Designing a Modular and Wireless Strut for a Tensegrity Robot and Learning Locomotion Using a Spiking Neural Network and Genetic Algorithm

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Abstract

The goal of the project is to design a modular wireless strut that can be used to create a n-bar tensegrity robot. This strut needs to meet many design requirements including size and power consumption. The newly designed strut should be able to run for about 1 hour on a single charge of the battery and be less than 15 cm long. The strut will be used in a closed loop system to produce motor frequencies. Feedback from inertial measurement units and motor encoders will be fed into a spiking neural network. The network will then output motor voltages that correspond to frequencies. A genetic algorithm can be used to assess the motion of the tensegrity at given frequencies. The fitness of the genetic algorithm can be a measurement of many factors including, how far the robot moves, how straight it moves, and how well it turns based on a given frequency.

1 Report Summary

At Union College in the Electrical Engineering and Computer Science departments each senior completes a senior thesis project. This project is the culmination of everything that we have learned this far at Union. By doing the project we learn many skills including prototyping, testing, debugging, and project management. For this project I am working on developing a new tensegrity robot that will better the research that is currently being done on it.

This project includes both a significant electrical engineering design project and computer science research project. The electrical engineering design task is to create a modular and wireless strut for the tensegrity robot. The computer science research question is defining to what extent does a closed loop system improves on an open loop system to exploit tensegrity's natural resonance to promote locomotion.

The most important part of the design of the modular wireless strut is figuring out what components to use. The components need to be small, low power and cheap to ensure the design requirements are met. Components need to be chosen so that they all interface together to develop a final system. To accomplish this task a large amount of online research was done into the many different components until they were chosen.

To succeed in answering the research question, a spiking neural network needs to be implemented onto a micro-controller. A genetic algorithm needs to be developed so that it can assess fitness of the motion and determine the best frequencies.

The final outcome of this project will include a working strut that provides a better way to learn locomotion of the tensegrity robot. Along the course of the project many design

decisions will have to be made that will impact the outcome of the project. In the future, exploring some of the rejected options could allow for finding a new design that could improve on this one.

This report will first introduce what a tensegrity robot is and what research has been done in getting the robot to move. Then describe the problem that has been reached with the current research. Next it will define the goals and requirements of the final outcome of the project. And finally discuss the work that has been completed with the project thus far.

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2 Introduction

There is a lot of tensegrity research that goes on at Union College. We have developed a system that uses a tensegrity structure and pager motors to generate locomotion. The pager motors vibrate at certain voltages which drive the robot in the desired direction. The tensegrity robot that is currently being used is the fastest based on it's size [1]. The way that the robot was designed allows it to be able to be operated for long periods of time, and be easy to repair. But there are many problems with the current design.

2.1 The Problem

The biggest issue with the tensegrity robot is that the motors are controlled and powered by a USB interface to a laptop computer. This means that the setup has a snake of wires that is always attached as seen in Figure 1. This inhibits the robot in many ways. This snake is easily tangled and is very weak so can easily be broken requiring the robot to be down for repairs. This means that someone needs to be monitoring the robot when experiments are going on so that it does not stress it's snake.

Currently there are three motor controllers that are connected to a laptop. The laptop is running a hill climber algorithm that asses how well the tensegrity moves in a short burst of time. Based on performance the computer will send different voltages to the motor and continue to asses. The way that this is done can be a source of error. The algorithm is dealing with voltages, but the actual tensegrity is moving based on frequency of the motor. Different factors like hysteresis and different surfaces can change how voltages map to frequencies. The current system is designed open loop so there is no way to self adjust the voltage to get the

