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A Simple Upper Limb Rehabilitation Trainer

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Abstract: Stroke is a leading cause of disability which can affect shoulder and elbow movements which are necessary for reaching activities in numerous daily routines. To maximize functional recovery of these movements, stroke survivors undergo rehabilitation sessions under the supervision of physiotherapists in healthcare settings. Unfortunately, these sessions may be limited due to staff constraints and are often labor-intensive. There are numerous robotic devices which have been developed to overcome this problem. However, the high cost of these robots is a major concern as it limits their cost-benefit profiles, thus impeding large scale implementation. This paper presents a simple and low cost interactive training module for the purpose of upper limb rehabilitation. The module, which uses a conventional mouse integrated with a small DC motor to generate vibration instead of any robotic actuator, is integrated with a game-like virtual reality system intended for training shoulder and elbow movements. Three games for the module were developed as training platforms, namely: Triangle, Square and Circle games. Results from five healthy study subjects showed that their performances improved with practice and time taken to complete the Triangle game was the fastest of the three.

Keywords: Stroke, rehabilitation, upper limb, shoulder and elbow, robot

1. Introduction

Cardiovascular disease involving the heart and circulatory system is a major cause of morbidity and mortality in Malaysia. Of this, stroke is ranked second after ischemic heart disease [1, 2] and is one of the most common medical emergencies [3, 4]. It is also a leading cause of severe disability in Malaysia [5], resulting from paralysis or loss of muscle control, usually on one side of the body [6]. The number of stroke patients discharged from Malaysian government hospitals increased from 17209 in 2012 to 33681 in 2015 [1, 7-9]. To maximize functional recovery, stroke survivors often undergo hospital-based rehabilitation sessions under the supervision of physiotherapists. Unfortunately, these sessions are often labor-intensive and limited to only a few hours per week due to time and staff constraints, resulting in patients not receiving adequate amount of therapy [10].

In recent years, many robotic devices have been developed for rehabilitation purposes. For example, MIT-Manus [11] and a two degree of freedom (DOF) elbow-shoulder robot [12], which were developed for unrestricted unilateral shoulder and elbow movements in the horizontal plane, showed the potential of additional therapy aided by robotic technology to improve motor function. Other robotic technology include the ARM Guide [13] robot which trains reaching movements in a straight line trajectory; and the ReachMAN [14] and Haptic Knob [15] which involve training using combination of reaching movements together with hand manipulation. These show the feasibility of simple robotic technology for the provision of intensive upper limb retraining after stroke.

However, the evaluation and implementation of such technology on a large scale basis is often difficult due to the high cost involved, limiting their cost-benefit profiles [16]. Reducing the cost of developing rehabilitation robots and increasing their portability to encourage their implementation in clinical practice is still a significant need. Doing so would further increase their accessibility for patients and further expand their application to homecare settings [17]. According to Celik *et al.* [18], unactuated rehabilitation devices or affordable motion capture systems can provide inexpensive and practical solutions for overcoming such issues. Hence, it would be beneficial if a simple unactuated device can be designed to retrain upper limb function of stroke patients.

This paper presents a simple, compact and interactive rehabilitation module for upper limb rehabilitation purposes. This module is intended to be used for training of shoulder and elbow movements integrated with a game-like virtual reality (VR) system.

2. Training Module Description

Three interactive games for the module were designed using Unity software, namely Triangle, Square and Circle. These games were developed as a training strategy to train the subject's upper limb function while

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playing an interactive game. The shapes of the games were selected based on the isolated and combined movement of shoulder and elbow movements [19, 20]. The yellow and blue cubes were the target position while the white ball represented the movement of the mouse. For the up and down movements of the white ball, it represented the forward and backward reaching movement of the mouse respectively. For right and left movements of the white ball, it represented the right and left movement of the mouse respectively.

The Unity software was linked with the Arduino Uno using serial communication. The haptic feedback was provided by a DC motor vibrator while the visual and audio outputs of the desktop board were used to match with the haptic vibratory feedback applied by the robot for a realistic sensation of the VR environment. The motor was programmed to vibrate through a modified mouse attached with a DC motor which was placed at a suitable position where the subject could easily feel the vibration in order to interact with the VR. Fig. 1 shows the system overview of the interactive rehabilitation module while Fig. 2 depicts the modified mouse with the vibration motor.

