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ORIGINAL PAPER

Development of the Wrist Rehabilitation Therapy (WRist-T) Device based on Automatic Control for Traumatic Brain Injury Patient

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ABSTRACT

In Malaysia, there are not many physiotherapists (PT) as well as rehabilitation centers. Limb rehabilitation is common in rehabilitation centers which include upper limbs and lower limbs. Generally, for upper limb, wrist, hand and fingers rehabilitation is frequently conducted in the centers by PT. The current scenario in Malaysia for wrist rehabilitation is the PT use conventional method to carry out the rehabilitation procedures. The problem with this procedures, it is time-consuming as the PT need to attend every patient for about 20-30 minutes. This could also lead to exhaustion both to PT and patients. The session can only be done with the assistance on PT, however, there are many patients could not commit to the therapy session due to logistic and domestic problems. This problem can be greatly solved with rehabilitation robot but the current product in the market is expensive and not affordable especially for low-income earners family. In this paper, a novel automatic control of wrist rehabilitation therapy; called WRist-T device has been developed. The novelty of the device is three modes of exercises that can be carried out which is the flexion and extension, radial and ulnar deviation and pronation and supination. By using this device, the patient can easily receive physiotherapy session with minor supervision from the physiotherapist at the hospital or rehabilitation center and also can be conducted at patient home.

INTRODUCTION

Traumatic brain injury or stroke is a common non-communicating disease in Malaysia. It is estimated in 2013 alone, 50000 new cases were reported yearly and keep on increasing every year (Kosmo, 2013). This is due to poor lifestyle especially the eating habit and stress from work. Kementerian Kesihatan Malaysia KKM 2016 Health fact report (2015 data) show overwhelming numbers related to stroke. Accordingly, they were more than 1 million medical rehabilitation was conducted which includes new and old cases (MOH, 2016). This data shows there is a very serious issue related to stroke. Statistically, it is estimated that 50,000 Malaysian suffer from stroke every year and that six Malaysians are hit by stroke every hour; 40 percent of stroke victims experience moderate to severe impairments requiring special care. Another 25 percent of stroke victims recover with minor impairments while 10 percent of stroke victims require care in a nursing home or other long-term care facility (Fact Stroke, 2017). There are two types of stroke which are ischemic and hemorrhagic.

In an ischemic stroke, a blood vessel becomes blocked, usually by a blood clot and a portion of the brain becomes deprived of oxygen and will stop functioning. Ischemic strokes account for 80% of all strokes. A hemorrhagic stroke occurs when a blood vessel that carries oxygen and nutrients to the brain burst and spills blood into the brain. When this happens, a portion of the brain becomes deprived of oxygen and will stop functioning. Hemorrhagic stroke accounts for about 20% of strokes. The fatality rate is high but it is not the current issue for this product development. In this project, it is regarding the survivors of stroke. The stroke is one of the major factors leading to a decreased motor function of the human upper limbs. Such patients are significantly restricted in their daily social and household activities. It is known that an appropriate post-traumatic care and rehabilitation therapy is required for recovering patient's lost abilities and their return to normal daily activities (Bayona *et al.*, 2005; Bonita *et al.*, 1988; Cramer *et al.*, 2008). Normally, this can be achieved through the repetitive and long-term rehabilitation process. Conventional rehabilitation method requires full commitment and with the present of physiotherapists which may lead to exhaustion both for the patient and the physiotherapists (Kwakkel *et al.*, 1999; Holder *et al.*, 1999). A post-stroke rehabilitation process needs to be undergone as soon as possible with the repetitive session.

Nowadays, automated therapy using the robotic platform is a promising part of post-stroke rehabilitation process (Reinkensmeyer *et al.*, 2004). Rehabilitation robotic systems provide intensive motor therapy, which can be performed in a repetitive, accurate and controllable manner (Marchal *et al.*, 2009). There are many variations of robot-assisted devices, some are using soft actuator (Takaiwa *et al.*, 2016; Al-Fahaam *et al.*, 2016; Dauria *et al.*, 2016) and some developed software so it can further assist and improve the rehabilitation process (Dauria *et al.*, 2016; Hsieh *et al.*, 2016; Hacioglu *et al.*, 2016). One of the important parts that affected by stroke is the wrist.

The common exercises include the wrist, strengthening, wrist stretches and etc. The exercises primarily convalesce or enhance the patient's range of motion of the wrist, including wrist flexion/extension, wrist radial/ulnar deviation and pronation/supination movements. Though these natural wrist exercises are helpful for improving hand strength and preventing future injuries, conventional rehabilitation exercise is quite boring, so patients find it tough to regularly perform the exercise, thus delaying full recovery

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(Hsieh *et al.,* 2016). By (Lu *et al.,* 2016), the conventional therapy demands specific medical instruments and occupational therapist, which is not convenient and a huge economic burden for patients. Meanwhile, the assisted robots described above focus on strength training and sensitivity training but neglect the important of neurological rehabilitation.

