Voice-based Hand Orthotic Device

Rajesh Kannan Megalingam, *Senior Member, IEEE*, Egumadiri Vijay, Polisetty Naga Venkata Koteswara Naveen, Chennareddy Pavanth Kumar Reddy, *Member, IEEE,* and Dega Chandrika

***Abstract*—Robotic systems are rapidly emerging as easy-to-use rehabilitation tools that enhance several of health-related infirmities. Frequently, stroke and spinal cord -injuries are impair normal healthful living by paralysis, albeit the affected patient's brains may remain functional. Such victims need long-term rehabilitation, by qualified therapists to regain motor and sensory controls, beyond the affordable reach of common citizens. This is where reasonably priced robotic exoskeleton systems come to their rescue. In the paper, we propose a novel design for hand orthosis, which is a lightweight pliable prototype can be calibrated to fit any average-sized hand. This device is controlled with a voice recognition module. Efficiency, delay, accuracy, realization, and robustness. Empirical results validate the efficacy, reliability, and robustness of the orthotic device that can be used in the rehabilitation of the stroke patients.**

***Index Terms*—Hand orthosis, Voice recognition, Bluetooth, Rehabilitation, Stroke, and Semi-stroke patients.**

I. Introduction

IN recent times, the conspicuous deployment of technological advancements in the healthcare domain have been occurring at an astonishing fast pace. Significant work has been done with the science of robotics as well. Ingeniously designed robots and robotic gadgets are being used for recovery and rehabilitation of patients, enfeebled with various ailments. Physically handicapped patients find some relief by exoskeletons, which are easier to be designed for larger body surface-areas like lower and upper limbs. However, design of orthotic devices for the hand can be a daunting exercise due to innumerous variations in size, shape and complexity of movements. In addition, these devices should be outfitted with tactile sensation to enable the touch, feel, and pick-up of an object. Besides, a device should be moderately priced so that it can serve the general population, rather than solely for the well-placed elites. Stroke patients who lost the touch sensation would greatly benefit from orthotic devices. This would obviate the cost of physiotherapy to restore (in part or full) functionality of their hand. In developing countries, stroke patients would benefit immensely, from low-cost hand orthotics. In this paper we present our research on voice-controlled hand orthotic device for rehabilitation of stroke patients. Users can manage this appliance through simple voice commands. The device's user friendly interface facilitates rapid learning, within minutes. Such tools help avoid frequent visits to hospitals or health rehabilitation centers. This paper is arranged as follows – section II talks about the problem statement and motivation behind development of this hand orthotic prototype; section III reviews related research being carried out in this field. Section IV presents the system architecture while Section V covers the system design. Section VI reports on empirical verification, where the experiments and results are discussed, followed by concluding remarks and suggested options for future research

Dr. Rajesh Kannan Megalingam, Egumadiri Vijay, Polisetty Naga Venkata Koteswara Naveen and Dega Chandrika are with Department of Electronics and Communication Engineering, Chennareddy Pavanth Kumar Reddy Amrita Vishwa Vidyapeetham, Amritapuri, India (e-mail: rajeshkannan@ieee.org vijayegumadiri@gmail.com naveenpolisetty0298@gmail.com chpavanthkumarreddy@ieee.org chandrikadega@gmail.com).

II. Problem Statement

Nowadays, we see large variety of applications of robotic instruments, oriented to influence human living. Robots in nearly every domain, are helpful to lead a very comfortable life. According to a study by the Christopher and Reeve Foundation, nearly 1 in 50 suffer from paralysis, and each year around 6 million people are affected by debilitative paralytic strokes Moreover, the Foundation strongly asserts that paralysis ensues from stroke and spinal injuries. Humans struck by partial paralysis feel great difficulty to carry out daily activities. Nevertheless, after rigorous therapy, their motor controls can be regained if the severity levels of the stroke are not quite high. This obligates patients to visit rehabilitation centers for the recovery of their motor impairments. In a developing country, like India, where most of the population can ill-afford proper medical treatment due to their economic status, or the inconvenient access to, or paucity of qualified therapists in remote villages. Rehabilitative robots would be really handy in such circumstances. The main goal was not only to design a comfortable hand orthotic device, to assist patients regain their motor control, but also to create an easy-to-use user interface, which can be quickly learnt by the patients in few hours. The operability of the conceived device can be fully controlled via voice commands or using touch screens on an Android app.

