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Passive Upper Limb Assessment Device

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Abstract

Stroke is the leading cause of disability. Reaching movement is the most important movement for many daily activities routine. Rehabilitation is to encourage and enhanced recovery process. Conventional rehabilitation is one-to-one intervention where labour intensive and lack of repeatability. In addition, the stroke assessments by physiotherapist are subjective and not independent. Thus, this paper will describe the design and development of non-motorized system for assessing the patients' motor function. This system will be used in the future to find the correlation between conventional assessments scales such Fugl-Mayer Assessment (FMA), Chedoke-McMaster Stroke Assessment Scale (CMSA) and Motor Assessment Scale (MAS) and robotic assessment.

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Keywords: Stroke; assessment scale; robotic; upper limb; rehabilitation.

1. Introduction

Reaching motion of a person is one of the most important and crucial for many daily activities such as eating, drinking and simply pick and place a book on the table so as to make them independent. Besides, the ability to reach enables support to increase the person safety and mobility[1]. This ability could be reduce when a person having stroke because of the death of the related brain cells that govern the activity. Rehabilitation is to encourage and enhanced

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the recovery process. Besides traditional physical therapy, repetitive and task-oriented movement can improve the motor outcome and prevent secondary complication[2].

Dedicated robotic device can fulfill these possibilities. In addition, the used of robotic devices for neurorehabilitation can lead to similar or larger improvement motor function that traditional therapy[3]. In particular, MIT-Manus[4] and two degree of freedom (DOF) elbow-shoulder robot[5], which were developed for unrestricted unilateral shoulder and elbow movements in horizontal plane, show that additional therapy aided by robot technology can improve motor function. The ARM Guide[6] robot train reaching movement in a straight line trajectory. The ReachMAN[7] was developed to simplify the complexity of the mechanical design that is able to train combination of the reaching movement in straight line and hand manipulation. The Haptic Knob[8], which is enables to train active practice of forearm and grasping, show also that use of simple devices makes possible intensive training of post stroke patient. These devices have built-in technology to measure position, displacement, velocity, force and quantify other derived parameters. Besides train the patient to improve the motor function, the quantitative assessment of motor recovery should include in order to define a custom-built and effective rehabilitation procedure.

Most of the stroke patient will undergoes conventional assessment by the physiotherapies before and after the rehabilitation process. However, there have several limitations with this assessment such as the scoring systems are relatively coarse, making it difficult to quantify impairment and disability, the measurement is always subjective, lack in reliability and depends on the ability of the rehabilitation professional. Thus, this paper will describe the design and development of non-motorized system for assessing the patients' motor function. This system will be used in the future to find the correlation between conventional assessments scales such Fugl-Mayer Assessment (FMA)[9], Chedoke-McMaster Stroke Assessment Scale (CMSA)[10] and Motor Assessment Scale (MAS)[11] and robotic assessment.

2. System design

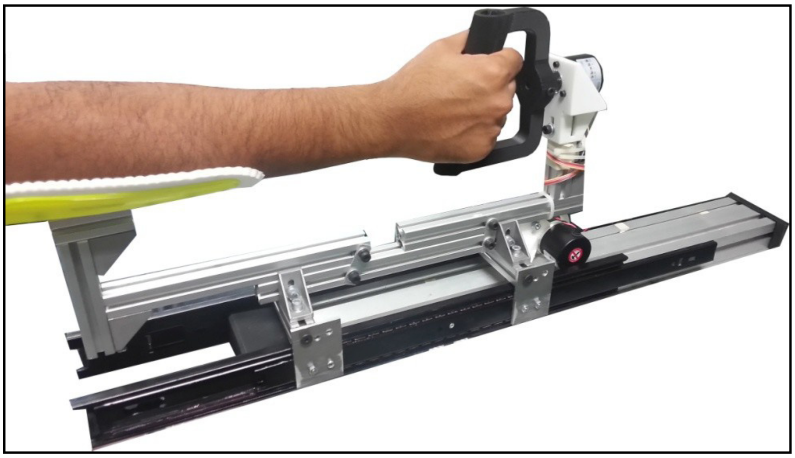

Fig. 1. Passive Upper Limb Assessment Device

This project aims to develop a simple assessment device for assessing upper limb of stroke patient before and after rehabilitation process. This system includes reaching and forearm pronation and supination movements as shown in Fig. 1. This system is non-motorized system, hence the safety of this system is much higher than motorized system. This system equipped with two optical encoders to record position during movement. The design of this system is similar to ReachMAN[7] except the grasping part. Game-like virtual reality are included in this system to indicate the movement while increase the motivation of the stroke patient. Different handles or knob are easily interchanged by using a custom-made coupling attached to the optical encoder. The handle of this system was design based on the biomechanics of the hand for comfortable grasping.

