Automated Convenient Ankle Mobilizer for Therapeutic Intervention

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Abstract

Background: Ankle spasticity is more common in children with CP spastic diplegic. Different types of stretching methods utilized to relieve ankle joint spasticity. Passive hand stretching administered by the therapist is the most common management in ankle spasticity. For availing therapeutic intervention, the parent of such children frequently visits the rehabilitation centre that put financial and psychosocial burden. In order to reduce burden and encourage home based therapeutic intervention an attempt was made to devise mechanical device. This newly designed mechanical device can be an alternative Assistive Technology device for the management of ankle spasticity in such children. Automated Convenient Ankle Mobilizer worked with motor driven ankle mobilizing unit in a controlled manner.

Aims: The goal of the study is to improve positioning and provide therapeutic advancement in spasticity reduction in subject with ankle spasticity.

Methodology: The enclosure having electronics components attached at the lateral side of the pre-tibial shell and servomotor at the anterior side of the pre-tibial shell of the AFO. The control cable is used to perform & control stretching activities. One end of the cable is attached at the shaft of the servomotor and the other end is attached at the anterior part of the foot shell. In 'ON' mode the servomotor starts pulling the foot part upward as well as downward with the help of control cable as per the programming done in an arduino UNO board. So, the stretching process continues without any other assistance.

Discussion & Conclusion: In this study, the automated convenient ankle mobilizer device allows the user & care giver to do a stretching exercise by themselves without any assistance from therapist. It can also reduce therapist effort to do an exercise for reducing spasticity. It reduces the repeated & frequent visit at therapy centre. The automated convenient ankle mobilizer prototype deign can provide controlled ankle mobilization for therapeutic intervention; it will reduce the hyper tonicity of affected muscles. However, as it is a prototype development so this study found no evidence for the reliability or accuracy of ankle stretching or mobilizing of ankle, an area ripe for future research.

Keywords: Ankle Mobilizer, Ankle Spasticity, Spastic Cerebral Palsy, Stretching Exercise, Therapeutic Intervention

I. Background: Cerebral Palsy (CP) is a non-progressive disorder which consists of impaired motor function secondary to injury of the immature brain. Two factors related to the impaired motor function are spasticity and muscle weakness. Spasticity has been characterized in a variety of ways including: muscle hypertonia, hyperactive deep- tendon reflex, clonus, and velocity-dependent resistance to passive stretch. Recently, an objective measure characterizing spasticity as a velocity-dependent resistance to passive stretch has been reported for the knee flexors. While there are many subjective reports about spasticity in children with CP, few investigations objectively quantify spasticity as a velocity-dependent resistance to passive stretch.
Physical therapy, occupational therapy and different type of spasticity reduction orthosis play significant roles in the management of spasticity. A number of interventions with vastly different proposed mechanisms

have been and continue to be utilized to decrease spasticity.
Spasticity has been defined as "a motor disorder characterized by a velocity- dependent increase in tonic stretch reflexes (muscle tone) with exaggerated tendon jerks, resulting from hyper excitability of the stretch reflex, as one component of the upper motor neuron syndrome.
There have been few reports on ankle stretching machines. Zhang et al. (2017), Zhou et al. (2016) and Toda et al. (2016) developed machines for dorsiflexing the foot for stretching using an electro-magnetic motor or linear actuator. Yamada et al. (2017) developed a machine for controlling the foot three-dimensionally using wire-driven mechanisms to stretch the muscles related to equino-varus. This machine moves the foot by pulling two wires with McKibben type pneumatic actuators, which are independently attached to the inside and outside of the foot plate. Saga et al. (2008) and Cordo et al. (2009) developed machines for ankle dorsiflexion or/and plantar flexion using a pneumatic actuator or an electro-magnetic motor. Others aimed to increase the blood flow of the lower limb. For example, Sasanuma et al. (2018) developed a sock-type ankle exercise machine driven by pneumatics that moves the ankle with the tip of the foot in the dorsi/plantar flexion direction. Burdea et al. (2000) developed a Stewart-platform type ankle exercise machine driven by double acting type pneumatic actuators. The patient flexes the foot to this machine and voluntarily moves the foot in the dorsi/plantar flexion direction as well as the inversion / eversion direction.
The above-mentioned devices are very advanced and complex in mechanism. To overcome the complex mechanism, in this article we have designed and develop a new ankle mobilizer device which is lightweight, amiable rehabilitative, domestic usage, economically preferred and modest mechanism useful in day-to-day life of the child with cerebral palsy.

