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Development of Visual-based Rehabilitation Using Sensors for Stroke Patient

Choon Chen Lim*, Kok Swee Sim, and Chean Khim Toa

Abstract - This project concerns on the development of applications using sensors for the rehabilitation of stroke patients. Thus, the leap motion sensor is employed for the finger motor rehabilitation training while the Microsoft Kinect sensor is utilized for the upper limb motor rehabilitation. Two applications which are named 'Pick and Place' and 'Stone Breaker' are developed. For the first application, the patient is required to pick up the virtual blocks and stack it up. The 'Stone Breaker' game requires the patient to move the upper limb in controlling the paddle movement in the game. At the end of the project, it is able to achieve the dominant objective of the project when the tested patient shows significant improvement in both the application.

Keywords—Stroke, Visual-based Rehabilitation, Kinect, Leap Motion Sensor.

I. INTRODUCTION

Stroke or Cerebrovascular accident (CVA) is the term used to describe the damage caused to the brain. It is due to an abnormality in the blood supply to the brain. Stroke is the leading cause of adult disability. Each year nearly 800,000 people experience a new or recurrent stroke. Besides, every year roughly 40, 000 people in Malaysia are suffered from stroke. In this case, stroke becomes the third largest cause of death in Malaysia [1]. Stroke is a very dangerous disease as someone dies from the stroke every 4 minutes in the world.

In this context, stroke can also be called as a brain attack. The brain depends on a continuous supply of energy to function normally. The energy to the brain, in the form of sugar and oxygen, is supplied by the blood. The oxygen is carried by the haemoglobin in the red blood cells and the sugar is carried in the serum. Any disruption of the blood flow to the brain will result in either a reduction or halt of energy supply to the brain. A brain damage resulting from such an abnormal blood supply to the brain is called stroke [2]. The term stroke is used because most of the times the person is struck suddenly by a vessel abnormality, and the resulting loss of function begins quickly [3]. Ischemic stroke is the most common stroke which is induced by an abrupt arteries blockage leading to the brain. For most of the stroke patients, the blood is not able to flow to the region of brain that controls a particular body function, then that part of the body will not function as it should be. Stroke can be classified into two major types: haemorrhage and ischemia [3]. Haemorrhage refers to bleeding within the skull, either in the brain tissue or the fluid surrounding the tissue. Ischemia is a stroke that results from the lack of blood supply to the brain. These two types of strokes are the exact opposites of each other. In haemorrhage there is an excess of blood in the skull, while ischemia is a lack of blood.

Finger motor dysfunction is the major problem experienced by patients among the effects of the stroke. Finger motor impairments is common symptom faced by the stroke patient due to deficits in motor execution and higher-order processes (motor planning and motor learning) [4]. Deficits in fingers motor due to stroke can influence the patients' mobility, their limitation in daily life activities, their participation in society and their odds of returning to professional activities. The daily living activities can be normal and simple such as, reaching, walking, gripping, swallowing, and dressing. The deficit of upper limb motor performance after a stroke is often affected the reaching movements and gripping ability of an individual [5]. All of these factors give rise to low overall quality of life. Thus, there are a lot of physical exercises for rehabilitation on the hand motor impairment. Examples of those physical training are finger stretch, towel grasp, wrist bend movement, wrist side movement, wrist curl, pen spin and so on. All of

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those hand finger exercises and wrist exercises are useful exercises that are able to faster the recovery rate of hand motor impairment [6].

Apart from that, upper limb dysfunction is a common impairment after a stroke. Result from a survey shows that roughly 75% of acute stroke survivors face upper limb failure while only 5% of adult stroke victims regain fully functional upper limb after finishing their rehabilitation program [7]. Early assessment of upper limb dysfunction and its recovery planning should be started as early as possible. In this context, early assessment results in earlier recovery so that the patient is able to carry out normal activity that requires the upper limb such as bathing, cooking, holding object and so on.

