Designing Wireless Tensegrity Robot

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Abstract

A tensegrity is a deformable robot made from struts and springs held together in a stable pre-stress form. We are doing research at Union to learn how to make the robot move by vibration. While successful, this research is limited by the current wired design of the robot. For example the current robot VALTR has a tether that tangles and has to be reset if it turns too much or moves too much. My research was to design and construct a new, wireless tensegrity robot controlled by a spiking neural network. This new robot allows us to conduct research without the inhibition of the tether. With it we can better control the frequencies of the vibrations by using an inertial measurement unit and motor encoders as inputs into a spiking neural network. This new robot will further allow us to continue research in using tensegrities to get a better understanding of how complex living systems move.

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. This robot will enhance the research currently being done at Union. The wireless aspect eliminates the problem of the robot being tangled from it's tether. The added control systems allow for better control of the vibration of the robot.

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 can we implement a spiking neural network on an embedded processor which will be used to improve on the current open loop system by creating a closed loop system where information is fed back from the strut to better produce motion.

The most important part of the design of the modular wireless strut is researching the different options for the components. The components need to be small, low power, and inexpensive to ensure the design requirements are met. All of the components need to be able to interface together to develop a final working system. To accomplish this task a large amount of online research was done. Research included what options were available for purchase, what protocols the components use, and if they would all be able to be connected at the same time.

To succeed in answering the research question, a spiking neural network needs to be implemented onto a micro-controller. This presents many challenges such as ensuring there is enough memory on the controller, learning which language the controller uses, and interfacing the electrical components with the network.

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.

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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 tether of wires that is always attached as seen in Figure 1. This inhibits the robot in many ways. This tether 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 tether. The tether also limits how far the robot can move inside the arena (seen in Figure 2), if the robot moves too far it needs to be reset before it can move again.

Currently there are three motor controllers that are connected to a laptop. The laptop is running a hill climber algorithm that assess 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 assess. The way that this is done can be a source of error. The algorithm outputs voltages to the motor controllers, but the actual tensegrity is moving based on frequency of the motors. Different factors like hysteresis and different surfaces can change how voltages map to frequencies. The current system is designed without feedback and is open loop. This means there is no way to adjust the voltage to get the correct frequency.

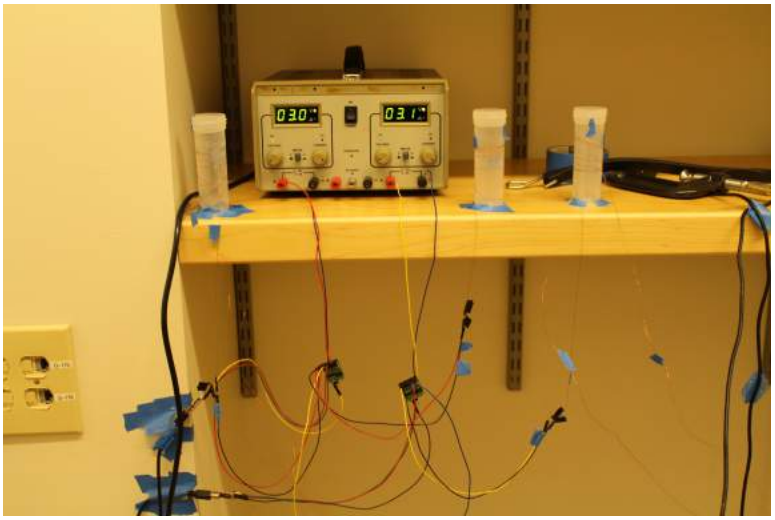

Figure 1: A picture of the tether that connects the power supply and computer to the tensegrity robot's motors. This easily tangles when the robot rotates and moves around.

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. The strut 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 many different components that fit onto it. The first are motors, a motor controller, a micro-controller, and a battery. These components are responsible for power and vibration of the robot, which is already implemented on the existing model with the tether. The strut will also need a new system to create feedback from the vibrations generated by the motors. This allows there to be a closed loop system when setting frequencies so that they can be set more repeatably. 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 the spiking neural network that will adjust the output to be the desired frequency.