In this paper, a novel automatic control of wrist rehabilitation therapy; namely WRist-T device has been proposed and the functionality of the device is to be measured. There are three modes of exercises that can be carried out from the device which is the flexion and extension, radial and ulnar deviation and pronation and supination. According to physiotherapist specialist, the most important exercise for wrist is flexion and extension. By using this device, it is not 100% to replace the role of PT but the patient can easily receive physiotherapy session with minor supervision from the PT at the hospital or rehabilitation center. The session also can be conducted at patient home especially for those with transportation problem and those who lived far away from the hospital.

WRIST REHABILITATION

Kinematic of wrist motion

In order to develop the ergonomically comprehensive design, a rehabilitation must obey to natural movements and limitations of a human wrist. The human wrist in combination with the forearm adds up to three-degree of freedom (DoFs). The forearm is capable of flexion/extension, radial/ulnar deviation and pronation/supination movements. The biomechanics of the wrist joint is more sophisticated than the resulting movement of the wrist would suggest. The wrist movements of interest are demonstrated in **Fig. 1** and the subsequent points explain the flexion/extension, radial/ulnar deviation and supination and pronation bending angles. The device was developed with three speed of motion; low, medium, and high and the duration of each training mode is around 15-30 minutes.

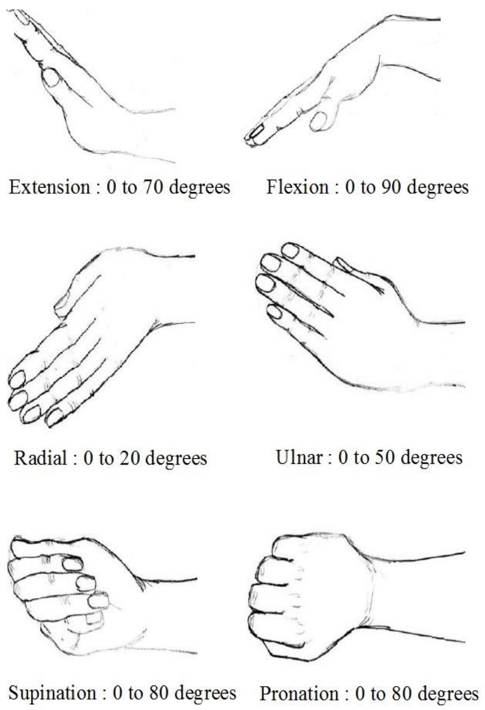

Fig. 1 Range of wrist motion (ROM) for flexion/extension, radial/ulnar deviation and supination/pronation bending angles (Al-Fahaam *et al.,* 2016).

MECHANISM

The proposed device

The general design of present invention of WRist-T device as shown in **Fig. 2**, characterised by: a channel (1) for supporting the wrist; a pair of platform arms (2) pivotally connected to two sides of the channel; a motor (3) operatively connected to each of the platform arms; and a hand support (4) detachably attached to the pair of platform arms, the hand support being constructed to allow multiple hand positions that cooperate with rotation of the platform arms for multiple-degree-of-movement of the wrist.

Automatic control system

The WRist-T device applied an automatic control system. The controller (5) provided with a power button (7) and LCD display (8). When the power button is on, the LCD display starts showing the parameters for setup. **Fig. 3** shows the flowchart of the WRist-T device function.

(a)

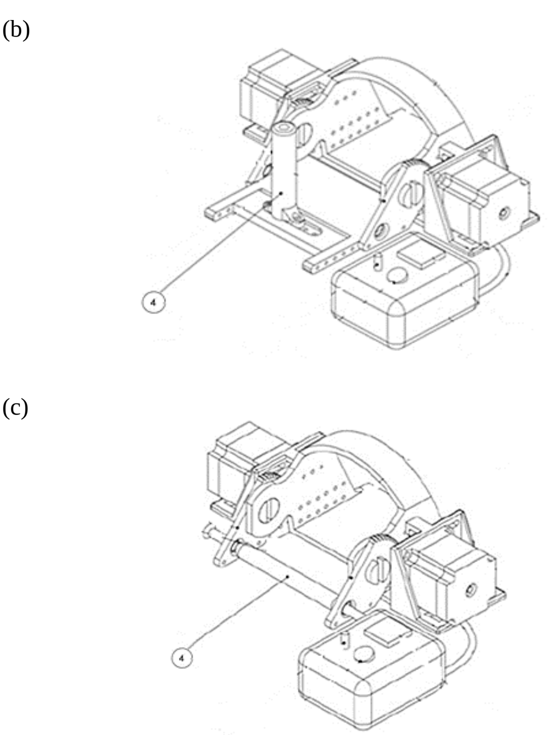

Fig. 2 Illustrated an embodiment of the Wrist-T device. The details of hand support include a). palm rest and finger rest; b). vertical hand grip stand; and c). horizontal hand grip stand. Notes: Description of the reference numerals used in the accompanying drawings according to the WRist-T device; (1) channel; (2) platform arm; (3) motor; (4) hand support; (5) controller; (6) toggle switch; (7) power button; (8) LCD display.

