Development of A Low Cost CONTINOUS Motion Machine That Acts Both Active and Passive for Wrist Rehabilitation

Vickneswari Durairajah¹, Suresh Gobee², John Lim Hong Aun³

¹School of Engineering, Asia Pacific University, Malaysia; ²School of Engineering, Asia Pacific University, Malaysia; ³School of Engineering, Asia Pacific University, Malaysia;

Email : ¹Vicky_nesa@apu.edu.my, ²Suresh.gobee@apu.edu.my, ³johnny1921@gmail.com

https://doi.org/10.26782/jmcms.spl.4/2019.11.00006

Abstract

The aim of the project is to rehabilitate the wrist of a stroke patient for three different wrist movements. The system developed is a continuous motion machine that has both active and passive motion mode which has three rehabilitation modes. The method used to solve this is to have a modular design that is able to be configured easily to different rehabilitation modes. The developed system has a position sensor, a motor and a controller. The outcome achieved by the overall system is 70%-90%. The flexion and extension mode is able to achieve an accuracy of 70%-90%, radial and ulnar is between 70%-85% and supination and pronation and is between 65%-85%. The limitation of the system is the angle sensor which has a non-working area, the precision of the angular movement of the motor varies from the system and the mounting mechanism of the motor has some stability issues. The future works of the system is to have a stepper motor with precise angle movement, better motor mounting mechanism to increase stability.

Keywords : Wrist Rehabilitation, Android Application, Passive Motion Rehabilitation, Active Motion Rehabilitation, Wrist Motions

I. Introduction

One of the all-time global health concerns is the rising number of people who suffer from a stroke. Stroke is also one of the well-known causes of disabilities. Annually approximately 15 million people suffer from a stroke whereby 6 million suffer death and 5 million suffer from total permanent disability [I]. The remaining 4 million who are recovering from a stroke may face some form of disability, and these people stand a chance of recovering most of their bodily functions if rehabilitation is done appropriately and within a curial time period. It is found that 77% of people suffering from a stroke face upper limb or arm weakness [II]. This study is aimed towards these people who are trying to get rehabilitated from their disabilities. This study will mainly revolve around designing and developing a system that is able to rehabilitate people who suffer from wrist impairment or wrist nerve damage due to a stroke. Although there are many other parts of the human body that can also suffer from disabilities due to a stroke, this system is targeted to the people who suffer wrist
impairment due to the fact that upper limb and arm weakness is one of the most commonly affected areas when a stroke occurs. When faced with disabilities such as wrist impairment, physiotherapy is needed in order to rehabilitate the wrist. However, with the wonders of technology today, many devices and system have been created in order to aid rehabilitation. The technology used is an integration of many different sectors such as robotic engineering, biomedical, computing and much more. The current available solutions for wrist and arm rehabilitation is commonly known as continuous passive motion machine also known as CPM in short. There is a wide range of CPM machines on the market, all having different features and functions, however these machines generally cost a hefty amount and are not very affordable.

II. Background

In order to design an optimized design for this application, there has to be an understanding on how the human wrist working. The crucial aspects for this application would be the type of movements the wrist has to perform on a daily basis to go about their daily routine. Another important factor to consider is the angle of motion for each of the wrist movements and in cooperate it into the system, this will help the user improve their mobility and also to ensure the system does not injure the user. In addition to that, is the type of motion that will be introduced into the system, a motion that forms part of the rehabilitation that is commonly used in physical therapy and motions that have also be used in another rehabilitation devices.

Type of Motion

1. Active Motion

Active motion is defined as a motion or action that is done by a person voluntarily without any external force [III]. Passive motion is defined as a motion or action that is done by a person with the aid of an external force [III].

2. Passive Motion

For rehabilitation devices, a passive motion machine will aid the patient by helping them move their wrist by using an actuator such as a motor, pneumatics or pistons. Active motion machines on the hand, will provide the patient with active resistance or force feedback, force feedback is a tangible simulation of a force that opposes the user or represent the hardness of an object, weight and inertia [IV].

Wrist Movement

1. Extension and Flexion

The vertical bending wrist movement known as extension and flexion as shown in Figure 1. Extension of the wrist when it bends upward and flexion of the wrist when it bends downward, when this movement is performed, the angle between the palm and forearm changes.
2. Radial and Ulnar Movement

The horizontal tilting movement from side to side of the wrist known as radial and ulnar as shown in Figure 2. Radial and ulnar can also be classified as adduction and abduction. When the wrist is tilting towards the thumb side it is known as radial movement and when the wrist is tilting towards the little finger it is known as ulnar movement. In this movement the wrist is at a fixed point whereas the angle of the palm changes from left to right in a horizontal motion.

