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Adaptation of Avatar Upper Limb with Patient's Capabilities in Rehabilitation Serious Games

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***Abstract*—Recently, several studies have explored the feasibility of serious games for physical rehabilitation. Serious games use the element of entertainment to promote other purposes such as learning or treatment. In this article, a serious game-based method for upper extremity rehabilitation is being introduced. The method is adapted to the patient's condition and flexibility, using fuzzy logic. Unlike other games that apply adaptation to the features and scenario of the game, in our method, the adaptation is applied to the patient's avatar. The game scenario consists of a preparatory phase in which the maximum amount of joint flexibility and error relative to the desired flexibility is measured. Then, by these data, the fuzzy normality was calculated and the amount of help delivered to the patient at different stages of the game was determined. To validate the game, the accuracy of measuring the range of motion of the patient's hand was considered through different angle measurement techniques and the results were compared with the standard goniometry method. In addition, the efficiency of the method was validated by occupational therapy experts through a questionnaire.**

Keywords— Adaptation; Avatar; Serious Game; Rehabilitation; Stroke; Upper Limbs.

I. Introduction

Many people who have suffered from a stroke, face limitations in their motor performance. Physical rehabilitation is a process that can restore the flexibility and mobility of injured joints and muscles. Recent studies have shown that between 55% and 75% of patients with motor disorders have been able to regain their motor ability with the help of continuous rehabilitation and exercises. Traditional rehabilitation has several drawbacks; lack of rehabilitation centers per patient population, the limited number of professional personnel, and treatment costs. Tele-rehabilitation methods, also, have been developed as a complementary, convenient and economical way of rehabilitation.

A new method that which has shown promising results in the physical rehabilitation process is the use of serious games that can be practiced both clinically and domestically. Serious games are games that are not intended for fun or pleasure, but for purposes such as training, research, and treatment. Serious rehabilitation games provide the patient with a system that allows tracking and improving the treatment process mostly at remote places with minimum assistance of a specialist. These games are commonly used to identify, record and track human bodies, with the aid of commercial products from the entertainment industry, such as Kinect. Kinect has been evaluated for monitoring the physical rehabilitation process in several studies and has been noted as a potential device with good accuracy for data acquisition [1]. On the other hand, the intrinsic appeal of computer games can be of great help to the morale and motivation of patients as a result of the improvement in patients' conditions. So, these games alleviate significant amount of problems that traditional rehabilitation methods face [2].

Different serious rehabilitation games have been developed up to the moment [3-6]. In [3], a serious game was implemented to evaluate the impact of the game on patient standing equilibrium. The game uses a pressure mapping page that records the size and the direction of pressure. Three different scenarios were implemented and evaluated in this study. The game's adaptability system is based on leveling. In this game, changing objects and features in the game such as the size of the selected area for each object, and their pace are used to make the process easier. After testing and validating the games, all patients reported less fall overs and a uniform standing time increased. In [4], a serious a series of games was developed by using virtual reality for stroke patients suffering from upper-torso motor disorders. These games require hand-held gloves and 4 sensors to detect arm and body movements. This set includes a dynamic adaptation game that uses the patient's medical record information and his / her performance during the game. The degree of difficulty of these games is adjusted by applying changes to the objects and physical characteristics of the game. To evaluate this set of games, eight patients volunteered to practice them, with very successful results demonstrating their progress over the course of the exercise.

Despite improvements in this field, several shortcomings of the previous method are being pointed out. The game or practice must be adapted to the patient's condition - not excessively difficult or easy-. This adjustment to patient conditions in traditional rehabilitation is performed by human practitioners, but in serious games, up to the moment, it has either not been considered or has been done manually [7]. In recent years, some games have been developed that utilize simple rule-based methods to match the level of difficulty of the game which best suits the patient [8]. But patients' performance in rehabilitation exercises is not a definitive variable that can be modeled by fixed rules. Hence, rule-based models are not efficient for this regard [9].

A considerable amount of recent studies has been addressing adapting the game's difficulty to patients' conditions and abilities intelligently and automatically. Fuzzy logic is one of the most well-known adaptation methods used in such studies. Patient performance and recovery are of a vague variable that is valued in common language by qualitative terms such as excellent, good, average, or poor. Fuzzy logic is needed to model such a variable. To our knowledge, previous studies that investigated serious games for physical rehabilitation, applied adaptation to the features and scenarios of games. Such methods could face several drawbacks. For instance, if conditions and scenarios become far easier, the patient will have a minor motivation for further efforts and the other way round [10].