II. METHODOLOGY

This chapter deals with the methods used for designing and developing of the contemporary automated device for ankle spasticity reduction. In order to design an automated convenient ankle mobilizer device for stretching exercises, the following components are used:

1. Ankle Foot Orthosis having pretibial shell, foot shell with dorsal cover
2. Arduino UNO Board
3. Servomotor
4. Hi-watt Battery
5. On/off switch
6. 3D enclosure

1. MODULAR ARTICULATED ANKLE FOOT ORTHOSIS

The modular Articulated Ankle Foot Orthosis with pre-tibial shell & foot shell with dorsal cover (Figure.1) fabricated by the certified Prosthetist & Orthotist.

Figure 1: Modular Articulated Ankle Foot Orthosis having pretibial shell, foot shell with dorsal cover.

2. **Arduino Uno Board:** Arduino UNO is a microcontroller board based on the ATmega328P (Figure.2). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started.

Arduino Uno Features: This board comes with all the features required to run the controller and can be directly connected to the computer through USB cable that is used to transfer the programme to the controller using IDE (Integrated Development Environment) software, mainly developed to program Arduino. So, let's dive into the features of Arduino Uno. More frequency and number of instructions per cycle:
Atmega328 microcontroller is placed on the board that comes with a number of features like timers, counters, interrupts, PWM, CPU, I/O pins and based on a 16MHz clock that helps in producing more frequency and number of instructions/cycle.
Built-in regulation: This board comes with a built-in regulation feature which keeps the voltage under control when the device is connected to the external device.

Flexibility & Ease of use: There are 14 I/O digital and 6 analog pins incorporated in the board that allows the external connection with any circuit with the board. These pins provide the flexibility and ease of use to the external devices that can be connected through these pins

Configurable pins: The 6 analog pins are marked as A0 to A5 and come with a resolution of 10bits. These pins measure from 0 to 5V, however, they can be configured to the high-range using analog Reference function and AREF pin.

Quick Start: Reset pin is available in the board that reset the whole board and takes the running program in the initial stage. This pin is useful when board hangs up in the middle of the running program; pushing this pin will clear everything up in the program and starts the program right from the beginning.

Greater Flash Memory: 13KB of flash memory is used to store the number of instructions in the form of code.

Low Voltage Requirement: Only 5 V is required to turn the board on, which can be achieved directly using USB port or external adapter, however, it can support external power source up to 12 V which can be regulated and limit to 5 V or 3.3 V based on the requirement of the project.
Plug & Play: There is no hard and fast interface required to connect the devices to the board. Simply plug the external device into the pins of the board that are laid out on the board in the form of the header.

USB interface: Arduino Uno comes with USB interface i.e. USB port is added on the board to develop serial communication with the computer.

Power alternatives: Apart from USB, battery or AC to DC adopter can also be used to power the board

More Storage: There is a provision of Micro SD card to be used in the boards to make them store more information.

Figure 2: Arduino board (ATmega328P)

3. Servo Motor

The features of servo motor are as followings:

a. Operating Voltage is +5V typically
b. Torque: 2.5kg/cm
c. Operating speed is 0.1s/60°
d. Gear Type: Plastic
e. Rotation: 0°-180°
f. Weight of motor: 9gm
g. Package includes gear horns and screws

Wire Number	**Wire Colour**	**Description**
1.	Brown	Ground wire connected to the ground of system
2.	Red	Powers the motor typically +5V is used
3.	Orange	PWM signal is given in through this wire to drive the motor

Table. 1 (Servo Motor Wire Configuration)

Figure 3: Servomotor (SG90)

4**. Hi-Watt Battery:** The hi-watt battery (Figure.4) is an affordable, reliable, dedicated low-power solution to provide sufficient energy to your application. Ideally used in circuits with low power consumption so that it can work for longer durations.

