DESIGN, FABRICATION AND CONTROL OF UPPER LIMB REHABILITATION ROBOT PROTOTYPE FOR STROKE PATIENTS

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ABSTRACT: Stroke is one of the prominent causes of disability in the world. In order to have chances for recovery, the stroke patients need repetitive and consistent rehabilitation activities or treatment. However, the increasing number of stroke patients with limited number of therapist and transportation problem for rural patients limits the possibility to have better treatment. This paper discussed the application of robotics system to support the rehabilitation activities focusing on the upper limb area of the body. The result shows two designs of upper limb rehabilitation device were fabricated and controlled. Both prototypes were emphasized on the compact, transportable/portable and simple operation concept. In order to evaluate the prototype, real patient test or experiment needs to be conducted.

KEYWORDS: *Stroke; Upper Limb; Rehabilitation; Medical Device*

1.0 INTRODUCTION

Stroke is a clinical syndrome characterized by rapidly developing clinical symptoms and/or signs of focal, because of blocked or burst blood vessels, causing the brain tissue to be damaged. The most common symptom of a stroke is the sudden feel of numbness or weakness on the face, arm or leg. It mostly happened on the patient's one side of the body. Besides that, symptoms like confusion, difficulty speaking, difficulty seeing with one or both eyes, difficulty walking, loss of balance or coordination, severe headache, dizziness or even fainting or unconsciousness are all leading to stroke.

According to [1] every year, approximately 15 million people worldwide suffer from stroke. Out of these, around five million patients die and another five million are left permanently disabled. Stroke is among the top four prominent causes of death in Association of South East Asia Nation (ASEAN) countries. In Malaysia, stroke was the top five leading causes of death and one of the top ten causes for hospitalization as reported by [2]. A stroke cause partial damage to cortical tissue and disturbing the generation and integration of neural commands. The interrupted neural commands from cortex's sensorimotor areas affects the motor-task performance. This is due to the disability to selectively activate the muscle tissue. The consequences are impaired arm and hand motor function. Hence, it is essential for stroke patients to restore the ability of arm and hand motor function to perform activities of daily living (ADL) and this is when stroke rehabilitation comes in place.

Rehabilitation has been defined by [3] as the combination and coordination usage of medical, educational, social and vocational measures for retaining a person to the highest possible level of functional ability. Stroke rehabilitation has been described as a process of motor relearning after stroke by [4]. It was mentioned by [5] that it is crucial for an individual to perform ADLs as movement disorders would reduce a patient's quality of life significantly, especially disorder of the upper extremities. Fortunately, various approaches are available to restore the functionality including physical therapy, orthoses and electrical stimulation. Out of these approaches, physical therapy shows a very encouraging outcome due to its' heavy dependence on duration, intensity, task-orientation and onset of the training, not to neglect also the health condition, attention and effort from the patient.

However, burden on the therapists starts to accumulate as more and more patients would require assistance due to the growing number of stroke. Intense repetitions of coordinated motor activities from the large scale of patients would certainly results in shortage of therapists in any hospital or rehabilitation center. To overcome this problem, many researches focusing on the application of robotic devices as the alternative or even replacement of physical therapists.

In this situation, upper limb robotic rehabilitation devices (RRDs) have emerged as one of the considered alternatives. This is due to the efficiency of upper limb RRDs towards assisting patients to recover from impairments. It was stated in [6] that therapy intensity from upper limb RRDs is acknowledged to have desired outcomes. This is due to the potential to implement intensive rehabilitation therapy towards the patients for a longer period of time. It also stated in [7-9] that compared to other rehabilitation techniques, the robotic devices produced encouraging results and have high potential to support the rehabilitation process.

According to [10] besides aiding and assisting therapist, the robotic rehabilitation devices might be useful to be transported to the remote locations or patients' home. In this case consistent rehabilitation process can be performed and it is crucial for the patients. There are several upper limb rehabilitation devices available in the market. However, the existing devices are considered large in size and not portable to be transported from one area to another for the usage of rural communities.

MIME (Miror image movement enabler) [10], MIT-MANUS [11], T-WREX (Therapy Wilmington robotic exoskeleton) [12] and ARMin (Arm in three dimension) [13] are the examples of upper limb rehabilitation robot device. MIT-MANUS and MIME is an end-effector types of device where the device contact to the patient's limb only at the most distal part and the structure of the device had been simplified. However, in the case of multiple degrees of freedom the device may complicate the control of the limb position [5].

On the other hand, T-WREX and ARMin are example of exoskeleton based device. The mechanical construction of the device mirrors the limb's skeletal structure. For example, each segment of the limb associated with a joint movement is attached to the corresponding segment of the device. The mechanical construction allow independent, concurrent and precise control of movement [5].

This paper is aimed to discuss and compare the development of two prototypes of upper limb rehabilitation robot device. This include the mechanism and control strategy applied for both prototypes. Both prototypes are based on similar concept design that will discuss in the methodology section.

