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Elbow Flexion and Extension Rehabilitation Exercise System Using Marker-less Kinect-based Method

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ABSTRACT

This paper presents the elbow flexion and extension rehabilitation exercise system using marker-less Kinect-based method. The proposed exercise system is developed for the upper limb rehabilitation application that utilizes a low cost depth sensor. In this study, the Kinect skeleton tracking method is used to detect and track the joints of upper limb and then measure the angle of the elbow joint. The users perform the exercise in front of the Kinect sensor and the computer monitor. At the same time, they can see the results that displayed on the screen in real-time. The measurement of elbow joint angles are recorded automatically and has been compared to the reference values for the analysis and validation. These reference values are obtained from the normal range of motion (ROM) of the elbow. The results show the average flexion angle of the elbow joint that achieved by the normal user is 139.1° for the right hand and 139.2° for the left hand. Meanwhile, the average extension angle is 1.72° for the right hand and 2.0° for the left. These measurements are almost similar to the standard range of motion (ROM) reference values. The skeleton tracking works well and able to follow the movement of the upper arm and forearm in real-time.

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1. INTRODUCTION

The upper-limb motion is very important in the human daily activities, such as lifting stuffs, playing sports, doing house chores, using computer and also taking care of themselves (e.g. eating, drinking, brushing teeth and washing face). However, it is sometimes difficult for the elderly that normally has physical weakness, disabled people and also injured individuals to perform daily activities that involve their upper limb [1]. Normally, disabled people and injured patients experience some limitations in fine motor control, strength and range of motion [2]. The elbow flexion and extension is one of the upper limb basic movements and sometimes, the rehabilitation exercise is necessary for this upper limb parts. The exercise can be performed alone or the patient and the physiotherapist are in a one-to-one interaction.

In the rehabilitation program, the goal in this process is to help the patients achieve a normal standard range of motion (ROM) for their upper limb and also to strengthen their muscles [3]. The ROM exercises reduce the joint stiffness and will prevent the freezing of the joints as the disease progress and move less often [4]. There are three types of ROM in rehabilitation, which are passive, active assistive, and active. The passive ROM is a method that needs the use of equipment or helps from the physiotherapist to move the joint through the ROM without effort from the patient. The active assistive ROM is a method where the patient uses the muscles surrounding the joint to perform the exercise, but need assistance from the physiotherapist or equipment. Meanwhile the active ROM exercise is a method that the patient is able to move each joint through its full range of motion without any assistance [5]. The elbow flexion and extension exercise is one of the ROM exercises that help to increase the mobility of the elbow joint. Figure 1 shows the illustration of the elbow flexion and extension movement. In this study, the proposed exercise system is developed for the elbow flexion and extension movement using the marker-less based method. The user or patient performs the exercise without any markers attached to the upper limb, but the motion of the upper arm and forearm is captured by using Kinect sensor. The user also can obtain the results in real-time and the results are recorded automatically. The recorded results can be used in the future for the evaluation and analysis. These features make the in-home rehabilitation is possible for the patient.

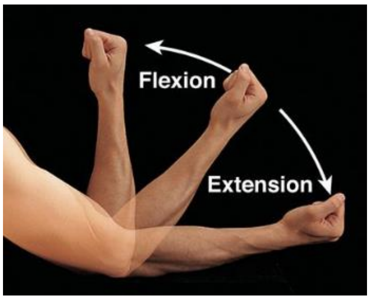
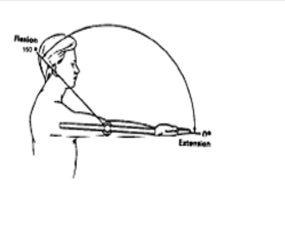


Figure 1. Example of the elbow flexion and extension movement

2. RESEARCH BACKGROUND

Nowadays, the study of physical therapy and rehabilitation have been explored actively. There are many types of physical therapy systems or applications that have been invented, such as virtual reality and motion-based games. These applications received many attentions and interests from the researchers, and at the same time these applications motivate the patient to move their body parts more often. These systems also provide the user with a sense of achievement via the interactive user interface.

In general, the traditional or conventional rehabilitation method of the upper limb is conducted and monitored by the physiotherapist at the hospital. For the specific elbow joint exercise, normally the physiotherapist observes the exercise session and measures the elbow joint angle for each movement. All measurements are recorded in the form as shown in Figure 2 [6]. The tool used for the measurement of the range of motion is called goniometer as shown in Figure 3. This tool has to attach to the related joint during the measurement [7],[8]. The disadvantage of this measurement method is, it cannot be done by the patient. The patient may need someone to hold the goniometer during the range of motion measurement. Therefore, the automatic range of motion measurement is needed to smooth the rehabilitation exercise process. Thus, the patient is able to perform the exercise repetitively without any interruption.



