AR-Arm: Augmented Visualization for Guiding Arm Movement in the First-Person Perspective

Ping-Hsuan Han[1,*], Kuan-Wen Chen[2], Chen-Hsin Hsieh[3], Yu-Jie Huang[3], Yi-Ping Hung[1,3,†]

[1]Graduate Institute of Networking and Multimedia, National Taiwan University
[2]Department of Computer Science, National Chiao Tung University
[3] Department of Computer Science and Information Engineering, National Taiwan University
[*]pinghsuan.han@gmail.com, [†]hung@csie.ntu.edu.tw

ABSTRACT
In many activities, such as martial arts, physical exercise, and physiotherapy, the users are asked to perform a sequence of body movements with highly accurate arm positions. Sometimes, the movements are too complicated for users to learn, even by imitating the action of the coach directly. This paper presents a fully immersive augmented reality (AR) system, which provides egocentric hints to guide the arm movement of the user via a video see-through head-mounted display (HMD). By using this system, the user can perform the exactitude of arm movement simply by moving his arms to follow and match the virtual arms, rendered from coach's movement of database, in the first-person view. To ensure the rendered virtual arms correctly aligned with the user's real shoulders, a calibration method is proposed to estimate the length of the user's arms and the positions of his head and shoulders in advance. In addition, we apply the system to Tai-Chi-Chuan practicing, our preliminary study has shown that the proposed egocentric hints can provide intuitive guidance for users to follow the arm movement of the coach with exactitude.

Categories and Subject Descriptors
H.5.1 [**INFORMATION INTERFACES AND PRESENTATION**]: Multimedia Information Systems – *Artificial, augmented, and virtual realities.*

General Terms
Algorithms, Measurement, Design, Human Factors.

Keywords
Augmented Reality, Body Movement Guidance, Visualization, Wearable Interaction.

1. INTRODUCTION
AR systems use augmented virtual objects to enhance real world information [1]. With the growth of HMD, AR applications have been developed to guide users to correctly operating certain devices [2, 3, 4] and to learn emerging technology. Henderson et al. [2] apply AR to armored vehicle turret maintenance. With a head-worn display, the mechanic could acquire steps in the form of texts, images and animations. White et al. [5] design visual hints in a tangible AR system for tangible gesture learning. The user can see tangible gesture operation hints through the video see-through display. Also, AR systems are used in training [6, 7, 8] or guiding hand movement [9].

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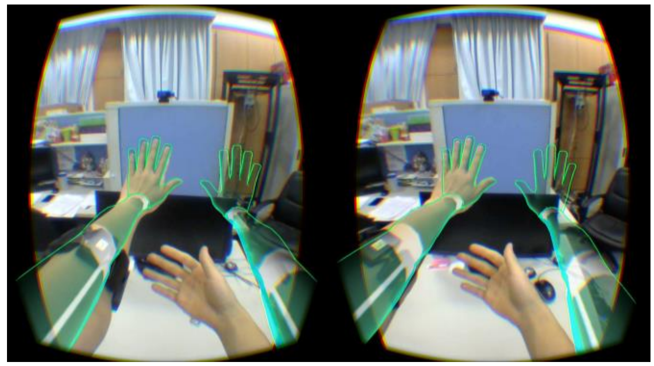

Figure 1. The first-person views of user using AR-Arm, where the semitransparent arms are used as egocentric hints to guide the user's arm movement.

For action learning activities, such as Tai-Chi-Chuan, most of them usually require a coach to teach in the field. Students are asked to perform the same actions after observing the coach's demonstration. To such learning activities in the field, there are some problems. First, students cannot do the self-correction in the same view. They need to remember the actions of the coach, turn to look at their own body, and adjust their own poses accordingly. Second, even with such visual aid from the coach, the sight distance, angle, or others students may prevent student from observing the proper moves of coach in the field. Third, it is not allowed to learn if the time of coach or students is not available. To overcome these problems, video material (such as YouTube) playing on the flat screen has been developed to allow student practicing at home. In addition, multiple views from different angles have been shown being required, and so students can understand the motion detail [10] more easily. However, even with a number of static angles, some motions are still difficult to learn.