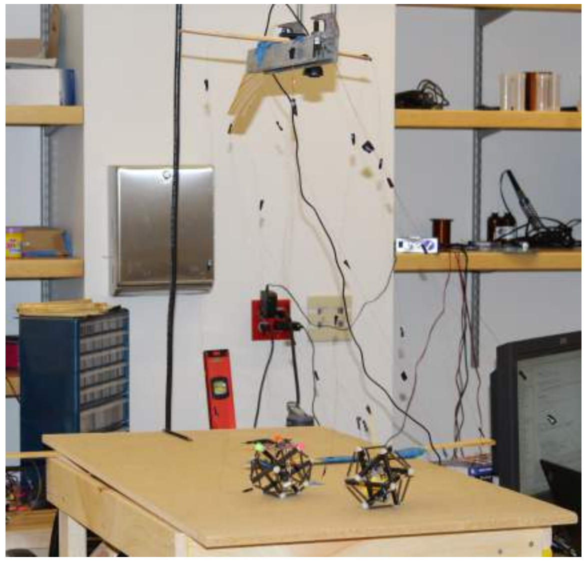

Figure 2: A picture of the arena that the current tensegrity robot moves around in. Seen at the top of the image is the camera used to assess the motion of the robot.

Finally in order to control the strut from the computer without having to tether it with a wire, a Bluetooth module will be used to communicate with the micro-controller. The link will send information in both directions; statistical data from the strut to a computer and desired motor frequencies from a computer to the strut.

With this advanced new robot we will be able to use a genetic algorithm more effectively to learn the best frequencies that get the robot to move. In the future this will allow us to explore how much better the new wireless robot is at being able to vibration to move.

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.

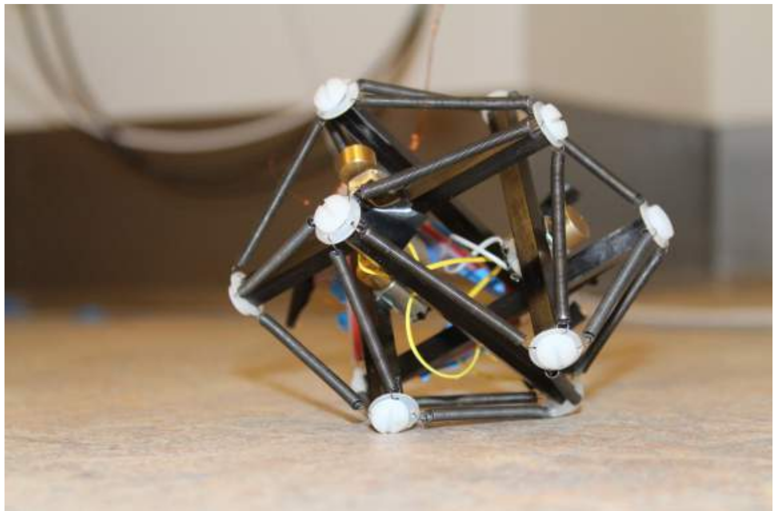

Figure 3: A picture of the tensegrity robot. It consists of 6 rigid struts and 24 springs.

3 Background and Related Work

A tensegrity robot is a deformable robot made up of rigid struts and springs. These struts and springs are connected in a disjoint manner such that the robot maintains it's shape [9]. 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 then return to the original shape. Because of their structures, learning how to make soft robots move is an important research topic. Seen in Figure 3 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[10].

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. This dynamic coupling is often found in biological systems. In the tensegrity research at Union College we aim to use the dynamic coupling of the tensegrity structure see if it helps in the motion of the robot. [10]

We have shown that 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 motor's frequencies are transferred throughout the robot causing it to move.

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 wont 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.

Traditional research of robots often attempt to eliminate dynamic coupling. This research will serve as an example where exploiting dynamic coupling is beneficial. The current research at Union and the future research will provide researchers more proof that dynamic coupling can be a good thing and perhaps allow others to exploit this coupling.

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. The robot is going to be designed to use rechargeable batteries, which means no waste will be generated by having to dispose of batteries. The rechargeable batteries will be easy to charge and swap when the current one runs out.

One downside of the new robot will be the cost. Currently the tensegrity is built of only a strut, springs, and inexpensive motors. The new robot will have many electrical components that are interfaced together. This would require an protoboard that would need to be designed and manufactured. The new robot would also require some sort of 3D printed plastic strut instead of just a simple square rod. This 3D printed strut would allow all the components or the board to sit nicely in the plastic instead of just being glued on the outside. All of these changes mean that there will be a significant increase in cost of each strut of the robot.

