Shape Memory Alloy (SMA) Assistive Technology to Mitigate Repetitive Strain Injury

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Term Project: Soft Robotic Glove to Assist Grasping in Users with Repetitive Strain Injuries

Abstract

Repetitive Strain Injury (RSI) is an umbrella term for injuries caused due to repetitive motion and overuse of a muscle. There is no full treatment for this class of injuries, and current assistive devices help with reducing pain when carrying out daily tasks. After interviewing an individual with this injury, we hypothesized that a tendon driven glove actuated by a Shape Memory Alloy (SMA) would allow the user to regain grip strength without increasing strain. The use of and SMA actuator allows for a slimmer and quieter assistive device, which helps keep it discrete. A functional prototype of this device was then built and tested against predetermined criteria to assess its efficacy as an assistive device for this injury. This work could motivate further research into SMA actuators for assistive devices, and can be iterated upon to create a novel device that benefit a large population of users.

I. Introduction

We are addressing the potential of assistive technology in the prevention and recovery from RSI (repetitive strain injury). This injury often occurs in industries where the user is performing an action, or series of actions, in constant and continuous rotation, stressing the hands and especially the wrist. Current assistive technologies are either bulky, uncomfortable or loud, and are more geared towards adapting to the injury rather than restoring hand functionality. This paper aims to explore the efficacy of using a shape memory alloy (SMA) to actuate a tendon driven glove.

A. Background

Repetitive Stress Injury (RSI) is an increasingly more prevalent injury affecting the general population. RSI is a term used to characterize pain felt in muscles, nerves and tendons [1] that is often caused by repetitive motion, movements and over use. This injury is witnessed in three primary locations: the forearms and elbows, the wrists and hands, as well as the neck and shoulders. These injuries can occur in multiple locations simultaneously. The symptoms of RSI are usually pain and tenderness in a muscle or tendon area, following a prolonged period of repeated motion (for example typing or assembly line work). If untreated or ignored these symptoms develop, with pain becoming more prolonged, constant, and significant, resulting in basic movements become troublesome. This illness is often accompanied by Carpal Tunnel Syndrome (CTS), which is tenderness in the wrist area where tendons flow through the small Carpal tunnel. This area can become constricted, applying a constant pressure on the tendons causing damage and reducing range of motion. It can occur in a wide range of situations, where a repetitive motion may not be as obvious, such as in individuals performing housework [2]. This condition can have adverse effect on an individual's social, occupational and emotional interactions, forcing changes in the way they interact with the world.

Types of Treatment: There are a broad range of generally applicable treatments, which are external and non-intrusive, failing which surgery is the only corrective option. Most Physicians prescribe rest and splints to hold the injured limb in a neutral position [3]. Other types of treatments include, but are not limited to: ultrasound therapy, full wrist support structures, heat therapy and stretching exercises. Although there are a variety of these treatments, they are often not rapid or effective. Generally the best treatment is identifying the injury as soon as tenderness is felt and adjusting the motion accordingly, allowing rest and time for recovery.

Impacts on life: Individuals affected by RSI can experience a vast range of impacts, generally centered around the additional pain and discomfort when performing a movement or applying a force. For individuals specifically afflicted by a wrist or hand related injury (often paired with Carpal Tunnel), applying consistent stresses with the hands as well as complex wrist and finger motion. Individuals suffering from upper arm and shoulder related RSI have a reduced ability to manipulate large objects, and occasionally lose complete range of motion with the affected limbs. Both situations make performing every day tasks tedious and painful, such as lifting and pouring a milk carton, writing and preparing food for cooking. There is an increasing range of assistive devices that are task focused, and the few that enable general locomotion are bulky, expensive and uncomfortable (such as braces or body powered manipulators).[4]

B. Overview

We hypothesize that using a tendon driven glove will allow us to restore grip strength to a user with RSI without causing further strain. The increased grip strength will allow the user to pick up everyday objects and using an SMA driven system will allow us to reduce the noise and size of the glove compared to a traditional motor driven system. In *Section II* an individual with RSI expresses their needs and challenges due to their injury, and this interview was used as the basis for our device. In *Section III*, we present our solution and detail a series of tests that we will use to prove our hypothesis. If proven true, this idea has great intellectual merit, as we will further discuss in *Section IV* and will assist in the development of SMA driven systems for assistive devices. Finally, in *Section V*, we discuss the impact our device may have on the wider community and how it could be further improved and made more accessible. As we plan on open-sourcing the implementation for further development, the CAD model, control circuit and code can be found in in *Appendix B*.

