Motor-Assistive Glove For Rehabilitating Finger Strength

Victor Ardulov, Kyle Cordes, Devin Cody

University of California, Santa Cruz
Santa Cruz, CA, USA

***Abstract*—Damaged neuro-pathways from an individuals brain to their peripherals, limits the mobility that a sufferer has in a given limb or body part. Patients recovering from neuro-trauma, must often spend months rehabilitating the damage through physical therapy, and specialized exercise. The Motor-Assistive Glove implements existing technologies to create a new, low-cost, non-invasive way to help sufferers regain their strength and freedom while trying to recover.**

***Index Terms*—Exoskeletons, Motor-Assisted Technology, Robotics, Medical Robotics, Rehabilitation**

I. Introduction

Among diseases, stroke is the fourth largest killer in the United States, and costs an estimated $34-billion annually. Aside from the pain felt during the stroke, a surviving patient will typically suffer from the a significant decrease in their finger strength.

Following a stroke, patients will often develop peripheral neuropathy, a sensitivity or weakness in the peripheral nervous system.[4] This degeneration of the peripheral nerves leaves patients with pain, muscle aches, and limited mobility in those regions. Currently there is a short list of options for treatment, especially in the non-invasive form. This results in a long and arduous process of recovery for a patient, hindering their freedom.

Figure 1. Finger extension (*left*) and grip strengthening (*right*) exercise equipment make up a large majority for rehabilitative therapy[1][2]

One of the generally successful non-invasive treatments is finger exercise, and physical therapy with equipment seen in Figure 1. However these methods typically take months to rehabilitate the strength in a patient's fingers. Furthermore, while they are in the early phases of recovery, a patient undergoing physical therapy will not be able to perform simple tasks at home, such as feeding themselves, or even grasping simple objects. On top of that, the exercises are typically guided by a doctor, adding to the already incredibly gradual process. While robotic solutions do exist they are, for the most part, focused on exercising the fingers, and are typically too expensive for home therapy, and as a result are found in a physical therapy facility or a doctor's office.

Lastly, it should be noted that even after all of these measures are taken, patients may not always regain complete finger strength, resulting in a life of hurdles and obstacles.

Advances in manufacturing technology and electronics have presented a novel opportunity to implement existing micro-controllers, sensors, and 3D-printing to develop a low-cost exoskeleton apparatus, which will allow patients to regain the strength they once had, and move on to complete simple everyday tasks at home. The *Motor-Assistive Glove* (MAG), uses the limited pressure that a patient can apply and compensates the rest, mechanically amplifying the patients finger strength.

II. Sensors and Actuation

The first step in determining the design of the system we had to find a method by which a user would interface with the apparatus. We made the assumption that patients will generally have some finger strength, which pushed us to choose pressure as an input to determine both the amount of contribution required, as well as the direction of motion.

Initially we looked into capacitive touch as method to detect the user input. However, capacitive touch generally used for a binary input. Most importantly, because the sensor would have to live inside the glove, the sensor would either have to live elevated from the patient's initial position, other wise the sensor would always be engaged. This complication in mechanical design also warranted an alternative sensor as the capacitive touch sensor limited our reading of patients input and did not meet the requirements well enough.

Force Sensitive Resistors (FSR) change resistance based on the pressure applied to the sensor[5]. This allowed us to design a circuit that would give us a range of pressure input readings. This meant that with a single sensor per finger the system could now observe not only the patients decision to move, as well as, intended direction and a range of finger strength. The FSR proved to be a ideal sensor for our purposes and proved to be incredibly affordable as well.

We also concerned ourselves with the ability to protect the user that from over bending their finger. Similar in nature to the FSR, a flex sensor varies its resistance based on the flexion of the sensor, one was added to each finger to limit the range of actuation and protect the user from potentially hurting themselves using the device.