Overall the new design of the robot will allow for betterment of the research at Union and even the soft robot community. The increased cost and decreased manufacturability of the strut is outweighed by the ease of research and better control of the vibrations.

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 [9]. This size is something that we want to keep as limited as possible. The goal for the final strut design is to keep strut width at a minimum. Ideally it would be less that 10cm 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 tensegrities can take many different forms. In Union College's current research a 6-bar tensegrity is used, but there can be any number of struts. In the future it is reasonable for Union's research to use different numbers of struts to see how the motion is generated.

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 many pauses. The battery should also be able to be swapped easily so that when one battery dies a charged one can be switched in so that research can continue without waiting for batteries to 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. The weight of the tensegrity also limits how vibration the motors can generate.

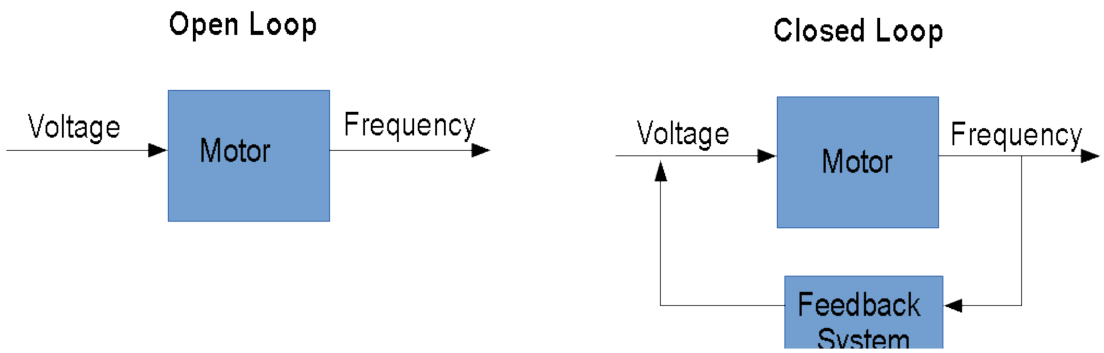

Figure 4: A diagram of the difference between open loop and closed loop systems. The closed loop system adds a feedback stage that changes the output based on the output.

The larger the weight of the robot the larger the offset weight needed to produce vibrations. It is hard to quantify the limit on the weight of the robot, but keeping the robot weight to a minimum is the goal.

4.5 Closed Loop

Functionally there are many new requirements for the tensegrity. For example, in order for the robot to be more robust to different environments and be more repeatable the motors will be controlled with a closed loop system as opposed to the current open loop system. An open loop system is one that has an input that always produces the same output. The closed loop system adds a feedback element that takes the current output and the input and creates a new output based on it. A diagram of open loop and closed loop systems can be seen in Figure 4. In order to accomplish this there are 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. This data from the output of the motor along with the motor voltages is taken and inputted into a spiking neural network. The network then produces a new set of voltages that will be closer to the ones desired.

