Single DoF Hand Orthosis for Rehabilitation of Stroke and SCI Patients

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Abstract: Many stroke and spinal cord injury patients suffer from paralysis which range from severe to nominal. Some of them, after therapy, could regain most of the motor control, particularly in hands if the severity level is not so high. In this paper we propose a hand orthosis for such patients whose stroke and spinal cord injury severity is nominal and the motor control in hands can be regained by therapy as part of their rehabilitation process. The patients can wear this orthosis and the therapy can be done with simple Human Computer Interface. The physicians, the physiotherapists and the patients themselves can carry out the therapy with the help of this device. The tests conducted in the lab and the results obtained are very promising that this can be an effective mechanism for stroke and spinal cord injury patients in their rehabilitation process. The hand orthosis is designed and fabricated locally so that it can be made available to such patients at an affordable cost.

Keywords: stroke, spinal cord injury, hand orthosis, rehabilitation.

1. INTRODUCTION

Paralysis inducing stroke is the third leading factor for deaths in the world. Usually people lose their control over motor organs due to some injuries or due to some accidents. Accidents might cause gross or fine motor impairment of motor organs and lead to spinal cord injury (SCI). In such cases they are prescribed to attend physiotherapy sessions with which they can gain some control over their motor organs. In most of the cases the rehabilitation course usually ends up after a long time and also the probability of people recovering from the stroke is comparably low. Even today most of the physiotherapists resort to the conventional physiotherapy which involves the patient to undergo through repetitive motor exercises. Today, a huge requirement of physiotherapists is there to match the demand of the patients. With the help of technology advancements the rehabilitation process became smoother.

This paper speaks about an Arduino based mechanical rehabilitation hand orthosis device for rehabilitation of mild stroke patients. The wearable device is configured and interfaced with Arduino which is worn to the hand of a stroke affected patient that can be controlled by the physiotherapist. The wearable device is of a single degree of freedom, that being at the thumb joint of the hand. With the help of such rehabilitation devices one can easily monitor and handle multiple patients at an instant. The rehabilitation devices tend to show better results in restoring the motor capability of the stroke affected patients to at least some extent as they are more focused on the point to point movements. In this paper we present our work on hand orthosis used for therapy in the rehabilitation process of stroke and SCI patients. The paper is arranged as follows – section II presents the motivation and the problem statement in detail whereas section III elaborates the recent research work in the area of harvesting all over the world. Section IV and V explains about the system architecture, implementation, experiment and testing and finally concluded in section VI.

2. Problem Statement

According to Oct 2014 report by Times of India, there are 2.5 million people paralyzed by spinal injury all over the world. About 50 million are affected by stroke worldwide and lose their mobility in limbs. Every year, many people meet with accidents involving the injury of motor organs which often result in a neck injury. Due to paralysis of the motor organs the patients experience a severe difficulty in doing their daily activities which in turn develops an inferiority complex in them. Moreover, the demand of the physiotherapists steeply increases which resulted in an immediate need for a solution to avert this situation. In a typical physiotherapy session, the therapist usually attends one patient at a time which increases the waiting period of the other patients. This brought the very need for the automation process of the manual physiotherapy where the therapist can control and handle the requests of multiple patients at the same time. In developing countries in India, the healthcare facilities are not affordable to middle class families which are majority in population. Hiring a therapist is too costly and hence people affected by stroke or SCI are ignored without any proper rehabilitation. Even if the patients undergo treatments and therapy at hospitals, they are not able to continue with the therapy after getting back to their homes due to high costs. In this scenario our low cost hand orthosis device which can be easily controlled by smart devices could be alternate solution.
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3. Related Works

Authors in the paper [1] discussed about the fuzzy control of the rehabilitation device which restore the senses from the fingertip. The paper discussed about the grasping abilities of the patients and the aftereffects of the rehabilitation period. The problem in this model is the control and reliability. Different patients have different requirements with different biological characteristics. To accommodate the needs the authors suggest to calibrate the rehabilitation device for every unique patient. The current rehabilitation model discussed in this paper can be a solution for which there is no need of calibration since the design is made according to the average size of the human thumb finger. This makes the rehabilitation model more sustainable. In paper [2], the authors designed a tendon-driven rehabilitation device. The device was successful in amplifying the gripping and pinching actions. The system architecture and the implementation of the device is a bit complex. Mild stroke patients might not prefer to wear such a bulky device whereas the currently discussed rehabilitation device can be implemented and worn very easily for mild stroke patients. Rehabilitation device discussed in paper [3] is designed such that it employs an elastic actuator which produces force controlled trajectories of fingers. This device mainly targets the acute and semi-acute patients. In one of our earlier work we discuss about the prosthetic arm for paralysis patients that can be controlled either by switches or thought [4]. The paper discussed should be worn continuously by the user who is a mild stroke patient which might be a discomfort for the patient. In paper [5] a similar exoskeleton just like in paper [2] and [3] is designed. This paper talks more about the data analysis and interpretation of the data on how various aged stroke patients respond to the treatment while using their rehabilitation device. Authors in paper [6] have mentioned about controlling the rehabilitation device using the technique called Brain-Computer Interface which lets users to just use their brain-waves to control the orthosis device. Authors are validating the model with people who are having tetraplegia.