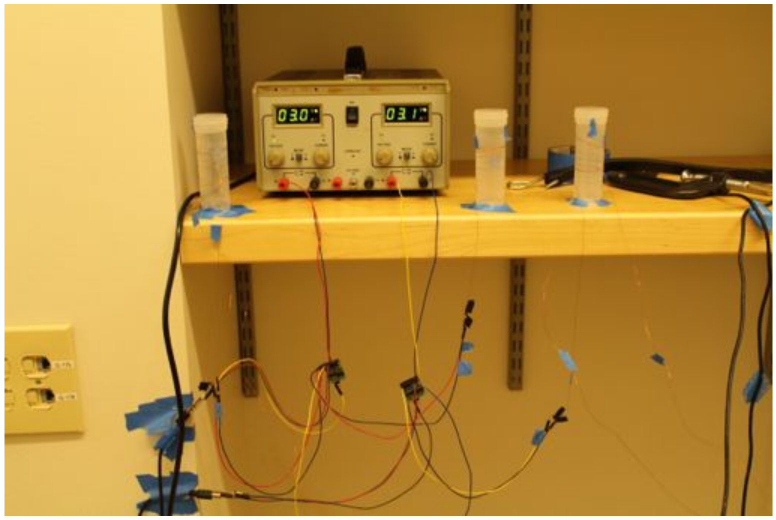

Figure 1: A picture of the tether that connnects the power supply and computer to the tensegrity robot's motors. This easily tangles when the robot rotates and moves around.

correct frequency.

2.2 The Objective

The goal of this project is to develop a system that will fix this problem of the tethered tensegrity and create a better system for generating motor frequencies. To do this a newly designed strut is needed. It needs to be wireless so that the need for the tether is no longer needed. The strut needs to also be modular so that it can easily be replaced if one was to fail. Modular also allows the entire shape of the tensegrity can be changed to include more struts.

To create the wireless strut there will need to be a motor, micro-controller and battery. The strut will also need a system to create feedback of the vibrations generated by the motors. This allows there to be a closed loop system when setting frequencies so that they can be more repeatable. To accomplish this a shaft encoder can be added to the motor and an Inertial Measurement Unit (IMU) can be added. The encoder and IMU will feed information into a neural network that will adjust the output to be the desired frequency.

Finally in order to control the strut from the computer without having to hook it into with a wire, a Bluetooth module will be used to communicate with the micro-controller. The link will send statistical data to the computer and receive motor frequencies from it.

With this advance new robot we will be able to use a genetic algorithm to learn the best frequencies that get the robot to move. This will allow us to explore the question of how much better is using a closed loop system with a genetic algorithm than the original tensegrity at learning motion.

2.3 Report Outline

The remainder of this report will first introduce research in tensegrity robotics. Then formally describe the requirements of the new tensegrity robot. Next the report will touch on some of the design alternatives that could have been chosen for the project. Finally the report will outline the final design of the project.

3 Background and Related Work

A tensegrity robot is a soft robot made up of rigid struts and springs. These are connected in a disjoint manner such that the robot maintains it's shape [8]. The field of soft robotics is expanding due to their ability to transform in ways that humans and typical hard robots can not. These robots are unique because they are able to be manipulated and return to

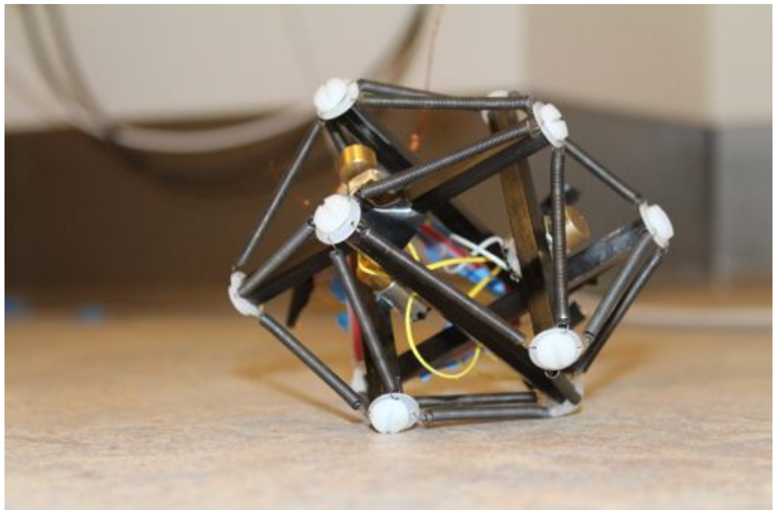

Figure 2: A picture of the tensegrity robot. It consists of 6 rigid struts and 24 springs.