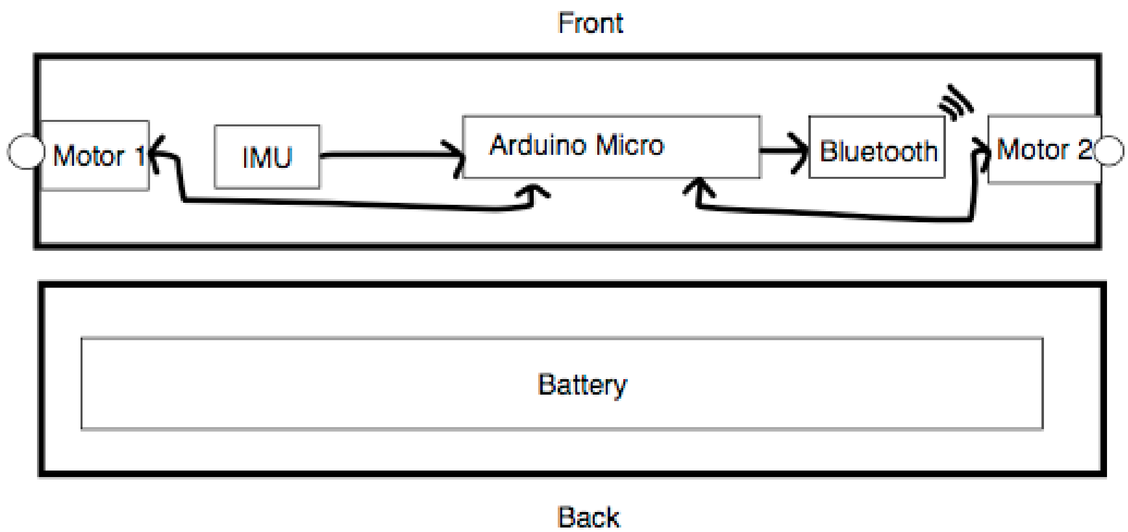

Figure 5: A sample layout of a wireless modular strut for a tensegrity robot. This drawing is intended to show layout as well as connections of the components.

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 has to allow multiple channels functioning at the same time so that every strut of the robot can communicate with the computer.

5 Design of the Strut

The strut of the tensegrity has several components on it, an IMU, motors, motor controller encoder, micro-controller, communication unit, and power supply. 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 5. Each of these components need to be able to interface together to produce a single strut of a tensegrity.

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 simultaneously. There are many different options for small micro-controllers. In order to select a micro-controller a lot of research was done. There are many different options that are available including AVR, PIC, and Intel 8051. I decided to choose to use an AVR chip mostly because of the availability of the Arduino platform. Arduino is a single board micro-controller that comes with a boot loader allowing easy programming. There is also a large community of people using the Arduino environment. The boards are all relatively cheap and the development environment is free.

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 6. The unit is extremely inexpensive and consumes only a small amount of current. The choice in micro-controller was an important design decision that needed to be made early 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 im-

Figure 6: A picture of the Ardunio Micro micro-controller which is the processing unit of the strut.

plantation 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 circuit that has many devices that measure inertia like 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 by using this data. This data is one of the pieces of information that the spiking neural network will use as an input to create a closed loop feedback system.

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 7 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 Arduino 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.

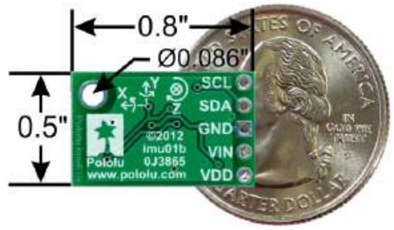

Figure 7: A photograph of the Inertial Measurement Unit that was chosen to be used in the final design.

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 the IMU can be seen in Figure 8.

5.3 Wireless Communication

There are many different protocols that are available to communicate wireless with devices. Some examples are WiFi, Bluetooth, radio frequency, and Zigbee. The protocol that I decided to use was Bluetooth. There are many different reason why Bluetooth was chosen, the primary reason was that most computers are produced with a Bluetooth module built in. This meant that connecting to computers is easy. WiFi is also readily available on computers, but the network at Union sometimes makes it hard to connect devices. To avoid potential network conflicts I stuck with Bluetooth. Overall bluetooth also uses significantly less power than WiFi does because it's broadcast range is about 10 times less.

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 pictured in Figure 9. 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 easily [5]. The BlueSMiRF board is controlled using a serial connection

