

Development of Reconfigurable Rehabilitation Robot for Post-stroke Forearm and Wrist Training

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Article history

Received :15 June 2014
Received in revised form :
15 September 2014
Accepted :15 October 2014

Graphical abstract



Abstract

Rehabilitation robots are gradually becoming popular for stroke rehabilitation to improve motor recovery, as robotic technology can assist, enhance, and further quantify rehabilitation training for stroke patients. However, most of the available rehabilitation robots are complex and involve multiple Degrees-Of-Freedoms (DOFs) causing it to be very expensive and huge in size. Rehabilitation robot needed to be useful but also should be cost-effective to be able to use in current rehabilitation process. This paper present the design of reconfigurable rehabilitation robot that able to adopt different training movement by changing the configuration of the device. The developed robotic system able to perform training for wrist, forearm and other functional rehabilitation training by using suitable modular units. Preliminary study with three stroke subject were presented to evaluate the functionality in different training modes for forearm and wrist rehabilitation training.

Keywords: Neuro-rehabilitation; stroke; rehabilitation robotics

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1.0 INTRODUCTION

Stroke affect up to 15 million of people each year worldwide and the numbers of stroke patient is on the rise every year. Based on the concept of neuroplasticity, the brain will reorganize itself and stroke patient can recover their muscle function through intensive and repetitive rehabilitation training [1-3]. However, due to large number of patient and limited physiotherapists, most of the stroke patients can only perform few hours of physiotherapy training in hospital.

Rehabilitation robots are becoming popular as they are proven to be able to provide a better recovery for stroke rehabilitation and increase rehabilitation training frequency [4-6]. However, most of the rehabilitation robots such as ARMin [7] and Gentle/s [8] are complex and involve multiple degrees-of-freedom (DOFs) causing it to be very expensive and forming the barrier to most of the rehabilitation centres, hospitals as well as individual patients in adopting the robotics system.

Rehabilitation robot needed to be useful but also should be cost-effective to be able to use in current rehabilitation process [9]. It would be beneficial if the complexity of the robot design could be simplified further making it affordable while performing the essential training for activity daily living in an engaging approach. Modular and reconfigurable rehabilitation robots are developed to

reduce the robot cost by adopting different therapeutic devices for various stages of patient [10]. For example, InMotion ARM [11] rehabilitation robot from Interactive Motion Technologies, Inc. can be extended by integrating InMotionWRIST [12] and InMotion HAND robot as a stand-alone system for more advance upper limb training. Universal Haptic Drive (UHD) [13], which consisted only two DOFs can be used to train either shoulder and elbow or forearm and wrist depending on the chosen configuration. Modularity and reconfigurability may help to reduce the cost of the robot therapy and increase the flexibility of the therapy, but there are only a few systems using these concepts and most of it system are yet to be implemented for home used [10]. Therefore, there is still a need in exploring the concept of reconfigurable robot for home-based usage as well as activity daily living (ADL) training assistance.

This paper will describe the developed reconfigurable and portable rehabilitation robot that able to train forearm, wrist as well as several functional training by integrating different training modules to suit different stages of patients. Several experiments with post-stroke subject had been carried out to evaluate the functionality of the robot in different training modes.

2.0 ROBOT DESCRIPTION

2.1 Robot Design

The robot consists of only one degree-of-freedom (DOF) with a single actuator. Figure 1 shows one of the stroke patients was training his forearm pronation-supination in National Stroke Association of Malaysia (NASAM). The robot enable the patient to train their muscle function while playing the virtual reality games provided in the display. To fully utilize the single DOF of the robot, the robot was designed to be reconfigurable which is able to use in training of multiple wrist and forearm movement with a single actuator by changing the configuration of the robot. Figure 2 shows the computer-aided design (CAD) drawing of the robot and Table 1 show the detail robot specification. The robot was designed to be compact in size and light in weight so that it is portable and can be easily carried with single hand by one person to suit for home use purpose.