III. Related Work

In hand rehabilitation robotics, we have two different categories of robots. 1) portable or compact hand-based and 2) ground-based device. Portable devices are mostly wearable ones and ground-based devices are fixed to table or flat surface. Since the proffered device is portable, this review of

978-1-5386-7595-3/19/$31.00 ©2019 IEEE

related work was mainly focused on papers that dealt with the same intent. Authors in [1] discussed a rehabilitation learning system, which records and analyzes common hand movements, to assist a patient in mimicking previously accomplished movements. The downside of this model is its design, which imposes extra weight on the hand that slows down hand functions. Our prototype is better in terms of speed and accuracy In addition, it is of lesser weight and is calibrated in such a way that it can fit an average size hand. In [2], positions of the orthotic arm are familiarized after the deformation through Electromyogram (EMG) signals like relax, flex, and semi-flex for stroke patients. But this device alone may not help the patients recover from the affected part. Paper [3] describes how authors trained two handicapped persons with their tailor-made exoskeleton devices. However, the training at different duration of sessions are giving some varied results which affects efficiency of the device. Authors in paper [4] talked about their work with ministroke and regular stroke patients, of different ages, and interpreted the data which helped analysis of how patients may respond to a particular exercise, and what comforts they would be looking for. In [5] authors discussed achievement of full feedback capabilities, from their mechatronic device, and presented preliminary hand anthropometric study. Authors in [6] implemented a novel device, based on human kinematic wearability, compatibility and portability criteria for thumb finger. [7] discussed a mechatronic design of HANDEXOS, which is very light weight and easily wearable. In [8] authors discussed how to have a perfect grip of an object, using strain gauges, and how to achieve certain grips by hand, using an exoskeleton. The authors in [9] developed an orthotic hand (HandSOME), using elastic cords, which assisted patients in therapy. But the problem with this prototype is that it has less grip strength. The main focus of paper [10] was on control algorithms, for faster interactions of desired motions, and minimal materials on palm side of a hand. Authors in [11] focused on the importance of a Bluetooth module to communicate with hand orthotic device. In [12], the authors have a Brain-Computer Interface (BCI) for a patient affected with Tetraplegia. Paper [13] successfully deduced the muscle power, required to pick an object, by using quasi-static process. Authors in journal [14] developed a unique Biomimetic Hand Exoskeleton Device, (BiomHED) to assist stroke patients with limited number of actuators. Here the authors mainly focused on exotendons of joint angular displacements and kinematic workspace of fingertip and thumb tip distance. This helps us in understanding kinematic workspace between fingertip and thumb tip position. The main focus of paper [15] was to actuate motors, by using force sensor values, at the fingertips to analyze the control motion of orthotic hand.

IV. SYSTEM ARCHITECTURE

The hand orthotic device, discussed in this paper, can be controlled in three different ways: a) passing text commands using Arduino microcontroller board with the help of the Arduino Integrated Development Environment (IDE) serial monitor in PC; b) sending voice commands through a Bluetooth module enabled mobile app called Arduino Voice App which is an open source app; c) control the device through a voice recognition module. The last option enables pre-calibration of a particular person's voice, prior to execution of commands, input by the user's voice. Fig. 1 shows the architecture diagram of the proposed system with text and voice control for the hand orthotic device[16].

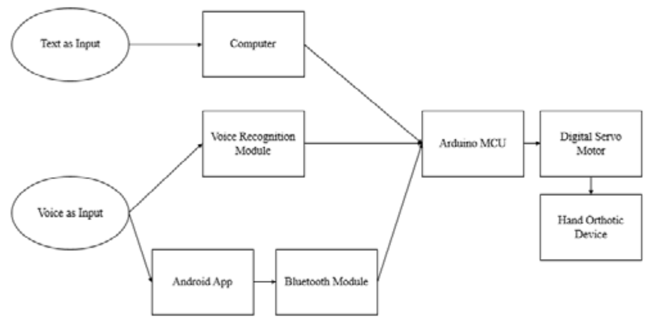

Fig. 1. Architecture of the proposed system

A. Text Recognition

The text commands can be input via Arduino IDE serial monitor installed in a computer to control the hand orthotic device. These text commands include OPEN and CLOSE to control the device. The MCU processes these commands and generated corresponding control signals to the digital servo motor to open or close the device.

