FOREARM ROTATION DEVICE: RELEARNING SUPINATION AND PRONATION THROUGH REPETITIVE MOTION REHABILITATION TRAINING

Ali Taylor, Adissa Silue and Kaitlyn Lafferty
Senior Design Advisor: Dr. Peter S. Lum

Dept. of Biomedical Engineering, The Catholic University of America, Washington DC, 20064

Abstract- **Stroke is the third leading cause of death in America and there are approximately five million stroke survivors living in the United States today. There are several consequences of stroke: memory loss, speech impairment, and temporary/long-term paralysis. Stroke patients often develop a "learned disuse" post-stroke in their injured limb. The goal of this project is to design, fabricate and test an innovative forearm supination device for home-based exercise by chronic stoke patients who have weakened forearm muscles.**

I. INTRODUCTION

Stroke is a cardiovascular disease that affects the arteries to and within the brain. When a stroke occurs there is a lack of sufficient blood flow to the brain, causing cells to die. Stroke is the third leading cause of death in America and there are approximately five million stroke survivors living in the United States today. There are several consequences of stroke: memory loss, speech impairment, and temporary/long-term paralysis. Stroke patients often develop a "learned disuse" post-stroke in their injured limb. Consequently, the muscles that are no longer exercised become significantly weakened and the patient can no longer complete motions that were once simple. There are many devices currently on the market that are for hand rehabilitation, but few for forearm supination rehabilitation. Forearm supination and pronation rehabilitation is critical in restoring the quality of life for stroke survivors, i.e. target end-users.

There are few existing products that deal with forearm rehabilitation for patients affected by stroke. A majority of these devices are hand held and custom made for labs, though there are some commercially used devices. One is the HapticKnob, which is a 2 degree of freedom robot developed at the National University of Singapore. It is designed to train hand grasping and forearm pronation/supination. Another device used at the Mayo Clinic (Rochester, MN) measures torque strength. Finally, the ARMin II® is a commercially used device designed to investigate the effects of intensive arm training on motor performance. Some advantages of these devices are that they are active (utilizing motors), supportive of the entire arm, and fluid in motion. However, several disadvantages of these devices are that they are not portable, which decreases the rehabilitation time, some are not user friendly, and some force patients to grasp a shaft, which can be a difficult action for stroke patients.

II. DESIGN GOALS

After researching the effects of stroke and reviewing the existing literature, it was concluded that the problem lies within stroke patients who suffer from temporary arm/hand paralysis who develop a "learned disuse" in their injured arm and consequently have weakened forearm muscles.

In studying existing forearm exericse devices and current rehabilitation techniques, it was found that there is a strong demand for a forearm supination device to assist patients in performing repetitive supination/pronation rehabilitation training. Thus the goal of this project is to design and develop an innovative forearm supination device to facilitate home-based forearm exercise in stroke patients.

III. DESIGN CRITERIA

The design criteria that were evaluated were the: weight, precision/accuracy, aesthetics, safety, portability, and user-friendliness of the device. A thorough and systematic design process and evaluation (i.e. rank order) was conducted and identified critical, important and desired criteria for the proposed design.

Critical components included safety, precision, and weight with total scores of 4.5, 3.5, and 3.5 respectively. Safety is a critical consideration since stroke patients will use this device. In order to ensure safety, the device will have 0.5 inch thick padding on all areas of the arm that the device comes into contact with to avoid cuts and abrasions. The second critical consideration is weight. Since the patient will wear the device, it needs to be equal to or less than five pounds so that the patient can carry and wear the device comfortably. This weight was determined through a survey conducted at Senior Center. The last critical design consideration is precision/accuracy. In order to ensure that the device is performing the correct rotation from 0-90 degrees, a flat coil potentiometer will be used.

