Wiimote Squash: Comparing DTW and WFM Techniques for 3D Gesture Recognition

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Abstract: *This paper compares Dynamic Time Warping (DTW) and Waveform Matching (WFM), the two gesture recognition techniques, applied on a specific Squash game application we have developed. Our application gets accelerometer readings by moving the Nintendo™ Wiimote in a 3D space. This application manipulates the Wiimote gestures in the form of signals. These signals are the effect of the movements, the positioning and the orientations of Squash racket (actually Wiimote) on the computer screen. We implemented five Squash shots (i. e., 3D uni-stroke gestures) in order to compare DTW and WFM. The results indicate that there is not a significant difference in the detection of gestures by both techniques (DTW and WFM) but there exists a strong degree of association between both techniques.*

Keywords: *Human computer interaction, 3D gestures, wiimote, squash game, DTW, WFM.*

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1. Introduction

Games not only provide a real source of enjoyment in daily life but are also helpful in improving the physical and mental health of human. Apart from daily life physical games, people also play computer games. These games are different than those of physical games in a sense that they do not involve much physical activity, rather mental and emotional activities.

People generally play computer games by using the common input devices like keyboard, mouse and joystick. A real sensation is not always achieved by playing these games with these traditional devices. This is due to the fact that the buttons on the keyboard and joystick do not truly reflect the mapping between game elements (characters, ..., etc.,) and their directional movements. For example, while playing a lawn tennis game on computer, by only pressing a keyboard button-to move the tennis ball on the other side of the net-does not truly imitates the direction and the force applied on the racket. That means the shot played is not like performing real tennis shot. Moreover, this does not conform to the real feelings and user satisfaction. Thus, there is a need to use such physical device (s) (other than keyboard and joystick) that mimic the exact shots of tennis and help (s) to create a clear mapping with 3D game user interface.

Such type of devices and related accessories [8, 13, 14, 19] has already been in the market. Kinect [8] is an input device that detects motion sensing for Xbox 360 video game console. It provides natural 3D gestures (bare-hand) and spoken commands to interact with the game. PlayStation controller [14] is also a motion sensing device for PlayStation 3 game console and uses a pair of inertial sensors to detect its motion. uWand [19] is helpful in 3D gesture control, direct pointing, selecting and manipulating numerous electronic devices. Wiimote [13] is a device-which has revolutionized the gaming world-by using accelerometer and optical sensor technology interacts with the game through pointing and performing gestures.

For our application, rather than playing the Squash game with bare hands and open palms (as probably is possible with [8]) we used Wiimote to play the game because it resembles closely with the scenario of a Squash racket in hand.

We used two techniques-Dynamic Time Warping (DTW) [12] and Waveform Matching (WFM) [15] for the recognition of the arm gestures for our 3D Squash game environment. The rationale for the choice of these two techniques is that:

1. DTW has proved to be less complex and provided encouraging results [12] for 2D gestures.
2. Both techniques (DTW and WFM) have not already been tested and compared for the detection of 3D gestures.

3. To check which technique provides better results than the other specifically for the Squash game scenario.

The rest of the paper is organized into different sections. Section 2 describes the related work. Section 3 briefs the design of Squash game court and section 4 discusses the working of Wiimote. Section 5 describes Wiimote pointing, while section 6 explains the Squash game we developed. Section 7 describes the experiment and the results. Section 8 discusses the comparison of existing techniques with the current work along with highlighting the contribution. We conclude our work in section 9 and discuss the future work.

2. Related Work

In our real life we use gestures to augment our feelings, emotions, social integration and communication [3] and to play different games. In a computing environment a gesture can be drawn by pressing and dragging a pen (or stylus) from one position to another without lifting it. This draws a single mark (or stroke or gesture) [22]. Similarly, the other physical devices like Wiimote [13] and PlayStation controller [14] perform gestures while playing a game. These gestures are different in a sense that these are performed in air (3D) and thus require different handling for their detection and recognition.

Different recognition techniques have been used like Hidden Morkov Model (HMM) [16], Dynamic Time Warping [12] and 2D Trajectories [21], ..., etc., to detect and recognize gestures. In some techniques it is required to use specific devices for gesture recognition. These include Data Gloves [4, 7], wearable motion sensors [1] and camera-based bare hand recognition [2].