its original shape. Because of their structures, learning how to make soft robots move is an important research topic. Seen in Figure 2 is a 6 bar tensegrity robot. The robot is made up of 6 struts, 24 springs, and 3 pager motors. The shape of the robot is created by the forces of the springs onto the struts.

In order for a soft robot to be useful the robot has to be able to move. Paul et al. explains, there are three main ways that a tensegrity robot can be actuated: strut colocated actuation, cable colocated actuation, and non-colocated actuation. Strut colocated actuation is done by using actuators to vary the strut length, this changes the geometry of the structure. Cable colocated actuation is changing the length of the springs. Non-colocated actuation is using a force between two struts, springs or a strut and spring [3].

Most research in robotics deals with trying to limit the dynamic coupling between components. Other researchers find that this coupling can inhibit motion of robots. In the tensegrity research at Union College we aim to use the dynamic coupling of the tensegrity structure to help in locomotion. [9]

Tensegrity motion can be created with three motors being used to actuate the struts and springs. The motors vibrate at different frequencies which causes locomotion. Because of the dynamic coupling of the different struts by the springs the motors can generate frequencies that are transferred throughout the device. The entire tensegrity vibrating can cause motion[3]. In the case of Paul et al., this motion was bad and research is done to limit it.

3.1 Outcomes

One outcome of this project is the social impact at Union College. The project is designed to help aid research that is happening at Union. The improvements to the current robot will allow students to more easily conduct research with the tensegrity robots. Not only will research be easier, since the tensegrity won tangle, but the tensegrity will also be more accurate and repeatable with the closed loop system.

This project also will have ethical effects on society. The tensegrity robot falls into a class of robotics known as soft robotics. This field has a very large positive impact on current health and safety issues. Soft robots are being used in situations where people are not able to get to. This is because the robots can deform and move into spaces that humans can not fit. They can be used as search and rescue devices that can help find victims under rubble.

The new design is also meant to increase the sustainability of the tensegrity robot. The current design of the tensegrity is put together with a magnet wire tether. This is a easy source of breaking of the robot often causing need for repair. The new design allows the robot to be more sustainable since the tether will no longer be needed.

4 Design Requirements

There are many requirements of the design of the new tensegrity robot. The requirements span many different categories each presenting a challenge in finding working components. The design needs to result in something that is small, cheap, efficient, and easy to build. To make a successful design each of the components need to be able to interface with each other and work well.

4.1 Size

One of the important parts of the tensegrity research is that the robot is small. For the size of the robot it moves the faster than anything else ever researched [8]. This size is something that we want to keep as limited as possible. The final strut length needs to remain under 15cm long and 5 cm wide. This is one of the most important design requirements of the design.

4.2 Modular

The strut is designed to be modular. In order to be modular the strut needs to be cost effective so that several can be purchased and created. The reason the strut needs to be modular is because tensegrites can take many different forms. They can be n-bar tensegrities. In Union College's current research a 6-bar tensegrity is used. But it is feasible that this can be increased to be larger or smaller in the future.

4.3 Battery

A wireless strut presents many challenges for a design. Wireless means that the entire device needs to be powered from a battery on the strut. Because of this every component needs to be extremely energy efficient. The more power the components use the larger the battery will be needed to power the device. Overall the device must be able to run for over an hour on one charge. This ensures that a large amount of research can be done without pauses. The battery should also be able to be swapped so that when one battery dies a charged one can be switched in so that research can continue without waiting for charge.