3. Supination and Pronation Movement

The wrist and forearm rotation movement pronation and supination as shown in Figure 3. When the wrist and forearm rotates to the position whereby the palm is facing down it is known as pronation, and when the wrist and forearm rotates to the position whereby the palm is facing up it is known as supination. When this movement is performed the forearm, wrist and palm are all in a fixed position whereby the forearm, wrist and palm rotates together.
Table 1 shows the range of motion which is required in everyday living to perform daily tasks. The device is configured to operate within these ranges to help wrist impairment users rehabilitate their wrist. The user is able to select the angular movement of the device to enable it to incrementally increase the angular movement to slowly rehabilitate their wrist without further injuring them.

| Wrist movement       | Average range of motion (degrees) |
|----------------------|-----------------------------------|
| Extension Flexion    | 60°                               |
| Radial Ulnar         | 20° 30°                           |
| Pronation Supination | 80° 90°                           |

### III. Methodology

#### User Approach

Figure 1 shows the methodology from a user’s standpoint, whereby this is the process the user will go through when performing their rehabilitation using this device. Before the rehabilitation can begin, the user will first have to select which wrist which can either be for the right or left wrist, the type of motion which is either active motion or passive motion, the type of rehabilitation which is the three different types of wrist movements: extension and flexion, radial and ulnar or supination and pronation. After all the appropriate selection is done, the user will then have to enter the angle of rehabilitation, which translate to the amount of angular movement the user would like, this angular movement will depend on how much mobility the user has in their wrist, the user can increase the angle in increments as the user’s wrist gains more mobility.

The device will then proceed to move its initial starting position which varies depending on the selections the user has selected. The initial position is dependent on which wrist and which wrist movement is selected. The will then place their hand on the device after the position is initialized, the device will the proceed with the 1st motion and the 2nd motion, once the motions are completed the device will stop and the rehabilitation session is completed as shown in Figure 1.
Device Approach

Figure 2 shows the flowchart that will be used in the design of this system. When the user starts the device, the device will prompt the user to select which hand he/she would like to rehabilitate. If the left hand is selected the motor will rotate the handle 180° to switch the orientation of the handle, if right hand is selected the device will perform any movement as the default orientation is set for right handed use.

The device will then prompt the user to select which type of rehabilitation mode they would like to perform which can either be passive mode or active mode. After selecting which mode, the device will then prompt the user to select which wrist rehabilitation motion they would like to perform which are Extension/Flexion, Ulnar/Radial or Supination/Pronation. The device will then prompt the user to place their hand into the handle and move their wrist to the maximum of their capability, the angle of which the user was able to achieve is stored into variable which is known as “User’s limit”. If passive mode was selected 5° is added to the angle achieved by the user and if active mode was selected 5° is subtracted from the angle achieved by the user, the final value is then stored into a variable which is known as “Set Target”. The rehabilitation now starts, if passive mode was selected the device will assist the user to reach the “Set Target” and if active mode was selected the device will resist...
the user’s movement to reach the “Set Target”. If the set target is reached the device will stop the training process and prompt the user to either set a new limit or continue their training session, if the set target is not reached the training session will continue until the user presses the stop button. At any given time during the training session if the stop button is pressed, the device will stop all motor movement as a safety feature, a torque limit will also be placed into the system to prevent the user from getting hurt.

3D Design
The overall concept design of the system is shown in Figure 3. The design in cooperates Modular design to enhance the usability aspect. The design is incorporated with the adjustability function that enables the device to be use on both the left and right hand.

![Fig. 3. The Overall System](image)

Extension and Flexion
Figure 4 shows the device in Extension and Flexion mode after being fully assembled. The entire device is mounted on an aluminum profile structure to act as a counter weight so the device will not tip over when extensive force is being placed on the device.
Radial and Ulnar

Figure 5 shows the Radial and Ulnar configuration, this configuration can be achieved by simply rotating the gripping handle from the previous extension and flexion configuration.

Pronation and Supination

Figure 6 shows the Pronation and Supination configuration, this configuration can be achieved by removing the shaft section of the device and attaching the gripping handle straight to the motor hub section.

Mobile Application

The mobile application will allow users to control the different rehabilitations modes and perform monitoring on the key information of the device. The user is able to select different rehabilitation modes and enter different rehabilitation angles, which is shown Figure 7.
The user will have to select which hand they would like to rehabilitate which has to be either left or right hand, if two hands are selected together the application will prompt the user with an error message. Similarly, the user can only select either active or passive mode and only one of the rehabilitation modes, if more than one of those options are selected the application will prompt the user with an error message. The Monitoring section of the application will display the target angle, which is the angle the user has selected for rehabilitation, the current found in Figure 8.