Lee *et al.* [10] used CCD cameras and Augmented Reality (AR) markers, attached on the wall, to play Squash game. The position and the movement of the racket are synchronized with the Squash ball by using a tracker. Being a prototype study, still it requires overcoming certain problems like jittering of image, the size and the resolution of the marker, and the distance of the racket from the marker.

Wedekind [20] developed Squash game which can be played by using Wiimote. No further exploration regarding the analysis and comparison of different gestures (and gesture recognition techniques) has been performed.

Liu *et al.* [11] proposed a gesture recognition algorithm for a virtual environment called VDOM. Eight different types of gestures have been performed with Wiimote and then trained and recognized by using Hidden Markov Model (HMM). Despite good recognition efficiency (>90%) still this algorithm requires defining clear mapping between the standard human gestures and HMM.

The study of [17] described the recognition of gestures by employing Hidden Markov Model (HMM). They tested their application against five different gestures which were drawn using Wii controller. The recognition results were in the range 85% to 95%. Another gesture recognition model was proposed by Kong *et al.* [9], which takes into account the x, y and z acceleration values of a 3D accelerometer. Moreover, the gestures performed were further divided into small units and each unit was analyzed and recognized by HMM. This model is still at preliminary stage and requires further enhancements with concrete experiments.

In the above mentioned studies, the use of extra hardware and the recognition of bare-hand features further complicate the gesture recognition procedures. This also requires reasonable computing power and extensive computations and thus results in the increase of time for gesture detection and recognition.

3. Squash Game Court

A Squash court is composed of a floor and four walls as shown in Figure 1. The floor is further divided into two sections. The front half section, close to front wall, is generally for player's moving area. The back half section is further divided into two boxes. These boxes are left quarter and the right quarter separated by half-court line. These quarters contains two service boxes. The front wall of the Squash court consists of three lines. The line close to ceiling is called outline and the line close of the floor is called tin line. The area between these two extreme lines is playing area (or ball hit area) and contains a line called service line. The playing equipments include a racket and a ball.

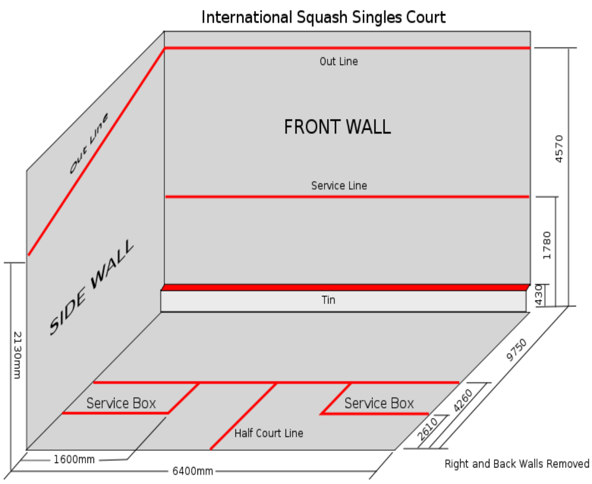

Figure 1. International Squash singles court, as specified by the World Squash Federation, adapted from [5].

4. Wiimote's Structure and Working

The device we used for the recognition of the Squash game gestures is Wiimote that has a built-in 3-axis accelerometer for sensing arm motion. It is a wireless hand-held device i.e., connected to computer via bluetooth connection. The device produces acceleration on x, y, and z (3D) coordinates as shown in Figure 2 while performing gestures (i.e., game shots). We used Wiimote's four buttons labeled '1', '2', 'A' and 'B' for performing and storing gestures respectively as shown in Figure 3. The buttons labeled "1 & 2" are used for establishing connection with the computer via Bluetooth.

Users can easily interact with the game by using these buttons. Buttons 'A' and 'B' are pressed with the thumb and index finger respectively as shown in Figure 3. Using these buttons is intuitive-than using the keyboard or mouse buttons-because the positions of thumb and index finger naturally maps with the location of these buttons on the Wiimote.

Figure 2. Wiimote as 3D device for performing Squash gestures.

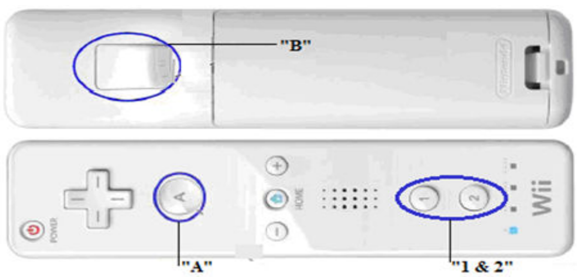

Figure 3. Wiimote buttons used for different actions in our application.