Important design components include portability, comfort and usability. Portability is an important design consideration; the device will be used in both hospital and home settings so that rehabilitation can continue after the patient returns home. The device should be user friendly, which is an important design consideration. Patients should be able to attach and detach the device to their arm independently. Velcro straps around the hand, forearm, and bicep will secure the device to the patient.

Aesthetics is a desired design consideration. Since the goal is for the patient to wear the device daily, the device should aim to be aesthetically pleasing for the patient.

Quantitative specifications are summarized in Table 1.

Table 1: Device Specifications

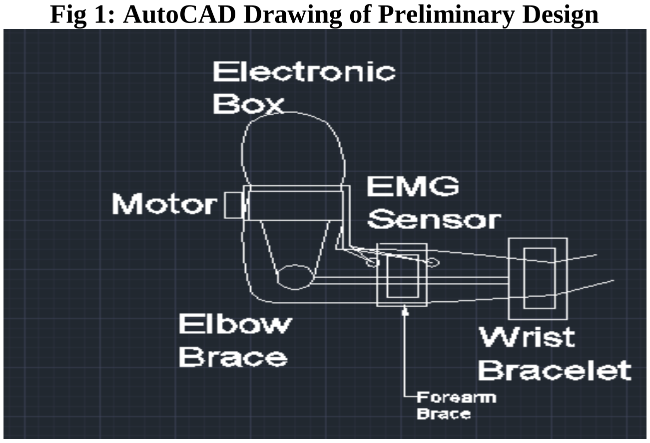
Description	Specification
Target weight for entire design	≤ 5lbs
Padding thickness for patient comfort	≥ 0.5in
Metal Bars: Aluminum	Area = 4 x 1 in
EMG sensor: Noraxon-Dual-Electrodes©	Area = 4 cm x 2.2 cm
Over-Extension Safety Features	Max 90° of wrist rotation
Constant force spring: stainless steel	~2 lbs
Bourns Potentiometer: 10 turns	Resistance : 50-200 ohms
Arm-bed and Track- 3D printer hard plastic	Arm-bed (diameter): 4 in Track (diameter): 5 in Rotation : 90

IV. DESIGN IMPLEMENTATION

A. Initial Concept Generation

A preliminary concept design (Figure 1) was generated which was portable with an elbow splint exoskeleton for forearm supination and pronation, and EMG electrodes located at the patient's supinator muscle for sensing muscle activity. The patient would exert their max force to rotate the forearm. Once that force was determined, it would be used as a threshold and used during rehabilitation training. During rehabilitation, the patient would strive to rotate the forearm outward. Once the muscle activity reached the predetermined threshold a motor would be triggered and the device would assist the patient in supination of the forearm. The goal was to double the patient's original threshold needed to trigger the motor; this signified that the patient was stronger post-training.

Fig 1: AutoCAD Drawing of Preliminary Design



However, this preliminary design was too ambitious to accomplish in one semester because the integration of the motor. In discussions with the project advisor, the design was modified to a passive device, utilizing springs rather than motors. Aside from the complexity, further analysis of the preliminary design resulted in more issues such as the monitoring muscular activity with the EMG and lack of arm mobility during rehabilitation training. It was discovered that the EMG would trigger the device to rotate when the patient would flex or extend his/her arm, resulting in a safety hazard. As a result, the EMG will only measure the muscle activity pre- and post-training to monitor progress in the patient's muscle strength.

B. INITIAL PROTOTYPE

A physical prototype was built in order to visualize steps needed to be accomplished to build a passive device. The prototype incorporated an exoskeleton arm-brace with an elbow hinge, allowing for 180° of arm rotation, semi-circle track for forearm rotation, and a spring located near the wrist to provide constant tension. A potentiometer was integrated with the spring mechanism to measure rotational displacement. EMG sensors will be added to the exoskeleton design to monitor the force that the patient applies to rotate his forearm as well as the progress of the patient.