2.1. Biomechanics requirement

To ensure the comfortable condition for grasping the handle during assessment with this device, it is important that the interface account for biomechanics of the hand. The shape of the object to hold is one of the factors influencing the posture of the hand during function[12]. For example, a short cylinder may be gripped as securely between the tips of the opposed digits as between the flexed finger and the palm as shown in Fig. 2(a) and Fig. 2(b) and this is the functional position during grasping a cylinder. This behavior consists of wrist ulnar deviation at 16°. According to health professional, keeping the hand in functional position will help avoid straining the hand and arm[13]. Thus, it is important to design a handle that able to maintain the functional position during training and assessment.

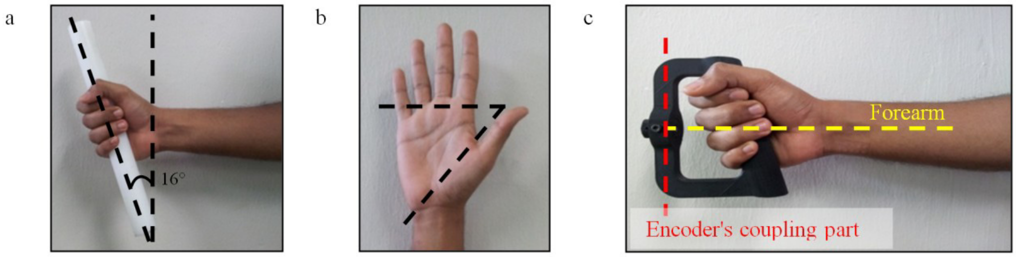

Fig. 2. Biomechanics of hand, (a) functional position during grasping; (b) axis rotation of the index finger and thumb; (c) design of the handle

3. Implementation

3.1. Hardware

The implementation of the device concept has two passive degrees of freedoms (DOF) which are for linear reaching movement and pronation/supination movements. An aluminum profile 70x35*mm* is used as the base of this system, attached with triple slider to generate freely linear movement. The custom made handle was constructed using 3D printer[14] with one gripping cylinder part (diameter, 30*mm*) and encoders' coupling part attached on its side as shown in Fig. 2(c). Both parts were coplanar, with symmetry axes at an angle of 16°[15], such that when the subject gripped the handle, the axis of the encoder coupling part was perpendicular to the forearm axis while keeping a natural posture of the wrist with a slight ulnar deviation. The mechanical stopper was constructed to limit the linear movement for safety issues.

3.2. Microcontroller

Microcontroller DSPIC33FJ128MC802 is the controller for the system, which communicates with PC for the GUI virtual environment output. This microcontroller contains two Quadrature Encoder modules that used for encoder position sensing. To overcome overheat, switching voltage regulator (PTN78020WAH, Texas Instruments, US) was used to supply the 5V from the 12V adapter power supply. Since the microcontroller operated in 3.3V, the 5V output from the switching regulator were used to as an input for 3.3V voltage regulator (TLV1117LV33DCYR, Texas Instruments, US).

3.3. Encoder

Two rotary encoders (3806-500B-5-24F, RJS, China) are used in this system for measure the linear movement (reaching forward/backward) and rotation movement (forearm pronation/supination). These rotary encoders support Quadrature Encoder Output that allows up to 2000 step per revolution for precise position sensing for clockwise and anticlockwise movements.

3.4. Communication between PC and microcontroller

Microcontroller communicates with the PC by receive and sending standardized data packet through UART. Start Bytes, ID, Length, Data(s), and Checksum are the basic element of data packet as shown in Table 1.

Table 1. Communication between laptop PC and Microcontroller.

Start Bytes	ID	Length	Data(s)	Checksum
Two 0xFF as the start byte	ID for the receipient	Length of the Data(s) + Checksum	Data(s)	1 Checksum byte for the verification

Start Bytes: The two 0xFF bytes indicated the start of incoming packet data. ID: The Unique ID of the recipient allows the microcontroller to communicate with more than one recipient. Length: Length of the packet where the value is number of data(s) plus one for the Checksum Byte. Data(s): The data array consists of the information needed to be sent to the recipient. Checksum: The computation for the checksum is shown in Equation (1):

$$\text{Checksum} = \sim (\text{ID} + \text{Length} + \text{Data1} + \text{Data2} + \ldots\text{DataN}) \tag{1}$$

If calculated value is larger than 255, the lower byte is defined as the checksum value) (~ represent the bitwise NOT operation). Data packet sent from Microcontroller to PC consists of two encoder reading and time to be displayed on the GUI. Since this system is non-motorized, the data packet from PC to Microcontroller only consists of command to reset the both encoders' value.