Left	
Extension 0°	Flexion 150°
Degrees	Degrees
Right	
Extension 0°	Flexion 150°
Degrees	Degrees

Figure 2. Example of conventional evaluation form for elbow flexion and extension exercise [6]

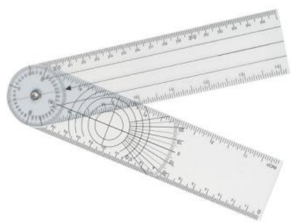


Figure 3. Goniometer

The researcher, Sardelli et. al [9] studied the functional tasks in range of motion of the elbow. In their study, the activity included in the experiment was accessing a computer using mouse and keyboard. To monitor the movement of the hand during the experiment, a few markers were placed on the subject's hand. The camera captured and recorded the movement based on the reflection from the markers. This research had achieved acceptable results. However, this approach faced some drawbacks such as the user needed to remove the clothes and attached the markers on hand, the markers wobbled and also it took time to set up.

Other researchers, Megan et. al [10] developed an application for the smart phone that measured the range of motion of the joints. They produced measurement comparison of the smart phone camera with the conventional goniometer. The proposed method needed the user to take an image of an elbow flexion and extension profile, and then they measured the elbow joint angle from the image. However, this system was not functioning in real-time, and someone had to help the user to capture their elbow image profile.

There were some limitations in the previous proposed methods that should be considered when developing the elbow flexion and extension exercise system. It can be concluded that the marker-based method has some drawbacks as described previously. Therefore, the marker-less based method that detects and tracks the shoulder, upper arm, elbow and forearm is chosen for this research. The input device that is used in this research is Kinect sensor, since it gives a better solution for the marker-less based motion tracking methods, compared to marker based system. To make the system is easy to be accessed, it can be seen that the rehabilitation exercise system for the elbow can be developed by using a depth image from the Kinect and using the sekeleton tracking algorithm.

3. RESEARCH METHODOLOGY

In this section, the proposed method is explained in several sub-chapters. First, the experimental setup will be explained in detail, followed by upper limb skeleton detection and tracking algorithm, the measurement of elbow joint angle, user interface development and finally, the experiment.

3.1. Experimental Setup

Kinect sensor is a peripheral device that commonly used with the Xbox 360 game console. The Kinect consists of the RGB camera and infrared (IR) projector combined with the IR camera, which is a monochrome complementary metal-oxide semiconductor (CMOS) sensor. Kinect produces a depth image, and it can be elaborated as a 3D data. The RGB camera and IR sensor have a resolution of 640 x 480 pixels at 30 Hz. Kinect sensor was chosen in this work because of its reliability as a motion sensing device and it is reliable to measure a distance. This IR sensor is able to capture video data in three dimensional under acceptable low light conditions [11]. This is the marker-less tracking methods that popular in recent year [12]. This project only required the function of the IR sensor for capturing the depth data, while the RGB stream was used to display the output for the user reference. Kinect sensor was able to work with the computer by using Kinect SDK from Microsoft or open source library OpenNI2 [13]. The platform of the software runs in the Visual Studio 2012 with the operating system Windows 8, 64 bit Core i5. Figure 4 shows the experimental setup of the proposed exercise system. The suitable distance range between the Kinect sensor and the user was 150 to 200 cm. The depth image resolution was 640 x 480 pixels with 30 frames per second (fps).

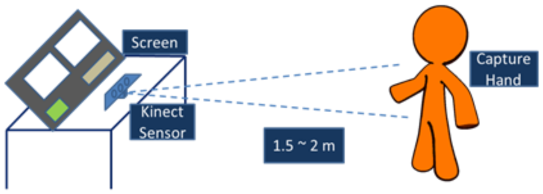


Figure 4. Experimental setup

3.2. Upper Limb Skeleton Detection and Tracking

Skeleton detection and tracking of the upper limb was the first process that had to be done after the depth image acquisition by the Kinect. In this study, the Kinect skeleton tracking method was used to get the location of the full body joints. The skeleton tracking algorithm was based on the NiTE middleware, and it came with automatic calibration of the skeleton joint. This skeleton tracking algorithm was a complex algorithm and was proposed by J. Shotton et. al [14]. This algorithm consisted of body part classification that used hundreds of thousands of training images. Then, the body joints were hypothesized by finding a global centroid of probability mass (local modes of density) through the mean shift algorithm. The final step was to map hypothesized joints to the skeletal joints and fit a skeleton by considering both temporal continuity and prior knowledge from the skeletal train data. The whole pipeline of Kinect skeleton tracking is shown in Figure 5.