This study aims to directly assist the performance of the patient by manipulating its avatar through a serious game interface. In this regard, a serious game for upper extremity rehabilitation is designed and developed which adapts the in-game avatar to the patient's condition. In our method, adjusting the game difficulty level is perfumed using fuzzy logic. To implement this game, a game scenario was designed where the patient stands in front of a Kinect camera and begins the exercise session phase. Using the Kinect data, fuzzy logic is used to estimate how and how much help the patient by altering its avatar. It is expected that the patient uses positive feedback from the increase in success rate when performing the task required in the game and increase the motivation levels to continue performing the exercises. The game designed in this study was evaluated by occupational therapy experts and also evaluated for its technical accuracy.

II. Proposed Method

A. Overview

The outline of the method is shown in Fig. 1-a. In our approach, the patient stands in front of the Kinect camera. The data from his body joints are extracted and sent to the game engine. The game engine detects how well the patient has been performing the exercise. The measure of success is the patient's Range of Motion (ROM). Based on the success of the patient, the amount of help that the system needs to deliver to the patient is calculated. Each component of the proposed method is described as followed.

B. Game Mechanism

The routine of the game is that the patient stands or sits in front of Kinect and runs the game. Kinect finds the main joints of the body. In each frame, typically 3p fps with Kinect, the

(a) (b)

Fig. 1. (a) patient standing in front of the Kinect camera. (b) Game scenario.

global coordination of the joints is stored. The initial frames from the starting point of the game, global joint coordinates are assigned the avatar joints. The coordinates of these joints are the same as those of the patient's body, and no changes have been made to them. T is considered 200 frames in this study. Until this point of the game, the avatar shows the same patient movements. For abduction and adduction exercises, only the angle between the arm and the body perpendicular is needed. In the abduction exercise, the hand and the arm are moving away transversely from the body, and in the adduction exercise the opposite movement happens and the hand and the arm approach the body to reach the side of the body. It is possible to calculate this angle by various methods. Throughout the game, this angle is calculated and recorded. The coin then appears within a specified area accessible to the patient's hand. To do this, the patient's hand’s length is calculated and the coin appears at different angles from the body. At this point, the patient is asked to reach his hand as close to the coin as possible. At this point, the angle of error of the hand that is opened is calculated against the desired angle, which is the location of the coin. To do this, we store the patient's hand angle in all frames and, ultimately, consider the maximum angle as the patient's potential ability to open the hand. Then subtract the angle of the coin from the patient's hand angle; the final number is the error of the patient's hand to reach the desired angle. In frames of 200 to 400, the same operation is repeated for the left hand and the patient's left-hand error is obtained. In frames 400 to 410, the fuzzy function is implemented. First, for consistency of the avatar display in the game, at the beginning of this section, the placements of Kinect joints are applied to the avatar joints without any manipulation.

The fuzzy function input is the patient hands’ error, calculated in the previous sections. The fuzzy function, based on the amount of patient hand errors, determines the value of fuzzy variable between 0 and 1. This fuzzy variable determines how many steps of help the patient receives to achieve the goal and score points. The process is to convert the fuzzy variable into a number between 0 and 10. We divide the error of the patient's hand by this number. The obtained number is the angle that helps the patient at each stage to reach the coin. As the patient reaches the target, the help stops and the patient will be able to gain points from that point on. This step is performed for both right and left hands and the fuzzy variable and help will be calculated separately. Then the main stages of the game start from here. In separate sections, divided by the number of frames, coins appear for the patient's right and left hands and the patient has a limited time to touch the coins and gain points. From the first step, the patient is helped to achieve the goal. For this purpose, the coordinates of the joints received from Kinect get changed (before being given to the Avatar joints). These changes rotate the patient's hand joints to the amount of help provided. From now on, the abduction and adduction exercises are repeated for the patient, and the patient is engaged in scoring, playing and entertainment system.