3.5. Data logging

While PC receiving data from the microcontroller, a button on the GUI control the start and stop of the logging data and the logged data will be store at text file. The data will be logging automatically at each incoming data from microcontroller every 4*ms*. The logged data for this system are two encoders' values, time, stabilization indicator, reach indicator and system indicator.

3.6. Assessment score

This system provides several customized game-like virtual reality to indicate the movement while increase the motivation of the stroke patient. The patient will be assessed through playing the game. The data will be recorded once the game started. Position, time, and number of success target reach will be recorded. From the recorded data, distance travelled, stabilization and speed score will be calculated. Travelled score, speed and stability score are the parameter that will be used to calculate the score for subject performance as these parameters interrelated[16]. The Equation (2) shows the total score for assessment process:

$$Total\ score = 0.7(Distance\ travelled\ score) + 0.2(Stabilization\ score) + 0.1(Speed\ score) \tag{2}$$

Where,

$$Distance\ travelled\ score = \left(\frac{DT}{TD}\right) \times 100$$

$$Stabilization\ score = \left(\frac{TA - (ST - 0.5s)}{TA}\right) \times 100$$

$$Speed\ score = \left(\frac{TA - max(ReT - RT, 0)}{TA}\right) \times 100$$

Where *DT* is distance travelled, *TD* is task distance, *TA* is time allowances which are equal to 10s, *RT* is references Time which is equal to 2.5s, *ST* is stabilization time, and *ReT* is reaching time. Fig. 3 shows the reaching movement movement of a healthy subject. Weight of each element was assigned based on the need for recovery[17]. The reaching time is similar to the rise time used in control theory, while stabilization time was the difference between the reaching time and the time after which the hand remained in the tolerance area for 0.5s. For reaching task, the tolerance was set to ±3*mm* and ±2° for pronation/supination task.

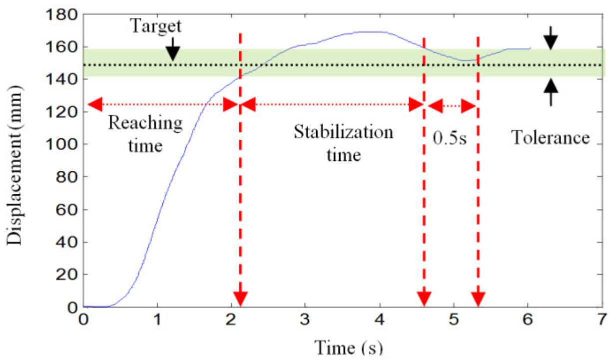

Fig. 3. Movement trajectory of a healthy subject performing reaching exercise. The target was 150*mm*. Reaching time was 2.10s and stabilization time was 2.50s.

4. Performance

The active workspace for exercise are [0-236] *mm* for reaching, [-180°, 180°] for pronation/supination of forearm. The device dimension is 925x255x95mm^3. The weight of this device is 3.62*kg*. The subject must sit during use this device while the arm rests on the arm support. The hand is place on the custom made handle while the subject looks at a monitor. The developed device with non-motorized system supports several types of virtual reality that include isolate movement (reaching or hand manipulation) and combination movements (reaching with hand manipulation). The isolate movement is to warming up the patient and the combination movement will be used for assess the patient since the conventional assessment include both movements. Since this system is non-motorized system, no haptic feedback will provide to the user. Since this system using a pairs of slider, friction interaction is felt during motion. This system can be used to measure the range of motion for forearm pronation and supination for both hands before and after the rehabilitation process.

5. Conclusion

This paper described the design and development of a passive upper limb assessment device. This design is similar to ReachMAN design which consists reaching in linear movement and hand manipulation. This design is non-motorized which reduce the cost and increase affordability and portability. We believe that this system is suitable for assessment and basic training of stroke patient with upper limb mobility. This system will be evaluated in clinical study on stroke patients for the sub-acute phase at the National Stroke Association of Malaysia (NASAM) or general hospital that will be decided later.

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