B. Voice Recognition Module

There are many voice recognition modules available in the market that can store anywhere between 15 and 80 voice commands. For us we need to have a minimal number of voice commands which would help us to code precisely. So, we opted Geetech voice recognition module which can store 15 voice commands, distributed in three groups, with five instructions in each. The voice of the user has to be recorded first before using this voice recognition module

C. Arduino MCU

Arduino is one of the open source electronic platforms to be used in any project for quick results. Arduino MCU is an integrated platform which has all the components like CPU (central processing unit), RAM (random access memory), some form of ROM, I/O (Input/output) ports and timers. Arduino has 14 digital pins in which 6 of them can be used as PWM (pulse width modulation) pins and 6 analog pins. The recommended input voltage is 7 to 12 Volts with a dc current of 40 mA. The clock speed of the Arduino microcontroller is 16MHZ. Arduino provides a various number of methods for communication with other modules, computers, and different microcontrollers. But ATMEGA328 microcontroller used in Arduino provides a serial communication with UART (universal Asynchronous receiver or transmitter) 5 V by using 2 digital pins from Arduino 0(Rx) and 1(TX).

D. Bluetooth Module

In this prototype we use Bluetooth enabled Android app as our other source for voice recognition. In wireless technology, Bluetooth has become one of the important sources for transmission of data for shorter distances. In this prototype, we use HC-05 Bluetooth module which can be easily interfaced with Arduino, Raspberry Pi and other microcontrollers via serial port interface. This module works in an Industrial Scientific and Medical (ISM) band of 2.4 GHZ, it requires a very low input voltage of 3.6 V to 6 V. This has an operating voltage of 3.3 V which can be used in a wide range of temperature (-200 ^{0}C to 750 ^{0}C).

E. Digital Servo Motor

A stroke patient who is undergoing a therapy will not be able to open the affected hand easily, as fine motor control of the nerves is affected. In order to open and close the hand to enable therapy, a high torque motor is required to be used in the orthotic device. We used a digital servo motor which can produce a high torque of 30 kg/cm2 for small voltage of 6 V with very high precision. The servo which we are using is HSR5990TG whose pulse width is from 600 to 2100 us with a pulse cycle of 20 millisecond. Moreover, we used this digital motor because of its compact size and less weight of 68 grams.

All the blocks mentioned in Fig. 1 work in coordination for the successful therapy using the hand orthotic device. The device can be used both by the physiotherapists and patients as well. In the initial stages of stroke, when the patient is undergoing treatment and therapy at hospital, the physiotherapists or doctors can control the device for the patient the help with the therapy of the hand. As the patient is discharged and expected to continue with the therapy, the patient can be trained to use the orthotic device without the need for physiotherapists at home. This will enable a huge cost saving for the patients in developing and under-developed nations. In order to use the device, the patient has to wear the device on the affected hand. To operate the device doctor/ physiotherapist/ patient can use voice commands or text commands (as mentioned earlier in this section) using a PC or Bluetooth enabled app or voice recognition module. Once the Arduino MCU receives these voice or text commands, it processes these commands and generate control signals to the servo motor to control the orthotic device. To keep the text and voice commands as simple as possible we use only two commands: OPEN and CLOSE.

