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A STUDY OF USING CONTACTLESS GESTURE RECOGNITION ON SHADOW PUPPET MANIPULATION

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Abstract. *Gesture recognition using depth and infrared image data has seen the greatest development and is the most acknowledged technological advancement in recent years. It has given rise to contactless scenarios, where the device and system capture changes in user movements and allow more intuitive input gestures. As a result, users need not learn specific knowledge beforehand, and can input commands using natural interaction. Shadow puppetry is an important art form in traditional Chinese arts and cultures, and is a key representation of intangible culture heritage as recognized by the UNESCO. Traditionally, the puppeteers use wooden rods to articulate the puppets' joints and produce a very stylized form of animation. However, with ever advancing media trend and technologies, the mastery of this art form is in danger of extinction and its popularity is in decline. The goal of this study is to utilize gesture recognition to develop a system to improve upon traditional puppetry manipulation and therefore encourage complete beginners to learn to use it, and lower the barrier to digital medium adoption. In this study both qualitative and quantitative analysis were conducted and yielded positive results.*
Keywords: Contactless gesture recognition (CGR), Gesture-based interaction, Natural interaction, Shadow puppet, Leap Motion

1. **Introduction.** Human-computer interaction (HCI) has greatly benefited from increasing computing power and advancing sensor technology, with rapid evolvement in gesture recognition technology. Besides contact-based gesture recognition application on mobile device, CGR technology based on image and depth information has opened a wealth of possibilities for HCI, because it allows users to "communicate" with computers through natural, interactive body movements. For many digital immigrants, this makes technology adoption significantly easier. The mechanism of early movement recognition technologies were mostly based on motion tracking using 2D images with a single camera [1,2]; however, the drawbacks include long rendering time and lack of tracking precision. With depth-sensing technologies improving at flying speed in recent years, depth information is now more readily available. For instance, in 2010, Microsoft launched 'Kinect' [3], which adopts PrimeSense' light coding patented technology. Kinect works by encoding the scene via near-infrared light (NIF). The infrared receivers (IR receivers) read the coded light back from the scene to acquire the depth image. By reconstructing the depth map of the image data, the system can capture movements and gestures more accurately. However, initially, Kinect was predominately used for XBOX360 motion-sensing games, and the sensor showed display resolution limitation, so even if able to capture overall body movements for interactions, Kinect struggled to read small movements such as facial expressions and hand gestures. Not long after the first Kinect was announced, the San Francisco-based company Leap Motion, founded in 2010, began to develop the technology by the same name, and the product was officially launched in 2013. Unlike Kinect,

Leap Motion works by detecting overall body movements in the scene and it works better with the player physically close to the monitor; it is able to accurately capture hands and even finger movements. Using two monochromatic IR cameras and three infrared LEDs, a 3D pattern of dots of IR lights is generated. The effective viewing range of the motion capture camera is 2 ft. above the device, 2 ft. to either side of the device (with 150° field of view, FOV), and 2 ft. in front of and behind the device (with 120° FOV). The camera captures image data at almost 300 frames per second (fps); the data is then reported back to Leap Motion service for the algorithms to make gesture calculations and deductions to produce a 3D coordinate system. For all programs developed using Leap Motion, the tracking data on player motion is fed through the Leap Motion server. This means any small player's movement can be recognized, and the interaction is processed by the computer, and then fed back to the user for natural interactive experience. This interactive mechanism is very similar to traditional shadow puppet manipulation; hence, the adoption of Leap Motion is to improve user control experience. Shadow puppetry is a key art form in traditional Chinese culture, and is a key representation of intangible culture heritage as recognized by UNESCO [4]. Traditionally, the puppeteers use wooden rods to manipulate the puppets through articulating their joints, creating an animated performance that portrays an art form rich in culture.

In light of the above, we have utilized Leap Motion sensor and developed algorithms to create a game system with a control mechanism that mimics traditional shadow puppet, where users can articulate the puppets' joint movements intuitively by moving their fingers. This game was tested on puppeteers, adults, and elementary school students from shadow puppet societies, and the survey data then underwent further analysis.