Finally, we had to investigate the methods of actuation. Initially we were interested in linear actuation systems. Linear actuators are system that uses magnetism and electricity to move a piston, retracting and extending. However, the necessary actuators that could respond with the necessary length, range, and speed proved to be too expensive to justify for this project.[3]

After observing how fingers were actuated in a low-cost prosthetic arm, we instead chose a spool and motor design as presented in the Open-Hand Project.[6] This allowed us to make a much more affordable design for moving the fingers.

III. Physical Design

After deciding on the sensors and actuators, the dimensionality of the system was characterized, and a physical design could begin. We began with building a model for moving the fingers using a cable driven system. Three rings one fixed to each ”limb” of the finger has a cable running through them down the finger, fixed at the tip and free running through the rest of the finger. The cable would be attached to a spool on the end of a motor. When the motor would rotate the spool the cable would wrap around the spool, thus shortening the cable and applying a force to the finger tip which causes the finger to bend at the joints and curl.

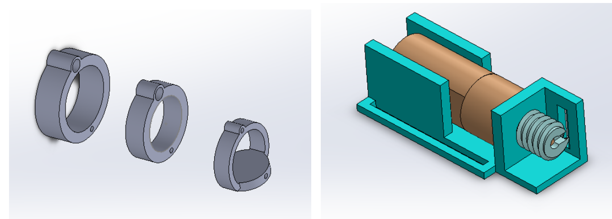

Figure 2. Rings that are worn on the finger with holes for spring, and cable(*left*) and entire motor mount and spool assembly that tensions cable.

The ring at the tip also includes a flat platform to support the pressure sensor, as we found that bending the sensor produces a poor sesor readings.

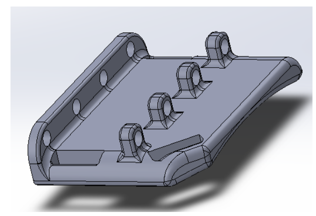

Figure 3. Attachment for fastening spring to the top part of patients palm

On the opposite end, the tip ring was also attached to a spring that was fixed to the top side of the hand. This would induce a opposing force, spring the finger back to the initial position of the finger.

Once all of these designs were created we used a 3D printer to produce the design and integrate it with the sensors and actuators to test the form factor and demonstrate that the entire system worked.