II. Preliminary results

To best design an assistive device for users with RSI, we interviewed a student who recently developed CTS and tendonitis, both types of RSI. To perform this interview, we arranged a meeting over Zoom and with consent of our need knower, recorded and transcribed the meeting for further analysis. We gained many insights about living with the condition and how it has effected the user's life, and the main highlights of the interview are summarized below.

The interviewee first started by describing her daily routine, which includes a series of wrist stretches and compression exercises to reduce the pain caused by RSI. They then described to us how they have had to adapt their routine to carry out tasks in smaller chunks with many breaks in between to reduce wrist strain. An example they gave was carrying their laundry in multiple trips to reduce the load.

When asked whether they use any assistive devices, the interviewee mentioned using text-to-speech frequently due to the motion of typing and handwriting being particularly strenuous on their wrist. The interviewee also mentioned having to use splints and braces throughout the day and while sleeping, which can often be very rigid and uncomfortable.

We then asked the interviewee which tasks they found the most challenging. They said that any task that involves repetitive wrist motion or grip strength is painful, and they often have to rely on someone else to do the task for them. This highlighted the extent to which RSI has affected the interviewee's life, as they have had to stop their hobbies such as dancing and drawing and have had their independence taken away from them. The interviewee also mentioned the social pressure that comes from this injury, as often they feel like a burden on their friends and must miss out on ordinary events. The injury has also affected their academic abilities, as they cannot write as much as they used to and carrying a laptop to class also causes pain.

Overall, the interview was very useful to find out what the needs of our interviewee were and highlighted some key pieces of information that helped our design. One major finding was that moving the user's joints for them caused them no discomfort, and this is what led us to design an actuated glove system. An abbreviated table of the interviewee's statements and our interpreted assistive device (AD) needs are shown in the table below. We believe that a glove that can increase the user's grip strength is the best path forward, as it addresses most of their needs and tackles the problem at the source, which allows for a more universal and applicable product.

TABLE I: Condensed need knower statements and interpreted needs

Statement	Interpreted Need
I have to be very selective about when I write and when I choose to save my hand	The AD needs to allow the user to write
For example, like fruits, I can't cut anything right now, because it hurts for me to do the knife action.	The AD needs to allow the user to be independent and cook
I can't open doors, opening like heavy stuff, anything that requires a lot of strength for my wrist	The AD must allow the user to lift and manipulate heavy everyday obejcts
I can't carry around many ergonomic devices for my laptop because they're quite large and heavy	The AD must be portable and lightweight
After that I do the stretches that my hand therapists told me to do.	The AD needs to stretch the fingers of the user for therapy

III. Methods

Concept and Design: With the goal of producing efficient, quiet and comfortable actuation of our interviewees fingers we visualized and developed a device using SMA wires. The Glove is a comfortable and easy to mount assistive device which fits snugly onto a users hand, and contains nylon wires connected to SMA springs as shown in *Figure 1*