4. SYSTEM ARCHITECTURE

The wearable is designed to work with three types of operation modes. They are - Serial Input (through the PC through the Serial Monitor of the Arduino board), using Bluetooth Wireless technology and, control of the Orthosis Servo with a Potentiometer. However, all of these methods are implemented with the help of Bluetooth Wireless Technology. There are basically two main Arduino Boards controlling the whole setup. One each for the Transmitter for the User Control and the other for the Receiver which is the Hand Orthosis as shown in Figure 1. The Receiver is actually the part where the servo is controlled. The Transmitter decides the control parameters like speed, angle and the no. of times the servo should sweep the angle. These two blocks are connected to each other via a Bluetooth link. This makes the whole setup wireless. The potentiometers can be accessed and altered with the change being remotely placed. The Bluetooth in the receiver can also be paired with a mobile device or a PC with a bluetooth connection capability. This helps us to manually input the parameters and control the orthosis accordingly. The user (or in this case, a physiotherapist) can input the required variables in a specified form or a required pattern.

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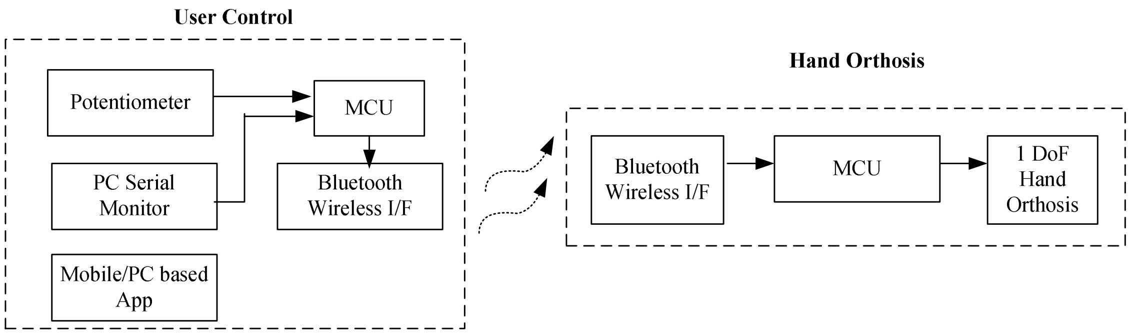

Figure 1. Hand Orthosis Architectural Diagram

4.1 Master Slave Configuration

For an effective transmission of parameters from the serial monitor to the Arduino interfaced with the rehabilitation device, two Bluetooth modules are used which are configured under Master- Slave configuration. The master Bluetooth transmits the data and the slave Bluetooth module receives and the Arduino process the data and drives the servo motors.

4.2 Arduino MCU

The Arduino MCU interfaces with the potentiometer, the PC serial monitor or the Mobile or PC based App. The Arduino MCU board is based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, an on-board resonator, a reset button, and holes for mounting pin headers. The potentiometer can be

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connected to any analog pins of Arduino. The PC USB port can be configured as serial port and the Arduino can be access via USB port through the RX and TX pins. It works with USART protocol. For the Bluetooth wireless communication via Mobile / PC based App, a Bluetooth I/F module is required.

4.3 HC 05 Bluetooth Module

HC-05 module is a Bluetooth SPP (Serial Port Protocol) module, designed for transparent wireless serial connection setup. The Bluetooth module at the transmitter is configured as master and paired solely with the slave receiver. The HC 05 module communicates with the MCU via serial communication at 34800 baud rate. Speed: Asynchronous: 2.1Mbps (Max)/160 kbps, Synchronous: 1Mbps/1Mbp. It has maximum emission power of 4dbm. Its operating voltage supply is 1.8V to 3.6V I/O. It uses UART interface with programmable baud rate. Table 1 shows the Arduino and HC-05 pin mapping.