C. Kinect

We used the Kinect camera to obtain patient’s joint coordinates. Kinect is a camera supplied by Microsoft. The camera is a cost-efficient smart device for voice and motion recognition. Kinect users will be able to interact with the console using voice commands and physical movements. The machine vision algorithms provided by Microsoft enables joints localization. In brief, the Kinect camera captures the depth image of the person standing before the camera and then the depth difference features are extracted and given to a random decision forest. The decision forest classifies each pixel in to a body part. From the body part map, the coordinates of each joint are extracted via the mean shift algorithm. Kinect V2 used in this study provides the location of 25 body joints that you can see in fig. 2-b.

D. Inverse Kinematics

In order to articulate the human skeleton obtained from the Kinect camera, Inverse kinematics were applied. The joints of the body rotate alongside each other with fixed distances from each other. Inverse kinematics (IK) is the mathematical process of recovering the motions of objects that move relative to each other. Using kinematic equations, we can calculate various joint parameters that determine the final position of desired joints. Inverse kinematics uses the relation between the joints to automatically implement the above-mentioned process. Mentioned relations shown in fig. 2-a. Furthermore, in the IK process, joints use a parent and child relationship among the joints. Hence, parent’s rotations are also directly applied to the child node. This makes articulating the complicated human skeleton system easier. For example, the rotation of the shoulder joint should be applied to all its subgroups (i.e., elbow, wrist, and fingers) as these joints rotate when the shoulder joint rotates.

In this paper, apart from the shoulder joints, an additional rotation is applied to the elbow joint. Similarly, we should apply this rotation to the subgroups of the elbow, wrist, palm, and fingers. To do this, we define the position of these joints relative to each other. The wrist joint is defined along with the elbow, the palm to the wrist, and the finger to the palm. For implementation, upon acquiring the location coordinates of the joints, a temporary variable for each of these joints in the subset was defined, keeping the difference of their coordinates with the parent joint as equation (1).

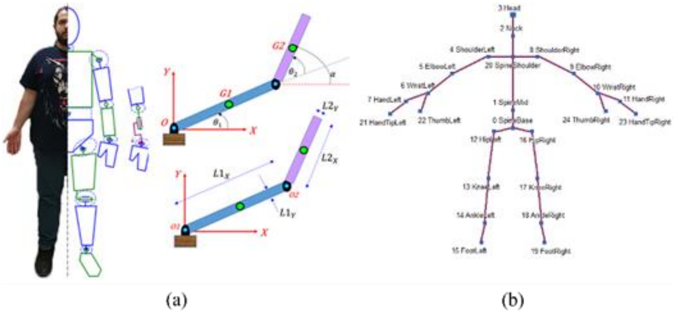

Fig. 2. (a) Inverse kinematics relations on the human body. (b) Skeleton joints obtained from the Kinect camera.

$$\begin{aligned} R\_wristRel.x &= Wrist.x - Elbow.x \\ R\_wristRel.y &= Wrist.y - Elbow.y \\ R\_wristRel.z &= Wrist.z - Elbow.z \end{aligned} \quad (1)$$

After applying the rotations on the elbow joint, we apply the same rotations to the relative joints and then add with the parent joint location as equation (2).

$$\begin{bmatrix} Wrist' \cdot x \\ Wrist' \cdot y \\ Wrist' \cdot z \end{bmatrix} = \begin{bmatrix} Elbow \cdot x \\ Elbow \cdot y \\ Elbow \cdot x \end{bmatrix} + \begin{bmatrix} R_{wristRel} \cdot x * \cos\theta + R_{wristRel} \cdot y * \sin\theta \\ R_{wristRel} \cdot y * \cos\theta - R_{wristRel} \cdot x * \sin\theta \\ R_{wristRel} \cdot z \end{bmatrix} \quad (2)$$

This will inherit all of the parent joints in addition to their independent movements and rotations.

E. Help Mechanism

In this game, the avatar of the patient is articulated so that the limitations of the patient are (to some extents) improved in the visual feedback process. That is when the avatar’s ROM is more than the actual ROM covered by the patient. To be more precise, to reach a game goal, the patient's hand angle needs to reach a certain angle, which is adjustable before each round. To reach the goal, the patient's hand angle needs to be increased to get closer to the goal. In linear algebra, the rotation matrix is used to execute rotation in Euclidean space. The three main rotation matrices rotate the vectors at an angle θ around one of the X, Y, or Z axes using the right-hand rule. This method was chosen because of its simplicity and efficient speed. The goal was to add a certain angle to the avatar's hand angle relative to the vertical axis of the body at each stage. The shoulder joint was considered the relative center. Universal Coordinates of the elbow joint have been subtracted from the universal coordinates of the shoulder to obtain the relative coordinates of the new origin, shoulder as equation (3).