In this paper, we propose an egocentric guidance for arms movement with a video see-through HMD, so that the user can easily follow coach's arm movement in the same view (as shown in Figure 1). The main contributions of this paper are summarized as follows. First, we propose a method to estimate the upper body skeleton through a HMD by computing the user's atlantoaxial joint and shoulder positions with arm length. Second, we build an immersive AR system with an egocentric guidance for action learning. Third, a preliminary study is evaluated by applying our system to Tai-Chi-Chuan practicing.

2. RELATED WORK

There have been some researches on movement guidance with AR or virtual reality (VR) technologies. Yang et al. [11] use ghost metaphor to train hand movements in VR-based motion training. With an egocentric view, students can put themselves into the trainer's shoes. Chua et al. [12] build a full-body training system in virtual reality environment and create the role of teacher in front of students. And then, students can watch teacher's movements beside the teacher and compared to the movement of themselves'. However, those systems can only let the users see their virtual hands instead of real ones.

LightGuide [9] uses a projector hanging from the ceiling, and guides the user's hand movements with three dimensional through visual information from a projection on the viewer's hand. It can only guide user in a fixed space with user's hand being under the projection zone of projector. Motokawa et al. [7] create a guitar learning support system using AR Display. The augmented objects appear overlaid onto the guitar. Users can see their hands, models of hand gestures, and guitar strings, which assist them in learning. However, the guitar needs to face the front and being in the visual field of the webcam. MotionMA [13] uses Kinect to analyze and model experts' motion. The result from the model analyzer will show the feedback information on the screen. YouMove [8] uses AR Mirror to enhance the user's movement training. Posture guides and movement guides are designed to allow users to learn both static and movement gestures. During learning, these Kinect skeleton systems are used to display the differences in movements from the trainer. Physio@Home [10] uses a detection device which is worn on user's arm and setups two cameras from different angles aside the user. By broadcasting information of guidance to the user in front of a TV and observing from different angles, this system is able to decrease the amount of mistakes from physiotherapy patients when exercising. This configuration allows feedback from multiple directions, but requires users to maintain a fixed space in the vision field of cameras. Although those approaches give users a great feedback, the user can only get the guiding information in front of the flat screen or projector.

Most close to our work, OutsideMe [16] uses Kinect and HMD to display external self-image in first-person view. Comparing to our work, we provide coach motion inside of our body. In contrast to prior literatures, our work explores the visual hint from the egocentric view, which provides arms movement guidance in an immersive AR system. Additionally, user can have free observation when he is following the movement.

3. AR-ARM

3.1 System Overview

Figure 2 shows the system overview. The measurement phase is to receive measurement data from Oculus Rift DK2 with position tracker, Leap Motion, and Myo to measure the positions and orientations of user's head and hands. In generating phase, the system constructs the upper body skeleton with two virtual arm models at both shoulder joints. There is an important issue here, i.e. the animated character's shoulder positions are not easily aligned with user's real shoulder positions well. This is because the upper body skeleton structure from our system and the animated character's skeleton structure are different. To deal with this problem, we have to retarget the shoulder joints on the user's shoulders, more detail can be seen in Section 3.3, to enable the virtual arms displayed correctly for user.

The guidance phase is to bring the result of guiding movement to the user. In this phase, the system constantly extracts the HMD

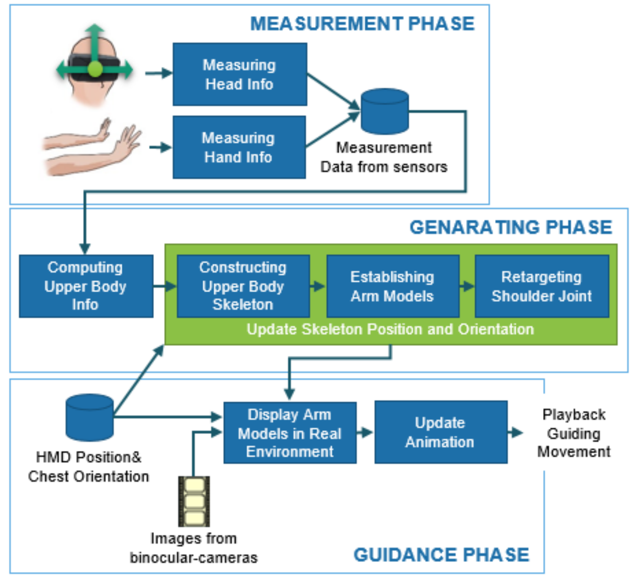

Figure 2. Overview of the proposed AR-Arm system.

