and GPU processors, it comes with the holographic processing unit (HPU). The HPU processor not only collects and processes data from the sensors, but can also perform actions such as spatial mapping, hand gesture recognition, and voice recognition.

Although the aforementioned head-mounted accessories have relatively good results in applications, the price is relatively high for the general consumers. Therefore, the smart glasses becoming more commercialized is difficult until they become more affordable. On the other hand, smartphones already have a remarkably high market penetration, and almost everyone has a smartphone. Hence, if smartphones are used as the main processing and display unit, the cost of the product will be reduced significantly. Therefore, in this study, we designed a 3D head-mounted interactive VR system based on a currently available smartphone, which is mounted on the cost-effective Homido headset. In addition, Leap Motion was applied as the interactive mechanism, thereby making a cost-effective 3D head-mounted interactive VR system possible.

II. Related Works

Headsets have obviously become the development trend of the ICT industry. A growing number of research experts have become involved in the research on headsets and their applications in different sectors, including medicine [3, 4, 5], education, and entertainment. The following subsections summarize related researches.

A. Medical [3]

Juanes et al. [3] utilized the Oculus Rift headset to establish 3D virtualization of a hospital operating room through stereoscopic rendering. This system provides the users with an immersive experience, thereby enabling learners to familiarize themselves with the operating room devices, monitors, and the installed equipment. Thus, this system provides learners with a practical and effective training experience. To achieve this purpose, Juanes et al. utilized Maya to establish 3D models for the relevant equipment installed in the operating room. Oculus Rift SDK and Unity3D were used to create the control and display mechanisms, which were presented through Oculus Rift, as shown in Fig. 1.

Figure 1. The virtual reality system developed by Jaunes et al. via Oculus Rift [3].

B. Education [6]:

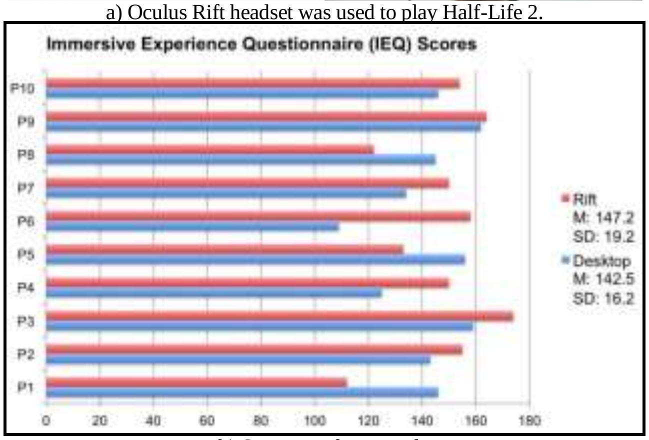
Silva et al. [6] applied the unique features of Google Glass to educational settings. The authors developed a software application named Glassist to assist teachers with management tasks. Glassist allows teachers to create a portfolio of students, and manage and share that information with other teachers. This tool was developed based on Google Glass. It has three modes, including classroom mode, meal time mode and outside mode. Take classroom mode as example, this application utilized Google Glass' AR features to recognize students' faces and display relevant information about them, as shown in Fig. 2.

Figure 2. The application of Glassist to classroom management.

C. Entertainment [7]

Headset accessories have been used in the games industry for several years. In order to understand the impact of headsets on player experiences, Tan et al. explored 10 players' (P1–P10) experience of playing the first-person shooter game Half-life 2 using the Oculus Rift headset. Prior to the experiment, Tan et al. analyzed the basic personal information of the 10 players that included age, gender, game interest, gaming habits, and prior experience of playing Half-Life. In the experiment, Tan et al. compared the gameplay experience in Oculus Rift and in the desktop setup gameplay mode. They surveyed the 10 players regarding the difference in their immersive experience when playing the game in these two modes. The results of the survey are shown in Fig. 3. The survey analysis results showed that the traditional desktop screen mode of gameplay scored an average score of 142.5, whereas the Oculus Rift mode scored 147.2. The results indicated that Oculus Rift offered a more immersive experience than the traditional desktop setup.

a) Oculus Rift headset was used to play Half-Life 2.



b) Survey analysis result.

Figure 3. The immersive experience of players (P1–P10) during Half-Life 2 gameplay.