$$\begin{aligned} R\_elbowRel.x &= Elbow.x - Shoulder.x \\ R\_elbowRel.y &= Elbow.y - Shoulder.y \\ R\_elbowRel.z &= Elbow.z - Shoulder.z \end{aligned} \quad (3)$$

In the abduction exercise, we have to multiply the new coordinates of the elbow in the rotation matrix around the Z-axis with the optimal θ as shown in equation (4).

$$[\text{R\_ellbowRel} \cdot \text{x} \quad \text{R\_ellbowRel} \cdot \text{y} \quad \text{R\_ellbowRel} \cdot \text{z}] \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (4)$$

On equation (5) we add the result with the universal coordinates of the shoulder joint to obtain the rotating joint.

$$\begin{bmatrix} \text{Elbow}' \cdot \text{x} \\ \text{Elbow}' \cdot \text{y} \\ \text{Elbow}' \cdot \text{z} \end{bmatrix} = \begin{bmatrix} \text{Shoulder} \cdot \text{x} \\ \text{Shoulder} \cdot \text{y} \\ \text{Shoulder} \cdot \text{x} \end{bmatrix} + \begin{bmatrix} \text{R\_ellbowRel} \cdot \text{x} * \cos\theta + \text{R\_ellbowRel} \cdot \text{y} * \sin\theta \\ \text{R\_ellbowRel} \cdot \text{y} * \cos\theta - \text{R\_ellbowRel} \cdot \text{x} * \sin\theta \\ \text{R\_ellbowRel} \cdot \text{z} \end{bmatrix} \quad (5)$$

F. ROM

ROM represents a range in which the joint or bone can move without intervention. In order to measure the desired angles, a local coordinate system must be defined for each joint. In spherical coordinates, the location of each point in space is determined by one size and two angles relative to the two axes. Therefore, hand angles should be measured in two axes. The shoulder joint is considered the center of the coordinates and the angles of the hand should be calculated relative to the negative part of the Y-axis and the positive part of the X-axis. To do this, the shoulder-arm vector has to be imaged on the XY and XZ pages, and then the angles between these images and the Y and X axes get calculated. The axes of the shoulder joint spherical coordinate system are defined using the definition of the vertical and horizontal orientation of the body. The connecting vector of the central hip and central shoulder joints is considered as the vertical axis or the Y-axis. The horizontal axis (or X) is also obtained by connecting the left and right shoulder joints. The third axis is obtained from the external multiplication of these two vectors. First, the size of both vectors of the image is obtained. The image vectors are then multiplied by the Y and X axes. Finally, using equation (6) and (7), two angles are calculated.

$$\theta = \cos^{-1}\left(\frac{\text{Interior\_Product\_xy}}{\text{abs\_Ellbow}_{\text{im\_xy}} * \text{abs\_Y}}\right) \quad (6)$$

$$\varphi = \cos^{-1}\left(\frac{\text{Interior\_Product\_xz}}{\text{abs\_Ellbow}_{\text{im\_xy}} * \text{abs\_X}}\right) \quad (7)$$

G. Fuzzy Unit

Using fuzzy sets, human knowledge can be applied to problems whose formulation is based on inaccurate concepts. The game has to be judge whether the patient's performance is good or bad. The good or bad range of the patient's hand movement, the high and low error of the hand, and the patient's progress compared to the previous stage, are all inaccurate

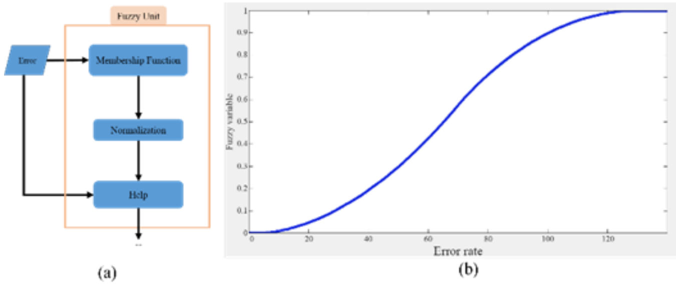

Fig. 3. (a) The fuzzy unit flowchart. (b) S-shape member function.