5. Wiimote Pointing

In our application a player, having Wiimote in one hand, stands in front of computer screen and performs Squash game shots (gestures) to interact with the application (3D environment). This requires two different types of pointing by Wiimote. In first type of pointing (absolute pointing), the Wiimote acts as a mouse pointer. Actually, the Wiimote is faced towards the sensor bar and by using its infrared capabilities it thus acts as an absolute screen pointer. This type of pointing is helpful in selecting multiple options from the main menu of the game as shown in Figure 9. As the menu options are clearly visible on the game user interface so it is required to move the Wiimote pointer precisely in order to select an option. This is where the absolute pointing is required.

In case of relative pointing, the user performs the gestures with the Wiimote without directly pointing or concentrating on the specific area of the screen. Thus the user can draw gestures virtually anywhere within the range of 5 to 10 meters (thanks to Bluetooth connection between the Wiimote and the Squash application). This allows users to move within this range and play shots freely.

6. Wiimote Squash Application

The main objective of Wiimote Squash application is to recognize different types of shots (actually 3D uni-stroke gestures) played by the player.

6.1. Gestures

Basically gestures are of two types: Uni-stroke gestures and multi-stroke gestures. A uni-stroke gesture is achieved when, for example, we drag the mouse (by keeping the left mouse button pressed) from a start point to an end point without releasing the mouse button. This is called a single mark or stroke and it could be simple like drawing a line of few pixels length or drawing a spiral. On the other hand, multi-stroke gestures are the combination of more than one uni-stroke gestures and thus are relatively difficult to perform. That means they require more than one continuous complex movements of the device (mouse/Wiimote, ..., etc.,). As each Squash shot requires simple one continuous movement of racket (hand) thus each shot (gesture) automatically falls in the category of uni-stroke gestures. In our application, uni-stroke gestures are performed by pressing a Wiimote button and releasing it when the shot is finished.

We store the gestures in XML format. Normally, on average 50 to 80 points (i.e., x, y, z values of Wiimote acceleration) are stored in XML file for each gesture. The gestures performed are scale-independent. It means the larger and smaller movements for a specific type of gesture do not differ widely. For example, if to perform a service gesture, a player draws a curve which makes a total of 80° of hand movement (of clock), the same gesture will be recognized if the player's hand completes a curve in the range 55° to 65°.

6.2. Application-Based Gestures

A gesture is initiated by pressing and holding the 'A' button of the Wiimote. The gesture is terminated when user releases the 'A' button. The Squash game requires performing multiple gestures with different orientations. Thus, it is better to group them into different types. This includes:

- *Service Gesture:* In this gesture, user moves the Wiimote in the upward direction and then hits the ball (visible on the game screen) to the front wall of the Squash court. The ball hits the front wall and takes the deflection depending upon the direction of the force applied on the racket (Wiimote) as shown in Figure 4.

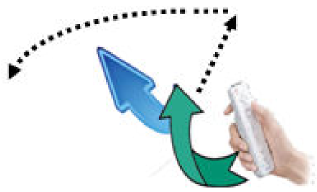

Figure 4. Service gesture using Wiimote.

- *Left and Right Gestures:* To perform the left gesture, the orientation of the Wiimote is taken as straight and bit tilted towards right. The user starts the gesture from the right side and swings the Wiimote to the left side with acceleration and force. While, to perform right gesture the user moves the Wiimote from the left side to the right side (Figure 5).

Figure 5. Left and right Wiimote Squash gestures.

- *Up and Down Gestures:* To perform up gesture, user moves the Wiimote from downward position to upward position. While, for down gesture the users moves the Wiimote from upward to downward direction. For example, the down gesture is like dropping the ball on the lower edge of the front wall of the Squash court (Figure 6).

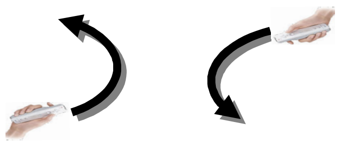

Figure 6. Up and down Wiimote Squash gestures.

6.3. Wiimote Squash Application Modes

A user performs a gesture by keeping the Wiimote in a specific orientation and moving it in a particular direction. Wiimote acceleration produces accelerometer signals (information) which is captured by our Wiimote Squash application. The application then compares the gesture with already stored gestures in order to recognize it. The application consists of two modes: registration and recognition modes.