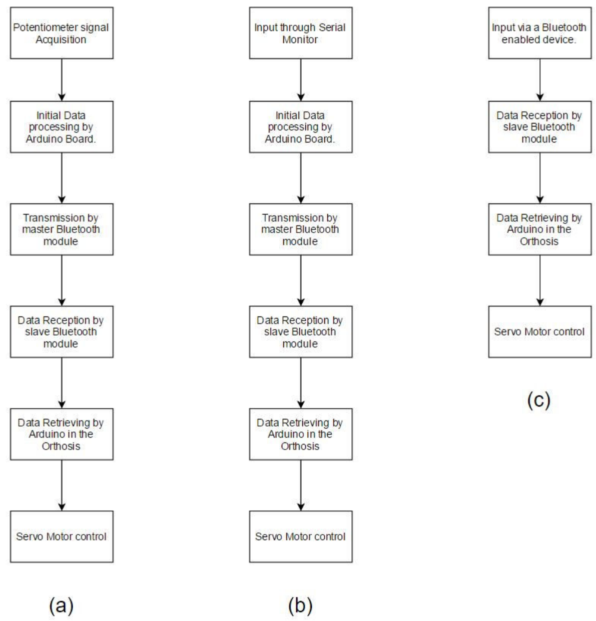

Figure 2: (a) – Flow chart for the potentiometer based control, (b) – Flow chart for the PC serial monitor control and (c) – Flow chart for the mobile/PC based App control.

Fig.2(a) is the signal flow chart for the system using the wireless potentiometer control. The signals are acquired from the potentiometer and then the initial data is processed by the Arduino and then it is transmitted using master Bluetooth module. The transmitted data is received by the slave module embedded on the rehabilitation device and the received data is pushed to another Arduino on the device for further processing. The required parameters are determined and the servo motor are driven. Fig. 2(b) is for the type of control in which we give our inputs through the Serial Monitor of the Arduino IDE. This involves same process as shown in the Fig.2c but only change would be is the source of control.

Controlling the system through a Bluetooth terminal application is shown with the flowchart in Fig. 2(c). In this process the transmitting device i.e. either a mobile or a personal computer already comes with an inbuilt Bluetooth module. Some pre-defined commands are sent over the Bluetooth channel and the data is received by slave Bluetooth module. The received data is fed to the Arduino embedded on the rehabilitation device for further processing. The processed data is then fed to the servo motor. As mentioned earlier, the whole setup (the controller and the end effector) is wirelessly connected. For now, the wireless technology employed is Bluetooth. Later, the protocol can be changed to a more advanced one like Wi-Fi or the internet itself.

5. IMPLEMENTATION

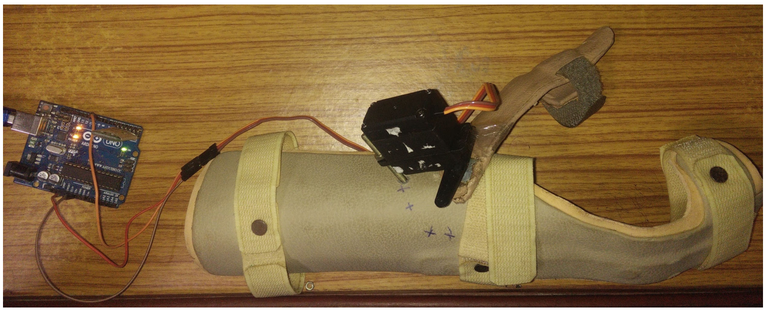

Figure 3. The hand orthosis fabricated and tested at the lab

The single degree of freedom wearable design is implemented using the servo motor which is operated in different methods. The initial angle and the speed are the two key factors. The control can be implemented by employing different methods. Potentiometers can be used for the control. One potentiometer can be used to set the initial angle of the servo while another potentiometer can be used to regulate its speed. The analog values from the potentiometers are fed to the Arduino board secured on the wearable. The analog values are processed by the Arduino and the corresponding speed and angle parameters are sent to the servo motor over a Master and Slave configured Bluetooth network. There can be another optional parameter which can control the count of servo motor rotations.