IV. Results and Discussion

A number of terms has been used when explaining and elaborating on the results and findings of this device. Those terms will be explained below for easier understanding of these terms.

Target Angle:-refers to the angle that the user has defined for rehabilitation, the device will move according to the target angle the user has set.
Stopped Angle:-is the angle at which the device stopped at after the rehabilitation is complete. The Stopped Angle is measured using the sensor that is placed on the device.

Actual Angle:-is the real angle the device stopped at after the rehabilitation is complete. This angle is measured using a protractor that is placed on the exterior of the device.

Current:-is the maximum current that is drawn from the motor while the user was performing the rehabilitation. This current is measured using the current sensor that is in the motor controller.

Testing Mode

In passive mode, the device will assist the user in moving their wrist to the target angle, which is 20°, 30° and 40° for flexion & and extension, and radial & ulnar. Whereas, for supination & pronation the target angles will be 10°, 20° and 30°. While in an active mode we are testing whether the DC motor is able to produce the appropriate amount of current to supply the torque needed for this rehabilitation. In addition to that, to test whether the user is able to overcome the force of the motor when performing this rehabilitation and to observe whether the motor will stop after the user passes the current limit.

The results obtain for the system which can be used both left and right hand for both active and passive mode are as shown in Figure 9 – Figure11. The results are obtain from 7 test subject.

No load Accuracy

Figure 9 shows the results of the no load test in passive mode. As shown in the figure, the left hand pronation and supination angle may be inaccurate but this may be due to a number of factors, in pronation & supination mode there tends to be and offset whereby, the default position is not exactly at 0° and with the slight change in angle of 20° there change in angle may not be very noticeable. With there being no load, the active mode results should be similar to the passive mode results, as passive mode will perform identical to active mode when there is no load present in terms of angle accuracy.
Passive Mode Accuracy

![Fig. 10. Overall Accuracy Passive Mode](image)

Figure 8 shows the overall accuracy of all the subjects after performing the whole suit of rehabilitation motions. The averages of all the rehabilitation modes and rehabilitation motions coupled with different settings have been recorded and averaged to the results you see above. The average accuracy for all subjects is between 70% - 82%. This shows that the average accuracy of this device is between 70% - 82% as shown by performing varies test.

Active Mode Accuracy

![Fig. 11. Active Mode Accuracy](image)

Figure 11 is use as comparison for subject 2 and subject 6 doing active mode rehabilitation with a current limit of >1200mA. It can be analyzed from the results seen that subject 2 is able to pass the current limit much quicker than subject 6, at some points subject 6 reaches the target angle as well. Reason being subject 2 is a male in his 20’s and subject 6 is an older 58-year-old individual, subject 2 being younger and stronger allows him to overcome the force of the motor easily whereas subject 6 finds it more difficult as an older female individual.

V. Conclusion

In conclusion, the major contribution in this project is by integrating active and passive functions together on the same device. Most researches only have one or the other both not both integrated into one device. The passive mode adds another layer of functionality to rehabilitation. The device not only assists the user in helping them...
move their wrist but as a user gets more functionality in their wrist, the can use the active mode as a strength exercise to resist the movement of their wrist forcing them to push against the force of the device. Integration of a mobile application for monitoring and settings also is another contribution in this project.

The user does not need to have a computer or laptop nearby, with only their smartphone which many people already own, they can download the wrist rehabilitation application which allows them to perform the rehabilitation and monitoring all from their mobile phone. This not only allows for better functionality but a better more user-friendly interface.

Therefore the system has able to assist in the rehabilitation for both right and left hand for both passive and active mode with mobile monitoring/ controlling with an overall accuracy of varying between 70% -90%

References

I. Bouzit, M., Burdea, G., Popescu, G., And Boian, R. (2002). The Rugers Master II - New Design Force Feedback Glove. Ieee/Asme Transactions On Mechatronics, 7(2). P. 8.

II. Anon., 2015. Stroke Association. [Online], Available at: https://www.stroke.org.uk/

III. [Accessed yuesday May 2017].

IV. Wayne, J. (2005). Mosby's Dictionary Of Complementary And Alternative Medicine. Michigan: Elsevier Mosby.

V. Ormarkulov, N., Telegenov, Kuat., Zeunullin, Maralbek, Z., Illiyas, T. And Shintemirov, Almas. (2016). Preliminary Mechanical Design Of Nu-Wrist: A 3-Dof Self-Aligning Wrist Rehabilitation Robot. Biomedical Robotics And Biomechatronics (Biorob). 26th - 29th June 2016. Pp. 6.

VI. Beekhuis et al., J. H., 2013. 2013 IEEE International. Design of a self-aligning 3-DOF actuated exoskeleton for diagnosis and traning of wrist and forearm after stroke, p. 6.