2.0 METHODOLOGY

2.1 Develop the Design Concept

Design concept was the main framework for the prototype development. In this research, similar design concept was applied for the two prototypes. The design concept was based on the three parameters; (i) compact, (ii) transportable/portable and (iii) simple operation.

Compact refer to the device that is solid and smaller in size. Transportable and portable refer to the device that is light weight where it can be used in the rural areas. Lastly, the simple operation refers to the easiness of the function and operation system where it can be understand by the ordinary people. In general, the device should be able to perform the vertical elbow flexion [14] and shoulder horizontal flexion and extension. These are the basic movement of the arm during the upper limb rehabilitation exercises.

2.2 Conduct Mechanical Design and Analysis

Based on the conceptual design in Section 2.1, mechanical design of the prototype was conducted using the computer aided design software. Kinematics analysis was conducted to determine the range of height and movement of the prototype. The analysis result was used to estimate the position, velocity and acceleration of the device. Different approaches were used for the analysis based on the design of the prototype. Further discussion is conducted in Section 3.

2.3 Design the Control System

Control system design refers to the programming and interfacing involved for the prototypes. Both prototypes used Arduino as the controller to control the motors and sensors. Arduino programs were written in C or C++. The process flow of the programming was developed to assist the control system development. Arduino controller was selected due to the size, weight and the operation system. The controller is considered small, lightweight and easy to operate. The characteristics were suitable to the research objective.

3.0 RESULTS AND DISCUSSION

The results and discussion focused on the mechanical design, mechanism involves and control system that was developed for the prototype.

3.1 The First Prototype

The first design and fabricated prototype is shown in Figure 1. The prototype consists of a platform, arm rest and independent mechanism. The independent mechanism drive the prototype to move in horizontal (X-Y axis) and vertical (X-Z axis) direction. The prototype was fabricated using aluminium material due to its strength, lightweight, corrosion resistance and reasonable price.

The prototype consists of 12 V battery to drive the DC motor, three sets of sensors, a microcontroller and a motor driver. The sensor was used to detect the location of the arm rest, to perform angle rotation movement and to count the number of completed oscillations of the arm rest. The prototype was controlled by Funduino UNO model R3 with stackable motor driver and DFRduino Input Output Expansion.

Figure 2 shows the kinematic analysis conducted for the first prototype at X-Y axis using the Working Model software. The analysis was conducted by adjusting the angular velocity value of the arm rest. The adjustment was required to complete the one cycle of movement in horizontal plane roughly in 25 seconds. This will cover the angular movement of approximately 110 degrees and total distance of 220 degrees. Details discussion of the prototype including the X-Z axis analysis was presented in [15].

Based on the test and evaluation conducted, the prototype takes 26 seconds to complete the one cycle of movement in the horizontal motion. At the same time, the prototype needs an average of 32.5 seconds to complete 10 cycles in the vertical plane. The angle of rotation was approximately at ~110 degrees (X-Y axis) and ~90 degrees (X-Z axis).

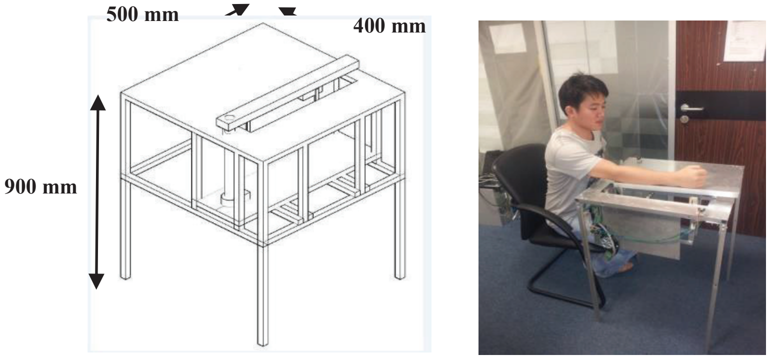

Figure 1: The first design (left) and fabricated prototype (right)

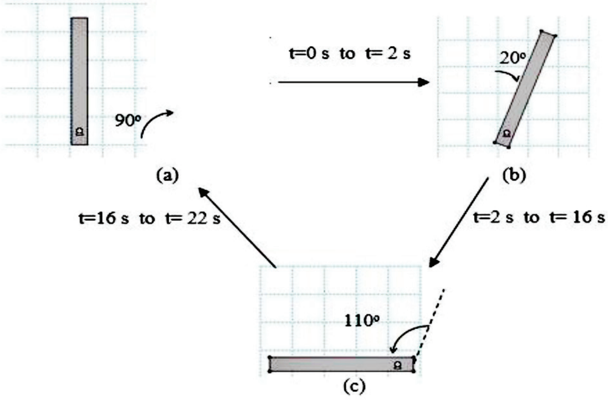

Figure 2: Kinematic analysis of the first prototype [15]

3.2 The Second Prototype

The second design and fabricated prototype is shown in Figure 3. The prototype consists of upper and lower platform with 770 mm in length, 135 mm in width and 220 mm in height. The prototypes consist of two mechanisms to move the shoulder and elbow namely the scissors lift and armrest.