In the skeleton tracking, the body parts were represented by 15 points of the joint. The skeleton consisted of two joints at foot, knee, hip, shoulder, elbow and hand. While, only one joint was located at the neck, head and at the center of the torso as shown in Figure 6. Each joint was represented by its 3D coordinate (x, y, z) as shown in Figure 7.

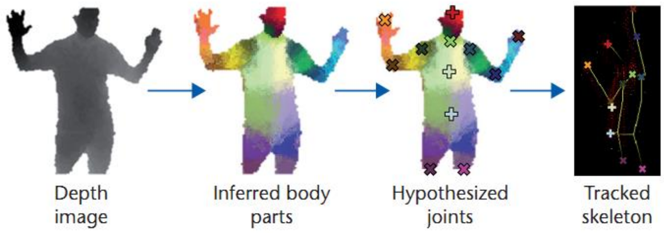


Figure 5. The pipeline of Kinect skeleton tracking [14]

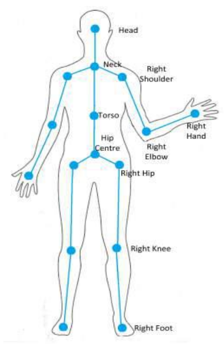


Figure 6. A human body parts are represented by 16 joints [14]

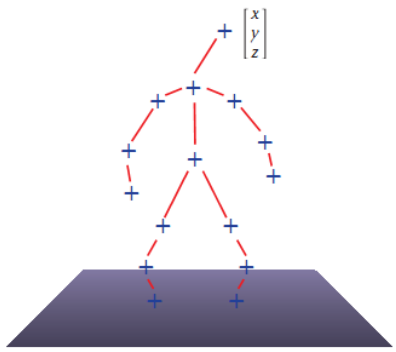


Figure 7. Each joint is represented by its 3D coordinate [14]

In this work, the joints of the skeleton were modified by selecting only 8 points joint for the whole upper limb. These points were located at two joints of the hand, elbow, shoulder, and one joint at the neck and head. Once the eight joints were detected, two points at the neck and elbow were set as the reference point in this method. These reference points were used to calculate the distance between the elbow and Kinect. After the selection of joint points for the upper limb, the skeleton was drawn and displayed in the depth image. Figure 8 shows the skeleton of the upper limb and its 8 points of the joints.

3.3. The Calculation of Elbow Joint Angle

In this method, the points that obtained from the skeleton tracking were used to calculate the angle of the elbow joint to determine whether movement can be categorized as flexion or extension. To calculate the angle, the cross product formula was used as a multiplication method of the two vectors. The cross product was defined only for three-dimensional vectors. In this study, the first vector was *V1*, which was a line from the joint of the shoulder to the elbow. While the second vector *V2* was a line from the joint of the elbow to the wrist. The angle that had to be calculated was between the vector *V1* and vector *V2* as shown in Figure 9. The equation of the cross product is shown in Equation 1, where *V1* × *V2* was equal to the Equation 2. Hence, vector *V3* will be produced from the Equation 3, 4 and 5. Finally, the value of the angle θ can be obtained by using the *arcsin( )* function, which was the inverse of the sine function.

The distance between the skeleton and Kinect was affected by the height of the user and the distance from the Kinect sensor. This was because of the relative distance that was not a scale invariant feature. The value of the elbow joint angle also depended on the accuracy of the skeleton detection. Once the skeleton had performed, the skeleton joint can be located.