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There are two methods to control the setup. The first one is the toggle switch (6), which sets the parameters manually on central processing unit (CPU). The mode of exercise is selected based on the 30 mechanical assemblies. The next step is the parameter setup. The parameter setup includes session time, speed and time delay, which need to be keyed in before starting the rehabilitation session/exercise. The toggle switch needs to be rotated anti-clockwise or counter clockwise to obtain the desired value and pushed to accept the selected value.

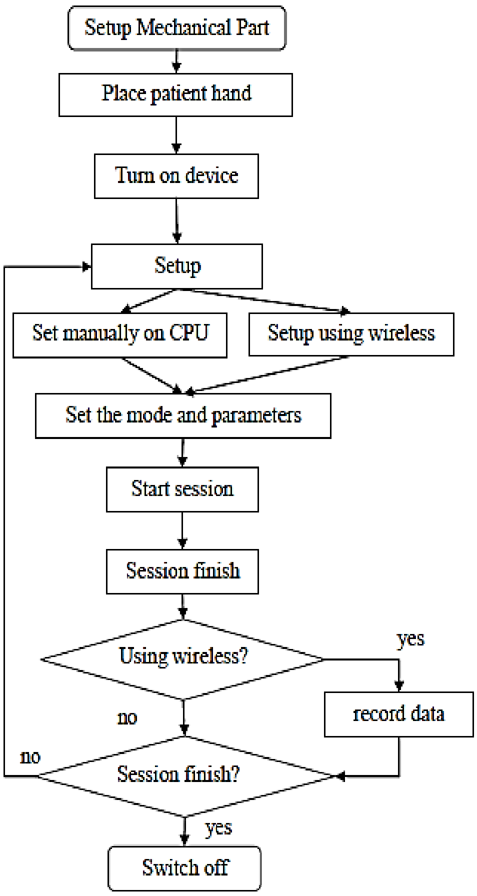

Fig. 3 The flowchart of the WRist-T device function.

The same process needs to be done for other parameter setups. The last push will start the rehabilitation session. After that, the motor will start running continuously and stop automatically when the time for that session ends. The set up can be reset again by a re-pushing toggle switch. The main problem that essentials to be properly addressed is the high impedance of electric motors that can be potentially harmful to patients. This can be simply overcome by executing in advanced of algorithms control.

The second method of setting up the parameters is by using a computer, tablet or a smartphone. The application is developed with a user-friendly interface. After all the setup is done, the application is connected to the wireless device inside the central processing unit (CPU) via Bluetooth or wireless module inside the central processing unit. Once the wireless connection is done, a button inside the application is pressed and the rehabilitation session will take part. Once the session is finished, the CPU will send a confirmation button and the details in the setup such as parameters, session details, and patient particulars then will be stored on the computer or the smartphone.

In wrist rehabilitation, there is a limited range of movements: flexion/extension, radial/ulnar deviation and supination/pronation. The main challenge is to perform all these movements by a single rehabilitation device without any help from a rehabilitation professional. By the WRist-T device, a small, lightweight, portable and easy to use, provides the capability of doing all rehabilitation exercises at home or anywhere instead of in a rehabilitation clinic. **Fig. 4** shows the perspective side view of the WRist-T device in use for wrist flexion/extension, radial/ulnar deviation and supination/pronation.

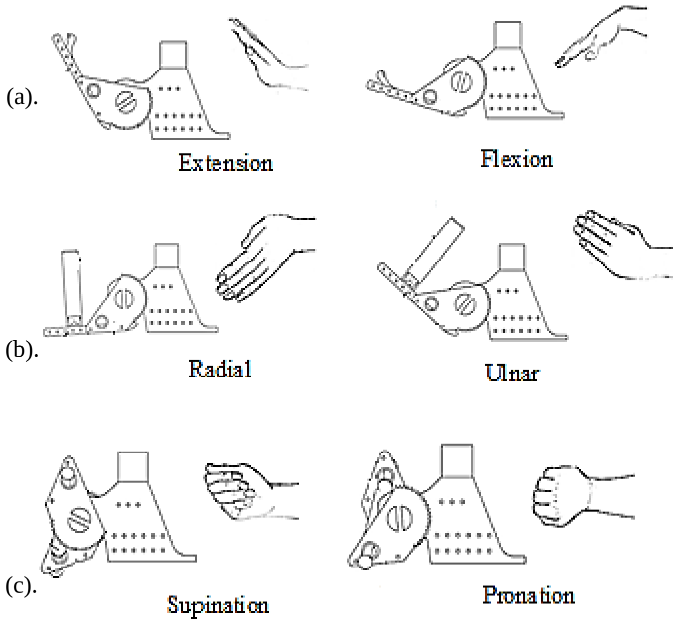

Fig. 4 A perspective views of the device in an embodiment to give a). flexion and extension; b). radial deviation and ulnar deviation; and c). supination and pronation of the wrist.