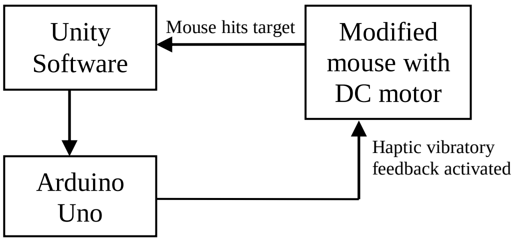


Fig. 1 System overview.

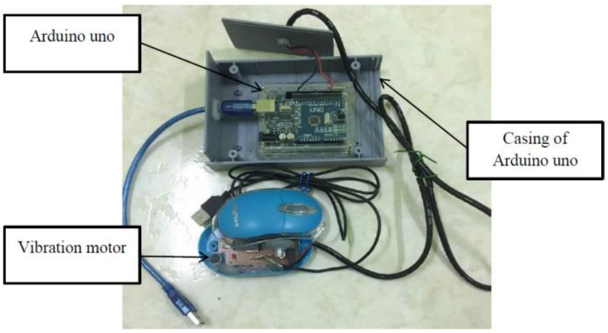


Fig. 2 Mouse with a DC motor as a vibrator

The DC motor was connected to the microcontroller through serial communication. The positive and negative pins of vibration motor were connected to pin 3 and ground pin, respectively, of the microcontroller. In order to activate the vibration effect, the Unity software will have to send a command to the microcontroller through serial communication with 9600 bits per second (baud rate). For example, if the subject hits the particular cube in the game mode, the mouse will vibrate.

Cubes in the triangle game were arranged as a triangle while those in the square and circle were arranged in the shape of square and circle respectively. The player was required to control the white ball by moving the mouse. There were two different colored cubes in these games which were in yellow and blue. The blue cubes were visible before the start of the game start and faded once the game started to indicate the pattern of the module. While the yellow cubes were in target positions which the player needed to hit and score points. Fig. 3 shows the interface of the triangle game.

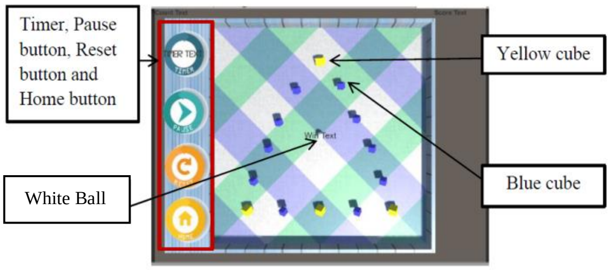


Fig. 3 Interface of Triangle game.

The selection of these three shapes was based on the required movements in activities of daily living, including combination movement of shoulder and elbow such as reaching for an object. The range of motion (ROM) for reaching movement of the Triangle game was 100 mm for horizontal movement and 120 mm for vertical movement. Thus, the total movement for one complete cycle was 340 mm.

The ROM for reaching movement of Square module was 80 mm for horizontal movement and 80 mm for vertical movement. Thus, the total movement for one complete cycle was 320 mm. Fig. 4 shows the interface of Square game.

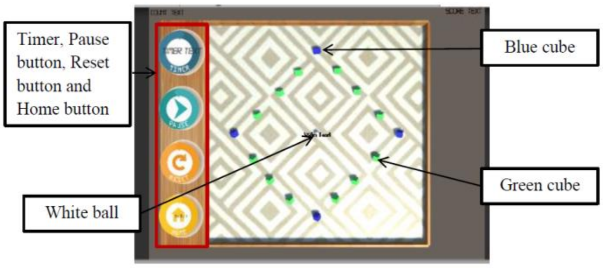


Fig. 4 Interface of Square game

The ROM for reaching movement of Circle game was 100 mm for horizontal movement and 100 mm for vertical movement. Thus, the total movement for one complete cycle was 310 mm. Fig. 5 shows the interface of Circle game.