The aforementioned research showed that headset-integrated VR or AR technology has become a new trend for the future. However, at the time of this study, the price of these headsets were still relatively high. In other words, if the VR technology was to become more widely available, the price reduction of peripheral equipment is a key factor. To achieve this purpose, this study proposed a low-cost head-mounted 3D interactive VR system. This system is a 3D display device mainly based on a smartphone. It utilized a headset frame (e.g., the Homido VR headset) to secure the phone. The side-by-side (SBS) technology was applied to create the 3D effect by rendering the left and right eye images. To facilitate user interaction, the Leap Motion hand tracking system was used to identify gesture-related information and achieve 3D object manipulation. The system construct was as shown in Fig. 4. In order to test this system, we have developed a mobile 3D dart game on the smartphone terminal that can be used to measure the 3D effect of SBS and the interactions of the Leap Motion control mechanisms.

Figure 4. The low-cost head-mounted 3D interactive system construct proposed in this paper.

III. THE PROPOSED LOW-COST HEAD-MOUNTED 3D INTERACTIVE SYSTEM

This system is composed of three hardware devices: a smartphone, a VR headset , and Leap Motion finger tracking sensors. Unity was used as the 3D software development environment and the established system is shown in Fig. 5. The user wears a VR headset, and the front of the headset frame could hold smartphone devices. Leap Motion finger sensors could be set below the smartphone. After the Leap Motion host processor analyzed the user's hand gestures, the analyzed information was transferred to the smartphone at a speed of 200 frames per second (fps). At the smartphone end, Unity-based 3D VR content and network connection functionality were utilized to make connection with the Leap Motion host processor , which established the analytical environment for Leap Motion. In addition, we established on Unity the network connection functionality required by the smartphone and the Leap Motion host processor for data transmission. Data transmission was facilitated by existing network setups (e.g., WAP). In other words, this connection functionality allowed the smartphone to receive Leap Motion-captured gesture information instantaneously.

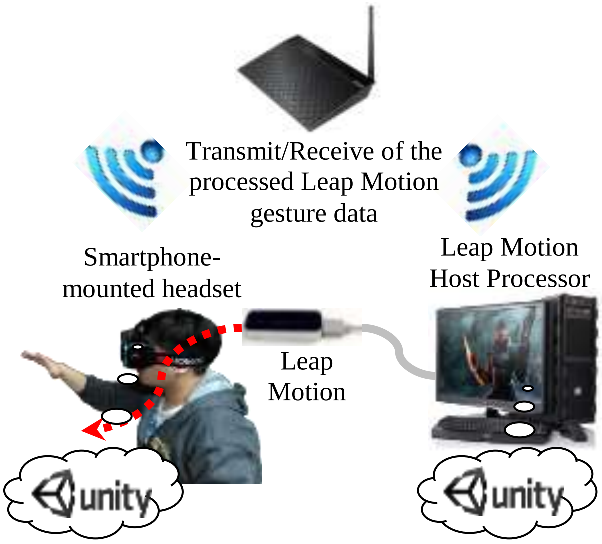


Figure 5. The setup and concept of the proposed head-mounted 3D interactive system.

Our implementation of the head-mounted 3D interactive VR system mainly included these four components: Leap Motion hand tracking system, Unity data transmission system, 3D dart game, and SBS 3D image conversion system. The detail of each component is summarized below.

A. Leap Motion hand tracking system

This system mainly detects the hand gesture of users via Leap Motion sensors and the host processor. The system utilizes Leap Motion SDK for Windows and the Unity Package of Leap Motion Core Assets to develop and detect hand movement-related information including, grips, gesture position, and gesture angle. The Unity data transmission system would transmit the data detected by the host processor to the smartphone, in order to synchronize the real hand movements with that of the hand models represented in the mobile 3D dart game. Therefore, synchronized change of postures, gesture angle, and grip motions was achieved.

B. Unity data transmission system

This system mainly consists of two parts: the host-side data transfer module and the mobile terminal's data receiving module. This system was developed directly in the Unity environment. We have developed a server-end program in the host processor with Unity. The program's main function was to transfer Leap Motion hand tracking detection results. Once the server-end Unity program was switched on, it can provide instant network connection to the Unity program on the mobile terminal. In addition, the Unity program on the mobile terminal would receive instantaneous hand gesture-related information transmitted from the sever-end program. The connection between the server-end and the mobile terminal could be established via wireless AP (WAP).

C. 3D dart game system

In order to test the developed head-mounted 3D interactive VR system, we developed a 3D dart game system on the Android smartphone. This system contains two parts: the hand model control module and the darts contact detection module. The hand model control module can integrate the Leap Motion hand tracking system with the Unity data transmission system, thereby allowing the users to use Leap Motion to directly control the dart model in the 3D dart game system. The change of hand grips was used to determine whether the dart was shot or not. The dart contact detection module was responsible for detecting whether the dart made contact with the target, as well as keep track of the scored points.