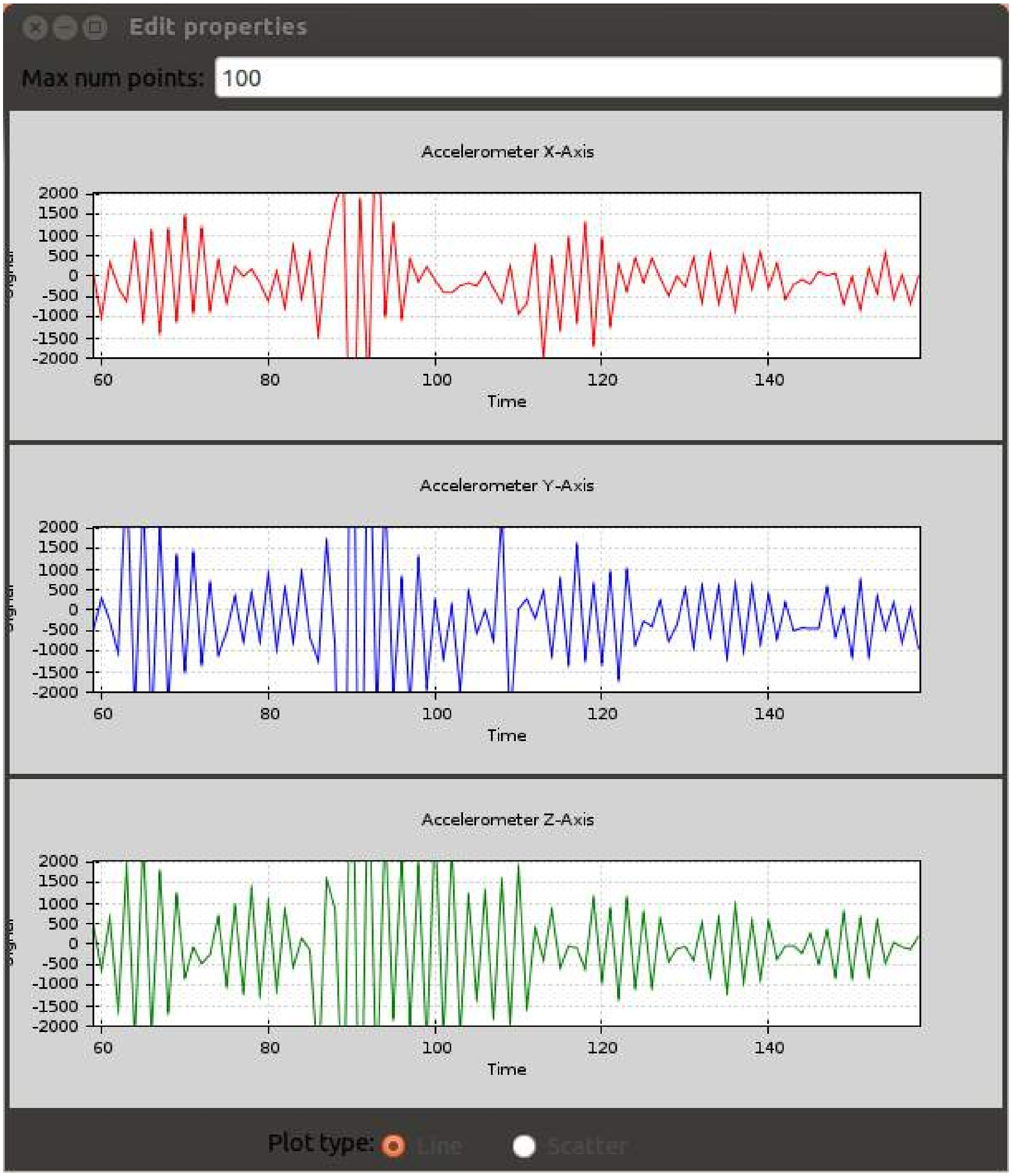

Figure 8: Sample output of the IMU being sent via a serial connection from the Arduino Uno to a python graphing script.

Figure 9: A photograph of the BlueSMiRF unit that was chosen to be used in the final design.

and the Arduino language has a Software Serial package which allows for easy creation of multiple serial ports.

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 perfect combination of size and capacity. There were also many different options that were available from retailers. The advantage of using the lithium polymer is that it is rechargeable so we would not be generating waste after batteries were consumed.

5.5 Motor, Controller, 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

Figure 10: A photograph of the 10:1 Micro Metal Gearmotor unit that was chosen to be used in the final design. The Optical Encoder is shown on the back of the motor.

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.

There are many different options for motors, but most of them were unable to match the torque and size that was required for the project. One that fit perfectly was the Pololu Micro Metal Gearmotor with extended backshaft (Seen in Figure 10) [6]. This motor has a gear ratio of 10:1 allowing for it to have a stall torque of 4 oz-in and runs at a no load speed of 3000 RPM. This motor had the closet configuration to the motor on the existing robot, but included the option of adding an encoder[2]. The one downside of this motor option was that it draws 1600mA when being stalled. This is a very high amount of current compared to the other components, but I decided it was necessary to match the vibration ability of the old robot.