Finger motor dysfunction and upper limb motor impairment bring inconvenience to the patient in their daily life and lower the quality of life of the patient. Thus, the impaired upper limb can be rehabilitated through the rehabilitation program offered by the rehabilitation center or hospital. Nevertheless, there are few drawbacks to the physical conventional rehabilitation process. The main problem is the lack of available stroke physiotherapists in Malaysia [8]. Besides, the physical rehabilitation process takes a longer time to rehabilitate the stroke patients. The main contributor is that the patient might feel unmotivated with the boring conventional rehabilitation training [9].

Hence, visual-based rehabilitation is introduced to overcome this problem. First, the visual-based rehabilitation system provides convenience to the patient with a home-based rehabilitation approach. The home-based system allows the patients to conduct the rehabilitation training anytime at home whenever they are free. Thus, this increases the frequency of rehabilitation training. It also can solve the problem of shortage of physiotherapists in this country. Besides, the visual-based rehabilitation training can attract the patients with the immersive and attractive gaming environment. Consequently, interest in conducting the training can be enhanced. As a result, the recovery rate of the patient can be improved. Thus, the design system aims to provide the home-based rehabilitation system so that the recovery rate of impaired upper limb can be enhanced. To serve this purpose, 'Pick & Place' and 'Stone Breaker' are developed in this paper.

II. METHODOLOGY

A. Pick & Place Training for Post-stroke

Leap motion sensor is the main hardware component for the Pick and Place training. The sensor is integrated with the VR headset in this training. The sensor is attached at the front of the VR headset to give the immersive experience to the player. The computer is also required because it is needed to process the input data from the sensor. Since the mobile VR headset is used, the mobile phone is inserted in the headset to provide the 3D screening to the user. The mobile phone displays whatever shown on the computer screen. The Trinus software is installed on both laptop and the mobile phone for the linkage in between them. The combination of the program and the hardware allows the player to carry out the training. Figure 1 shows the block diagram of fingers rehabilitation system with virtual reality.

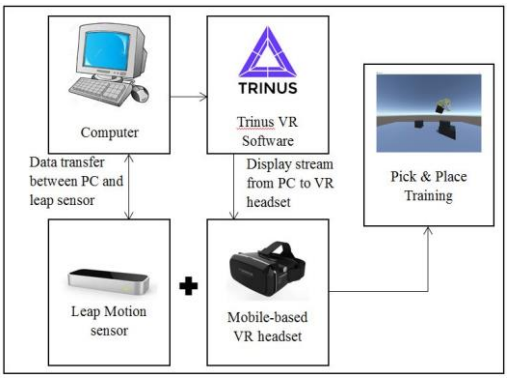

FIGURE 1: Block Diagram of Fingers VR-based Rehabilitation System.

The training content is a simple exercise of pick and place. It allows the patient to exercise and train their fingers movement, gripping ability and hands muscle. The training content is designed with reference to one of the post-stroke training, pick and place task. In this application, few blocks are randomly scattered on a virtual table. The player is required to pick them up and stack it according to the size from the largest cube at bottom to the smallest cube at top. Strengthening post-stroke patient's upper limbs trajectories and improving fingers motor dysfunction will be the primary target of the application. Figure 2 shows the demonstration of Pick & Place application from developers.

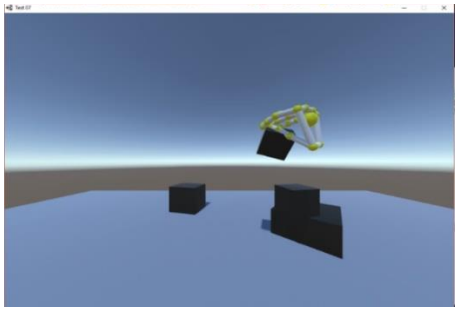

FIGURE 2: Demonstration of Pick & Place Application.

In order to develop the Pick & Place training with virtual reality, a virtual environment is required to be established. Unity is a great platform to build a virtual environment as it has a home growing library. Besides, it also has native support for VR devices.