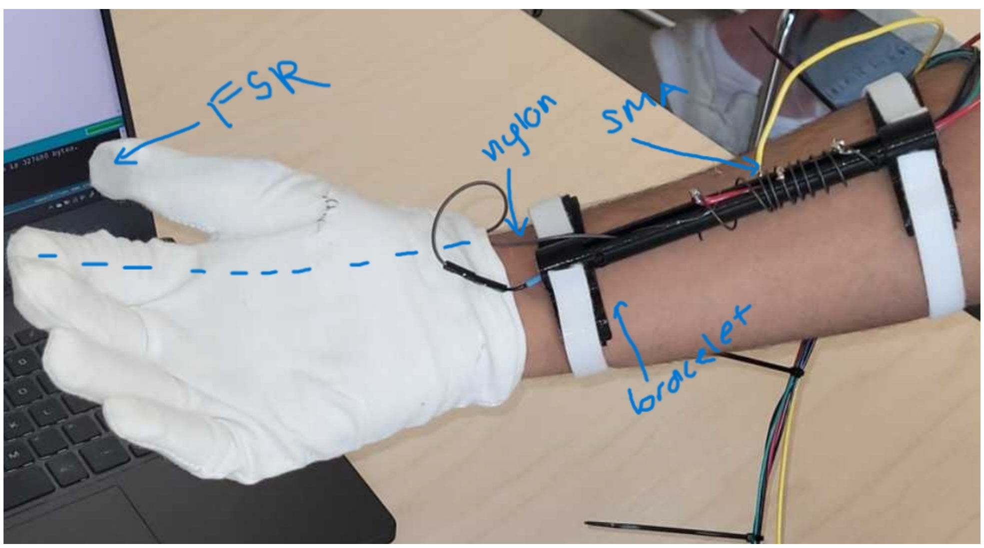

Fig. 1: Functioning Final Prototype mounted on user's arm using Velcro straps.

The entire glove device fits over the hand and three-quarters of the length of an average arm (6 inches), which provides ample room for complete spring compression. The springs are plastically stretched and attached to the nylon wire which runs into the glove, through a series of joints till the vertex of the finger. The springs change shape when a current is applied across them: they can be plastically deformed, and will return to their original shape when they heat up. The Glove essentially provides efficient quiet actuation of the users fingers, grasping for them. When the system is triggered, the micro-controller switches the BJT to provide a current to the spring, which will rapidly compress to its original shape, applying tension to the nylon wire. This tension (6 to 8N) is enough to cause a contraction of the intended finger.

Following initial alpha testing it became apparent that a user might not be able to apply adequate force to un-stretch the fingers, as the SMA springs take time to cool down before they are deformable again.

In order to combat this, we have attached two ground wires to the spring, effectively splitting it into two springs which can be triggered independently to release tension on the nylon wires, and subsequently the fingers. The springs are mounted sans a protective housing in order to facilitate efficient convective cooling to reduce the cycle time. This is demonstrated in *Figure 2*. The finite state diagram showing the full functionality of the glove is shown in *Figure 3*.

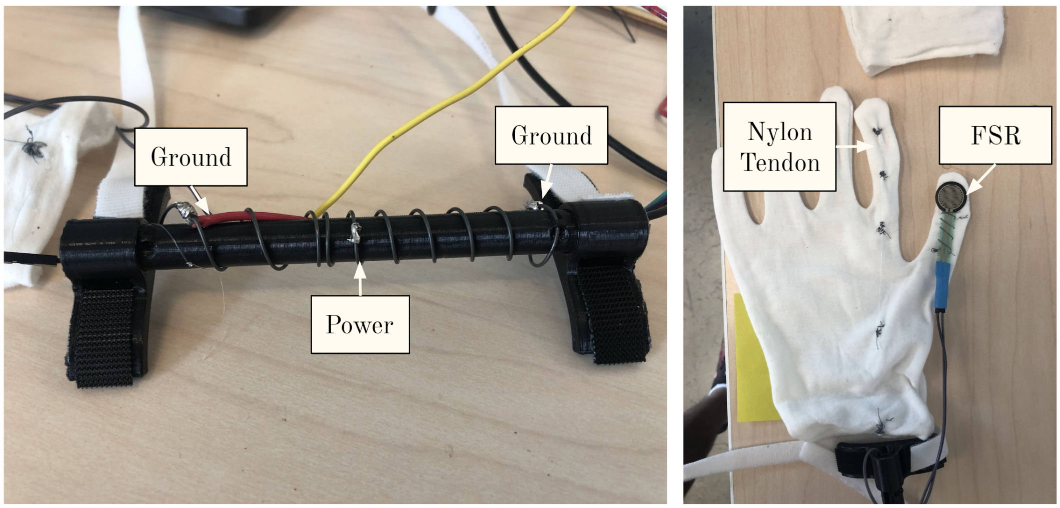

Fig. 2: Breakdown of Final Prototype showing the key components.