2. **Literature Review.**

2.1. **Application of contactless gesture recognition (CGR).**

CGR application increases day by day. For instance, using depth sensors and the software development kit (SDK) provided by PrimeSense NITE allows player hand coordinates and image data on the hands' positions to be quickly obtained. Next, through a series of hand shape features and records of hand gesture coordinates' trajectory, hand gesture movements are segmented into units; then by arranging the order of the movement units, a set of password sequence can be generated. This technology can be applied on security access control [5]. Robotic development has resulted in a variety of applications including robot vision with CGR. Depth sensors can capture hand shape features including position, length and number of fingers, as well as the position and radius of the palms, to generate robot motion instructions [6]. Furthermore, experimental studies have been conducted on contactless mouse control for computer operation through gesture recognition using depth cameras, whereby the movement trajectory of the controlled cursor as well as the left and right click finger movements are captured and reflected to trigger mouse events [7]. Due to the rapidly advancing virtual reality (VR) technologies in recent years, many CGR related studies have been conducted on incorporating player hand gestures in the virtual world [8]. The literature summarized above illustrates the development trend of CGR; however, it is also apparent that CGR application on traditional arts and culture is relatively scarce; therefore, this experimental study focuses on CGR application on shadow puppet art and demonstrate tangible achievements.

2.2. **Studies on digital shadow puppetry.**

Advancing technology has inspired the idea to digitalize shadow puppet manipulation. In 2000, Güdükbay et al. proposed the study 'Digital Shadow Theater', which discusses using multimedia technologies to manipulate puppets in traditional Turkish shadow theater, dating back to the 16th century [9]. In Taiwan, the Taiwan Folk Artist Digital Museum and Taipei National University of the Arts collaborated to produce an interactive puppet figure fighting game called

'Puppet Fighters', which utilizes keyboard and mouse to articulate shadow puppet joints and create movements [10]. For the 2010 Kaohsiung County Puppetry Festival, the team from Shu-Te University created an interactive installation piece – 'The Tiger Killer' using multi-touch technology. The manipulation mechanism works by using IR to detect touch points of the two fingers that act as the wooden rods attached to the puppets for movement control [11].

Innovative application of digitalized traditional arts and cultures is a way to preserve national art forms. Modern technologies can retain, as well as expand on the traditional features, and they boast many advantages, including dynamic display formats, good compatibility, and allow complex combinations, as well as appropriate expressiveness; these advantages mean such technologies can bridge gaps and improve upon the weaknesses of traditional art forms, and therefore, the art forms can be sustained and revitalized [12].

3. **Research Method.** An analysis was carried out on existing digital shadow puppetry case studies, which are mostly concerned with vector operations where user control is made possible by paring digitalized puppet data with vector input method. However, this method works only on a computer user interface using a keyboard or mouse. As touch-screen technology became more common, people began to study puppet manipulation using touch-control; however, the animation quality is below par and its manipulation method is rather different compared to traditional shadow puppetry; not only is the number of simultaneous control points limited, but the mandatory physical contact with the screen means users are unable to watch the manipulation process from a suitable distance. The realization of the Leap Motion technology is able to offer a better solution. For this study, we have utilized Leap Motion to develop a CGR shadow puppet game – 'Addiction of Shadow Play'. In this game, players can use their fingers instead of wooden rods for manipulation. The players point their fingers to the screen, the positions indicated by the directions in which the fingers are pointing are recognized by the game system as the control points, and players can articulate the puppet's joints within that point (see left image of Figure 1). Moreover, one technique employed in shadow puppetry is moving the puppet closer to or away from the screen to create depth of field and thus give the illusion of near and far on screen (see right image of Figure 1). This special feature is an imperative element of traditional shadow puppetry but not achievable by conventional contact-based gesture recognition. However, it is now made possible by the CGR system developed in this study.