In the application, the program starts when the application is launched. Then, leap motion can start to detect user hands motion. The application subjects to stack the blocks in order. If the blocks are successfully stacked up, a result will prompt out to notify the user about the time used for this training. The application restarts or resets if leap motion detected a left thumb up. The application will prompt a message box with current result if leap motion detects a right thumb up. The algorithm is written with MonoDevelop. The flow chart of the overall algorithms is illustrated in Figure 3.

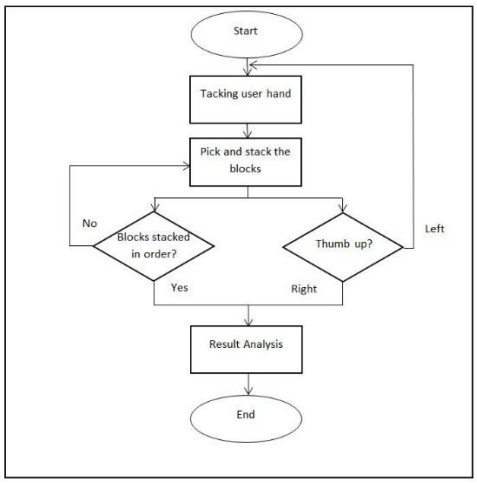

FIGURE 3: Flow Chart of First Application: Pick & Place Training.

B. Stone Breaker training for upper limb dysfunction

The concept of this rehabilitation training is using the Microsoft Kinect sensor. The sensor is able to track the full body of the user. It is totally different from the leap motion sensor because the leap motion sensor is only able to track the finger movement. The main functions of the Microsoft Kinect are tracking colour image, tracking skeleton, speech recognition, depth image processing and so on. The skeleton tracking function is used in the developed application in order to track the upper half body of the patient.

Stone breaker is a game developed for the rehabilitation of the upper limb motor dysfunction. In this case, the patient has to move either their left or right hand in order to move the plate to catch the ball. Once the ball touches the paddle that is controlled by the patient, it will be bounced back to hit the stones and break them down. Once all the stones are broken, then the user is able to proceed to the next level of the training which is more difficult as compared to the previous level. There are initially 3 lives for the player, the life will be deducted once the ball is not successfully caught by the player. The game is over when all lives are used. Figure 4 shows the graphical user interface developed for the game.

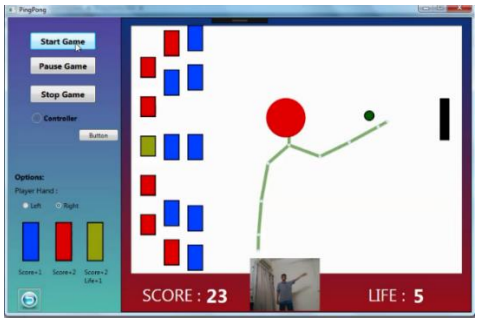

FIGURE 4: Demonstration of Stone Breaker application.

The application training is divided into 3 levels of difficulties. Once all the stones in the level are broken, then the application will proceed to the next level of difficulties. There are a total of 3 types of stones which are blue stone (adding 1 score when broken), red stone (adding 2 scores when broken) and green stone (adding 2 scores and 1 life when broken). Once all the three levels of game are completed, then the player wins the game.

The Stone Breaker application is developed in the Windows Presentation Foundation (WPF) application of Microsoft Visual Studio 2015. The programming language that use is C#. The WPF application is very useful because it is able to create the graphical user interface for the game. The buttons can be inserted into the interface. The buttons can then be programmed according to the desired function of the respective button. Besides, stones, ball and plate are drawn by using the coding. In this case, the skeleton tracking and the image tracking programming language are drawn in another class. The classes are called in the main class of Stone Breaker coding in order to detect the human skeleton and image for the game playing purpose. The most major function that is used is the 'If Else' function which is a very common programming function. There are a lot of conditions may happen in the designed application. For example, the direction of the movement of the ball is uncertain and thus the conditions that possible to occur are listed by using the 'If Else' function. For instance, the stones are deleted once the ball exceeds the predefined dimension in the X-axis of the game canvas.