position, chest orientation, and the binocular-camera's images, and further updates the skeleton structure's position and rotation. Finally, the virtual arms are displayed through the immersive HMD, and allow the user to follow the coach's guidance movements. During this phase, the animations of virtual arms can be slowed or paused to allow the user to observe the differences between their own arms and the virtual arms (coach's arms).

3.2 Prototyping

Figure 3 shows the hardware setup of our system. It consists of four parts of hardware components: (1) Oculus Rift DK2, (2) Leap Motion, (3) Myo and (4) Chest Strap. Oculus Rift is a HMD with a built-in IMU and an additional near infrared CMOS sensor which are used to tack the user head position and orientation within 0.5-2.5 meters and 72H×52W degrees FOV. Leap Motion is a depth sensor attached to the front surface of Oculus Rift, which is used to track both hands of the user within 2 feet in length and 120H×150W degrees FOV. Myo is a wireless armband including Bluetooth 4.0 LE and highly sensitive 9-axis IMU, and is used to tack the user's arm orientation (both). Finally, we track the chest orientation by using the Arduino Nano board and SparkFun 9DOF Sensor Stick to create a chest strap with an IMU. This wearable device used an elastic cloth to strap on the mechanism at the very center of chest.

The head-mounted video see-through AR display of our system consists of Oculus Rift and binocular-cameras module like AR-Rift [14]. In our paper, we used Oculus DK2 to build our system. The distance between the two lenses of the video cameras is 6.4 cm, which is the same distance as the Oculus DK2's papillary distance. Although above-mentioned system can provide user a video see-through display, this cannot be considered a true see-through AR display. The proposed HMD architecture is actually a VR display, but with textures from real environment.

Our system runs on a workstation. It is equipped with a Core i7 4790K CPU (Quad-Core with @4.0 GHz), 24GB of RAM and an NVIDIA GTX980 running Windows 8.1. The overall rendering performance is more than 75 fps. The entire software system is developed based on the game engine Unity3D 4.6. The Leap Motion SDK and related palm tracking provided by the unity packages are used to collect palm location information. The HMD

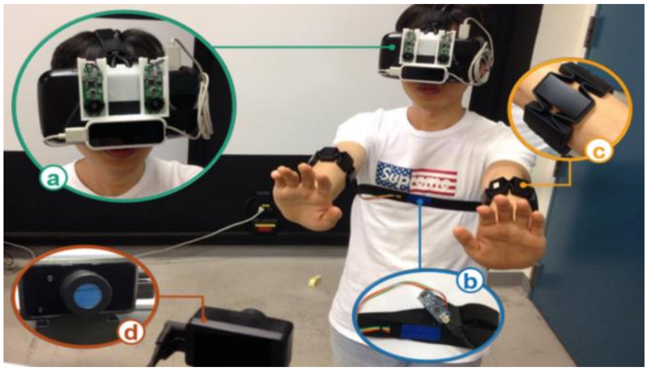

Figure 3. The system physical layout: (a) See-through AR display with Leap Motion, (b) chest strap, (c) Myo and (d) infrared CMOS sensor from Oculus.

uses Oculus SDK 0.4.4 and the related Unity 4 integration package. The Chest orientation is acquired from Arduino's connected IMU, which is transferred to Unity3D through a serial port. The camera calibration of the head-mounted video see-through display uses the Zhang's method [15]. The camera calibration method is written in shader for speeding up.

