

A Simple Position Sensing Device for Upper Limb Rehabilitation

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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. Rehabilitation under the supervision of physiotherapists in healthcare settings is to encourage the recovery process. Unfortunately, these sessions are often labor-intensive and limited intervention time between physiotherapist and the stroke patient due to staff constraints. Dedicated robotic devices have been developed to overcome this issues. 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 portable unactuated interactive rehabilitation device for upper limb rehabilitation purposes. This device has been developed by using a conventional mouse integrated with three interactive training modules, namely the Triangle, Square, and Circle modules intended for training shoulder and elbow movements. Results from five healthy subjects showed the more deviation from the path will be happen when the subject move their hand to the other side of their dominant hand. Besides, the shape of the module that includes combination of X and Y axes directions appear to be more difficult compared to either X or Y axis.

Keywords: Stroke, rehabilitation, upper limb, shoulder, elbow, optical mouse

1. Introduction

One of the major causes of morbidity and mortality in Malaysia is cardiovascular disease, which involve the heart and circulatory system. Of this, stroke is one of the top five leading causes of death and one of the top 10 causes for hospitalization in Malaysia [1, 2] and is one of the most common medical emergencies [3, 4]. The mean age of stroke patients in Malaysia is between 54.5 and 62.6 years. Ischemic stroke incidence is estimated to increase annually by 29.5% and hemorrhagic stroke by 18.7% [5]. It is also a leading cause of severe disability in Malaysia [6], resulting from paralysis or loss of muscle control, usually on one side of the body [7]. The number of stroke patients discharged from Malaysian government hospitals increased from 17209 in 2012 to 33681 in 2015 [1, 8-10]. Rehabilitation is to encourage the recovery process. Unfortunately, these sessions are often labor-intensive and limited intervention time between physiotherapist and the stroke patient due to staff constraints, resulting in patients not receiving adequate amount of therapy [11].

Many dedicated devices have been developed in recent years for rehabilitation purposes. For example, MIT-Manus [12] and a two degree of freedom (DOF) elbow-shoulder robot [13], 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 [14] robot which trains reaching movements in a straight line trajectory, the ReachMAN [15] and iRest [16, 17] which involve training and assessment respectively using combination of reaching movements together with hand manipulation. In addition, CR2 robot was developed to train hand and wrist rotation movements by reconfigure the setting of the device [18, 19]. These show the feasibility of simple robotic technology for the provision of intensive upper limb retraining after stroke.

However, due to high cost involved in these devices, the evaluation and implementation of such technology on a large scale basis is often difficult, limiting their cost-benefit profiles [20]. To encourage their implementation in clinical practice, reducing the cost of developing rehabilitation robots and increasing their portability is still a significant need. Doing so would further increase their accessibility for patients and further expand their application to homecare settings [21]. Celik *et al.* [22] reported that unactuated rehabilitation devices or affordable motion capture systems can provide inexpensive and practical solutions for overcoming such issues. Therefore, 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 and portable unactuated interactive rehabilitation device for upper limb rehabilitation purposes. This device is intended to be used for training of shoulder and elbow movements integrated with a game-like virtual reality (VR) system.

2. System overview

The overall system overview is shown in Fig. 1. An ADNS-2633 optical mouse was used to sense two dimensional motion relative to its supporting surface. This sensor has 1000 dot per inch resolution, which is able to measure movement of 0.03 mm per dot in any direction. It can track the movement up to 63.75 mm change in any direction. The optical mouse sensor has six pin and only four pin needs to be connected with microcontroller which is Arduino Uno as shown in Fig. 2. The Arduino Uno was the main controller for the system, which communicated with PC through Bluetooth (HC-05 Bluetooth module) communication for data processing and recording.