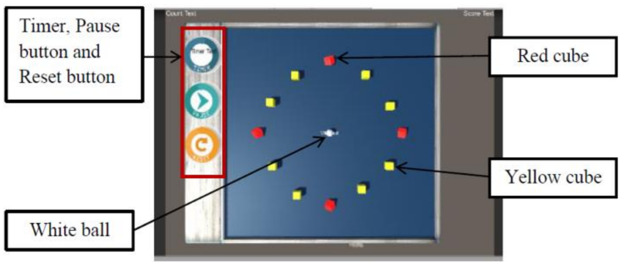


Fig. 5 Interface of Circle game

3. Performance and Discussion

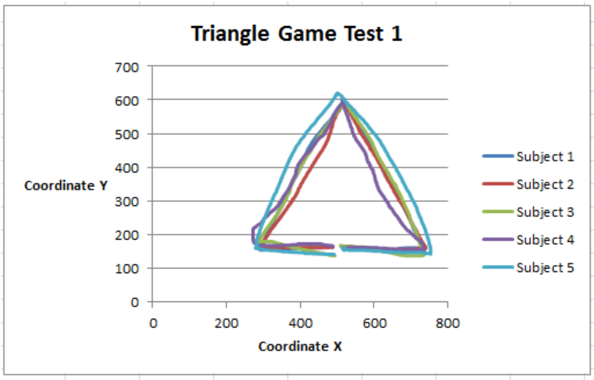
A total of five healthy subjects gave their consent to participate in this study. All subjects were selected randomly among students from the Faculty of Electrical and Electronic Engineering. Before the experiment was started, each subject was informed of the purpose and instructions for the experiment.

Subjects carried out a session of five minutes starting with the Triangle game followed by the Square and ending with the Circle game. Subjects were asked to sit comfortably on a fixed-height rest chair with high back, place their right arm on the table and hold the mouse. A short demonstration was conducted to show subjects how to play the games and they were asked to practice for one minute. Subjects were asked to perform three trials for each game. Each subject performed a total of nine movements to complete the study, three movements for each game, and all these movements were recorded.

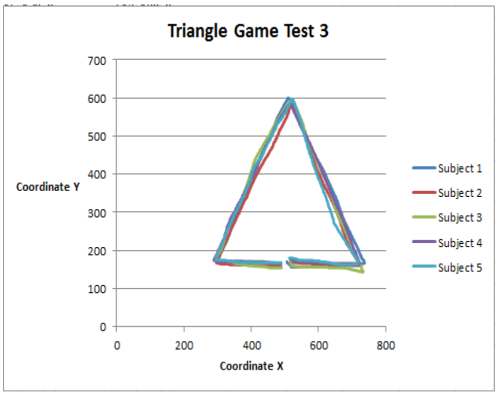
Fig. 6-8 show the paths covered by the subjects for the three games with the modified mouse. In addition, these figures also illustrate the differences between the first (early stage of training) and third trials (final stage of training). The second trial data is not display but for the time taken analysis, the all data were included.

The hand movement pathways for all the subjects were highly variable for the first variable as it involved large corrective movements. In the third trials however, the pathways were relatively closer to the shapes in each game with smaller corrective movements. These results show that the subjects were learning by training which suggests that stroke patients may have to be provided with repetitive movements in order to familiarize themselves with a certain activity or task.

Results for the third trial also suggest improvement in cognitive skills pertaining to the game as the subjects were able to follow the pathways better. This suggests that the training may also have a potential to be used in improving cognitive skills in stroke patients, however more research needs to be done in this perspective.

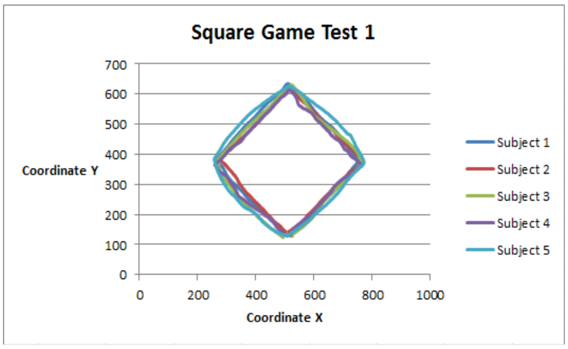


(a)

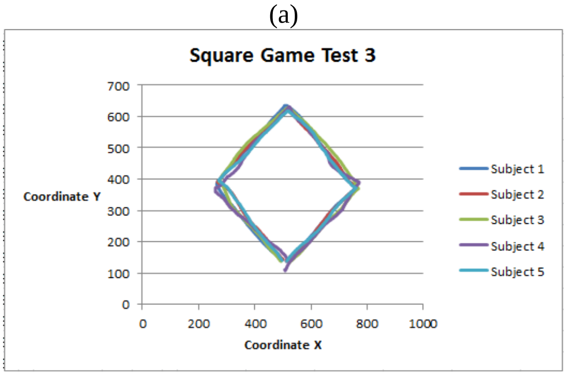


(b)

Fig. 6 Hand paths covered by five healthy subjects to complete the Triangle module: (a) first trial and (b) third trial.