D. SBS 3D image conversion system

The main purpose of this conversion system was to generate a SBS 3D stereoscopic image of the developed mobile 3D dart game. In addition, the conversion system allowed the user to place the phone on the VR headset frame. Thus, users can view the displayed 3D image of the game via this system and their sense of immersion can be enhanced.

When the system is started, the game scene will be displayed first. In this time, a user can see 3D stereoscopic images if he/she wears the VR headset equipped with the smartphone. The Leap Motion hand tracking system will detect the user's hand. The hand model will display when the user's hand is in the detection area. Then, the system will check whether the dart in the scene has been grabbed by the hand model or not. If it has been grabbed, it can be controlled or thrown by user. The above major execution steps is represented in the schematic diagram, as shown in Fig. 6.

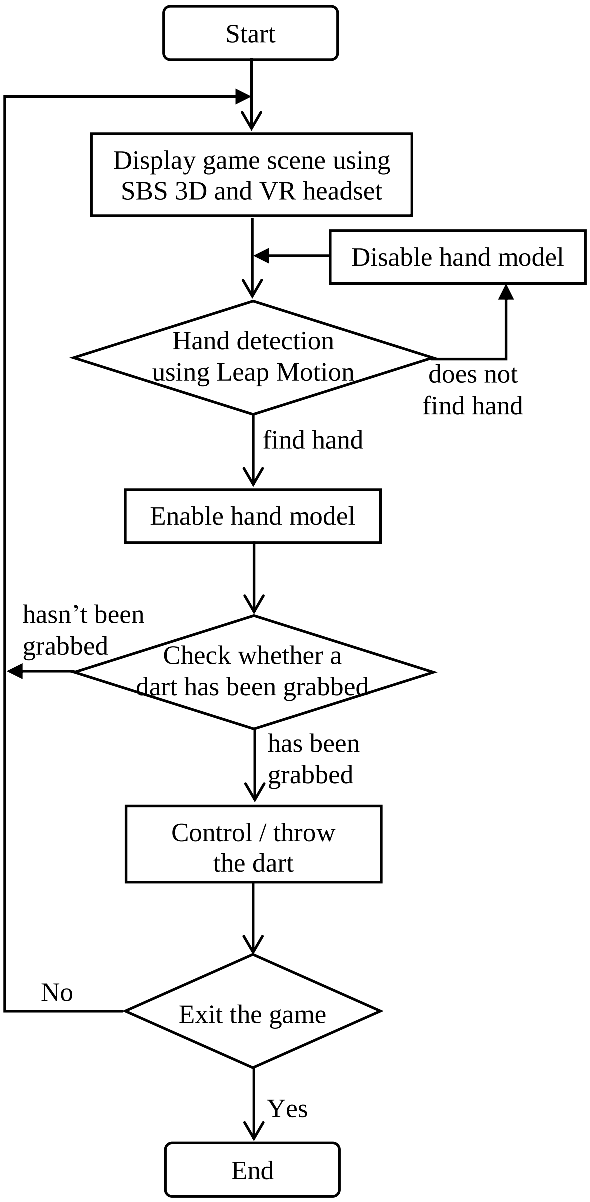


Figure 6. The schematic diagram of proposed system.

IV. RESULTS

Based on the requirements and the purpose of the system, we conducted tests for the various functionalities and the system display results are presented below.

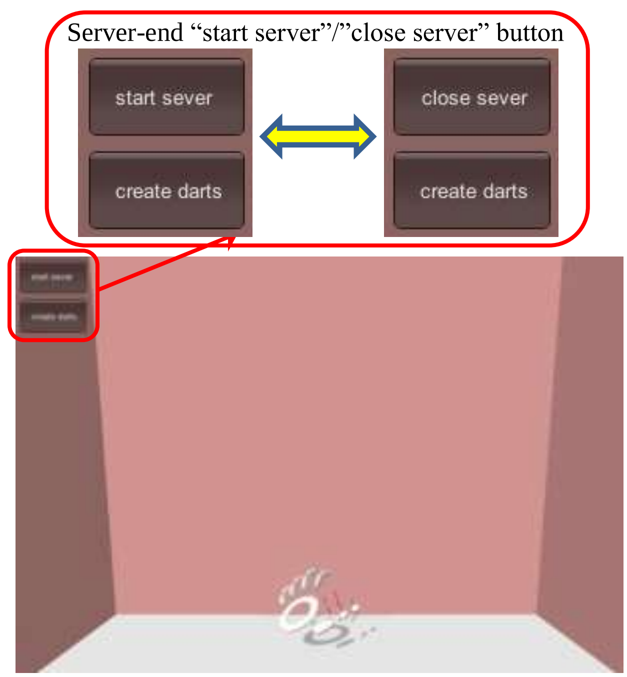
A. Leap Motion Hand Tracking Display (server-end)

In the host processor, Unity and Leap Motion SDK were applied to develop hand tracking results, which were displayed in real-time on the host system's screen, as shown in Fig. 7. As the user changes gestures, the hand model in the environment would immediately reflect the changes.