The game system was developed using the game engine Unity with Leap Motion interaction and the coding was done using C#. Leap Motion SDK provides two types of

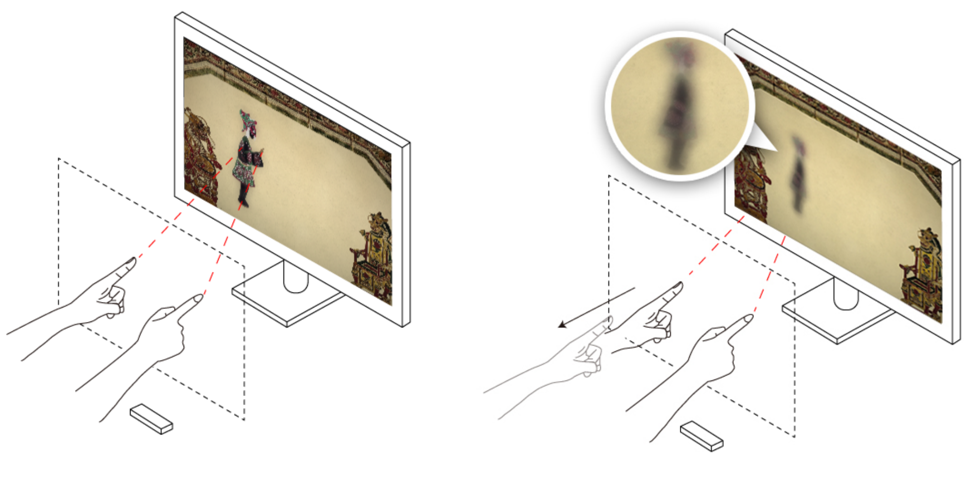

FIGURE 1. 'Addiction of Shadow Play' – Illustrations of control methods

tracking data obtainable from the server, namely native interface and WebSocket interface. The dynamic library is able to provide the Leap Motion application interface. It connects to the Leap Motion server to provide tracking data to the program. The Leap Motion WebSocket interface runs its server on the localhost domain at port 6437. The webpage is able to provide tracking data as JSON messages. A JavaScript client library can receive the JSON messages and present the tracking data as regular JavaScripte objects. The Leap Motion system uses a right-handed Cartesian coordinate system with the origin centered at the top of the Leap Motion controller. The x- and z-axes lie in the horizontal plane; to the right of the x axis are positive values, and to the left are negative values. The z-axis has positive values increasing away from the monitor. The y-axis is vertical, with positive values increasing upwards. The Leap Motion server transmits hand gesture tracking data, which includes hand model, finger and tool model, and gesture type data. In our game system, the data on fingertip movements detected by Leap Motion is mapped to the coordinates of the corresponding joints of the digital puppet models. The program maps the fingertip movement data, it immediately detects to the puppet's torso, and then it maps the remaining fingertip movements to the puppet's wrist joints. The elbow joint movements are calculated using inverse kinematics so the puppets' arms will flex naturally and adapt to the relative distance of the hands to the player. In addition, to make the shadow play more realistic, a physics simulation feature was developed for the game system so that when the coordinates of the puppet joints change, the remaining joints without any player fingertip movement attached, will also move in according to the physics of inertia and gravity, and thus provides a realistic simulation of shadow puppetry.

Permission was granted by the Kaohsiung Museum of Shadow Puppet and the Lin Liu-Hsin Puppet Theatre Museum for us to use professional equipment to create digital copy and data on traditional shadow puppet elements including the sets and backgrounds. We then digitally removed the image background and dismantled the digital puppets by their joints. In order to properly portray the features of traditional shadow puppetry, we designed the 'practice mode' and 'mission mode'. In practice mode, the player articulates the puppets' joints by moving their fingers intuitively, and there is no need to learn additional special gestures for manipulation. The mission mode has the easy, medium and hard difficulty levels (see Figure 2), and was given a competing element. The players manipulate the puppet using fingers of both hands, and have to fight monster characters from famous folk stories. They need to change the position of the puppet in the scene to dodge attacks, and at the same time they need to articulate the puppet to attack back with its weapon. The interactive feature offered in this mode not only properly reflects the mechanism of the traditional method, but adds the additional interactive function made possible only with the recognition system. It is hoped the incorporation of the gaming element will interest modern audience more, and increase their motivation to learn about this art form.