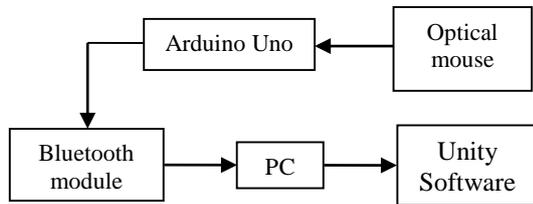


Fig. 1 System overview

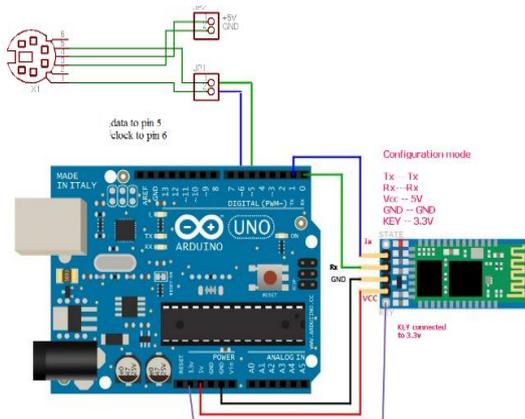


Fig. 2 Connection of the system

3. Training Module Description

Three interactive games for the module were designed using the Unity software, namely Triangle, Square and Circle. These games were developed as a training strategy to train the subject's upper limb function while playing an interactive game. The shapes of the games were selected based on the isolated and combined movement of shoulder and elbow movements [16, 23]. These modules were reported in our previous study [24].

In the Square module, the range of motion (ROM) for the vertical line is 240 mm and for the horizontal line is 200 mm. Hence, the total length movement is 880 mm.

In the Triangle module, the ROM for the side of the isosceles triangle line is 230 mm and for the horizontal line is 240 mm. Hence, the total length movement is 700 mm. In the Circle module, the diameter of the circle is 100 mm, thus the total length movement is about 314.16 mm.

4. Performance and Discussion

Fig. 3 shows the hand position sensing device. The linear reaching movement was tested using this device. The purpose of this experiment is to evaluate the performance of finding the error during reaching movement. The maximum distance a hand can reach depends on the arm length and which is generally about 550 mm from shoulder to hand tip. The further the hand moves away from body, the more shoulder movement is involved. In addition, stroke survivors, in particular in the subacute phase, should avoid large shoulder movements [15]. Therefore the distance the travel of the movement were limited to 350 mm. Besides the linear reaching movement, the subjects were asked to perform the three developed training modules which are Triangle, Square and Circle modules.

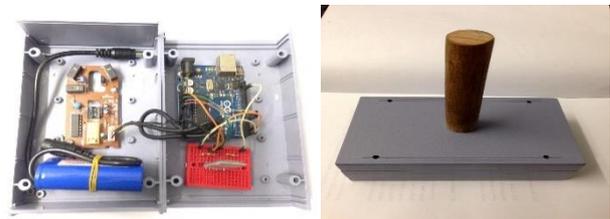


Fig. 3 Illustration of reaching movements

A total of five right handed male healthy subjects gave their consent to participate in this study (age: 22-25 years old). All subjects were selected randomly among students from the Universiti Tun Hussein Onn Malaysia (UTHM). Before the experiment was started, each subject was informed of the purpose and instructions for the experiment. The subjects were instructed to move the device to three targets with 350 mm path length located along three linear paths rotated -30° , 0° and 30° respectively from the midsagittal plane as shown in Fig. 4.

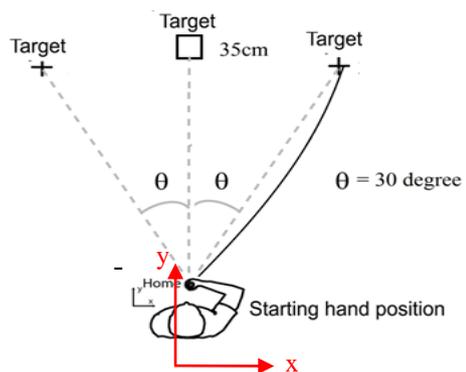


Fig. 4 Illustration of reaching movements

Each subject carried out a session of five minutes starting with the linear reaching movement, followed by the Triangle game, Square and ending with the Circle game. At the starting of the session, they 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 following which, they were asked to practice for one minute. Subjects were asked to perform three trials for each task. Each subject performed a total of 18 movements to complete the study (9 for linear reaching movement, 3 for Triangle module, 3 for Square module and 3 for Circle module) and all of these movements were recorded.