Device specification

The prototype design is done in the SolidWorks 3D CAD software that allows direct prototyping with 3D printing technology (Zortax M200) as shown in **Fig. 5**. The designed WRist-T device implements mechanical limits preventing the device motions beyond the specified human wrist range of motion.

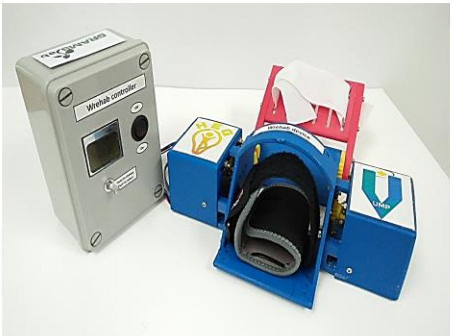

Fig. 5 The structure of the wrist rehabilitation therapy (WRist-T) device.

The initial prototype employs Nema 23 Steppers motors as a joint of the control algorithms. The Arduino Uno microcontroller based on the ATmega328 has been used and sent over a serial interface as a very powerful control mechanism. Moreover, since it is programmed through the open source Arduino Software, this Inertial Measurement Unit (IMU) of 3 DoFs outputs its roll, pitch, and yaw data, characterizing the orientation of the wrist, via serial. We used Arduino IDE to program our code onto the 3 DoF, connecting to the serial TX and RX pins.

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FUNCTIONAL VALIDATION

To validate the functional of the proposed device the first proof-of-concept prototype has been manufactured using 3D printing technology as presented in **Fig. 6**. Preliminary investigation has been completed focusing on evaluating of kinematic and dynamic parameters required for proper functional use of the designed Wrist-T device as shown in **Table 1**. The device well reproduced the subject motion, thus demonstrating repetitive passive therapy action.

Table 1. Functional validation among stroke patients.

Patients	Comfortable	Discomfortable	Good handling	Bad Handling
1	X			X
2	X		X	
3		X	X	
4	X		X	
5		X	X	
6	X		X	
7	X		X	
8	X			X
9	X		X	
10	X			X

Same tests conducted with several stroke patients confirm that the compliant handle link mechanism of the WRist-T device show slight bending to either of the three configurations in **Fig. 4** during active motion. The subjects did not feel any discomfort or applied interaction forces imposed by the device and could freely work with the device.

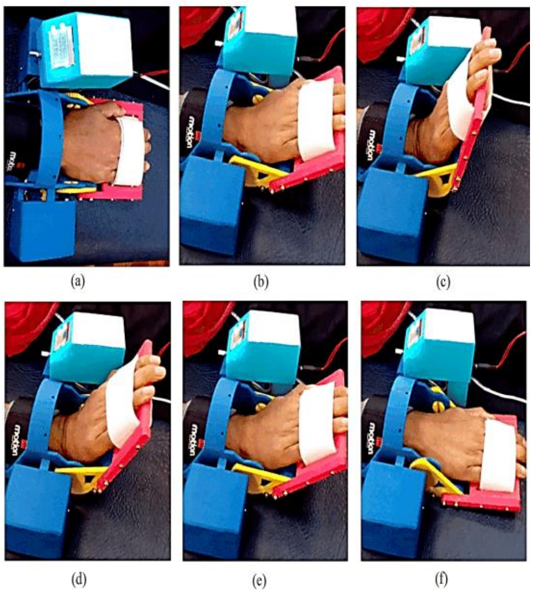

Fig. 6 A 3D printed proof-of-concept prototype of WRist-T device tested by a stroke patient. The (a-f) shows details the example wrist of motion on extension exercise.

CONCLUSION AND FUTURE WORKS

This paper presents the novel of automatic control wrist rehabilitation therapy (WRist-T) device for a stroke patient. The present invention device provides a device which has multiple degrees of freedom. This device also provides a portable, small and lightweight wrist movement.

In overall, it can be confirmed that the proof-of- concept prototype of the WRist-T device meets the imposed design objectives. It offers cooperative and flexible training/exercises among patients.

In the future works, the authors plan to improve the design and functionality of the device, especially for the operation and safety aspects. Moreover, to conduct the clinical study and expand the efficiency of therapy treatments as patients will remain more focused through the frequently extended rehabilitation process. The subjective features like the convenient handle and forearm support will be introduced in the next device.

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