- *Registration Mode:* In this mode gestures are recorded first. This is done by pressing the input button 'B' of Wiimote. At the start of the gesture button 'B' is pressed and at the end of gesture the button is released. The recorded 3D gesture (i.e., accelerometer value) is saved in the library as XML template.
- *Recognition Mode:* In this mode the currently performed gesture is matched with the recorded gesture. It means, when a user performs a gesture by pressing the 'A' button of the Wiimote, the acceleration values are compared with the existing set of gestures as described in next section.

6.4. Gesture Recognition

Our application recognizes the 3D uni-stroke arm gestures by comparing the accelerometer values. The first phase in the recognition is to analyze the accelerometer readings. These readings are based on the start and the end of the gesture. This phase obtains accelerometer signals and filters them (i.e., unwanted noise within waveguide). The output of this analysis phase is the noise free data which is then input to the recognition phase.

The gesture recognition phase uses two techniques DTW and WFM. The main purpose of DTW technique is to find the similarities between two sets of signals as shown in Figure 7. In our application, where the gesture data is in the form of signals, we recognize human arm gestures by using DTW. Basically, DTW compares the already registered gestures and currently played gestures by calculating the minimal distance between different acceleration points. If we move the Wiimote around (i.e., to perform a gesture), it measures the acceleration and produces variable sine waveforms (accelerometer signals in x, y and z plane) accordingly. Our application then calculates the distance between two data points (for the current gesture and the already registered gesture). This minimal distance is calculated using Euclidean distance. This technique finally recognizes the gesture by finding the close relevance with the gestures already stored (Figure 8).

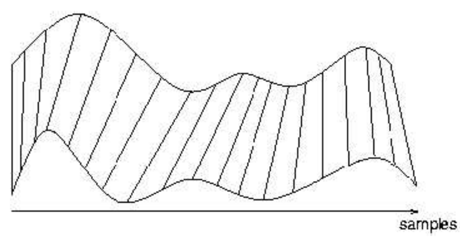

Figure 7. Comparison of two curves by using DTW technique (retrieved from [12]).

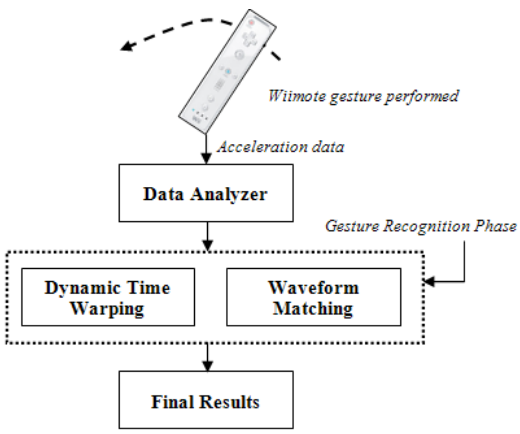

Figure 8. Wiimote gesture recognition process.

The second technique is WFM [2] where accelerometer signals as sinusoidal waves are compared. In this technique, the peaks (sinusoidal acceleration signal) created by the currently performed gesture are compared with the peaks of the already stored gesture. The values are stored in a 3×3 (low, middle, high values of peaks) grid. The values are based on the weights of 1 (when two peaks are identical), 0.25 (not identical but close together) and 0.10 (diagonal neighbors). These peaks values are matched accordingly and the gesture is recognized.

6.5. Game Display

The first graphical user interface as shown in Figure 9 contains the menu to start the game. This interactive interface provides multiple options such as instructions to play the game, starting a practice session and choosing from a set of levels.

The score and the sound functionalities provide real feelings of the interactive Squash game. The score is incremented according to the shot played. If the player hits the ball within a certain time period (threshold time: which actually depicts the level of difficulty) the score increments otherwise the score remains same and player again plays the service shot. Moreover, the sound (smash, ball hit/ bounce) produced is of the same quality as of playing a racket shot in a real Squash court.

The game has three levels: easy, medium and hard. We have defined certain rules for our game. Every shot counts 10 marks. Easy level has maximum score of 100 i.e., when a player completes the score of 100 the game ends. The threshold time given to the player to pick/play the ball is 5 seconds. Similarly for medium and hard levels, the score is 200 and 300 and the threshold time is 4 and 3 seconds respectively. The positioning of the ball and racket are displayed on the screen and their movements are controlled by the player by moving the racket (Wiimote) in hand accordingly. The second interface as shown in Figure 10 describes the gesture recognition process. The connect button is used to connect the Wiimote with application. The graph shows the active state of Wiimote. This interface also describes the results produced by DTW and WFM and also displays the final result for the current gesture performed.