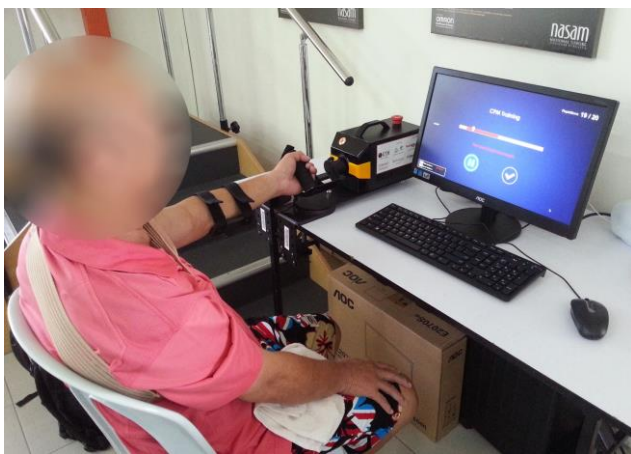


Figure 1 One of the stroke patients was training with the robot in National Stroke Association of Malaysia (NASAM)

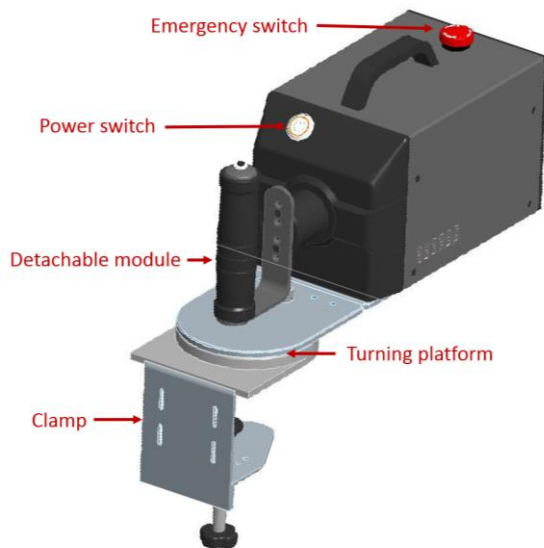


Figure 2 CAD drawing of the robot

Table 1 Robot specification

Specification	Value
Maximum rotation of interface	±135 degree
Maximum generated torque	1.8 Nm
Friction torque for rotation	0.02 Nm
Rotational inertia	0.325 kgcm ²
Power supply	DC 24V/17A
Dimension (L x W x H)	0.4m x 0.15m x 0.17m
Weight	0.6kg

2.2 Robot Set-up

To fully utilize the single actuator of the robot, a flexible turning platform was integrated with the robot to enable wrist and forearm rehabilitation training as illustrated in the Figure 3. The robot is capable to be reconfigured to perform forearm pronation-supination, wrist flexion-extension and abduction-adduction rehabilitation training by changing the orientation of the platform and modular unit. The flexible platform can be fixed at the desired position for different patient needs. To prevent daily use of the device from becoming a burden for the patient and therapists, the set up procedure was designed to be as simple as possible, which take about 2 to 3 minutes for the patient to train in every training session.



Figure 3 Different robot configuration for forearm and wrist training

Functional training are one of the crucial training in stroke rehabilitation, as it enable patient regaining their capability in performing different ADLs by themselves in their life. Therefore, the robot is designed to provide different basic functional training with different modular unit as shown in Figure 4. Various functional modules can be changed different for functional training like turning key, opening bottle, opening door and etc. This design able to give the flexibility for the patient to select the training option by changing the orientation and the suitable modules of the robot for different functional training movements in a limited working space.