There are a lot of advantages of the developed applications. The stroke seriousness level of the patient can be determined through the application. For the 'Pick & Place' operation, the difficulty level is divided into 3 levels which are 3 blocks for beginner level, 4 blocks for intermediate level and 5 blocks for the difficult level. The more the blocks the patient is able to stack, the healthier the finger of the patient. Thus, the recovery rate of the patient can be seen through the difficulties level that the patient is able to achieve. On the other hand, the 'Stone Breaker' game consists of 3 levels as well. A normal healthy person is able to complete all the 3 levels in the game. For the stroke patient, the recovery can be achieved when the patient obtains a higher score than the previous training.

III. UNIQUENESS OVER EXISTING METHODS

A. Pick & Place Training for Post-stroke

There are a lot of the existing visual-based rehabilitation applications in the market. However, the devices that are used in helping the patient to rehabilitate are different. One of the common training is the development of rehabilitation game by using the integration of webcam camera and controller [10]. In this case, three games are designed which are turning the steak, cleaning the window and fly killer [11]. All of these games have to be played by holding the controller. This is due to the reason of webcam is not able to detect the accurate position of the patient's hands. Another option is the use of accelerometers and gyroscopes provided by the Nintendo Wii remote [12]. The same theory applied here is playing the game by holding the Wii controller. One of the best uniqueness of Pick and Place application over other designs is that the utilization of Leap Motion sensor in sensing the user's hand. The patient is not required to hold or grip any of the controller in playing the game. There is no any of gripping force required in picking up the blocks. Instead, the patient just needs to open and

close their finger in the task. There are a lot of the stroke patients facing the difficulty of picking the object because of the finger motor dysfunction. Therefore, it is hard for them to grip the controller. Thus, some serious stroke patient is not able to carry out the training that requires controller. However, the Pick and Place application is suitable for all range of the stroke patient.

Another well-known virtual reality rehabilitation is the mirror therapy. It used mirror therapy with immersive virtual reality to make the patient believe that he is controlling his arm even though his arm is paralyzed and disable [13]. For example, right arm of the patient is disabled, then the patient is required to put on the Oculus Rift Virtual Reality headset to see that he is actually moving his arm in the virtual environment even that the disabled arm is only able to slightly move in the real world. This is able to stimulate the arm muscle to move and exercise the arm muscle so that the patient is able to recover. In this context, Pick and Place application which also provides a similar rehabilitation effect requires only the mobile-based VR headset which is very much cheaper than the Oculus Rift headset.

B. Stone Breaker Training for Post-stroke

There is a similar training for the rehabilitation of upper limb which is Ping Pong game [14]. The Ping Pong game requires 2 people in the game playing. This design uses the same concept in which the players have to move their arm in order to control the moving plate. One of the player who fails to catch the ping-pong ball causes the opponent player to obtain one score. The first player who is able to achieve 10 points is considered as the winner. This game has some drawbacks compared to the Stone Breaker. First of all, this game requires 2 players in the game playing. Since one person alone is not able to carry out the training, so it reduces the frequency of the training because the training can only be done with the family members of patient when they are free. On the other hand, Stone Breaker which only needs one player means that the patient is able to play the game at any desired time. The high frequency of training fastens the recovery rate.

Besides, Stone Breaker is a task-oriented game in which the player is required to break down all the stones in order to proceed to the next higher level. This is able to increase the motivation of player in carrying out the exercise. For example, the patient will be disappointed if he failed to complete the game and he will try again in order to complete the level. In this case, Ping Pong game is not a task-oriented game. The opponent side of the patient will be a healthy normal person. Thus, the normal participant possesses a higher chance of winning because they will always be able to catch the ball. In this case, the patient feels bored if they always lose the game.