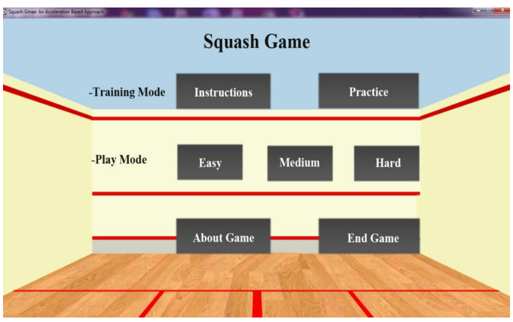

Figure 9. 3D interface of the Squash game.

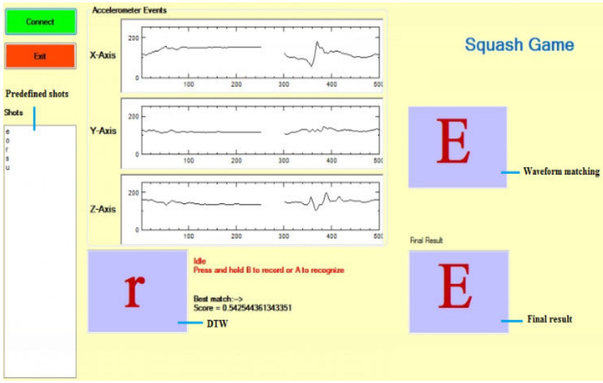

Figure 10. Gesture recognition interface.

7. Experiment and Results

We conducted an experiment to compare the efficiency of DTW and WFM based on Wiimote arm gestures. The users performed different set of gestures (shots) like service gesture, left and right gestures, etc.

- *Software/ Hardware Requirements:* We developed our application at Microsoft Windows 7 platform by using Visual Basic .NET Framework. For the development of Graphical User Interface (GUI), a 3D game engine, "Unity," was used. On hardware side, a Wiimote with a sensor bar was used to perform the menu selection and Squash gestures.
- *Participants:* Our focused participants were mostly the students of the university. Total of 15 participants (12 males and 3 females) participated in the experiment. All the participants were right handed. The summary of the design is: 15 participants x 5 gestures per participant x each gesture performed 5 times by each participant = total of 25 gestures per participant (and a grand total of 375 gestures for all participants).
- *Procedure:* The participants were not quite familiar with the use of Wiimote and playing the Squash game. Thus, a training session was held before the actual experiment. In this session the users were provided the instructions to play the Squash game. The gestures performed during this session were recorded by pressing the 'B' button of the Wiimote. This training session lasted for about 20 minutes. After training session the participants performed the actual experiment. In order to avoid the learning effects (which may cause biasness in the final results) of training session, participants were assigned the gestures in random order and in random intervals.

The results of both techniques DTW and WFM were noted separately. We compared these techniques based on the number of recognized gestures. The graph as shown in Figure 11 explains the overall results of the experiment performed. Along x-axis the graph describes the gestures performed and along y-axis the total of number of gestures recognized (out of 75) for each technique. The recognition percentage of each gesture for each technique can also be deducted from the graph. For example the recognition percentage for service gesture, for DTW technique is 76% (57/75*100) and for right, left, up and down gestures is 89%, 80%, 83%, 84% respectively. Similarly the recognition efficiency for all these gestures under WFM is 76%, 83%, 80%, 84%,79% respectively. Furthermore, the average result of DTW and WFM for all gestures is 80% and 77% respectively. If we evaluate the DTW and WFM at each gesture level as shown in Figure 11 or for all gestures, it is clear that there is not a significant difference for gesture recognition in both techniques (with minimal exception for the right and down gestures).

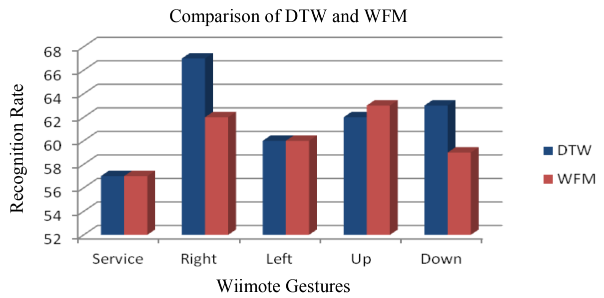

Figure 11. Percent recognition of different gestures.