$$V_1 \times V_2 = |V_1||V_2|\sin(\theta)\, n \quad (1)$$

$$V_1 \times V_2 = V_3 = (V_{3x}, V_{3y}, V_{3z}) \quad (2)$$

$$V_{3x} = (V_{1y} \times V_{2z}) - (V_{1z} \times V_{2y}) \quad (3)$$

$$V_{3y} = (V_{1z} \times V_{2x}) - (V_{1x} \times V_{2z}) \quad (4)$$

$$V_{3z} = (V_{1x} \times V_{2y}) - (V_{1y} \times V_{2x}) \quad (5)$$

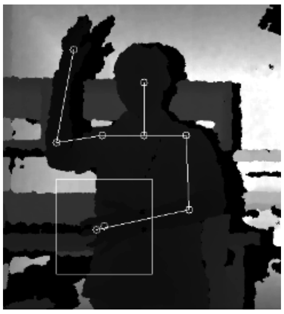


Figure 8. Skeleton of the upper limb with 8 joints

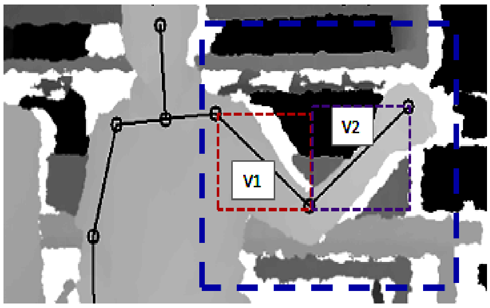


Figure 9. Multiplication of two vectors and angle calculation

3.4. User Interface Development

In this part, a user interface was developed by using the OpenCV library to guide the user performed the elbow flexion and extension movements. The user can see some instructions and outputs from the movement on the display. Figure 10 shows the template of the user interface that was drawn using OpenCV library. Refer to Figure 10, the two reference lines are used to guide the user to place their hand and to set the limit of the hand movement. A horizontal reference lines are used to set the limit angle as 0°, and the limit angle of the slanting line is 150°. The red circle is the location of the elbow joint and it is set as the initial reference point that is used in the entire experiment. On the upper side of the display template is the instruction for the user and also the output of the distance between the user and Kinect sensor. The user needs to make sure the distance always in range, between 150 cm to 200 cm. The second line of the displayed text is used to inform the user about the measurement of distance, and it will be updated in real-time. The elbow joint angle is displayed at the bottom of the display template.

The data collection was carried out by comma-separated value (CSV) format type data. The evaluation table will be generated automatically after the user completed their exercise. Figure 11 shows the evaluation table produced from the exercise system. The angle of the elbow will be recorded automatically in this evaluation table.

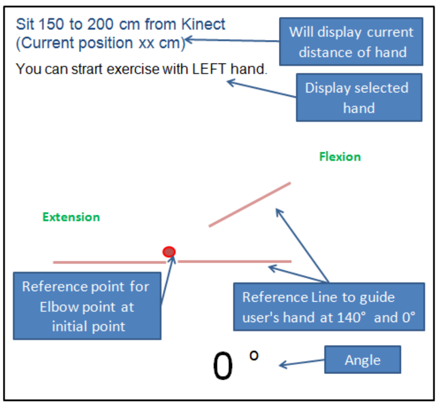


Figure 10. Template of the user interface

Evaluation Table		
Name:		
Reference No:		
Name of Exercise:	Elbow Extension & Flexion	
Hand Position:	Right / Left	
Date and Time:		
No.	Extension (0°)	Flexion (140°)

Figure 11. Generated evaluation table and data

3.5. Experiment

The experiment was conducted with five subjects; three males and two females with age between 25 to 30 years old. Each subject had to perform five times of flexion and extension movements. The duration for each subject performed the flexion and extension movements were two minutes. Before the experiment was started, a few instructions regarding to the flexion and extension movements were given to the subject. The subject had to select whether should start with the right or left hand. This was because of the template for each hand was different. The initial position of the elbow point was different from the right and left hand. The subject selected the template by inserting "Left" or "Right" through the keyboard.

To perform the flexion and extension movement, the arm reached out to the side with the elbow straight and the shoulder should be at 45°. Hold for a few seconds, then bent the arm and brought the hand toward the shoulder. Hold for a few seconds and slowly brought the arm to the starting position. Figure 12 illustrates an example of the hand in flexion and extension positions and also the reference points. In this template, there were two reference joint points, one point was on the shoulder and another point was at hand (green circle with red outline) that was used to measure the angle of the elbow. Meanwhile, the blue circle with the red outline is the reference point of the elbow and it was set as the initial point for this system. The distance from each joint point was measured to make sure the calculated angle in the computer was same with the manual measurement in real-world. The maximum distance for each joint point was approximate 10 cm and the program alerted the user if the point was exceeded the range.

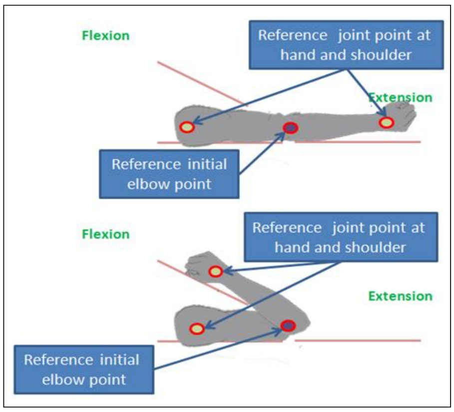


Figure 12. Illustration of elbow flexion and extension exercises

Figure 13. Example of elbow flexion exercise in real-time

4. RESULTS AND DISCUSSION

This section presents the results of the elbow extension and flexion movement. Figure 14 shows the graph of the elbow joint angle measured for the flexion and extension movement. Below the graph are examples of depth image for each movement. The duration of these movements is about 100 ms. As a result, it shows that the angle of the elbow of the flexion movement is about 140° while the angle of elbow for extension is almost at 0°. Based on the reference degree acquired from ROM standard [15], a normal person can perform the flexion movement by achieving 140° ± 10° of angle, and 0° ± 10° of angle of extension movement.