Figure 7. Leap Motion Hand Tracking (server-end).

B. Server-end and mobile terminal Unity connection and data transmission

Fig. 8(a) shows the server-end display, and Fig. 8(b) shows the mobile-terminal display. As the "start server" button located on the top-left corner of the server-end program (Fig. 8a) is pressed, the system enters the connected state. At the same time, the mobile terminal would connect automatically to the server-end. Hence, it is possible to establish a connection between the two ends. Once the connection is established, the "start server" button would be converted to the "close server" button. If the server-end button is pressed again, it would enter the offline status. In the connected state, Leap Motion hand tracking results of the server end's program (Fig. 8a) would be displayed directly on the mobile terminal (Fig. 8b). The user can thus observe the instantaneous change of interactions between both ends.



a) server-end

b) Mobile terminal

Figure 8. Server-end and mobile terminal Unity connection.

C. Homido headset with the application of SBS dimensional rendering to display 3D darts game system (mobile terminal)

The SBS 3D image conversion system was utilized to convert the mobile terminal 3D dart game into the left and right eye viewing images for the user, as shown in Fig. 9. As the smartphone was placed in the Homido headset frame, the user was able to view the 3D display of the game.

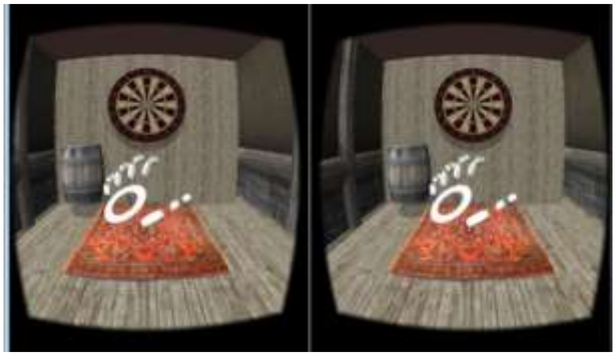


Figure 9. SBS dimensional rendering of the 3D dart game.

D. Head-mounted 3D interactive system setup

The entire system comprising the host processor, Leap Motion, smartphone, Homido headset, and WAP setup is shown in Fig. 10.

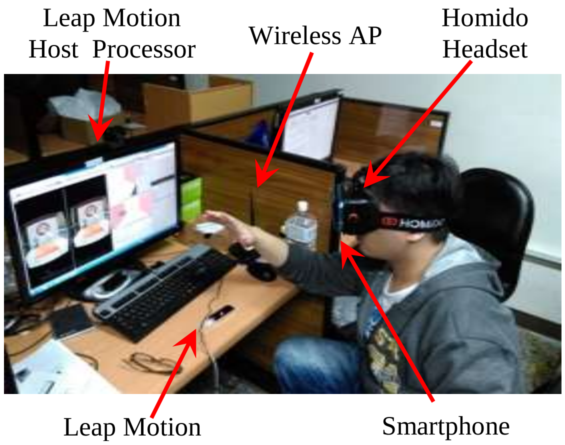


Figure 10: A photograph of the head-mounted 3D interactive system setup.

V. CONCLUSIONS

In this study, we not only implemented the proposed "head-mounted 3D interactive system", but also made a solid VR environment based on the concept of Oculus Rift. In the Oculus VR system, Leap Motion's interactive system must be used to make gestures. As Oculus is connected directly to the host processor, when wearing the Oculus Rift headset, the user's space would be restricted by the cables. In contrast, our proposed system, the "head-mounted 3D interactive system," transfers data over a wireless network. Thus, this system has less space limitations and provides the user with a more spacious control environment. A major advantage of the system is that it uses a smartphone, which is a commonly used device. With the exception of the host processor and Leap Motion, this system only required a 10–80 USD VR headset (e.g., the official price of Homido headset is approximately 80 USD). On the other hand, the Oculus system setup requires the same host processor, Leap Motion, and an additional 350 USD Oculus Rift (official price). In other words, the hardware cost of the proposed system is considerably less than that of the Oculus system. Therefore, our system provides a more cost effective choice for an equally immersive VR system.

VI. FUTURE WORK

The proposed system is developed using Unity 3D, which can integrate with many hardware devices and software tools, such as arduino, kinect, open cv, Vuforia and so on. Therefore, our system is also easy to be integrated with other hardware devices and software tools. That is, in the future, our system can be not only used in entertainment, but also applied in other fields, including medicine and education.

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