4.4 Weight

Forces in the tensegrity struts and springs hold it together in it's unique form. This form will be compromised by increasing the weight of each strut. Different springs can be used to connect the struts together and keep the tensegrity shape, but this can only account for so much weight.

4.5 Closed Loop

Functionally there are many requirements that the new tensegrity needs to have. In order for the robot to be more robust to different environments and be more repeatable the motor system needs to change from open loop to closed loop. An open loop system is one that has an input that produces an output. The closed loop system needs to add a feedback element that takes the current output and creates a new output based on it. A diagram of open loop and closed loop systems can be seen in Figure 3. In order to accomplish this there needs to

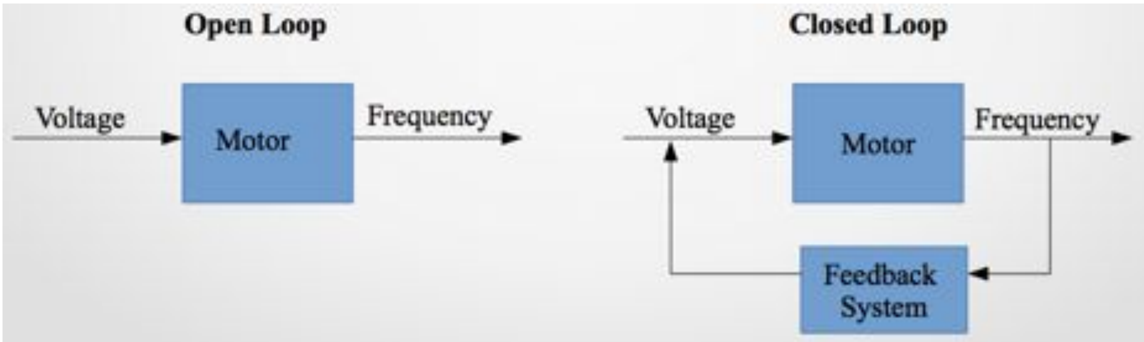

Figure 3: A diagram of the difference between open loop and closed loop systems. The closed loop system adds a feedback stage that changes the output based on the output.

be two main components, an IMU and an shaft encoder. These two components are able to measure the frequency of the motor's vibrations and the location and speed of the shaft.

4.6 Wireless Communication

In order for the robot to be controlled by a computer the robot needs to have some method of wireless data communication. This will allow measurements from the robot to be sent to the computer and the computer to be able to send new instructions to the robot. This method needs to be able to have multiple channels functioning at the same time so that every strut of the robot can be communicated with.

In order to answer the research question of the project there needs to be a significant design of a system to control and evaluate the robot. This system will use an genetic algorithm to evaluate the fitness of each trial and bread new generations. The genetic algorithm process is designed so that with each iteration produces better frequencies from the last.