FIGURE 2. 'Addiction of Shadow Play' – Illustration of three game levels in mission mode

For the study we invited five subject matter experts to evaluate our prototype game. We conducted a survey using questionnaire as well as in-depth interviews on three Taiwanese shadow puppeteers, and two interactive interface programmers. The evaluation results then became the basis for making improvement on the prototype game. After the improvements, the game was further tested by children and adults test subjects. The children sample group consists of 30 elementary school senior graders aged between 10 and 13 (16 boys and 14 girls); the adult sample group consists of 87 adults aged between 18 and 25 (33 male, 54 female). Each person was asked to play the game by themselves for five minutes, during which we observed and recorded their behaviors and reactions. After the test play, they were asked to fill in a questionnaire [10] in order to provide analytical data on the content design, interface design, function design, and user experience.

4. **Results.** The three experts agreed that compared with other existing digital methods, the mechanism of this newly developed game system is more similar to traditional shadow puppet manipulation. Nevertheless, more work is required to make it even more similar to the traditional art form, in which some techniques involve pressing the wooden rods and puppet against the screen. Having said that, they also reckoned the interactive feature of this research-based game is fascinating for the general public. In addition, it was suggested we incorporate the storyline of traditional puppetry by adding more characters, scenes and props, and also make it more educational so it can also be a learning material to foster interest in the art form. Moreover, the test subjects acknowledged the game's potential to aid further development in shadow puppet culture. It is hoped the results of this study can be well publicized so that more people will grow to understand and enjoy shadow puppetry.

The results shown are derived from 112 effective questionnaires. The Cronbach's α of the children and adult sample group results are 0.892 and 0.942 respectively; both values are larger than 0.85, indicating the questionnaire survey offers good reliability.

The one-sample t-test was carried out for each aspect of the game design as indicated in the questionnaire administered to children. All dimensions show significance level of < 0.05, mean of > 3, and mean deviation of > 0.5, indicating the subjects were satisfied about all aspects of the prototype game. From our gameplay observation, the children showed no issue in understanding the interface design and reading the instructions. The majority could operate the game by themselves after we gave them the instructions just once. However, they displayed lower awareness of the device's effective range, so their gameplay was interrupted when they moved outside of the effective range. Hence, even with overall satisfactory results, the score for the contactless control experience is on average lower than that of other game design aspects. We also observed a few small-framed children experienced movement detection issue. The speculated reason is their fingers are too small for Leap Motion's algorithm to identify and determine.

From the questionnaire results of the 87 adults, all dimensions show significance level of < 0.05, mean of > 3, and mean deviation of > 0.5 which suggests the subjects were satisfied with all aspects of the prototype game. A few taller adults also experienced the effective range and motion detection issues. It is suspected because these players are relatively taller, when their gesturing fingers are pointing to the screen at an downward angle, and Leap Motion has a higher detection error rate when the angle of the fingers is greater; as a result of this, player experience was adversely affected. Therefore, even with an overall satisfactory result, the score for the contactless control experience is on average lower than that of other game design aspects. Therefore, with ever advancing hardware technology, future improvement should be focused on program optimization.

5. **Conclusions.** This study proposed the use of CGR technology to mimic traditional shadow puppet manipulation. The goals are to revive this traditional art form through

digitalizing its content, replicating its original manipulation method, and giving it a modern type of player experience by adding in the popular gaming elements. Several findings have been identified. First, the limitation posed by the effective range of the Leap Motion sensor means the intuitiveness of user movement and natural interaction will undoubtedly be affected to a degree; therefore, device installation needs to be investigated. Moreover, CGR technology has allowed us to design control gestures that are not over complicated and are user friendly based on what people are familiar with. During the tests, all players, including puppeteers, and players from the children and adult sample groups, adopted the interactive gestures very naturally. This outcome proves CGR technology provides a good solution for digital shadow puppet manipulation; other limitations identified during the tests, including effective range, and ineffective recognition due to height and finger size, are therefore likely to be resolved with further hardware or algorithm improvement in the future.

The test results were very positive and the game was very well received by the players, as a result the Kaohsiung Museum of Shadow Puppet approached and asked us to set up a system inside the museum as one of their resident exhibits. 'Addiction of Shadow Play' has received fantastic reviews from visitors. Future studies based on the outcome of this study have been planned and we will develop multi-player modes and incorporate many more elements from traditional shadow puppetry, and at the same time we will make the new version of 'Addiction of Shadow Play' available on Leap Motion's airspace platform, so that more people can play the game and provide their user feedback for further improvement.

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