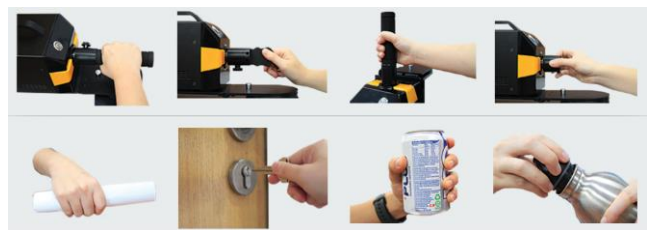


Figure 4 Basic functional training with different modular units

2.2 Therapy

The robot provide assessment software enabling the therapist to access the performance of the patient in term of passive range of movement (PROM), active range of movement (AROM), strength as well as quality of movement. The robot therapy program can be easily customized by the therapist to fit different requirement of the patient's need. They can set different parameter like training range, modes, sequence, speed, as well as duration of the training. The program will run all the training automatically in the set sequence to ease the patient to perform the training easily without much supervision needed by the therapist.

The three training modes, which are passive, assistive and active mode. The passive mode is for the patient who cannot move at all and the robot will help to move their wrist. In assistive mode, the robot will help the patient to move if they can only move in a small range of movement. In active mode, the robot can improve

the muscle function of the stroke patient by increasing the resistance according to their recover rate.

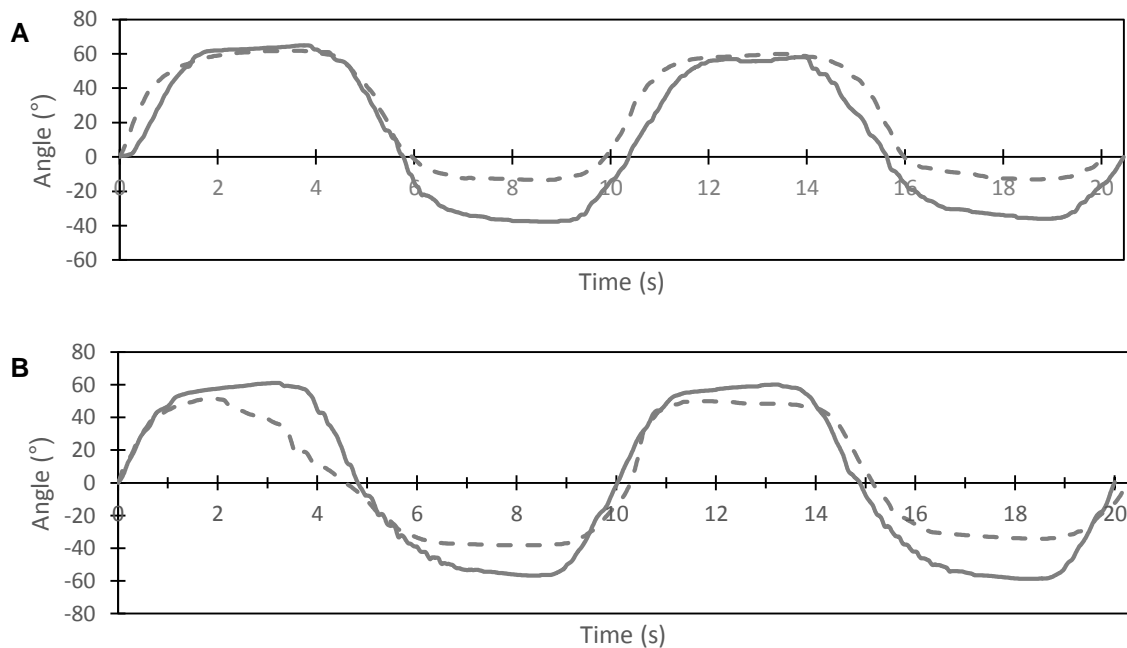
3.0 RESULTS AND DISCUSSIONS

3.1 Preliminary Experiment With Stroke Patients

The robot had been tested by two sub-acute stroke patients and one chronic patient with left hemiplegia and all are right handed. The objective of this preliminary test was to evaluate the functionality of the device in providing different mode of training to different stages of patient. Prior to participating, the subjects gave written informed consent. Table 2 shows the demographic and performance of the subject after the assessment performed by the robot. The passive and assistive mode were tested with the three subjects according to their forearm and wrist range of movement (ROM).