concepts and factors that fuzzy logic must be used to formulate and make decisions based on them. To this point in development, only one fuzzy membership function has been applied. Because decision-making about patient performance is made using the degree of error of the patient's hand towards the stated goal. So there was no need to define fuzzy rules to deduce the various variables. The fuzzy unit is designed so that patient with poorer performance receives more help in each step to gain more points. The flowchart of the fuzzy unit used in the game is shown in the fig. 3-a. The membership function used in this section determines how badly the hand misses the target. The greater the error gets; the function must return a larger number. Sigma and S-shaped functions are ready-made functions that have the desired feature. The sigma function is a linear function. According to the scenario of the game, the goal was to help the patient with fewer errors, to gain more points. Hence, the S-shaped membership function is more appropriate for fuzzy hand error. As you can see in the fig. 3 -b, the S-shaped function has a turning point at which the concavity changes. For the error rate from zero to the inflection point, it underestimates the badness of the error, but from the inflection point onwards the trend is reversed. The greater the error, the larger the number returned. On the other hand, due to the type of curvature, it lessens the hand error of patients who have fewer errors, in fact, it helps them more. Likewise, it evaluates the error of patients who have a high error rate, more than usual. This function, F, has two variables "a" and "c". "a" denotes the endpoint of a value of zero, where "c" specifies the beginning of a value of one. The turning point of this function is (a+c) / 2, represented by "b". The variable "c" is the amount of error from which the degree is then considered inacceptable. This grade should be determined by a specialist for each patient separately. The ability to set this variable for each game round is embedded. The formula for the S-function is given in equation (8).

$$F = \begin{cases} 0. & z < a \\ 2\left(\frac{E}{130}\right)^2. & a \le z \le b \\ 1 - 2\left(\frac{E-130}{130}\right)^2. & b \le z < c \\ 1. & z > c \end{cases} \quad (8)$$

III. Results

In this section, we review the results of the proposed method. Initially, the results of a questionnaire answered by rehabilitation experts are presented. The accuracy of the game's performance in helping patients is then demonstrated. Finally, the measurement of range of motion by the game is tested by different methods implemented and validated by the angle measured by the goniometer.

A. Questionnaire

A questionnaire was designed to evaluate the proposed method and to be approved by rehabilitation experts. The questionnaire was answered by 15 physiotherapists and occupational therapists from different rehabilitation centers in Tehran and Isfahan, Iran. The questionnaire contained questions on different aspects of the game, and the results of each aspect were pooled together, reflecting the opinion of experts about that aspect of the game. The results of this survey are depicted in fig. 4. 5 aspects of serious games for rehabilitation were scored. High indicates the positive impact of serious games in favor of physical rehabilitation. At first, the possibility of home rehabilitation, along with practicing in rehabilitation centers, was asked and experts' opinions reflected positive outcomes for such practices. Combining rehabilitation exercises with video games was also questioned. Most specialists agreed with the intrinsic attractiveness of computer games and rehabilitation exercises. They also found the effect of this compound on the patient's motivation and performance, to be very high. In another section, we asked about the importance and difficulty of accurately measuring patients' range of motions. The importance of this work has been of great importance to most experts, but its difficulty has been more moderate. The next part of the questions was about the importance and role of the mental readiness of patients. To find out whether it is better to induce patients to feel better or to force them into physical training and to inform them of their true condition, two questions were proposed; their tendency was toward the importance of greater mental readiness and a sense of progress. They also believe that mental and psychological fitness and the sense of the progress in a patient has a great impact on their motivation, performance, and recovery. The latter part of the questionnaire asked about how the adjustment of the difficulty level of the game with the patient's condition and abilities affects their motivation and performance. Experts have greatly appreciated the impact of this adjustment on the degree of difficulty.

B. Evaluating the performance of the game in helping patients

In this section, we review the results of the game performance and demonstrate the accuracy of the proposed method in helping patients with different range of motion. To do this, we simulated the performance of patients with a range of motions of 20, 30, 45 and 90 degrees and recorded the results of the game. The results of this evaluation are shown in Table1.