I chose the motor controller and encoder that were recommended by Pololu on the product page for the motor. The Qik 2s9v1 Dual Serial Motor Controller (Seen in Figure 11) is capable

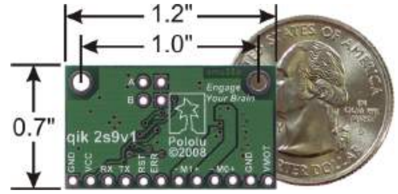

Figure 11: A photograph of the Pololu Qik 2s9v1 Dual Serial Motor Controller unit that was chosen to be used in the final design.

of controlling two motors at once and has a complete Arduino library written to allow for easy interfacing with the software serial package[8]. The board also draws a very low current for the logic board of less than 15 mA.

The motor encoder that was chosen was the Optical Encoder for Micro Metal Gearmotors. This encoder is designed for the motor so it made sense to use it. It is very small and fits perfectly on the motor as seen in Figure 10. It also uses a very small amount of current for operating, only 12 mA. The encoder produces an analog signal that can be inputted to the Arduino through the analog pin.

6 Final Design and Implementation

The overall design of the robot was broken down into several smaller systems: micro-controller, communication, feedback, and motor. Each of these systems work together to produce the wireless tensegrity strut. Seen in Figure 12 is a graphical view of the systems and how they interact. The overall design of a strut is pictured in Figure 13. This shows all of the components connected together on a breadboard.

6.1 Micro-controller

The most important system on the final tensegrity strut is the micro-controller. This system is in charge of interfacing all of the other systems together. The Arduino Micro was the micro-controller that was chosen to be used. The choice to use the Arduino platform meant that many of the components already had libraries made. This allowed the implantation of

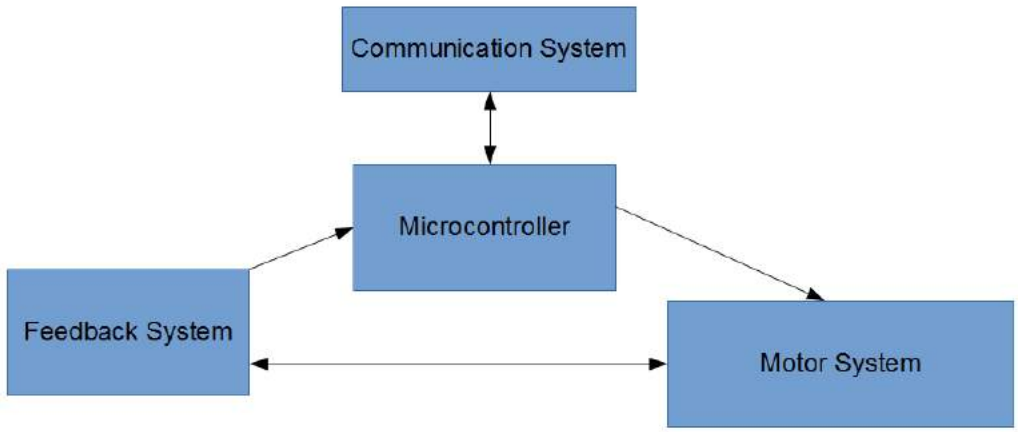

Figure 12: A view of the overall systems of the final design as well as how they interact with each other.

some of the systems to happen quickly. Other components took a lot longer to implement because they needed to be created.

The biggest part of the micro-controller system is the spiking neural network. Implementing a spiking neural network on an Arduino was not an easy task. There were many problems that were encountered. For example there is no C standard library implemented. This means that many classes that are normally used to write programs were unable to be used. The biggest problem that arouse from this was there was no Vector class. This mean that everything had to be done using arrays. Even though there were many difficulties using arrays over vectors, I was able to implement the SNN on the board and successfully tested that it works by creating test cases.

Anther large part of the project was starting to create the framework for wireless control. This framework allows for someone to send a command from a computer over Bluetooth to the strut. The current strut is able to take a value between 0-255 which represents the range of full speed counter clockwise to full speed clockwise. The value of 127 represents no motion in either direction.