For the prototype, a constant-force spring was selected because of its size and mechanism. As the patient rotates his/her arm, a constant force will be exerted on the device, which can be increased or decreased by changing the spring according to the patient's needs. As previously stated, a string potentiometer measures the displacement of the arm. For the project, a potentiometer which was less than 3 in by 3in and inexpensive was needed. Because a potentiometer with these specifications did not exist, a string potentiometer and constant-force spring was developed.

C. Material Selection

When the design of our device changed from active to passive, the initial materials did as well. Originally, an aluminum design was envisioned for the whole device. For strength The main material for the elbow brace was replaced with thermoplast, 3D plastic for the arm bed and track, and aluminum metal rods to link the elbow brace to the track.

D. FINAL PROTOTYPE

Following development and testing with the initial prototype, a revision was designed using SolidWorks (Figure 2). The arm-brace was made out of thermoplastic, the expandable bars out of aluminum, the track and arm-bed out of the 3D printer plastic, and the spring potentiometer out of wire, a potentiometer, and constant-force spring.

The arm-bed and track was custom designed and fabricated using a 3D printer shown in Figure 2. Finally, the 3rd device that we printed seen in Fig.4 and Fig.5 for the arm-bed and track respectfully was scaled down to 70% of the original SolidWorks dimensions. Tracks were added on all sides of the arm-bed that come into contact with the track in order to reduce friction by using 1/16 inch steel ball bearings.

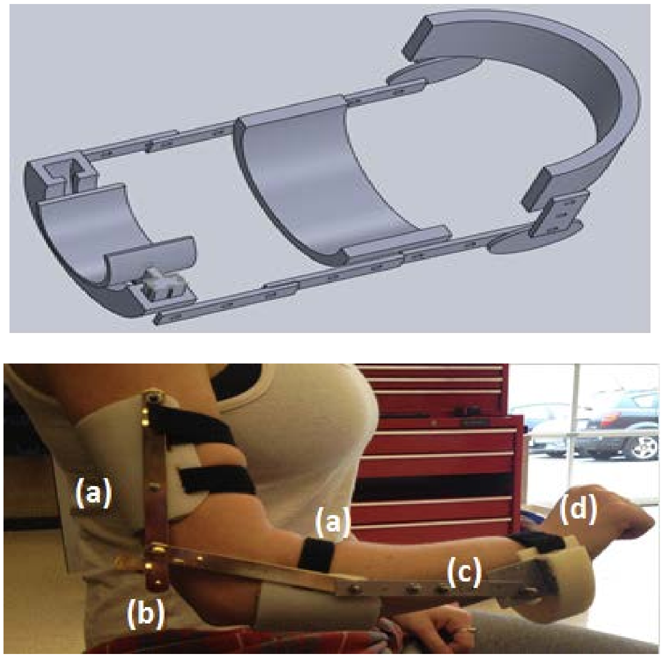


Figure 2: Concept drawing and final prototype shown below. Arm-brace, track, and arm-bed with expandable bars, bicep and forearm brace (a) connected by an elbow hinge (b), aluminum bars (c) connecting brace to track and arm-bed (d)

The spring force needed to rotate the forearm was theoretically calculated to be 2-4lbs. However, when a 2lb spring was used, the force was still too great to overcome to rotate the forearm back to the neutral position. Thus, a 1.12lb spring was used in the design which generated enough tension to rotate the forearm, but allowed the user to rotate her arm back to the neutral position during testing.