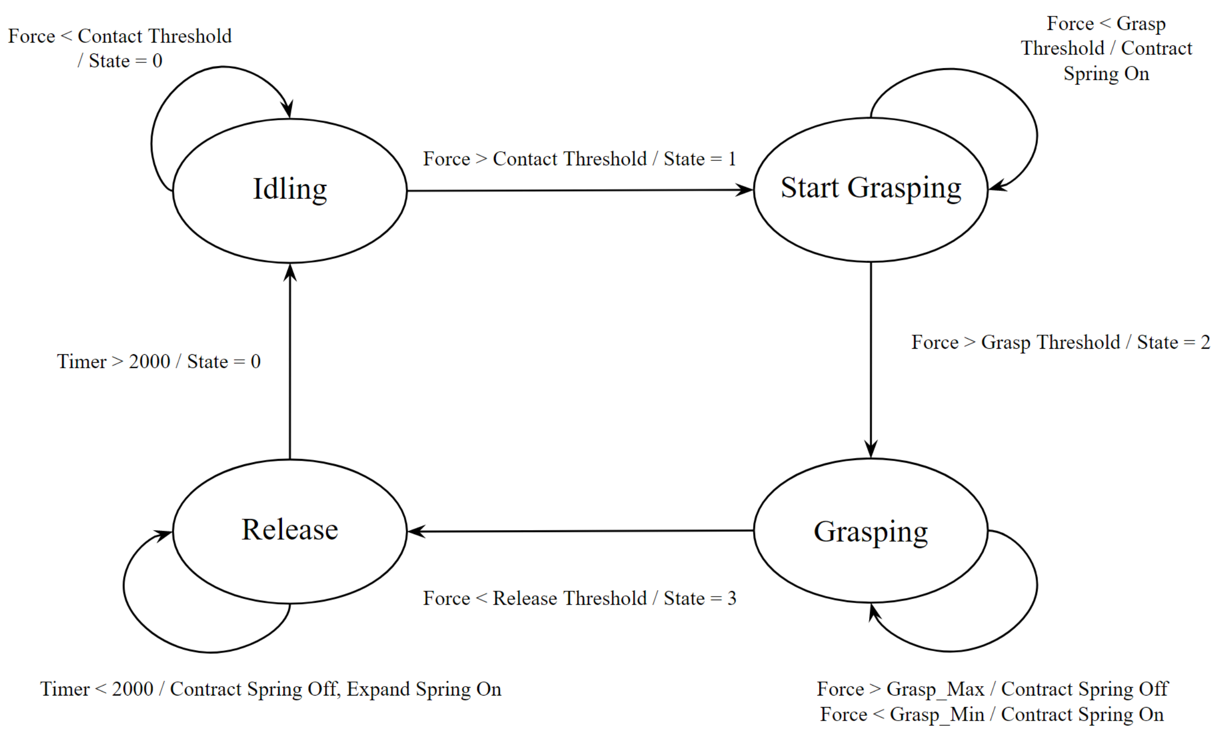

Fig. 3: Finite State Diagram showing the control loop.

While this system is meant to be universal, we acknowledge there is a wide range of finger and hand geometry, and the amount of force and positions of force application might not always be enough to induce an efficient grasp of the user's hand.

Proposed study: Once we manufacture multiple prototypes we will select 10 volunteers to participate in a study. The participants will be from a range of different backgrounds with RSI injuries: age, sex, occupation. We will use the study to compare the user experiences when using the device to grasp and apply forces to a carefully selected range of everyday objects: pens, milk cartons, door knobs etc. The subjects will be given a series of tasks they must perform with each object, and data will be collected about the the time it takes them to perform each action, the amount of force detected by the FSR, the average energy usage (from battery) for each action and the time taken for a complete actuation cycle. The time data will be compared to data collected from any number of un-injured volunteers performing the same tasks as well as the participants themselves performing the tasks without our device. This data will be used to assess the general efficiency of our device, identify areas where mechanical or electronic adjustments could improve usability, and the viability of introducing our product to the consumer sphere.

We will ask them to fill out a survey that asks for their experience in several areas: comfort, estimated social acceptance, practicality, ease of use, successes and failures when performing the prior selected activities. As we are running human subject tests we will submit our study protocol for review by the Internal Review Board for the Protection of Human Subjects, to ensure we are being ethical and humane in the scope of our research. We have completed the CITI training Group 1: Biomedical Research Investigators as of March 2022, and have the necessary knowledge to perform this study respectfully.

