SR (SUPERNUMERARY ROBOTIC) FINGERS

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Abstract: A wearable robot, namely Supernumerary Robotic Fingers, can be developed to augment the capabilities of the human hand that can help perform a variety of prehensile, bimanual, and manipulation tasks single-handedly. The patients can use the fingers to recover their grasping abilities presenting an active compensatory tool in the initial phases of therapeutic recovery and rehabilitation to promote the use of the arm even if the hand grasp function is not recovered. The patients can intuitively control the two robotic fingers using the flex sensors attached to their fingers through a hand glove and IMU. These robotic fingers may provide chronic hemiparetic patients with the needed assistance to lead independent and productive lives. The proposed solution is intended to act as a rehabilitation device to assist the hands in bimanual tasks like grasping and manipulation of objects.

Keywords: rehabilitative robotics, gesture recognition, hemiplegic patients.

1. Introduction

Hemiparetic patients, such as stroke survivors, patients who have Parkinson's diseases, multiple sclerosis, spinal cord injuries, traumatic brain injuries, cerebral palsy, poliomyelitis, motor impairments, weakness, spasticity, arthritis, and older people may have limited or non-functionality in one of their hands. They must face challenges in completing simple everyday activities such as eating, dressing, carrying their walker, and other bimanual tasks. This causes the patients to rely on the assistance of their family or nurses to help them, compromising their independence and quality of their life.

Robotic limbs to assist hemiparetic patients by increasing their workspace. It can also be helpful for therapeutic purposes and rehabilitation [1] [2].

2. Proposed Design

In our solution, we present a rehabilitative medical device with two robotic fingers to enhance the manipulation capabilities of the hand. By Increasing the workspace volume these extra fingers can grasp bigger objects and even manipulate more things simultaneously. We have developed a machine-learning algorithm to detect the hand gesture and orientation from the data collected from the sensor glove which has flex sensors and IMU and actuate the robotic fingers accordingly to accomplish the given task. Haptic sensors are connected to the robotic fingers to render haptic information, which is interfaced with vibrotactile motors attached to one of the patient's fingers to warn them about the force exerted by the device and control it using the hand gestures for different types of objects [3]. The device can also switch between various states using event triggers using specific hand configuration, for instance, to maintain the current configuration of the supernumerary fingers so that the rest of the hand can perform other tasks.

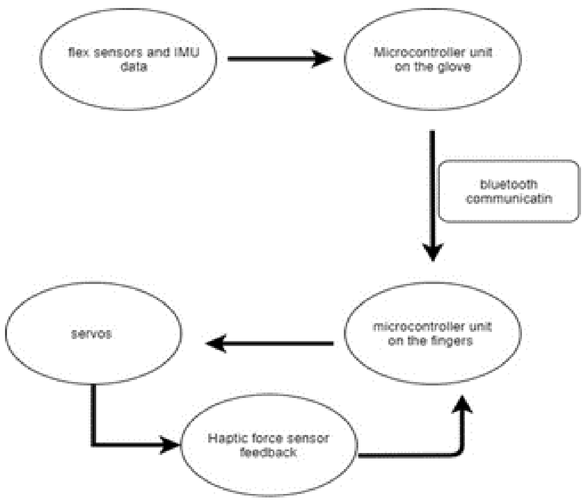


Fig. 1. *Block Diagram of SR fingers*

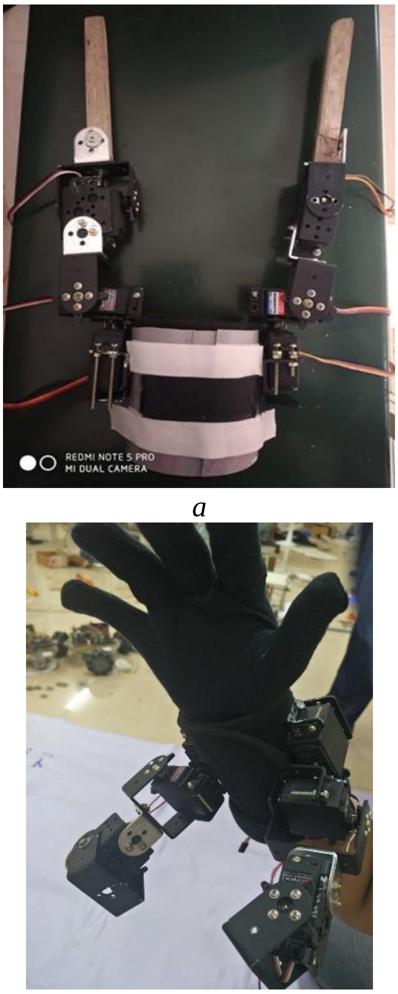
3. Methodology

The two fingers, each having 3Dof, are actuated by three high torque servos whose specific angle configuration is obtained from the inverse kinematics for the required position of the fingers.