3.3 Augmented Visualization

To overlap the coach's and the student's upper body for providing egocentric hints in an immersive AR system, there are three main problems of using HMD position tracker to build upper body skeleton. The first issue is the difference between the rotation of head and that of HMD. When user turns head, the head does not rotate by the center of the head. Instead, it rotates by its atlantoaxial joint. This problem causes the arms moving up when the user looks up. The proper result should be like Figure 4(b). To build an upper body skeleton (Figure 4(a)) for egocentric hint, we need to know the user's upper body information. The virtual upper body skeleton in our system is estimated based on HMD position tracking. In order to properly display the virtual arms in the proper locations and with proper sizes, we have to measure the following upper body information as seen in Figure 4(c): (1) atlantoaxial joint, (2) shoulder width, (3) neck length and (4) arm length. The reason of using the atlantoaxial joint as arm model's root point is that when a user is observing their surroundings the virtual arm will not follow because of HMD's rotation.

The procedures of measuring upper body information are as follows. First, after the user wears the HMD, the system will get $\boldsymbol{P_{track}}$ from infrared cameras in front of the users after they turn their head to 30 degrees left and then 30 degrees right. Then we can estimate the user's head radius as seen in figure 5(a)'s orange line. The head center can be inferred based on the HMD's position and orientation as well as the previously acquired radius. Head circumference radius here refers to the distance from the head center to the outer center of the HMD. Second, the head center and the atlantoaxial joint have a height difference as shown in Figure 5(b). This difference affects the model's upper body movement when the user raises their head. Therefore, we perform another estimation by asking the user to raise their head up for 45 degrees and then face the front. According to trigonometric functions, we can easy calculate the length of h from the head radius. Then, the atlantoaxial joint can be estimated by

$$P_{Real} = (x_c\,, y_c - h\,, z_c) \qquad (1)$$

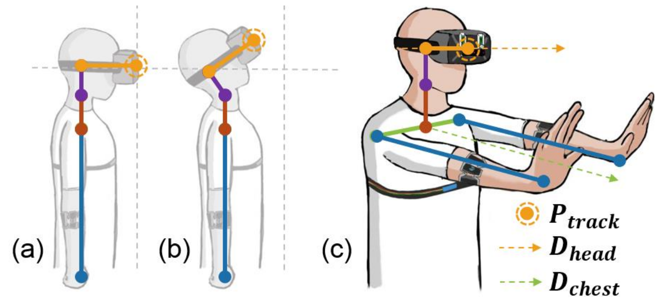

Figure 4. The problem of using HMD position tracker for building upper body skeleton.

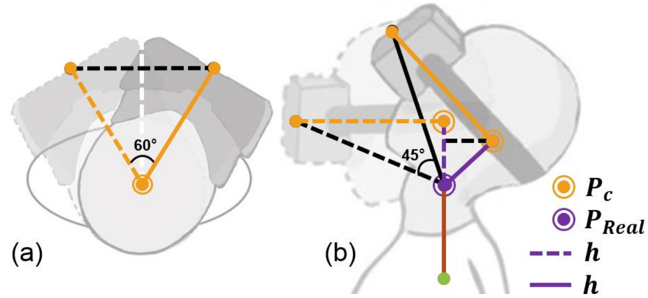

Figure 5. Estimating the atlantoaxial joint.

The second issue is the difference between chest direction and head direction. As shown in Figure 4(c), some of the moves require user's head and chest to face different directions. If the system uses only head direction without knowing the chest direction, the hand will always follow the head movement. It will be very strange for user, if he does not turn his body actually. To deal with this issue, we use a chest strap with IMU to distinguish chest direction and head direction.

The third issue is the length and the position of upper body part. The visual arm should be the same length as users' arm, and it makes user to do the same arm movement and compare the differences more easily. To deal with this issue, first, we use Leap Motion to track the user's palm position for calculating arm length and shoulder height. During this process, the system requires the user to raise both arms to shoulders height, and the HMD and Myo's internal IMU will check if it is parallel to the horizon to ensure that the calculated data is correct during the measurements from holding both arms forward. The palm positions relative to the HMD can be calculated by asking the user to hold both their arms forward at their shoulder's width, as shown in Figure 4(c). The distance between palms can be used to estimate the shoulder width, as shown in Figure 4(c)'s green line. In terms of shoulder measurements, the user can perform some small adjustments by themselves. The length of the neck is acquired from the height from the middle of the HMD to the palm position, as shown in Figure 4(c)'s red line and purple line. The arm length, the blue line in Figure 4(c), is estimated from the sum of the head circumference radius and the relative distance between the HMD and the palm finally.