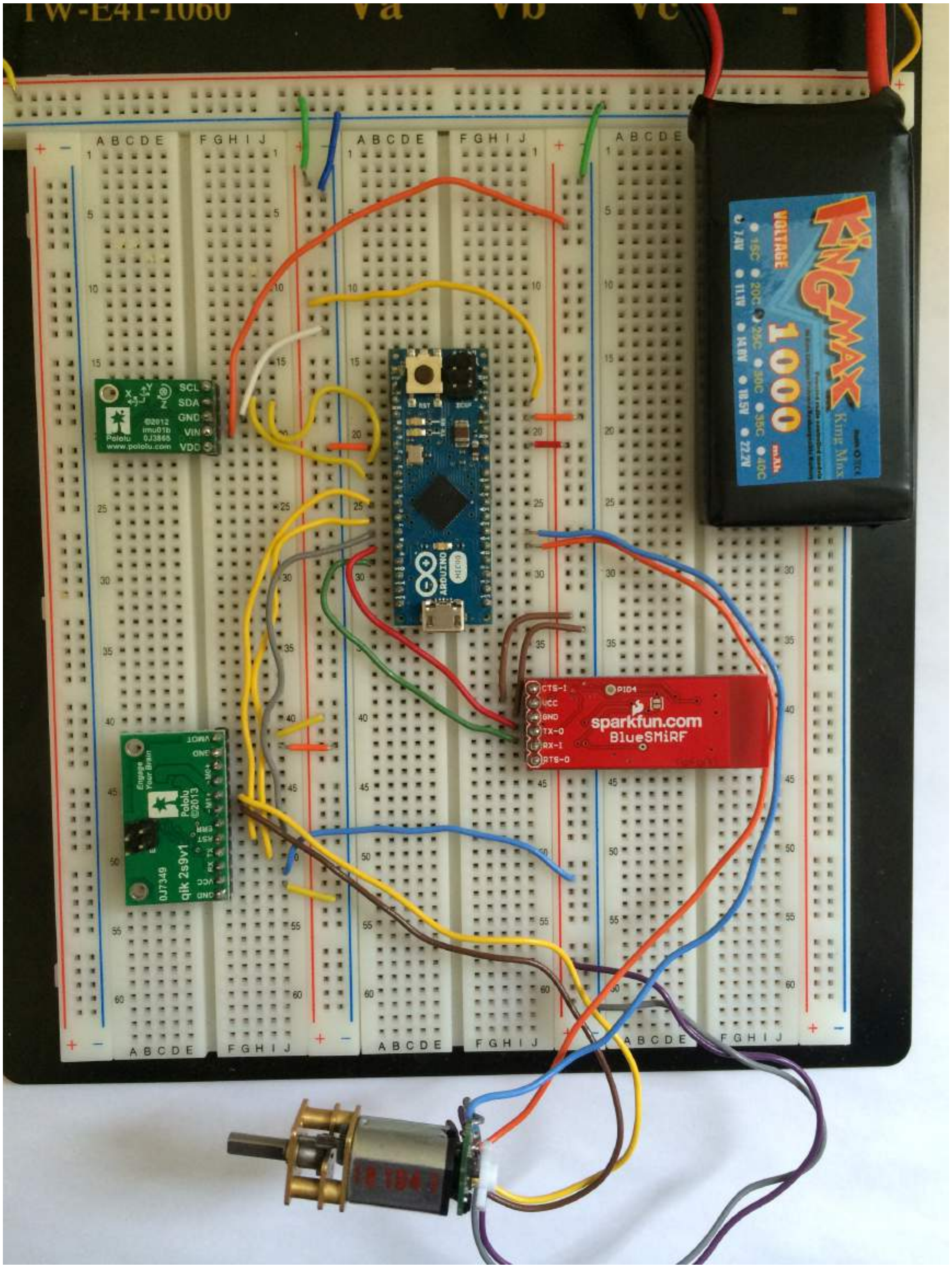

Figure 13: A picture of the final design of a strut on a breadboard. This design features all of the components needed.

Another task of the micro-controller is able to get data from the IMU. The data is acquired from the IMU and then is stored in variables. This data can then be both fed into a SNN and/or sent over Bluetooth to another computer. This allows for any data created on the strut to be transmitted to a computer and then potentially used to make other calculations.

Finally, the micro-controller is also responsible for powering all the other systems. The Arduino is capable of taking an input voltage over a large range of values: 6-20 volts. The micro-controller has a built in voltage regulator that takes this voltage and reduces it to a constant 5 volts. This is important because all of the other systems require there to be a 5 volt power source.