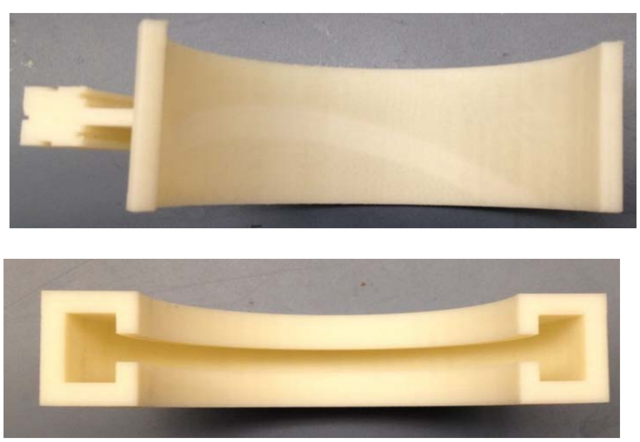


Figure 3: Arm-bed used in device (top) and mating track (bottom) for arm wrist rotation. Components were fabricated using a 3D printer.

The spring force needed to rotate the forearm was theoretically calculated to be 2-4lbs. However, when a 2lb spring was used, the force was still too great to overcome to rotate the forearm back to the neutral position. Thus, a 1.12lb spring was used in the design which generated enough tension to rotate the forearm, but allowed the user to rotate her arm back to the neutral position during testing.

E. INTERFACE DESIGN

The computer system interfacing with the hardware device was a coded MATLAB Pong Game that will be used for rehabilitation. The patient plays the game and has 5 tries to block the ball from entering the goal, while performing supination and pronation movements. The end of the 5 tries signifies the end of one rehabilitation session.

The game was coded to be played like a regular one-player Pong Game. During rehabilitation, the patient places his forearm in the device. Then, with the supination and pronation movement of the forearm, the patient will be able to control the movement of the paddle and play the Pong Game. To allow the patient to control the movement of the paddle, the spring potentiometer, which is placed on the device and connected by a string to the arm bed of the device, will be connected to an Arduino Leonardo board. The Arduino Leonardo board, which already has an embedded program that allows it to take control of the mouse on any computer, will be coded to first recognize if the patient has performed a supination movement and move the paddle to the left. If the patient has performed a pronation movement, then the paddle will be moved right.

The Pong Game code is divided in 8 major functions; mainLoop, createFigure, newGame, moveBall, movePaddles, refreshPlot, checkGoal and close(fig). The mainLoop function calls all the subfunction using a while loop, which runs the program code continuously until the figure is closed. The createFigure function sets up the main program figure, plots the ball, walls and paddles and is called once at the start of the program. The newGame function resets the game to starting conditions, which are the placement of the paddle and the placement of the ball at the point of origin, in the middle of the court. This function is called from the mainLoop at the start of the program, from the keyleft when the user hits the ‘r’key, and from the checkGoal function after someone wins. In this newGame function, the velocity of the paddle movement is set to zero when the game is called and when the game is reset, as well as displays an intro message when the game is paused. The moveBall function is called from the mainLoop on every frame, calculates the location of the ball when it moves, checks if it will hit the wall or the paddle. If the ball hits the wall or the paddle, it will bounce back. Then, after the ball has bounced back, the function will then acquire the new location of the ball. The movePaddles function determines the location of the paddle on every frame, and uses the paddle velocity to set the location of the paddle when the function is being called from the main loop. The refreshPlot function is called from the main loop, sets the data (x-axis,y-axis) in plots, draws the plots using matlab's drawnow, and creates the animation frame, while the embedded resetGame function resets the ball location and the paddle location. The checkGoal function checks the ball's position to see if it passed through the call, updates the score and sees if the first session is over. If the first session if over, the game is paused, displays a thank you message and calls the newGame function, but if the session is not over, the checkGoal function calls the resetGame function to reset the location of the ball and paddle after every try till the 5 tries are over. The close(fig) function closes the whole game when the 'q' key is pressed.

MICROPROCESSOR CONTROLLER

The Arduino Leonardo is a microcontroller board interfacing between the device and Ping Pong game. In addition to having 20 digital input/output pins, a 16 MHz crystal oscillator, a micro USB connection, a power jack, an ICSP header, and a reset button, it also has a built-in USB communication, eliminating the need for a secondary processor. This allows the Leonardo to appear to a connected computer as a mouse and keyboard, in addition to a virtual (CDC) serial / COM port.