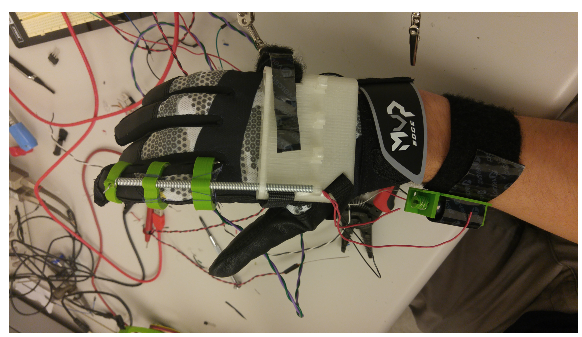

Figure 4. The physical implementatior of the MAG system for one finger

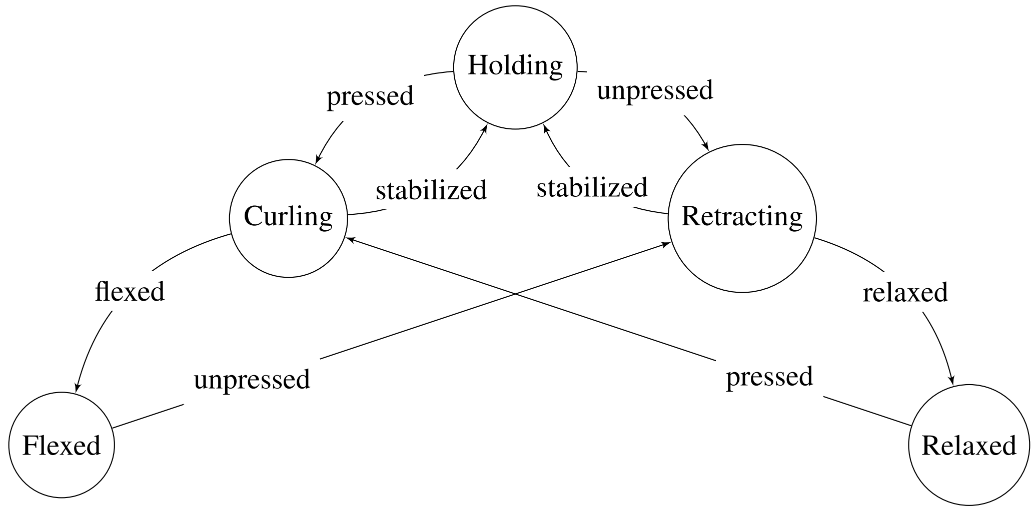

Figure 5. State-Machine Diagram: Control algorithm for a single finger

IV. Controls and Software

Following the completion of the sensor and actuation models, as well as our physical design, a control algorithm for the system was necessary. First, to determine how the operation worked, a State-Machine was designed. The State Machine maps the state of the actuator based on different events that occur. The events are triggered by patterns being registered in sensor readings. When a particular pattern is recognized from a particular sensor, when the actuator is a particular state, an inference is made as to what the user intended. Figure 5 shows the derived state machine, defining each node as a state and each edge labeled with an transition event. In a given state the system will ignore all events occurring outside of the ones that will transition it to other states.

The controller was implemented using a micro-controller capable of sampling analog voltage values, output control signals (Digital and Pulse-Width Modulated), and be operated in software. This provided the most amount of flexibility and robustness to changes and fine tuning and future expansion for the system. Once a micro-controller was selected to meet the design requirements, samples were taken from the flex and pressure sensors in a variety of states (i.e. flexed, relaxed, pushed down, stable, etc.) to record hysteresis values, which act as baselines for the control of the apparatus. Once values were selected, software services were introduced to making sampling the sensors from the state-machine simpler.

Finally, after loading the code base onto the micro-controller and plugging in the sensors, we observed to total system integration operate, and function for a single finger physical model.

V. Future Work

While the project has shown a tremendous amount of success, there are redesigns which need to addressed. Currently the physical implementation has a number of limitations, namely the the ring at the can slip from its intended position and thus will ruin sensor readings. Different design for a glove tip are currently being redesigned in order to fix the sensor to the appropriate position of the finger with out fear or it migrating.

Due to the non=lateral nature of the deflection of the finger, it has been observed that the spring struggles to completely restore the finger to it's initial state. For this reason investigation into other elastic material, or a different spring implementation system is currently underway to improve the overall response of the system.

Lastly, the current control module presents a controller which is considered "bang-bang" meaning that it operates in a full-forward or full-reverse manner. However different patients will need different levels of compensation, for this reason a gradual, or tracking digital controller should be implemented to allow patients to develop their own finger strength, rather than simply

Acknowledgements

This project was done with laboratory support from CITRIS, in conjunction with the University of California, Santa Cruz.

References

[1] URL: http : / / www . amazon . com / MANUS - physical - therapy - hand - exerciser / dp / B00HY4PP8C / ref = pd_sim_sbs_121_3 ? ie = UTF8 & dpID = 41oOK7NNuDL & dpSrc = sims &

preST = _AC_UL160_SR150 % 2C160_ & refRID = 0Z6YGC5BEVS3TB59VF7H.

[2] URL: http : / / www . amazon . com / Hemiplegia - Exercise - Trainers - Rehabilitation - Equipment / dp / B00KW4ZVIU.

[3] *Actuator LD3 /LD3Q*. URL: https://www.pololu.com/file/0J860/LD3_datasheet.pdf.

[4] Center for Disease Control and Prevention. *Stroke Facts*. URL: http://www.cdc.gov/stroke/facts.htm.

[5] Interlink Electronics. *Force Sensing Resistor Integration Guide and Evaluation Parts Catalogue*. URL: https : / / www . sparkfun . com / datasheets / Sensors/Pressure/fsrguide.pdf.

[6] *Open Hand Project*. URL: http : / / www . openhandproject.org/.