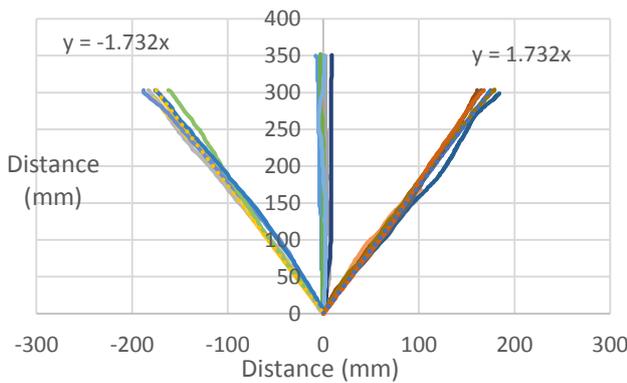


Fig. 5 Hand paths covered by five healthy subjects to complete the linear reaching task.

Fig. 5 shows the paths covered by the subjects for the linear reaching movement task (the task is illustrated in Fig. 4) with the position sensing device. Overall, the mean deviation error of all subjects from the linear lines are between 1.20 mm to 6.10 mm as shown in Table 1. The error was calculated by measuring the movement deviation from the linear line. All Subjects recorded highest deviation error during performing the linear movement at -30° direction and was lowest at the vertical direction (0°). Results also showed that the standard deviation for movement error in all linear paths had similar ranges.

Table 1 Deviation from the linear line for three different angles

Subject	Vertical movement 0° (mm)	Linear movement 30° (mm)	Linear movement -30° (mm)
1	3.50 ± 2.20	3.70 ± 3.30	6.10 ± 2.50
2	3.60 ± 1.80	4.40 ± 2.80	5.60 ± 2.90
3	1.20 ± 1.10	2.30 ± 1.30	5.30 ± 3.50
4	4.00 ± 2.40	3.50 ± 2.80	5.60 ± 4.30
5	1.80 ± 1.40	3.70 ± 2.70	5.10 ± 3.30
Mean \pm std	2.80 ± 0.50	3.50 ± 0.80	4.60 ± 0.70

This is because all the subjects happened to be right-handed. When the subjects move their dominant hand to the non-dominant side, the deviation is expected to increase depending on how far they move their hand to the

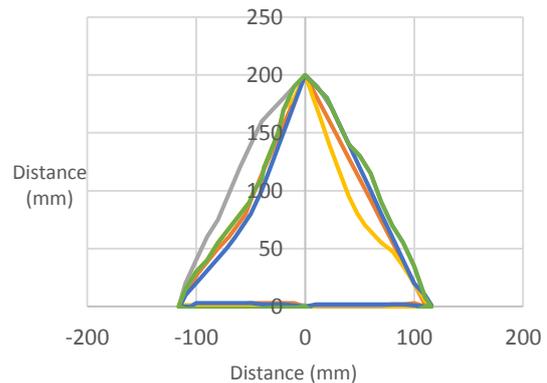
non-dominant side. Therefore, these results indicate that the deviation allowance for benchmarking purposes must be based on the dominant hand side of their hand.

Fig. 6(a), (b) and (c) show the paths covered by the subjects for the three modules with the position sensing device. The hand movement pathways for all the subjects were highly variable during performing the Triangle and Circle modules as it involved large corrective movements. In the Square module however, the pathways were relatively closer to the shapes in each trial with smaller corrective movements as shown in Table 2.