An interesting observation-that these two techniques reveal-is the correlation between them. Correlation actually describes the degree of association between two variables [18] (here DTW and WFM). In our research work, the correlation value is considered by taking into account the recognition percentage for each technique. The correlation value (Microsoft Excel CORREL function) measured is +0.68. This positive correlation coefficient describes the direct proportionality between DTW and WFDM i.e., if the value of one variable (e.g., DTW) increases the value of the other variable (WFM) also increases. However, it is to be noted that this coefficient does not describe the perfect positive correlation (value of +1.00) but a value of +0.68 (inclined towards perfect) which indicates that DTW and WFM are positively correlated in, some, but not all cases [6]. Moreover, the magnitude of correlation (i.e., 0.68), which is close to the +1 rather than that of 0 or -1, indicates that there is a strong relationship between these two variables i.e., DTW and WFM (Figure 12).

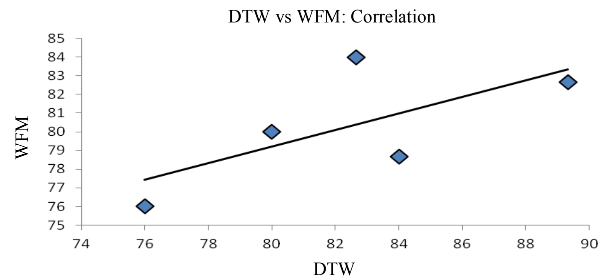

Figure 12. The correlation result between DTW and WFM based on the number of recognized gestures.

8. Discussion

The studies [10, 17, 20] already conducted remain at preliminary level and describe somewhat different direction than this work. Lee *et al.* [10] used different experimental setup than the setup of this work. Seok-Han Lee et al. used augmented reality markers and CCD cameras to capture the movements of the markers (and then finally display the virtual Squash ball on computer screen). In [10], the problems such as the jittering and the marker occlusion result in the poor or no detection of the racket and thus effects of flow of playing the game. In our technique, playing the Squash game with Wiimote is rather smooth because it correctly maps the movement of Wiimote with the movement of virtual racket and Squash ball. Furthermore, in [10] the focus was on the motion modelling and collision detection of the Squash ball, while, the current work analyzes the working of different gesture recognition techniques. Furthermore, in [10], the AR markers when moved fast (while playing a shot/gesture) are not well detected by the camera and thus cause the reduction in detection efficiency. This is because the marker image is not always and consistently visible to camera. This is not the case with the current work as the detection of the movement of Wiimote is smooth which is evident from the experimental results.

The work [17] is mainly focused on using Wiimote gestures to control different applications like browsing album photos etc. Our work, in contrast, emphasizes in the recognition of Squash gestures by using DTW and WFM techniques. To our latest knowledge, there are no proofs that the study [20] has been expanded further. Still, the existing work is not in the form of a regular published work and thus is not comparable with the current work.

This research work contributes in various aspects:

1. It confirms the soundness of existing gesture recognition techniques i.e., DTW and WFM.
2. It tests and analyzes these techniques for 3D gestures.
3. It tests these techniques in a real game environment i.e., by playing the actual physical Squash shots (though with limited set of 5 gestures only).
4. It proves the degree of association between DTW and WFM by calculating the correlation factor between them.
5. The users find it very interesting and simple to play the Squash shots using Wiimote (verification of two usability factors i.e., ease of use and satisfaction).

Our work could further be helpful for new studies especially when interacting with the virtual environment by using the physical 3D tangible objects such as Wiimote, ..., etc.

9. Conclusions and Future Work

In this paper we discussed: The uni-stroke 3D gestures drawn with the help of Wiimote, their recognition, and the comparison of DTW and WFM gesture recognition techniques. We implemented five different Squash shots and performed controlled experiment. The results indicate that there is not significant difference in the recognition of DTW and WFM for Wiimote gestures.

As future work, we would like to enhance this application especially for Kinect game console. We are hopeful that the comparison of both, Wiimote and kinect, could provide interesting results. Extending the vocabulary of gestures (other Squash shots currently not implemented) is also another aspect of consideration.

We would also like to compare the efficiency of right-handed vs left-handed users for drawing Wiimote gestures. Moreover, we also want to explore, in case of left-handed users, the change in the design of gestures. Transforming the Wiimote Squash game into multi-player game is also the area that requires further exploration.

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