V. IMPLEMENTATION

A. Procedure for configuring voice recognition module

The voice recognition module has to be pre-recorded with the voice commands using a software called H-TERM access port software. The user has to open H-TERM application and select the respective communication port and configure the characteristic table with baud rate as 9600 bauds/sec. As mentioned earlier, we opted Geetech voice recognition module which can store 15 commands that are divided into three groups with five instructions in each group. After successful configuration of characteristic table, set the voice recognition module to command mode using the command word 0xAA37 and then use the command 0xAA11 to record the first group. After passing the command 0xAA11, START instruction will be displayed on the H-TERM application. Then we need to give the required voice command for recording. This is done by the user (patient or physiotherapist) speaking the voice commands through a mike connected to the voice recognition module. Even though we need only two voice commands OPEN and CLOSE, for pre-recording we need to record five voice commands as this is the condition imposed by the voice recognition module. So we used three dummy commands other than OPEN and close commands. We ignored the remaining two groups as we use only two voice commands that serves our purpose. This whole process is called pre-recording of a voice recognition module. Once this process is completed we can use it for controlling the hand orthotic device. The entire process is shown in the process flow diagram in Fig. 2.

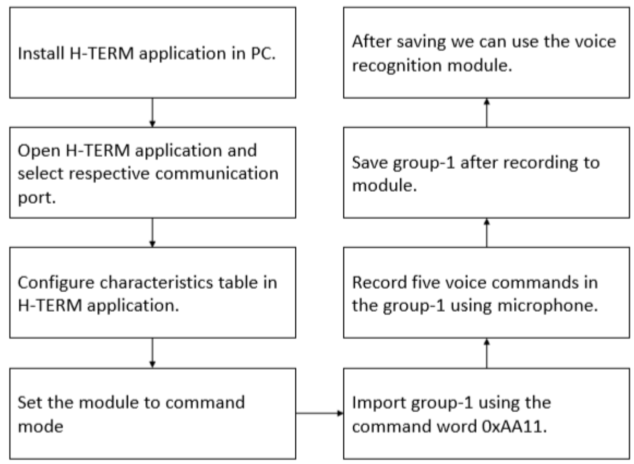

Fig. 2. Procedure for configuring Voice Recognition Module

B. Hand Orthosis Design

The hand orthotic device model that we used for conducting the experiments is shown in Fig. 3. It helps in the rotation of the metacarpal-phalangeal joint of the thumb. There are two parts of the device: one is the thumb part and the second is the rest of the hand and arm part. The device is made of hard plastic with cushion on the inside for the better feeling of the user who is wearing this device. Straps are provided to strap the thumb, fingers and the arm.

Fig. 3. Hand Orthotic Device

C. Voice Command based Control

Now the required hardware connections can be set up as shown in the Fig. 4. The user who recorded the voice commands (OPEN and CLOSE) speaks them through the microphone connected to the voice recognition module. The current voice command will be compared with the already pre-recorded voice commands in the module. If there is a match between the spoken voice command and the recorded voice command, the respective command word of the voice command is sent to Arduino MCU. The command word will be processed by the Arduino MCU and respective control signals will be sent to digital servo motor for controlling the hand orthotic device.

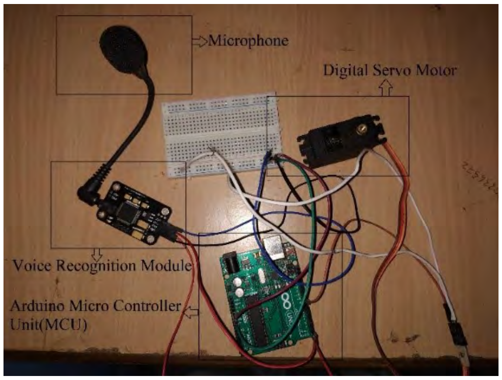

Fig. 4. Control Circuit with mike, MCU, voice recognition module and servo motor.

D. Android Application based Control

Arduino Voice Control app which is a free downloadable application from Google playstore is used in this case. The app initiates the pairing of the mobile Bluetooth with that of the device Bluetooth module. Once pairing is completed, the 'Connected' status appears which is shown in green text in Fig. 5. Then the user can start speaking the voice commands OPEN and CLOSE to control the device. The voice commands of the users are sent to the Arduino MCU via Bluetooth receiver installed in the device. The MCU processes the command and generated control signals to the servo motor which in turn controls the device.