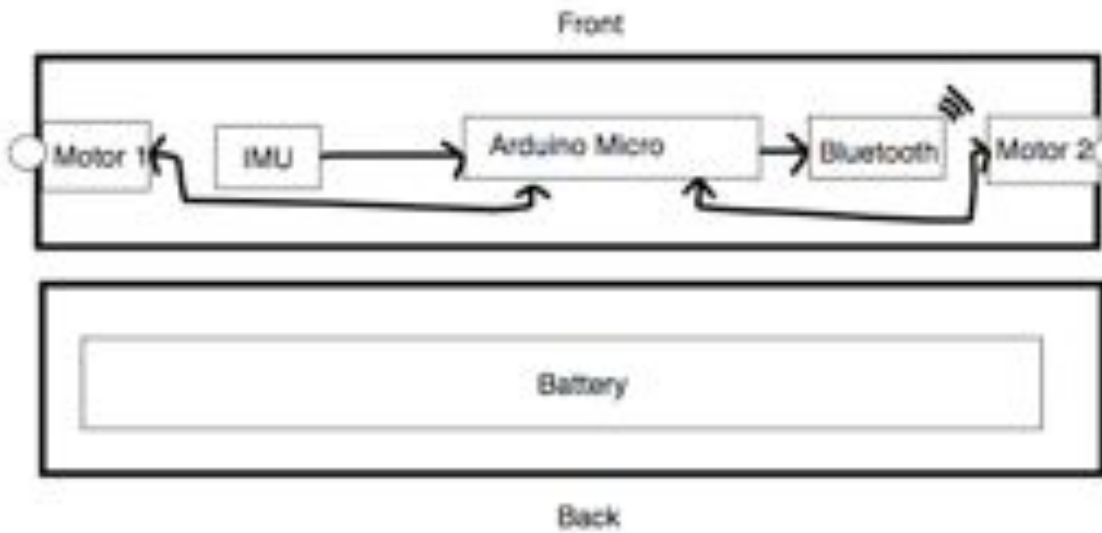

Figure 4: A sample layout of a wireless modular strut for a tensegrity robot. This drawing is intended to show layout as well as connections of the components.

5 Design of the Strut

The strut of the tensegrity has several components on it, an IMU, motor, encoder, micro-controller, communication, and power. Each of these components have many different choices for both overall category as well as the exact component. A sample layout of the strut can be seen in Figure 4. Each of these components need to be able to interface together to produce a single design.

5.1 Micro-Controller

The micro-controller is the the main unit of function for the strut. It is where all the other devices interface with. Consequently it becomes one of the largest and most expensive items on the strut. The micro-controller needs to be able to interface with every component

Figure 5: A picture of the Ardunio Micro micro-controller which is the processing unit of the strut.

simultaneously. There are many different options for small micro-controllers, so it is useful to design this on one that is very common. So the arduino family seemed like a logical choice for micro-controller.

There are many different arduinos that exist, but only two of them are really small enough to be considered for use on this tensegrity: Arduino Micro and Nano. In a lot of ways these two micro-controllers are very similar, but there are some key differences. Both micro-controllers have support for I2C and UART, which are common protocols for communication with other components. Both devices have 14 digital pins of which 6 support PWM which should be a sufficiently large amount for this project. One of the categories where the Micro is better than the Nano is the amount of analog pins, the Micro has 12 while the Nano only has 8. The amount of current supported by each pin is 40mA for each. Finally the real deciding factor to choosing Micro over Nano was price and availability. The Micro was the only board that was stocked by many retailers and for only $22.95, while I had trouble locating a seller for the Nano [4].

Overall the Arduino Micro fits the design requirements very well. It is very small as seen in Figure 5. The cost of the unit is cheap compared to other micro-controllers with similar specs. The choice in micro-controller was an important design decision that needed to be made quickly so that other components could be chosen to work with this micro-controller.

Having a micro-controller picked out has allowed work to happen on starting the implantation of a spiking neural network on the board as well as some work with the inertial measurement unit. This spiking neural network is part of the fundamentals needed for the closed loop system to be effective.

5.2 Inertial Measurement Unit

An inertial measurement unit is a combine circuit that has an accelerometer, gyroscope and compass built in. These units are able to measure the orientation, position, and motion of the strut at any given time. By using mathematics one can calculate the frequency that the strut is vibrating at. This information is required for the closed loop system of the design.

The IMU that has been chosen for this project is the Pololu MinIMU-9 V2 [7]. This device was chosen because of it's small size, free arduino library, and efficiency. As seen in Figure 6 the IMU is very small and contains all the information that is needed for the feedback system. The device's manufacturer also provides libraries written so that interfacing and using the device is simple. When the IMU is running the total current draw is only 10 mA which is a very small amount.

This device has already been successfully interfaced with the ardunio and a program has been written before starting this project, so it was natural to use this IMU for the project. This program takes the IMU's accelerometer data and creates a live plot of the output. This allows visual inspection of the frequency the robot is operating at. In the future using mathematics we can figure out the exact frequency of the vibrations. A sample output of

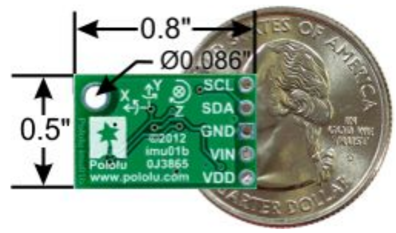

Figure 6: A photograph of the Inertial Measurement Unit that was chosen to be used in the final design.