The features are as follows:

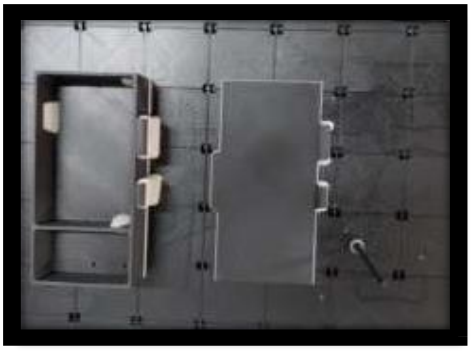
Model Number: 9V 6F 22; Battery Type: Zinc Carbon; Size: 6F22 006P; Jacket: Metal; Single Battery Dimensions (mm): L- 26. 5, H – 48. 5, W – 17. 5 (Max); Nominal Voltage (V): 9V; Discharge Resistance (Ω): 620; Cut-off Voltage (V): 5.4

Figure 4: Hi-watt battery

4. **ON/OFF SWITCH:** One small size convenient switch is used to do the on/off functions of the operation.

5. 3D Enclosure: The enclosure is made in 3D (Figure.5), for the housing of all the components according to the dimensions. It can also prevent damaging of component and provide cosmesis appearance. A 2D diagram of the enclosure drawn as per the dimension of the electronic components. Later, a 3D model has drawn in the AUTOCAD software. Once the design was completed, it was exported in the format such as .stl or .obj for use in 3D printing. After exporting, it was imported into GRAB CAD 3D PRINT Software for slicing operation, after which we directly gave print command and printed the part in 3D printer. The process of 3D printing was carried out by using the Stratasys F370, a series F123 printer, which is a fascinating blend of technology and materials. Operating on the principles of either FDM (Fused Deposition Modeling) technology, this printer utilizes model material-ABSCF10 and supportive material-QSR, to create 3D objects. The entire process, from design to completion, typically took around 4 hours. The 3D printing marvel lies in its extrusion mechanism. As the desired 3D design file are uploaded into a pen drive and the drive was inserted into the printer. It efficiently feeds the model and supportive materials into the nozzle by the help of dual extruder, where heat is applied at the tip of nozzle. This controlled extrusion and heating process helps in printing the model on to the build tray. Layer by layer, the printer constructs the desired 3D object, moving along the XYZ axis on the print bed within its chamber. This additive manufacturing process results in the creation of precise 3D model. Once the printing was completed, the model was carefully removed from the build tray. This operation typically requires the use of a spatula tool to gently separate the model from the tray. Subsequently, the model was placed into a dissolving tank filled with a water-soluble solution. The purpose of this step was to dissolve and eliminate any support material that was used during the printing process. Taken out the model design from the tank then cooled it on the normal water.

Figure 5: 3D design of the enclosure



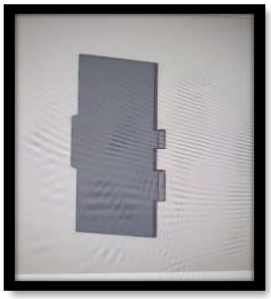


Figure 6: 3D printed enclosure on printer build tray

Alignment Procedure of Electronics Component: We have assembled all the components of this project (Figure.7) with help of electronic engineer. The servomotor has three wires (red, brown, orange), red wire connects at 3.3v port, brown wire connects at the ground port, orange wire connects at the -9 port of arduino board. (Table.1)

On/off switch has connected at the one end of two jumper wires and the other end of the wires are connected at 5v port and ground port of the arduino board. We upload a servomotor programme into the arduino board with the help of connecting cable which connects the arduino board with computer. Once the programme uploaded in the arduino board, the servomotor start runs. Later the connecting cable were ejected from the arduino board and computer. The Hi watt battery connected at the DC power jack of the arduino board. The servomotor starts running with the power of the battery.