For the scope of this project, the Arduino Leonardo board was coded to first recognize if the patient has performed a supination movement and move the paddle to the left, and if the patient has performed a pronation movement, then the paddle will be moved to the right. To do so, we first initialize the serial communication at 9600 bits per second, and then we set with digital pin we are going to get the signal out of. After the digital pin has been determine, the void loop () is created that reads the current value that the potentiometer emits through the analog pin, then an 'if statement' is implemented to use the voltage value gotten from the analog pin to move the paddle. This is done by taken the current voltage value and comparing it to the previous one. If the voltage value difference is greater than zero, the Arduino Leonardo board instructs the computer to press the left arrow key, moving the paddle to the left when the game is playing. If the voltage value difference is less than zero, the Arduino Leonardo board will instruct the computer to press the right arrow key, moving the paddle to the right.

The schematic of the process begins when the string connected to the spring on the potentiometer is pulled by the patient during rehabilitation (Figure 4). The potentiometer is connected to the Arduino Leonardo, which is then connected to the computer. When the potentiometer is connected to the board, the Arduino code is uploaded to the board. Then, the board is then connected to the computer. When the MatLAB code is launched, the Arduino board will take control of the keys and the game will be played

PATIENT MEASUREMENTS

The ability for the patient to rehabilitate is essential but so is monitoring the progress of the patient. In order to monitor the progress of the patient, a pre-rehabilitation exercise will be run where the patient will be asked to rotate their forearm as far as he can. The displacement of that rotation, determined by the potentiometer, will be converted to degrees to measure forearm rotation. This will be performed before every session to determine if there is an increase in the degree of rotation post and pre-rehabilitation training. Since, the maximum voltage output will correspond to a maximum degree, the voltage output detected by the Arduino multiplied by the maximum degree and divided by the maximum voltage to compute degree of rotation performed by the patient. A second method to monitor the progress of the patient will be by placing EMG sensors on the pronator and supinator muscles of the patient. While, the patient is engaging in the rehabilitation session, the EMG sensor will record the force emitted by the muscles for the duration of the session. The force emitted will be graphed for each session but its average will also be graphed to show clear progression.

A sample signal trace from the prototype device is shown in Figure 5.

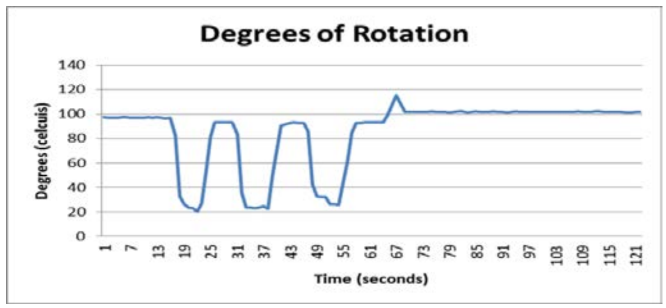


Figure 5: The data collected from rotating the forearm during 3 consecutive trials with the assistive device

VIII. DESIGN EVALUATION

From preliminary test measurements, the device successfully met the design specification and goals that originally set at the beginning of the semester. The device weighs a total of 3.8lbs, fulfilling our under 5lb limit. The padding is 1.2in thick on the wrist, and 0.5in on the forearm and bicep brace, also fulfilling our design specifications. Lastly, the device rotates the forearm 89° ± 3° compared to the original specification was 90°.

IX. FUTURE IDEAS

Future improvements to the system include making our device completely portable using a wireless connection between the potentiometer and Arduino Leonardo Board. Another modification would be to implement an easy way to interchange springs to fulfill the needs for different patients and to improve the connection between the spring potentiometer and Pong Game output. Lastly, the spring potentiometer should be enclosed as an added safety precaution.

NOTE: A video of the device's function can be seen at: http://youtu.be/ROO9eK1ft_s