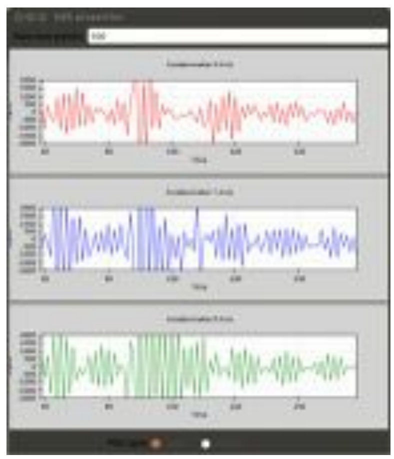

Figure 7: Sample output of the IMU being sent via a serial connection from the arduino uno to a python graphing script.

the IMU can be seen in Figure 6.

5.3 Wireless Communication

There are many different protocols that are available to communicate wireless with devices. The protocol that I decided to use was Bluetooth. This is because it is a more well known protocol to me then the other options available. Once I choose Bluetooth there were still many different options available within that protocol. The choice that I made ended up being to use the BlueSMiRF Silver. This bluetooth modem had many advantages other the other ones that I had found. One of the biggest impacts in the decision to use this one was the cost of the device. This device was only $39.95, which was the cheapest for Bluetooth communication. The unit also consumed a low amount of power, only 3mA when connected and 30mA when transmitting. The last important consideration in choosing this component was that it interfaces with the Arduino Micro easy [5].

5.4 Power Source

There were really not many options when considering what type of power source to use. The source had to be something that was small and portable but powerful. Battery and supercapacitors were the only things that would fit this restriction. The problem that arose with supercapacitors was their ability to be charged quickly and have enough charge. It was determined that it would be best to use a battery solution rather than supercapacitors.

The type of battery had to be one that was small and powerful. Lithium Polymer seemed like it would be a perfection option and there are retailers [sparkfun.com] that sell many different sizes of them. The advantage of using the lithium polymer is that it is rechargeable so we would not be generating waste after batteries were consumed. The exact model of the battery has yet to be determined until the rest of the final design has competed.

5.5 Motor and Encoder

The last component that needs to be determined for the design of the strut is the motor. There is already a motor on the existing tensegrity, but the new design hopes to improve on it. The new motor needs to be of a similar size and torque so that it can produce the same amplitude of displacement. But the goal is that the motor can have a larger range of frequency output. This would allow the motor to run at both slower and higher frequencies to allow for a larger range of discovery.

The other flaw with the current motor is that there are no encoders that can be fit to it. An encoder looks at the position of the shaft and can report it to the micro-controller. This is important because the position of the offset weight on the motor may have an effect on how the robot moves. This also gives us information of the shaft speed so that we know it's frequency.

Both the motor and encoder still need to be purchased and tested. This component seems like the hardest one to find. Most motors that are made with encoders are too big or can not produce the desired frequency range. The motor encoder pair is essential in the success of the strut and will be a top priority moving forward [6][2].

6 Conclusion

The goal of this project is to both come up with a design for a modular and wireless strut for a tensegrity robot and defining to what extent does a closed loop system improves on an open loop system to exploit tensegrity's natural resonance to promote locomotion. In order to build this strut there are many components that need to be decided on and interfaced to work together. The outcome is a brand new robot that will better the research that is being done at Union College about tensegrities. The newly designed robot will present an opportunity to use genetic algorithms to answer the research question. The goal is to learn many new things about how the tensegrity robot behaves and perhaps being able to apply the robot to a real world scenario to help accomplish a task.

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