The control loop starts with the sensor glove, where the finger movements are detected by the onboard flex sensors [3] and the Inertial Measurement Unit (IMU). This data is conditioned and processed using the Kalman filter, and then it is fed to the machine learning model. The machine learning model based on

LSTM architecture with three layers with ReLu activation was trained on the flex sensor and IMU data [4] for gesture prediction. The data from the sensor glove is then fed to the ML model, which outputs the recognized gesture. Based on the gesture, the microcontroller actuates the servos to the desired angle configuration, which was obtained based on the inverse kinematics discussed above.

The output angle configurations are then fed to the servos. When the servo touches the object to be manipulated, it will get feedback from the pressure sensor on the end effector. A better grasp stability can be achieved by controlling the contact forces rather than simply controlling the hand posture in order to allow for adaptation to irregularities and uncertainties of the object, as reported in the literature of human fingers [5-9]. If the force applied to the object is too much, then the user gets feedback through the vibrotactile motors so that the fingers do not crush the object to be manipulated.



a

b

Fig. 2. *Prototype images*
(a) Final prototype, **(b)** Pre-final Version

Table 1 Bill of Materials

Component	Usage
Flex Sensors	To get the finger position to get the orientation of robotic fingers
IMU	To get the orientation of the hand for different holding positions
Servos	Primary actuators
Haptic Sensors	To obtain feedback of force exerted by the device
Vibrotactile motors	Part of feedback system for users to know amount of force exerted
Li-po Battery	Power Supply
Microcontroller	To process the sensor input and actuate the servos
Bluetooth modules	To establish communication between the fingers and glove
Buck Converter	To convert 12V from battery to 7V for servos
Raspberry Pi	To run and train the DL model on go

Based on various usages, the SR fingers have various modes of operation to handle various objects. Some modes are bottle holding/opening mode, tablet mode, irregular object holding mode, and more.

4. Innovativeness

The robotic fingers increase the workspace and allows better control of the object to be manipulated by increasing the area of contact thus allows better stiffness and stable manipulation. Such technology could significantly improve the living conditions of hemiplegic patients and elderly people. The additional fingers can aid the thumb to minimize its usage thereby reducing the pain in case of thumb severe arthrosis. Conventional rehabilitation therapy, which generally relies on manual assistance from a therapist to position, guide, and/or support the limb's weight, requires the patients to exert their affected limb to perform repetitive actions training their muscles. An important part of effective stroke training is repetitive task training [10]. Other techniques such as electrical and cortical stimulation may also be used as part of the treatment to encourage muscle contraction. However, since the stroke survivors experience severe degradation or loss in their visual-field, cognitive and sensorimotor capabilities thereby reducing the success rate of regaining functional independence to perform the everyday activities after even after the treatment. Frequent failures in completing simple tasks may aggravate post-stroke depression, an after-effect observed in nearly 30% of the patients, and further negatively impact rehabilitation processes and outcomes.

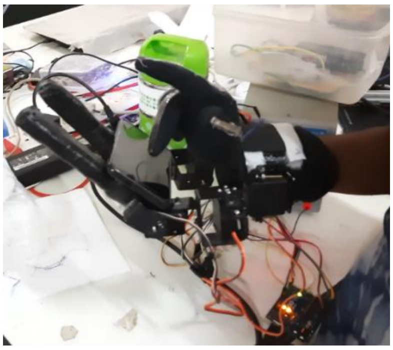
Current solutions for biomedical applications primarily include protheses, which are beneficial in providing assistance for upper life amputees, but this might not work in case of hemiplegic and hemiparetic patients because their dysfunctional limbs are still physically attached to them and have to be severed to install the prostheses. Moreover, current prosthetic devices, including rigid gloves with no functionality at all, hooks that have problems manipulating delicate items, multi-jointed hands that are too expensive and difficult to use, still provide only limited assistance. Other technologies like EMG and FES implementation have their disadvantages. The need to be connected to a more extensive circuit hinders the mobility of the exoskeleton, and the processing of the signals is much more complex.

Due to the cost and size of these devices and the availability of therapists, everyday usage at home is out of the question. The development of these devices creates a new field of research to investigate and develop these robotic limbs which can connect with human cognitive system [11].

The ML model that we are perfecting for this project is also novel because the dataset is made by us using the sensor glove. Using this device regularly will increase the accuracy of the ML model, like how facial recognition gets better over time by re-training on collected data. This device can also function in multiple modes like rehabilitative or therapeutic devices and is very mobile compared to other solutions in this field. The recovery phase seems to favour intensive training involving high repetition and task specificity that promotes better outcomes [12]. Patients with mild upper limb paresthesias that are associated with higher hand and finger weakness in the first week after stroke may be benefited from our proposed method [13]. The prototype of SR fingers weighs around 550g with an onboard computer and a lithium polymer battery, which is much less than other solutions and can be brought down even more on mass production. The device has a payload capacity of 2.5-3kg depending on the shape of the object to be manipulated. This weight range is more than enough for the hemiparetic patients to manipulate to complete their everyday tasks.