IV. Result and Discussion

A. Pick & Place Training for Post-stroke

The hardware required for the Pick and Place training are portable laptop, VR headset and leap motion sensor. The sensor is connected to the laptop by the cable while the headset can be connected by either wireless or using a cable. The leap motion sensor is attached in front of the VR headset as shown in Figure 5.

FIGURE 5: Setup of VR Headset and Leap Motion Sensor.

After the successful development of the visual-based pick and place training, 20 normal people are invited to test the performance of this application. They try the training for three times while the time required to successfully stack up the blocks is recorded. Out of the 20 people, only result of 5 people is taken down and recorded in the tables below. Table 1 demonstrates the result of time completing the pick and place application for the beginner level (3 blocks) while Table 2 shows the result of time completing the pick and place application for intermediate level (4 blocks). Both tables show that the time of the third attempt reduced compared to the first two attempts.

TABLE 1. Result of Pick & Place Training for beginner level.

User/Time (second)	1st Attempt	2nd Attempt	3rd Attempt	Average
1	32.0	32.0	35.0	33.00
2	31.0	30.0	30.0	30.33
3	45.5	45.0	42.0	44.17
4	42.5	42.0	40.0	41.50
5	37.5	38.0	36.5	37.33

TABLE 2. Experimental Result of Pick & Place Training for intermediate level.

User/Time (second)	1st Attempt	2nd Attempt	3rd Attempt	Average
1	65.0	66.0	62.0	64.33
2	61.0	60.0	59.5	60.17
3	72.0	71.0	71.0	71.33
4	76.0	73.0	74.5	74.5
5	68.5	68.5	67.5	68.17

TABLE 3. Experimental Result of Stone Breaker.

User	First Attempt				Second Attempt			
	Lvl	*Score*	*Life left*	*Time used (s)*	*Lvl*	*Score*	*Life left*	*Time used (s)*
1	3	45	4	265	3	45	5	250
2	3	45	4	280	3	45	4	276

3	2	18	0	162	3	41	0	240
4	2	20	0	170	3	45	1	261

B. Stone Breaker Training for Post-stroke

For the setup of the training, the Microsoft Kinect sensor is connected to the laptop and the power supply. The user is required to stand 3 m away from the sensor for the effective sensing effect. The distance is optimal distance for the player to move the plate up and down within the range of the canvas. Table 3 shows the result of the training.

The maximum allowable score that can be achieved is 45 points. Table 3 shows that the result below 45 points the life left is zero which means that the player fails to break all the stones in three levels. The second attempt shows the great improvement in such a way that all the players are able to achieve level 3. No one fails at the level one because level one only consists of 5 stones. The plate to catch the ball is very big so it is hard to fail at the level.

V. Conclusion

To put it in the nutshell, the main aim of this project which is the development of visual-based rehabilitation by using sensors for stroke patient is achieved. In this case, two training applications which are Pick & Place and Stone Breaker are successfully developed with the function to cure fingers fine motor dysfunction and the upper limb dysfunction respectively. On the other hand, improvement also has been done on the physical rehabilitation training. With the designed applications, the patient tends to carry out the rehabilitation exercise more frequently than the conventional boring exercise. As a result, the recovery rate of the stroke patients may improve. Nevertheless, the project only focuses on upper limb rehabilitation. In the future, more virtual rehabilitation games will be developed to cover rehabilitation of the lower limb as well. For instance, the walking ability of the stroke patients can be enhanced by requesting the patients to cross a virtual bridge. Thus, the visual-based rehabilitation using the sensor brings a bright future to the future post-stroke rehabilitation and hospitality field.

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Author Contributions

Choon Chen Lim: Conceptualization, Data Curation, Methodology, Validation, Writing – Original Draft Preparation;

Kok Swee Sim: Supervision, Project Administration, Writing – Review & Editing;

Chean Khim Toa: Validarion, Writing – Review & Editing.

Conflict of Interests

No conflict of interests was disclosed.

Ethics Statements

Our research work follows The Committee of Publication Ethics (COPE) guideline. https://publicationethics.org.

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