IV. Intellectual Merit

Through the proposed study of our assistive device, we can demonstrate the efficacy of a SMA actuated tendon-glove system at restoring grip strength. If our hypothesis is proven true, academics in the field can further study the use of SMA actuators to explore the benefits and drawbacks compared to motor driven systems as they are significantly lighter and quieter. One major shortcoming of our current system is the fact that we only tested single finger actuation and were limited by our resources to more advanced SMA spring shapes. Further studies and user testing involving a multiple finger system can verify if our design is scalable, miniaturizable and addresses the needs of its users. These tests could also implement more grasping poses, as in theory our design allows for the finger to be held at any angle. Should our hypothesis prove false, this study will still be a valuable exercise in highlighting the shortcomings of SMA, and perhaps future research can be done on improving upon these areas. With comfort and weight being a key area of research within active prosthetics, we believe our findings will contribute greatly to this field.

V. Broader Impact

This study showcases an assistive device that may greatly help users with symptoms of RSI. Allowing them to grasp objects without causing further strain is immensely helpful and allows the user to be independent, a key desire highlighted in *Section II*. This device is not just limited to users with RSI and can be adapted to help a wide variety of people. If miniaturized enough, it could be used by people without any injuries to augment their grip and prevent RSI from developing in the first place and can also be used for people with full paralysis of their hands. Due to their quiet and sleek designs, SMA prosthetics have the potential to destigmatize the use of assistive devices, which can improve its accessibility. We plan to open source this design to allow the maker community to further iterate on the device and adopt it for more uses than what was presented. The device details can be found in *Appendix B*.

References

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Appendix A
Discovery Decomposition

Paper 1

In 2021, Scott.C wrote an article describing his journey dealing with RSI, and some solutions he came across.[1] He knew and self diagnosed with RSI due to typing, confirmed medically. He could not perform most daily tasks unassisted for a period of an year, typing for 3. He quantified the potential signs of RSI, and technology that could be used to prevent it. It was discovered that using a mouse can be more harmful for the hands than typing, due to the force being applied. Now it is known that rest and reducing the use of hands through assistive tech is incredibly important in preventing and curing RSI

Paper 2

This seminar details the scarcity of information available about treatment for upper limb RSI. [5] There are few large scale studies that deal with RSI, limiting the information available. Various exercise schemes were tested to check their effectiveness with addressing RSI. The response in terms of pain levels and freedom of movement was measured using immobilizing hand braces and various strengthening exercises. It was discovered that while exercise helps with neck and shoulder pain, it is not enough. It is now known that more formal investigation is required using specific working populations as test subjects.

Paper 3

Occupational RSI has not been well documented, this paper discusses RSI in assembly line workers. [4] The prevalence of elbow tendinitis and Lateral Epicondylitis is high amongst industrial workers. The study explored the appearance of RSI in this assembly line workers. They videotaped and measured peak contact stresses, peak hand force and peak posture of the elbow, to determine loss of movement through RSI.It was discovered that women and older workers are more likely to have persistence symptoms, with a 16 % rate amongst all the subjects. It is know known that older workers must have ergonomic considerations taken with repetitive work.

Paper 4

RSI in women working in households takes a serious tole, emotionally and physically. [2] The paper addresses the lack of information about how RSI affects women at home. The authors interviewed 30 participants with RSI, addressing potential stigmas and how they were coping. They women gave detailed daily accounts of how RSI was affecting their lives, and the researchers discovered that women were very picky with the assistive tech they chose: it has to have as high a standard of efficiency as they do as these women take pride in running a house hold efficiently. It is now known that home RSI devices must be highly effective and practical to use.

Paper 5

The paper reviews common repetitive strain injuries that occur in the workplace. [6] RSI injuries occur from repeated stress to the body's soft tissue structures including muscles, tendons, and nerves. Physical examination focused on the soft tissues,beginning with inspection for signs of inflammation. or muscle wasting. Measuring the mean duration of chronic tendon stress was key, resulting in the symptoms lasting generally between 6 and 9 months. Diagnosis requires a history of work and leisure activities, and magnetic resonance is best for confirming RSI.