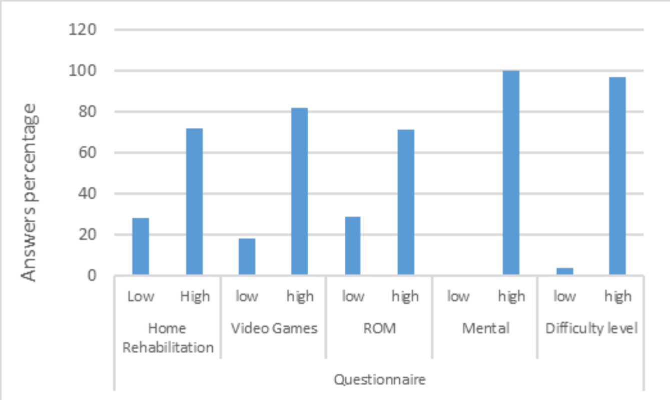

Fig. 4. Questionnaire results chart by fields.

The maximum angle of the hand in the first column is the maximum angle that the patient was able to reach in the preliminary phase. The second column indicates the error of the hand relative to the coin location, which is also calculated in the first stage of the game. This variable is used as an input for the fuzzy unit and it is used to calculate the fuzzy variable and the patient's help at each stage. The fuzzy variable and the degree of the patient's help angle at each stage are shown in columns 3 and 4. Also, the last stage in which the patient's help is stopped - which is specified at the end of a game round - is in the last column. These data show that if a patient has a ROM of 20 degrees, and the coin is positioned at 130 degrees relative to the patient's body, the fuzzy variable becomes high and the patient receives less help at each step. This makes the patient reach the coin later and collect fewer points. It is clear in the table that the patient can reach the coin in step 7. This number was also 6, 5 and 1 for the ROM of about 30, 45 and 90, respectively.

C. Evaluation of Angle Measurement Methods

The purpose of this section is to evaluate different angle measurement methods and select the best method for rehabilitation games. To do this evaluation, three different angle calculation methods have been implemented. The methods are Spherical Coordinate system (SC), Right Triangle Trigonometry (RTT) and Plane Relative Angle (PRA). In this evaluation, a healthy participant volunteered. This participant was asked to be in a stable position to measure his range of motion using a goniometer. After recording the goniometry result, the shoulder angle was measured using three implemented methods and then compared with the goniometric results. The error of measurement using different techniques mentioned above is shown in fig. 5. The results indicate that the spherical coordinate

TABLE I. Measured angles and calculated variables with different ranges of motion.

Max Angle	Error	Fuzzy Variable	Help	Stopped help stage
19	107	8.35	12.8	7
28	92	7.00	13.1	6
43	83	6.00	13.8	5
78	50	2.22	22.5	1

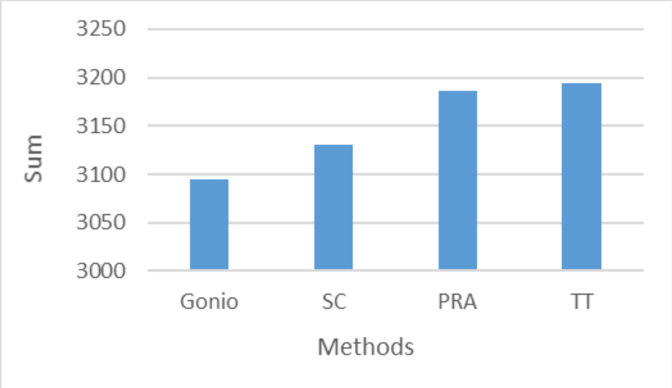

Fig. 5. Comparison of the sum of calculated angles using Gonio and 3 methods; Spherical Coordinate (SC), Plane Relative Angle (PRA), and Right Triangle Trigonometry (TT).

method is superior to the other methods tested in this research. In this evaluation, 40 different ROMs were measured using goniometry and used to evaluate our method for ROM measurement. For Kinect angle recording, only values that were at least ten consecutive frames of the same value were considered acceptable. Fig. 5 shows the sum of the angles calculated using Goniometry and SC, PRA and TT methods. It is clear that the spherical coordinate method has the least difference with the goniometer reference method.

IV. Conclusion

In this study, a new strategy in serious games was made by how the game was adapted to patients' conditions. Instead of adapting the parameters and specifications of the game environment, this adaptation would apply to the patient avatar. From the point of view of rehabilitation experts, all the features applied in the game can be helpful for patients. The game also has the ability to accurately record all the angles of the patient's upper limbs. Finally, the game itself was tested with different ranges of motion and its results were evaluated. The results were as expected, and the game worked well in the different range of motions.

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