a

b



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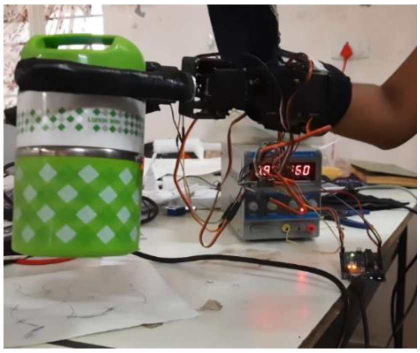

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Fig. 3. *Various Operating Modes (a)Free State (b)Bottle grabbing mode (c) Tablet Mode (d) Heavy/Big objects manipulating Mode*

5. Impact

One out of seven Indians suffers from some limb disorders. Consider stroke, for example, about 90,00,000 people in India experience one or more strokes every year, and 80% of the survivors must live with hemiparesis of the limbs contralateral to the brain lesion, ranging from mild weakness to complete paralysis. Stroke is a brain attack affecting 17 million people worldwide each year [14], and it is the second most common cause of death and a leading cause of adult physical disability. Post stroke patients often experience many long-lasting disabilities like degradation of their visual prowess, stuttered speech and loss of memory; sometimes even changes to their personalities accompanied by fatigue and depression. Post stroke hemiplegia is one of the most common problems for the stroke survivors. Recent studies conducted by World Health Organization observe that over 24 million people around the world suffer from hemiparesis and hemiplegia. Given the steady increase in life expectancy and high incidences of stroke in older adults, the number of hemiparetic patients is expected to double over the next three decades. With this novel device, the patients will be able to adjust to their condition and will be able to perform bimanual tasks without supervision or help from others.

6. Technical Specifications of the Prototype

The prototype was tested against various objects for manipulation, and we have identified the limiting conditions for its functioning. The SR fingers have six high torque servos, with each servo having 25Kgcm torque. The end effector is about 10cm in length and factoring the base servos to be used for holding the finger setup without stalling, the servo that has the end effector attached can provide 2.5 Kg of force without stalling.

The battery used in SR fingers is a 3000mah lithium polymer battery that produces 12V as output. The net power consumption for the electronics in SR fingers are as follows:

For maximum load conditions:

- Raspberry Pi – avg consumption 3W
- Servos stall current 1A@7V = 7*6 = 42W
- Flex sensors and feedback sensors = 0.5W*5 = 2.5W
- Arduino + Bluetooth module = 0.5W

Total power including the efficiency of buck converter=50W

Time of usage on full load condition =12V*3Ah/50W= 43.2 minutes of operation during full load condition.

For regular load conditions:

- Raspberry Pi – avg consumption 3W
- Servos current 250mA@7V = 0.25*7*6 = 10.5W
- Flex sensors and feedback sensors = 0.5W*5 = 2.5W
- Arduino + Bluetooth module = 0.5W

Total power including efficiency of buck converter = 18W

Time of usage on regular/medium load conditions = 12V*3Ah/18W = 2hours of operation.

7. Comparison with existing prototypes:

The prototype was compared against some of the earlier designs. Among the previous prototypes, the EMG controlled robotic extra finger by Hussain et.al.,[2] seems to be the most mobile one. Table 2 compares the technical differences between our prototype and the soft sixth finger.

Table 2 Comparison of prototypes

Parameter compared	Soft Sixth finger	Supernumerary robotic fingers
Ease of wear	Different location for different people based on the nerve location	Standard model fits on the wrist and can be adjusted if needed.
Maximum payload	1.4Kg	2.5-3Kg (depending on shape of object)
Total degrees of freedom	1 DOF	6 DOF
Mobility of the exoskeleton	Very mobile	Very Mobile
Control Mechanism	EMG sensors (need more processing power)	Flex Sensors (uses lesser processing power
Unique features	Single actuator-based mechanism	Continuously training ML Model
Disadvantages	Might not be able to manipulate all objects	Heavier when compared to soft sixth finger model.

As we can see from the table, having 2 extra fingers increases the amount of force that can be exerted on the object. Our prototype also has force feedback sensors at the end effectors which allows us to reduce the damage to soft objects when they are manipulated. The ML model used also yields better results than EMG sensors over time.

8. Conclusion

This paper presents a set of wearable robotic fingers for hemiparetic and hemiplegic patients as a rehabilitative device to perform bimanual everyday activities. The initial prototype was designed in SolidWorks and fabricated using pipe housing, metal clamps, and 3D printed components. The stall torque and force were identified by mechanical load test and by mathematical calculations based on the material used and the specifications of the servos. The DL model running on the raspberry pi is programmed to train on the go, increasing the accuracy over time for the user. The weight of the total model is 500grams which is much lighter than current alternatives and can be brought down on commercial manufacturing, increasing the feasibility of this device. Future works include building better housing for the microcontroller and raspberry pi, reducing the weight and modifying the end effector shape to have optimum grip over objects, and increasing the accuracy of the DL model.

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