The hand orthosis model is designed such that the user's thumb finger is secured to the locomotive joint which is driven by the servo motor. The other fingers are secured to the stationary part of the model. In this model, the servo motor moves the flap that is secured with the thumb finger of the patient to and fro thereby providing the patient an exercise without the help of a therapist. The control of the rehabilitation device can also be done either by a mobile or by a personal computer. The rehabilitation device is interfaced with a Bluetooth module along with the Arduino board. The Arduino sketch was parsed in order that the Arduino accepts the commands sent over the wireless medium and turns the servo motor with the transmitted parameters which was sent either by a mobile or personal computer through terminal, provided that both the mobile and the personal computer must be enabled with the Bluetooth wireless technology. The baud rate set for the transmission of the data is 9600 bits/s. This transmission rate is sufficient to transmit the three parameters namely angle, speed and the number of rotations of servo motor. The parameters can also be sent through serial monitor of the Arduino and can be monitored.

These systems can be further remodeled as closed loop control systems in a way that they are bounded by the software or the microcontroller which is controlling the servo motors in the first place. The output parameters can also be read through the same way as they are given out. This can help stabilize the system rather than have a risk of making an open loop system which, at some point of time, become unstable. The program can be set in such a way that the system halts if the output goes out of control. These control parameters or the limits can be set by understanding the limits of the human thumb.

6. Experiments and Results

In Table 1 and 2, the errors for various parameters have been significantly noted. The device is subjected to operation for recording measurements for three parameters namely Angle in degrees, speed in degrees per second, number of rotations. The average angle deviation is 0.04 degrees lagging than the required angle. The speed of the servo motor is measured by Arduino.

Table I. Angle measurement and Speed measurement with the potentiometer

S NO.	Angle(in degrees)			Speed (degrees per second)		
	required	Obtained	error	required	obtained	error
1.	0	0.5	+0.5	40	43	+3
2.	15	16.5	+1.5	50	53	+3
3.	35	37.5	+2.5	66.67	64	-2.67
4.	45	47	+2	100	97	-3
5.	75	78	+3	142.86	138	-4.86
	Average error		+1.9	Average error		-.906

Table II. Angle, Speed and RPM measurements with Mobile/PC based App

S NO.	Angle(in degrees)			Speed (degrees per second)			No. of Rotations		
	required	obtained	error	required	obtained	error	required	obtained	error
1.	0	0.3	+0.3	40	36	-4	10	10	0
2.	15	15.2	+0.2	50	52	+2	15	15	0
3.	35	34.9	-0.1	66.67	62	-4	20	20	0
4.	45	44.8	-0.2	100	99	-1	25	25	0
5.	75	74.6	-0.4	142.86	140	-3	30	30	0
	Average error		-0.04	Average error		-2	Average error		0

The average error obtained is 2 degrees per second lagging than the input speed. The number of rotations of servo motor is programmed earlier in the Arduino sketch. Hence, there is no error obtained at the output of the system. Table 1 shows the angle and speed measurements in degrees and degrees per second using the potentiometer. The average error in angle calculation using the pot is 1.9 degrees and for the speed it is 2.106 degrees. When the same tests were repeated with the Mobile/PC based Bluetooth enabled app, the average error in angle calculations is only -0.04 as shown in Table 2. This is pretty much less than the average angle error with pot measurements and is expected as the pot is controlled manually by rotating the knob and hence prone to high error. This is true in speed calculations as the average speed measurements is -0.2 deg/sec in case of pot where as it is only -2 deg/sec in case of Bluetooth app. An extra parameter measurement is possible in case of app, i.e. the number of rotations as given in Table 2.

7. Future Works

The system, implementation, experiment and the results presented in this work is an indicator that we are proceeding in the right direction. However these results are preliminary and we need to test the arm with the real time scenario. The orthosis has to be tested for various corner cases in the lab and then with the intended users, i.e. the patients at rehabilitation centers at hospitals. More degree of freedom can be included so that the therapy is effective. If a second degree of freedom is included, it can be used for the wrist exercise, moving the wrist up and down. For each degree of freedom angle, speed and number of times to repeat the exercise can be programmed and automated.

8. Conclusion

Rehabilitation of the stroke patients is made simple with the help of such rehabilitation device that is mentioned in this paper. There is a mutual advantage for both the therapists and the patients. Therapists can effectively monitor and handle multiple patients at a time with the help of such rehabilitation assisted mechanical devices. With help of such devices there is necessarily no need of any therapists to take care of the patients. The caretakers of the patient can easily control and operate the device thereby not subjecting the patient to pain by making him travel to and fro from hospital. Currently the rehabilitation device can be controlled from few yards away provided that the range of Bluetooth wireless module is comparably good. Further research advancements can help the therapists to understand, monitor and regulate a patient's status and can also help them to control the rehabilitation device from wherever possible.

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