Paper 6

This paper provides an overview of Carpal Tunnel Syndrome (CTS) and the different treatments currently available. [7] The paper starts by covering how CTS can be diagnosed through a series of tests involving wrist mane and highlighting its main symptoms. Most users with CTS experience pain, numbness and tingling in the fingers, and can get worse at night. It also may lead to decreased grip strength and loss of dexterity. The main types of treatment are classified as non-surgical and surgical. Non-surgical methods include options such as improved ergonomics, reduced use of motions that may worsen symptoms (such as using vibratory tools), wrist splints and medical injections and pills. Most of these treatments alleviate symptoms, but may not fully treat the injury, in which case surgery may be required.

Paper 7

This paper evaluated the efficacy of wrist splints in assisting users with CTS. [3] They studied the effect of custom moulded wrist splints on full-time and nightly only users. They hypothesised that longer usage of wrist splints leads to a greater recovery, which they measured in distal latency. They found that those that wore it full time showed greater improvement, and this led them to conclude that neutral wrist splints are effective in treating CTS. They also found that while wrist splints can help ameliorate some symptoms, they do not help with other factors that contribute to higher carpal tunnel pressure, such as certain postures and fingertip loading.

Paper 8

This paper examines the effect of finger posture on CTS and measured which wrist and finger postures are best to alleviate CTS symptoms. [8] They measured the pressure in the carpal tunnel using a catheter, and carried out a range of tasks to measure the changes in pressure. A higher pressure means that the symptoms are worse in a patient. They measured a range of wrist flexion and metacarpophalageal (MCP) motions and found that a 0°MCP angle, coupled with a fully extended wrist led to the highest pressure (straight fingers). The lowest pressure was at a 45°MCP angle and a neutral wrist position. This is an important result when it comes to designing wrist splints and CTS devices.

Paper 9

This paper outlines a methodology to make niche, specialized assistive technologies adaptable to a mass market. [9] They start by saying that no product is suitable for everybody, but starting with a top-down approach is a good way of designing a universal product without giving up on functionality. A top-down approach starts with designing a product for a specific user and then finding reasons why other people might use it, known as extending its reach. They also highlight the importance of aesthetic and human centred design in making a product not only functional, but also appealing and socially acceptable. They then analyse three products that used their framework and assessed their successes and failures. This was a very useful paper as it illustrated the importance of appearance when designing a product meant to be used everyday.

Paper 10

Tendonitis is defined as the “inflammation of tendons and tendon-muscle attachments”. This paper provides and overview of the diagnosis and treatment of this injury and comments on the current state of academic literature surrounding it. [10] Tendonitis is very common in sports and is often due to overuse of a muscle or joint. They occur as a result of repeated micro injuries of tissue due to a mechanical load. This injury reduces flexibility and muscle strength, and can often have symptoms similar to CTS. The primary method of treatment is to correct factors that led to the injury in the first place, such as overuse and ergonomics. For muscles that are shocked repeatedly, such as when using a hammer, shock absorbing devices are recommended, this is where assistive technology may be useful. Physical therapy is also used to relax and retrain the muscles to regain strength, however this is poorly documented and nit much factual evidence about its efficacy is available.

Appendix B
Investigational Device Details

CAD Model

Fig. 4: CAD Model for 3D Printed Housing: https://a360.co/3vTbETu

Arduino Code

```
#define contractPin 13
#define relaxPin 12
#define FSR A0

const int freq = 5000;
const int contractPinChannel = 0;
const int relaxPinChannel = 1;
const int resolution = 8;
int force = 0;
int state = 0;
int contact_thresh = 10;
int grasp_low = 1500; //minimum required for sucessful grasp
```

```
int grasp_max = 2000; //max needed for sucessful grasp
int grasp_thresh = grasp_low; //threshold for grasping
int release_thresh = 50; //threshold for releasing

void setup() {

  Serial.begin(9600);
  ledcSetup(contractPinChannel, freq, resolution);

  // attach the channel to the GPIO to be controlled
  ledcAttachPin(contractPin, contractPinChannel);

  ledcSetup(relaxPinChannel, freq, resolution);

  // attach the channel to the GPIO to be controlled
  ledcAttachPin(relaxPin, relaxPinChannel);
  pinMode(FSR, INPUT);

}

void touchChecker() {
  force = analogRead(FSR);

  if (force > contact_thresh) { //start_grasping
    Serial.println(force);
    state = 1; //start grasping state
  }
}

void graspReachedChecker() {
  force = analogRead(FSR);
  if (force > grasp_low) { //entered grasping state
    state = 2; //enter grasping state
  }
}

void releaseChecker() {
  force = analogRead(FSR);
  if (force < release_thresh) { //release grasp
    state = 3; //enter release state
  }
}

void springOn() {
  ledcWrite(contractPinChannel, 255);
}

void springOff() {
  ledcWrite(contractPinChannel, 0);
}
void expand() {
  ledcWrite(relaxPinChannel, 255);
  delay(10000);
  ledcWrite(relaxPinChannel, 0);
}
void constantForce() {
  if (force > grasp_max) {
```

```
    springOff();
  }
  if (force < grasp_low) {
    springOn();
  }
}

void loop() {

  switch (state) {
    case 0: //idling state
      touchChecker();
      Serial.println("Idling");
      Serial.println(state);
      break;

    case 1: //start grasping
      Serial.println("building up to grasp");
      springOn();
      graspReachedChecker();
      break;

    case 2: //grasping
      Serial.println("grasping");
      constantForce();
      releaseChecker();
      break;


    case 3: //releasing
      Serial.println("releasing");
      springOff();
      expand();
      delay(2000);
      state = 0;
      break;

  }
}
```