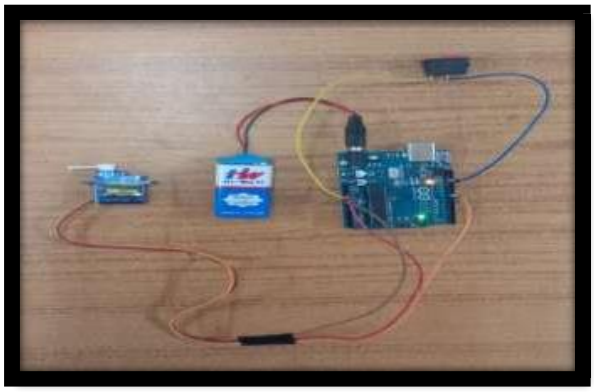


Figure 7: Alignment of electronics components

Figure 8: Process of Arduino programming

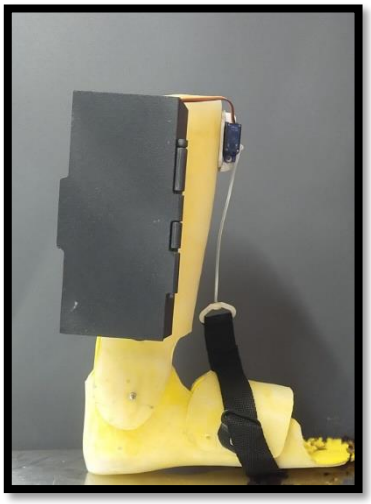
The 3D enclosure with the electronics components attached at the lateral side of the upper shell and servomotor at the anterior side of the upper shell. The control cable is used to do a stretching activity. One end of the cable is attached at the shaft of the servomotor and the other end is attached at the anterior part of the foot shell. Once you on the switch, the servomotor starts pulling the foot part upward as well as downward with the help of control cable. So, the stretching process can happen here without any assistance. (Figure.9)

Figure 9: Prototype Mo

Anterior view

Posterior view

Figure 10: Different View of Prototype Design



Lateral view

Medial view

III. Discussion: Waldman G et al. (2013) conducted a study to evaluate the effectiveness of robot-guided passive stretching and active movement training for ankle and mobility impairments in stroke survivors with ankle impairment. The study found that this approach led to a reduction in spasticity, improved movement ability, balance, PROM, and load bearing of the affected limb during gait. The researchers suggest that future comprehensive studies should include a larger population and cover a variety of body positions and different joints.

An automated convenient ankle mobilizer device can also assist a traditional stretching method in subject of ankle spasticity, Passive hand stretching, typically administered by a therapist, is commonly employed to alleviate spasticity. This therapeutic approach necessitates the dedicated efforts of both the physician and the patient, who must frequently attend rehabilitation sessions at a specialized center. Consequently, this treatment regimen has a significant impact on the patient's valuable time and financial resources. Additionally, parents of children with cerebral palsy face considerable challenges when commuting from their homes to the rehabilitation facility. Furthermore, the patient may experience fatigue during travel and may become agitated or disturbed during the stretching procedure.

This research demonstrates how the automated convenient ankle mobilizer device enables patients to perform stretching exercises independently, without the need for therapist. Additionally, it minimizes the effort required by therapists to address spasticity. By facilitating at-home stretching, it decreases the frequency of patient visits to rehabilitation centers. An automated convenient ankle mobilizer device will be effective for the children with spastic cerebral palsy having 2 & 3 grade of Modified Ashworth Scale (MAS).

IV. Conclusion: In conclusion, the automated convenient ankle mobilizer prototype deign can provide controlled ankle mobilization for therapeutic intervention, it will be helpful in reduction of hypertonicity of affected muscles. However, as it is a prototype development so this study found no evidence for the reliability or accuracy of ankle stretching or mobilizing of ankle, an area ripe for future research. Also, as the frequency & time setter programming of prototype was not done, so patient education and appropriate user instructions are needed for efficient operation of this ankle mobilizer. Future studies need to overcome the aforesaid issue and to improvise the technology.

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