Fig. 5. Arduino Voice Control Application

VI. Experimental Results

First the device response time for OPEN and CLOSE commands were measured for the Bluetooth enabled Android app followed by using voice recognition module. The response time is the time taken by the device to react to the OPEN/CLOSE voice commands, i.e. how long the device takes to start to open on OPEN command and start to close on CLOSE command. Fig. 6 shows response time plotted when using the Bluetooth enabled Android app and Fig. 7 shows the response timings when using the voice recognition module. The orthotic hand which is connected to voice recognition module is speaker dependent. Fig. 7 shows an average delay of 1.67 seconds for OPEN command and 1.67 seconds for CLOSE command. But when the orthotic hand is connected with Bluetooth enabled Android app, the delay is high. Fig. 6 shows an average delay of 3.49 seconds for OPEN command and 3.17 seconds for a CLOSE command which wide variations when compared to delay values of voice recognition module.

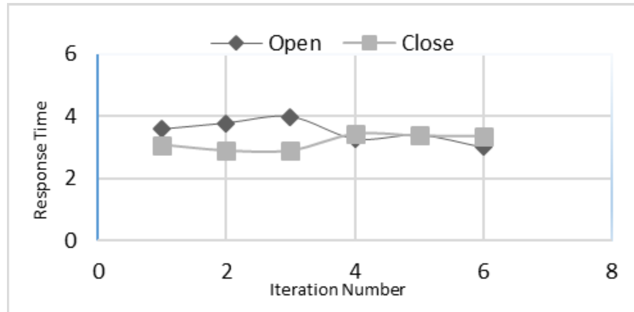

Fig. 6. Response time of the device for the commands using Bluetooth enabled mobile app.

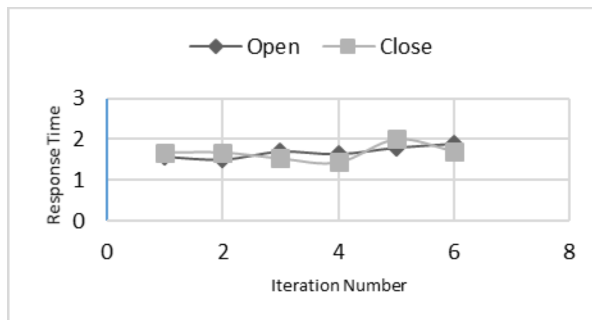

Fig. 7. Response time of the device for the commands using voice recognition module.

After measuring the device response time, the time taken by the device to open and close to the desired angle is measured and tabulated in the Tables I and II. This test is necessitated as the users who are stroke patients have varied control of motor functions of their hands during the period of the therapy. Immediately after the stroke, the patients won't be able to open up their hands at all. In such a scenario, the hand orthotic device angle should open to its maximum of 90 degrees. As the therapy continues for these users, their control of motor functions of their hands improves and hence the device can open to a less desired angle.

Table I
Bluetooth Enabled App Based Open/Close Timings Of Device For Desired Angle

S.No	Desired Angle (degrees)	Device open time (s)	Device close time (s)
1	0	3.58	3.08
2	30	5.14	4.88
3	45	5.33	5.87
4	60	5.89	7.34
5	90	7.51	9.34

TABLE II
VOICE RECOGNITION MODULE BASED OPEN/CLOSE TIMINGS OF DEVICE FOR DESIRED ANGLE

S.No	Desired Angle (degrees)	Device open time (s)	Device close time (s)
1	0	1.79	1.54
2	30	3.07	3.76
3	45	3.88	4.59
4	60	4.20	5.64
5	90	5.75	7.38

The Table I shows the opening and closing timings when using Bluetooth enabled Android app and Table II shows the opening and closing timings when using the voice recognition module. Even in this case, voice recognition module performance is much better compared to the Bluetooth enable Android app.

VII. CONCLUSION

In this paper we have presented the design, implementation and evaluation of hand orthotic device which can be used in the hand therapy of the stroke patients by physiotherapists or doctors or by patients themselves. The device can be operated in multiple ways: using text commands and voice commands with Arduino base IDE, Bluetooth enabled Android app or using voice recognition module. The experimental results show a promising future for the stroke patients. As the device is low cost, it could potentially decrease the cost for the rehabilitation of the stroke patients.

ACKNOWLEDGMENT

We would like to express gratefulness to Humanitarian Technology (HuT) Labs and Amrita Vishwa Vidyapeetham for helping in accomplishing this research work successfully.

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