Video

A video showing our device in action can be found here: https://youtu.be/liqg7_9N4Tk

Circuit

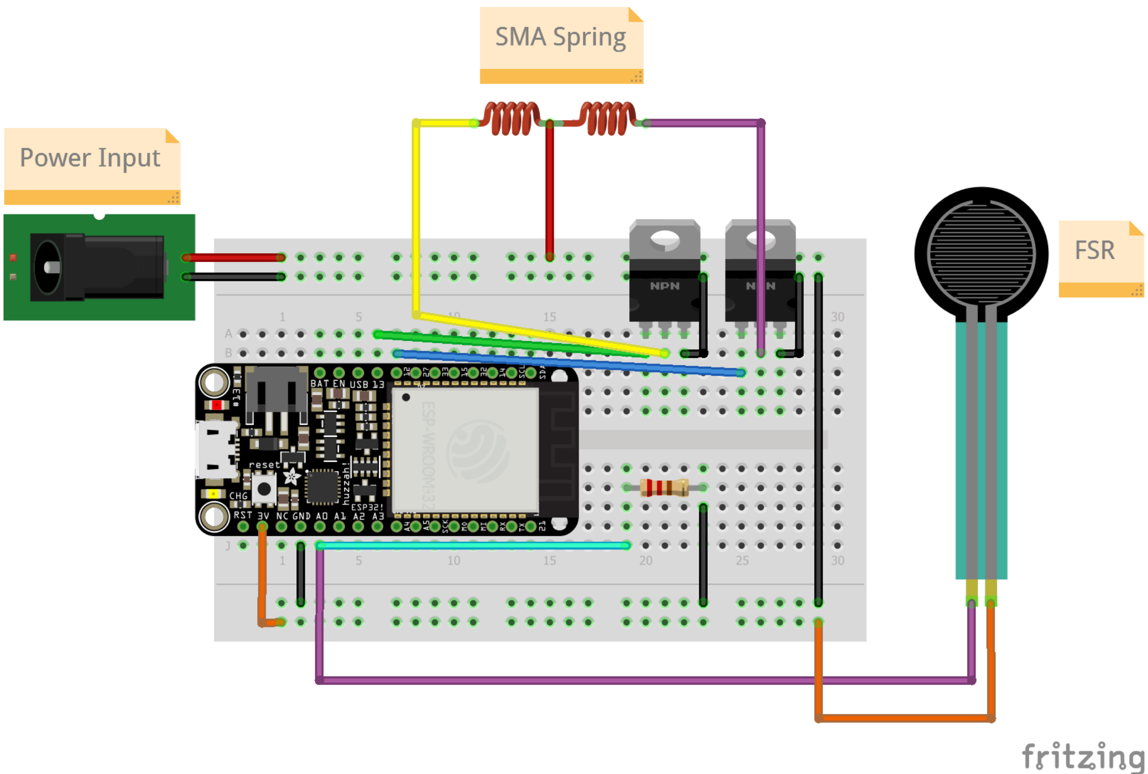

Fig. 5: Control Circuit for SMA Actuation