Table 2 Demographic and performance of subjects

Subject	Gender	Lesion side	Passive Range of Movement (°)		Active Range of Movement (°)	
			Pronation/Supination	Flexion/Extension	Pronation/Supination	Flexion/Extension
1	F	Left	-55/90	-23/72	-26/34	-5/40
2	M	Left	-90/83	-78/52	0/31	-53/10
3	M	Left	-90/90	-50/82	-10/39	0/1



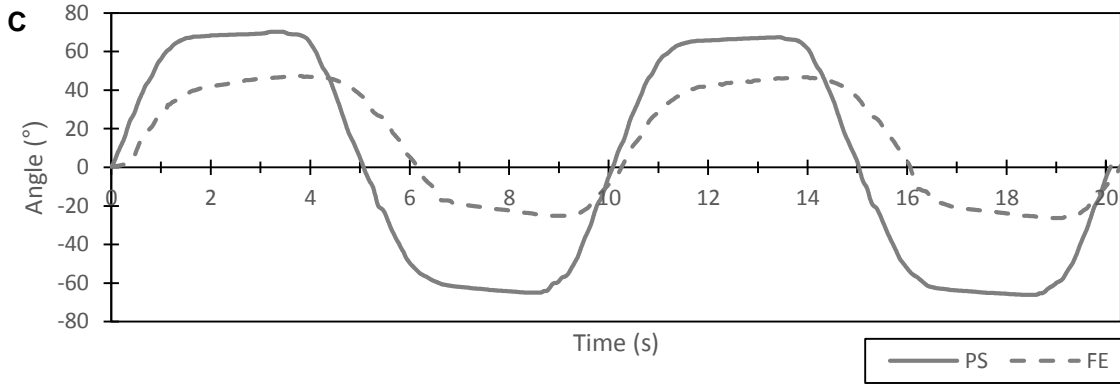


Figure 5 Output response with different patients in passive mode according to their PROM. A, B and C indicated the response of the subject 1, 2 and 3. (PS: Pronation/supination, F/E: Flexion-extension)