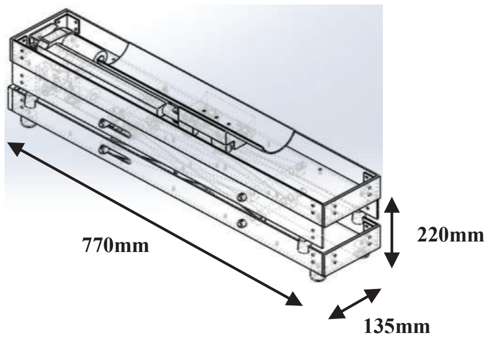

Figure 3: The second design (left) and fabricated prototype (right)

The scissors lift mechanism was used to lift the shoulder and elbow in Z-axis direction. At the same time the armrest mechanism was used to move the shoulder and arm in line bi-directions. The bi-direction refers to the X or Y axis direction movement. In overall the prototype was able to perform the X-X and X-Z or Y-Y and Y-Z axis direction movement based on the position of the device and patient.

Figure 4 shows the kinematic analysis of the second prototype. The analysis was conducted to determine the maximum height required for the scissor lift mechanism. The maximum height data was used as an input for the controller programming design. As shown in Figure 4, L is the distance between the holes at both end of each link. L is 340mm while L34 and L35 are equal to 1/2L.

S is the distance between link 4 and 5 and H is the height of the mechanism from link 1 to 4. S = 303 mm when the mechanism at rest and S = 335 mm when the mechanism is fully extended. By using Pythagoras theorem, the maximum height of the scissors mechanism can be determined. Based on the analysis conducted, the scissors mechanism was able to extent up to 96 mm.

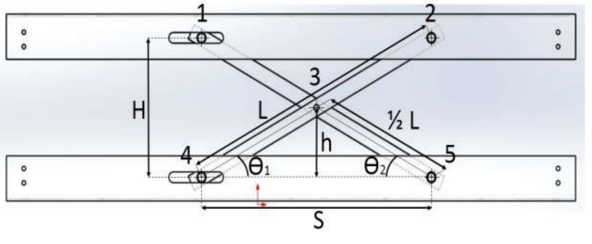

Figure 4: Kinematic analysis of the second prototype [16]

The prototype was fabricated using aluminum and plywood. In order to give comfort for the patient to place the arm, non-slip rubber pad was attached to the platform. The prototype consists of two 12 V DC linear motors with 50 mm and 200 mm stroke length. The prototype also consists of four channel motor drivers. The total weight of the prototype is around 7 kg. Details discussion of the prototype was presented in [16].

3.3 Comparing First and Second Prototypes

The two prototypes were compared in order to reflect on the research objective and to understand the gap between the existing devices. The focus is on the dimension, weight, mechanism, applied motion and the control strategy. The comparison is important to further enhance the development of upper limb rehabilitation device for stroke patients. Table 1 shows the comparison between the first and second prototype. The device can be considered as compact and transportable since both prototypes are around 5 kg and 7 kg respectively.

Table 1: Comparison between first and second prototype

No.	Area of Discussion	First Prototype	Second Prototype
1	Dimension (mm)	900 × 500 × 400	700 × 135 × 220
2	Weight (kg)	5	7
3	Mechanism	Platform, Armrest and Independent	Scissor lift and Armrest
4	Applied motion	X-Y and X-Z axis movement	Linear for all axis (X-X, X-Z, Y-Y and Y-Z)
5	Control strategy	Adruino as controller. Sensor to give feedback	Arduino as controller. Linear motor drive the movement without any sensor

However, the dimension and weight is depending on the type of the actuator used for each prototype. Besides, although both mechanisms are trying to support the rehabilitation exercise, there is no variety on the applied motion. Applied motion refers to the movement that can be performed by using the prototype.

First prototype only focuses on the rotation movement while second prototypes only have linear movement. In order to support the rehabilitation exercise, there is a need to combine the rotation and linear motion to the device. Only first prototype consists of set of sensors to give feedback on the movement. Lastly, there was no testing and evaluation conducted using real patient.

4.0 CONCLUSION

This paper discussed the development of two prototypes of upper limb rehabilitation robot device based on similar conceptual design. Both prototypes were designed, fabricated, controlled and tested. The objective to develop a compact, transportable/portable and simple operation of the device is considered achieved. Both prototypes were capable to perform basic movement that is required for the upper limb rehabilitation exercises. As a future development, ethical approval need to be considered before the prototypes can be tested using the real patient.

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