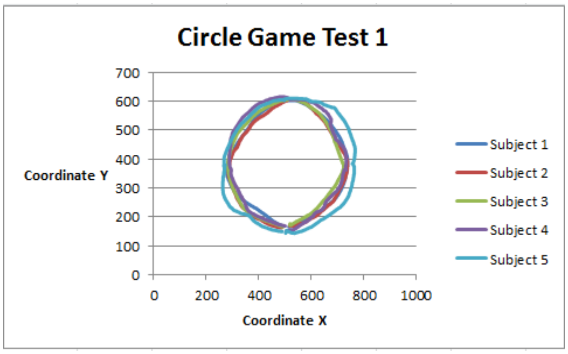


(a)

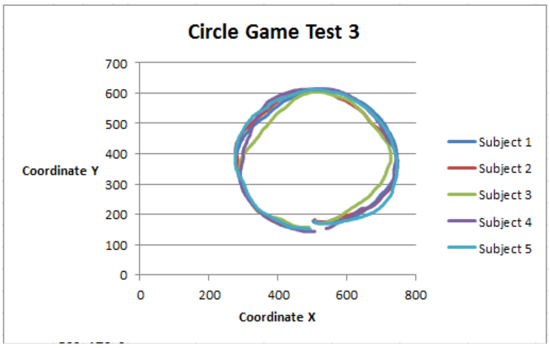


(b)

Fig. 7 Hand paths covered by five healthy subjects to complete the Square module: (a) first trial and (b) third trial.



(a)



(b)

Fig. 8 Hand paths covered by five healthy subjects to complete the Circle module: (a) first trial and (b) third trial.

Mean values and standard deviations of the time taken for the three interactive games are shown in Table 1. These results indicate that recorded fastest mean time in Triangle game and was slowest in the Square game. Result also showed that the standard deviation for time taken in Triangle game had the largest range while the Square and Circle games had similar ranges. These results suggest greater inter-individual variability among subjects for the Triangle game, while the Square and Circle games were completed more consistently. This may be because of the geometrical shapes used in the game. Although the perimeter to complete Triangle (340 mm) was larger than Square (320 mm), in the former, subjects only needed to move in three directions as opposed to the four comprising a square which also had more edges than the triangle. In the Circle game however, although the subjects needed to move in only one path without edges, non-linear movements were involved.

Table 1 Time taken of healthy subjects to complete for each task

Module	Time (s)
Triangle	20.27 ± 2.47
Square	22.27 ± 0.61
Circle	20.67 ± 0.58

Thus, in summary, the game with a lower number of edges and a linear pathway may require less time compared to games involving larger number of edges and non-linear pathways. The findings from this study can be used for baseline comparison with performances by stroke patients. However, further research need to be done to verify these observations.

4. Conclusion

This paper presents the design and development of an interactive rehabilitation module for stroke patients. The design of this system is compact and portable which makes it suitable for hospitals and home settings. This compact device has been developed by using a conventional mouse with additional DC motor as a vibrator integrated with three training games, namely the Triangle, Square, and Circle games which were developed using Unity, an open source software

This interactive rehabilitation module can record the movement pattern of the stroke patient and keep track of their progress. Besides that, it may also be used to inculcate motivation using the score point approach which makes the game more enjoyable and competitive than conventional rehabilitation methods. Also, the immersive environment provided by the VR interface may provide visual focus for the user. Nevertheless, more studies are needed to validate and determine the effectiveness of this system in recovering reaching movement impairment experienced by stroke patients. This system will be evaluated in future clinical studies on stroke patients in collaboration with the National Stroke Association of Malaysia (NASAM) and other hospitals in Malaysia.

Acknowledgements

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