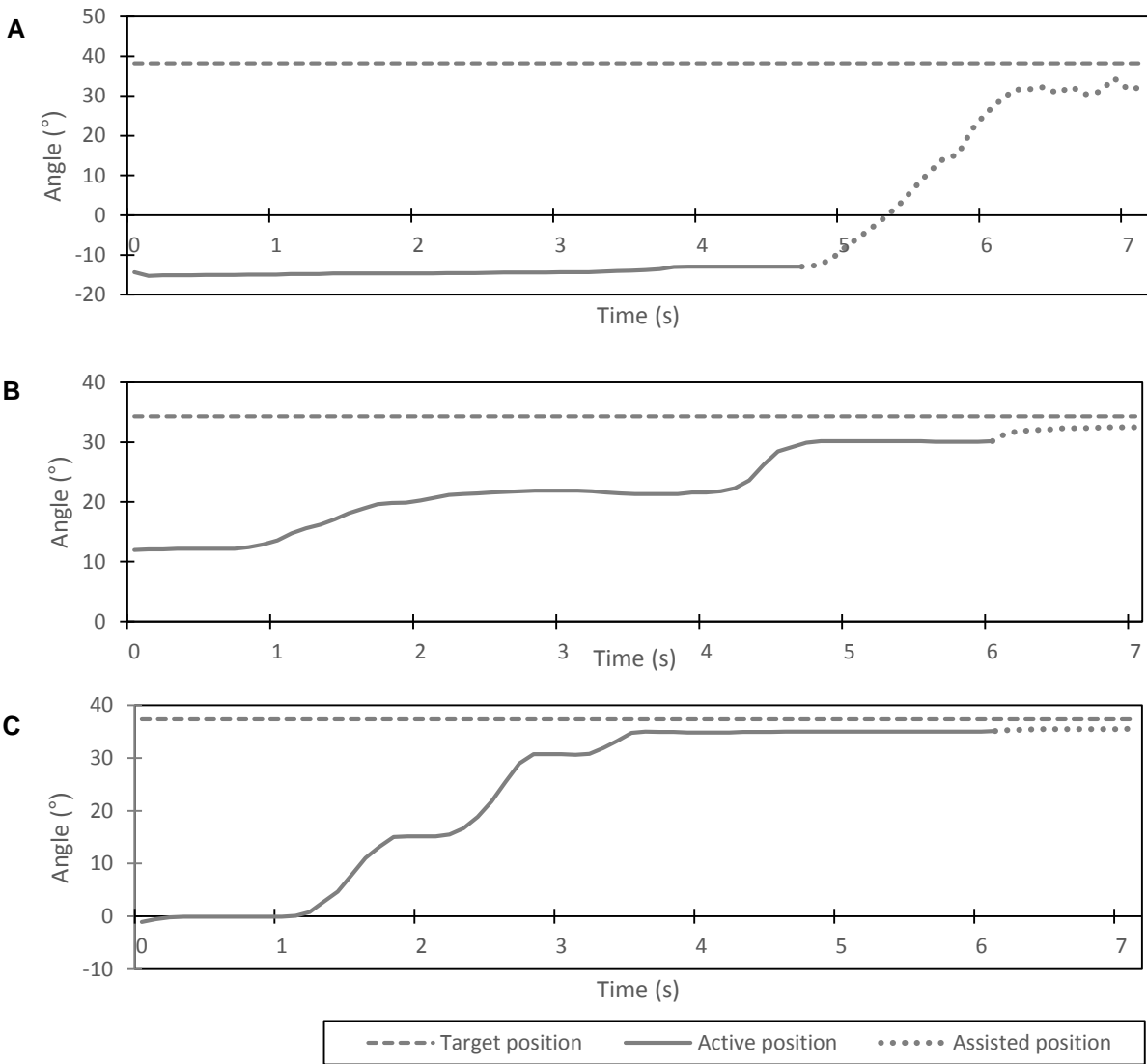


Figure 6 Output response with different patients in assistive mode with an additional 10 degree of their AROM for pronation/supination training (- / +). A, B and C indicated the response of the subject 1, 2 and 3.

Figure 5 shows the output response of passive mode for both pronation/supination and flexion/extension with the subjects according to their PROM. Figure 6 shows the output response of

assistive mode according to the subject current AROM. The training targets were set at 10 degree more than their maximum AROM, the dotted line indicated the assistant given by the robot

to complete the movement with a tolerance of +/- 5 degree if subjects could not achieved the target within a set period of time.

■4.0 CONCLUSIONS

One DOF reconfigurable rehabilitation robot was presented and the preliminary test with different training modes were shown. The robot provide virtual reality game for the patient to train and also provide different training movement of forearm and wrist by changing the configuration of the robot. Several basic functional training movement can be performed by attaching different modular unit on the robot. The parameter of the therapy like training mode, range, speed and duration can be easily customized by the therapist in a set sequence. The preliminary test showed that the device is safe to train and capable to perform passive and assistive training with the stroke patients at different stage with different range of movement. In passive mode, the robot able to move the hand of the patient passively and in assistive mode the robot able to assist the movement of the patient if they could not complete the movement.

However, the preliminary test only limited to three subject, therefore more subject testing are required to evaluate the performance of the device. Further study will be carried to show the effectiveness of the robot to improve the movement of the patient with different modularity and rehabilitation strategies.

Acknowledgement

The authors would like express their gratitude to Hospital Sultanah Aminah, National Stroke Association of Malaysia (NASAM) and Ministry of Higher Education, Malaysia. This work is supported by the Universiti Teknologi Malaysia Research grant [04H66, 06H86], Lab2Market commercialization grant [08906] and Collaborative Research in Engineering, Science and Teknologi Center (CREST) R&D grant [P37C2-13].

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