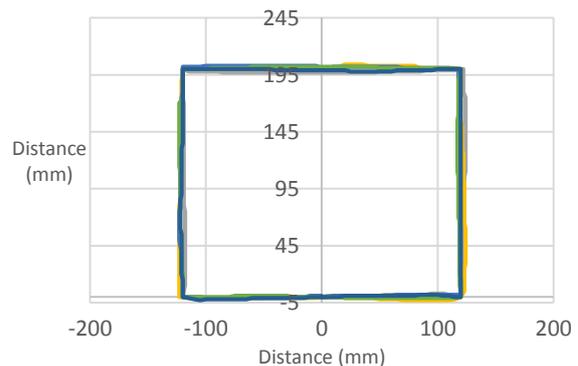
Table 2 Deviation error and speed to complete the three modules

Module	Error (mm)	Speed (mm/s)
Triangle	0.37 ± 0.10	40.76 ± 4.66
Square	0.14 ± 0.02	31.56 ± 2.60
Circle	0.36 ± 0.23	16.91 ± 1.28

These results show that the shape that includes combination movements in X and Y axis directions is more difficult compare to the movement that only in X or Y axis direction. In addition, the results also indicate that the lesser the deviation during the movement, the better in cognitive skill of the subject. However, this result could be improved with learning by training which suggests that user may have to be provided with repetitive movements in order to familiarize themselves with a certain activity or task. This suggests that the training may also have a potential to be used in improving cognitive skills in stroke patients, however further study needs to be conducted in this perspective.



(a)



(b)

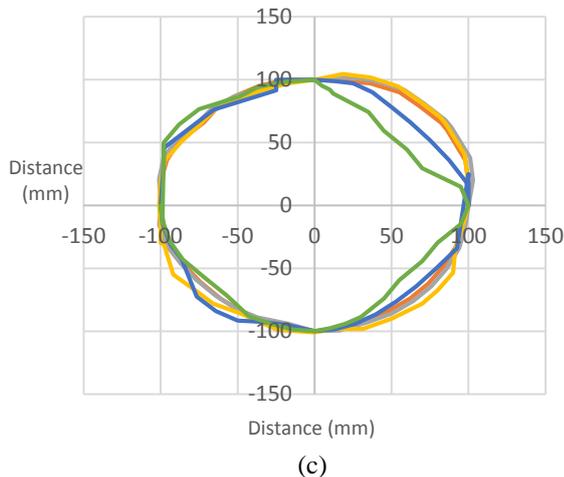


Fig. 6 Hand paths covered by five healthy subjects to complete the tasks: (a) Triangle module, (b) Square module and (c) Circle module.

Table 2 also shows the mean values and standard deviations of the speed for the three modules. These results indicate that recorded fastest mean speed in Square module and was slowest in the Circle module. Result also showed that the standard deviation for deviation error in Circle module had the larger range compare to the other modules. These results suggest greater inter-individual variability among subjects for the Circle module, while the Square and Triangle modules were completed less variable.

These results proved that the Square module is easy to perform due to geometrical shape that only involve X or Y axis at one time. These results show that the shape that includes combination movements in X and Y axis directions is more difficult compare to the movement that only in X or Y axis direction. While Triangle and Circle modules include combination movement in X and Y axis in a same time, thus, increases the difficulty.

5. Conclusion

This paper the design and development of an unactuated interactive rehabilitation device for upper limb rehabilitation purposes. The design of this system is simple and portable which makes it suitable for hospitals and home settings. This device has been developed by using a conventional mouse integrated with three interactive training modules, namely the Triangle, Square, and Circle modules which were developed using the Unity, an open source software. Besides, this device able to record the distance of the user while moving their hand. In addition, this study found that the deviation from the path will be increased when the user move their hand to other side of their dominant hand. Thus, the deviation allowance could be considered based on the dominant side. Apart from that, results found that difficulty of the task is based on the geometrical shape of the task. The shape with combination of X and Y axis directions is more difficult compare to the shape that include either X or Y axis. Nevertheless, further 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.

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