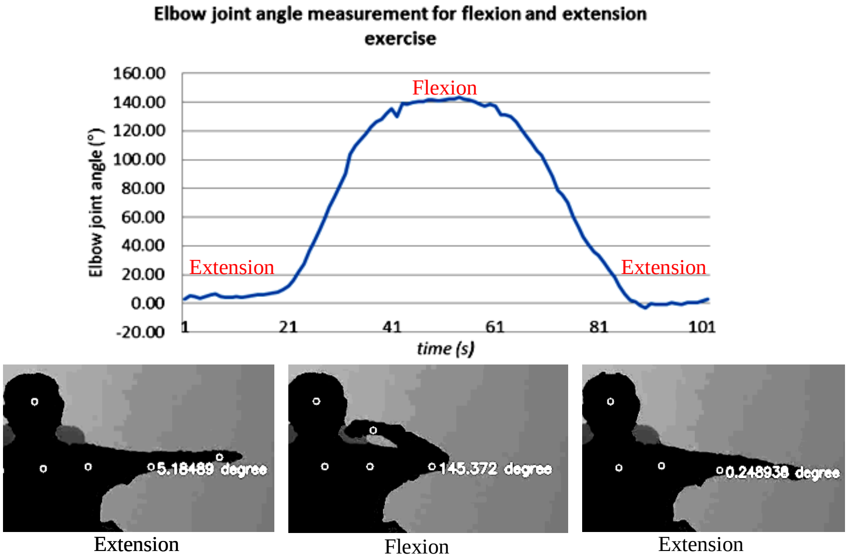


Figure 14. Graph of elbow joint angle measurement for flexion and extension movement and depth images of each movement

Table 1 shows the results of elbow extension and flexion exercises for five normal subjects. The exercises were performed by their right and left hand. The angles of elbow of each movement were recorded, together with the time taken in performing this experiment. As results, the average angle of flexion that performed by five users was 139.1° for right hand and 139.2° for left hand. The average angle of extension of the right hand was 1.7° and 2. 0° for left hand. From the results, it can be concluded that the proposed method which consisted of skeleton tracking and angle calculation were successful to detect each joint correctly and the angle of the elbow also calculated correctly. The results were almost similar to the main reference from the ROM standard.

During the experiment, the user had to make the position of the shoulder; elbow and wrist were proportional with the Kinect. It means that, all positions must have the same depth (or distance) to the Kinect. If these positions were not proportional with Kinect, the calculated angle values will be different. This was because of the different depths that affected to the vector value, the calculation of cross product and angle. If the hand position was not proportional to the Kinect sensor, the recorded measurement and the real-world measurement were different because of the angle calculation was in a different view.

Table 1. The results of the measurement of elbow joint angle for the flexion and extension movement

	Angle (°) of flexion movement			Angle (°) of extension movement		
Subject	Right hand	Left hand	Standard ROM	Right hand	Left hand	Standard ROM
Subject 1	135.0	140.8	140° ± 10°	2.2	1.8	0° ± 10°
Subject 2	145.2	139.2		0.8	2.6	
Subject 3	134.8	137.4		2.2	2.2	
Subject 4	138.4	141.0		2.4	1.4	
Subject 5	142.0	137.8		1.0	2.0	
Average	139.1	139.2		1.7	2.0	

5. CONCLUSION

This paper proposed the elbow flexion and extension exercise system to increase the mobility of the hand. This exercise is a part of the upper limb exercise system that is being developed. The exercise is well performed with the use of Kinect sensor and skeleton tracking algorithm. The proposed method can perform fast tracking without the use of markers that attached to the upper limb parts and this method is able to perform in real-time. The experimental results show the normal subjects are able to complete the exercise and the measurement of joint angle is almost similar to the standard range of motion (ROM) reference values. The results of the exercise can be used as a training data for the analysis in the future. However, it still needs further improvement with more data collection and other types of hand exercise can be added to make a complete upper limb rehabilitation system.

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