4. PRELIMINARY STUDY

There are many applications with movement guidance required. In this paper, we choose Tai-Chi-Chuan (one of famous martial art) as the applied applications because it includes many arm actions that are elegant and detailed. While we are planning on a larger user studies using our system, we want to know the most important features of AR-Arm work for untrained users in a first preliminary

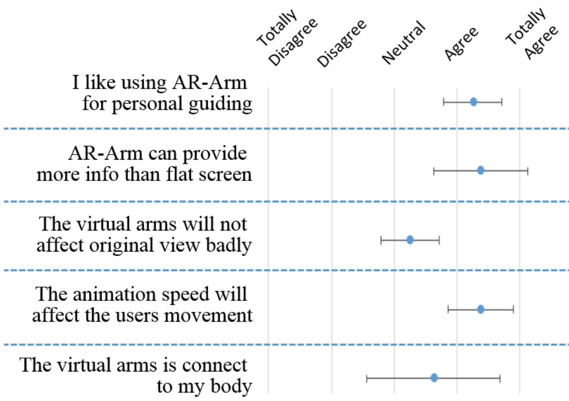

Figure 6. Questionnaire feedback.

investigation. Eight participants (6 males and 2 females) are recruited to identify strength and weaknesses of current implementation. All participants had no previous knowledge of using our system. We overlay the coach's virtual bone structure action onto the student's real body and play the previously Tai-Chi techniques recorded by MVN Motion Capture. The coach is performing Tai-Chi techniques within your body by impression, and we asked students to follow the movement such as raising arms, flipping palms, backwards-flinging arms, pushing palms forward, etc. In the end, we made an interview and asked few questions, as shown in Figure 6. Although, we find out some moves need to be played slowly for participants. All participants said they can be guided moving their arms to perform maneuvers well. It is difficult to express such delicate movements with words or pictures. Especially detailed movements like the Tai-Chi technique or other motions. More details of the Tai-Chi guidance system can be seen in the video sequence https://youtu.be/Zha0X6Wpz7E.

5. DISSCUSION

In an immersive AR system, using a virtual model to simulate a real person's movements as its guiding information has many advantages. The user is able to check whether coach's movements are the same as the models' easily, and adjust the angle and position of their arms. When designing the model's presentation method, the following aspects are taken into consideration: (1) size (2) material (3) movement speed (4) shading effect. To allow the user to compare and see if their arm positions are correct, an arm model with the same length as the user's is required, as seen in Figure 4(c). In addition, the arm model's joint has to be connected to the user's shoulder to act as a reference comparison point. In order to allow the user to compare their arms with the virtual ones, the transparency needs to prevent the model from blocking the user's arm as shown in Figure 1. Additionally, the material's transparency and complexity needs to be considered together. The movement speed is another important problem when users are following coach's movement. In some actions, system has to provide different speed setups for users to adjust as they need. Finally, shadow effects can be used to enhance the overall visual effect and create information of depth or height.

6. CONCLUSIONS AND FUTURE WORK

In this paper, we present the AR-Arm, which is a novel upper body movement guidance system. Users can use our system with egocentric hints to learn maneuvers, and have more references to compare differences between their movements and coach's movement. Furthermore, when the user changing the direction, the system can still display the virtual arm positions correctly. The proposed HMD system also provides a private learning space where can be highly personalized. Our proof-of-concept prototype's preliminary results have shown that AR-Arm has a great potential and help users learning actions more intuitively. In the future, we will build a wireless module for our system to prevent users being disturbed when using the system, and further, a more complete study will be made to prove its usability.

7. ACKNOWLEDGMENTS

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