Overall the micro-controller system has a lot of responsibilities. It takes input at the right times from all of the other systems and is able to decipher what to do with that input. The micro-controller is also doing a large amount of processing on the data to create the closed loop system. It is by far the most important system on the strut, if it is to fail the rest of the strut is unusable.

6.2 Communication System

The key research topic of Union's tensegrity robot is setting a motor frequency and seeing how the robot moves. In order to accomplish this we need to be able to easily change the frequencies the motors are vibrating at. The old design used a wire tether to send commands to a motor, the new design uses a wireless communication system. This system is built using a Bluetooth module.

The Bluetooth module is capable of both sending and receiving messages from a computer. Having two way communication means that a user can set a command and also receive feedback when the command is executed. It also means that the strut can send all sorts of information about what is going on for logging and other analysis. Seen in Figure 14 is a sample of the IMU data being sent wirelessly to a computer. To implement this a simple Software Serial connection is made. This connection allows the Bluetooth unit to act as

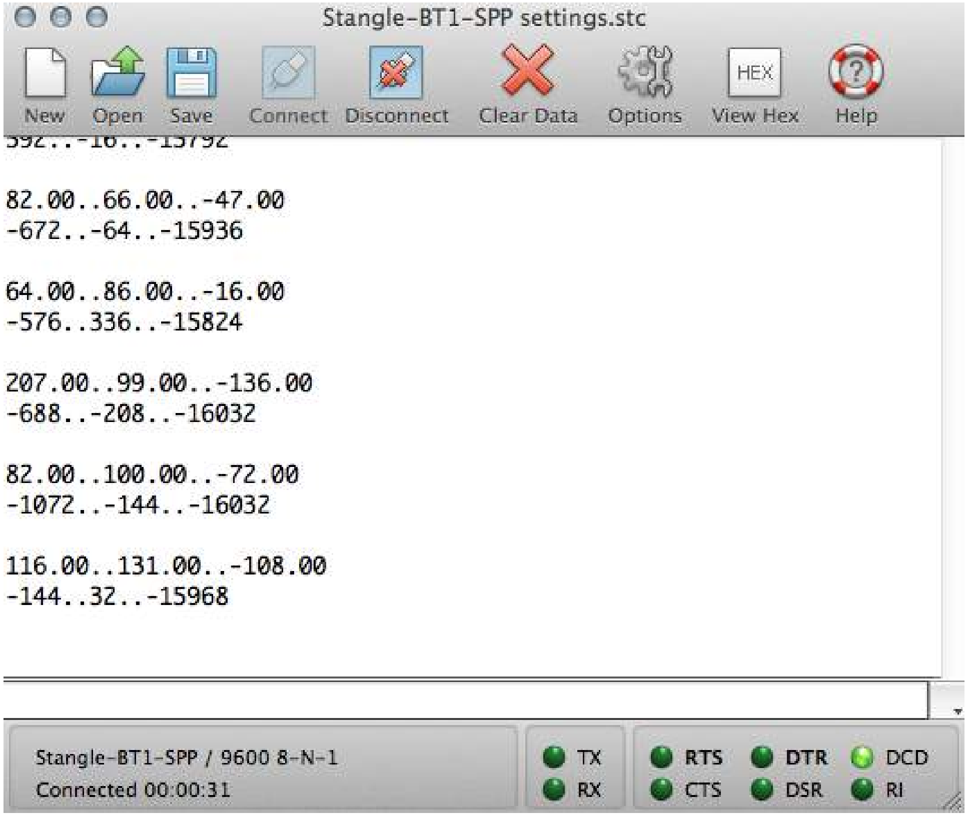

Figure 14: Pictured here is a screen shot of the terminal window receiving data via the Bluetooth wireless connection from the strut. It is sets of x, y, and z data from the accelerometer and gyroscope.

serial pipeline. To understand commands from a computer the microprocessor parses any input and uses that to change states. Currently the only command that is configured is to change the unit's motor frequency, but is should be easy to expand functionality to offer many other commands if they are needed.

6.3 Motor System

The motor system is a very crucial part of the tensegrity, without it the robot would not be able to move. It was important to design the system so that it improved on the old design of the robot. This means that the motor would be able to provide both lower and higher frequencies. This is good since it is still unknown what the best frequencies for making the robot move are.

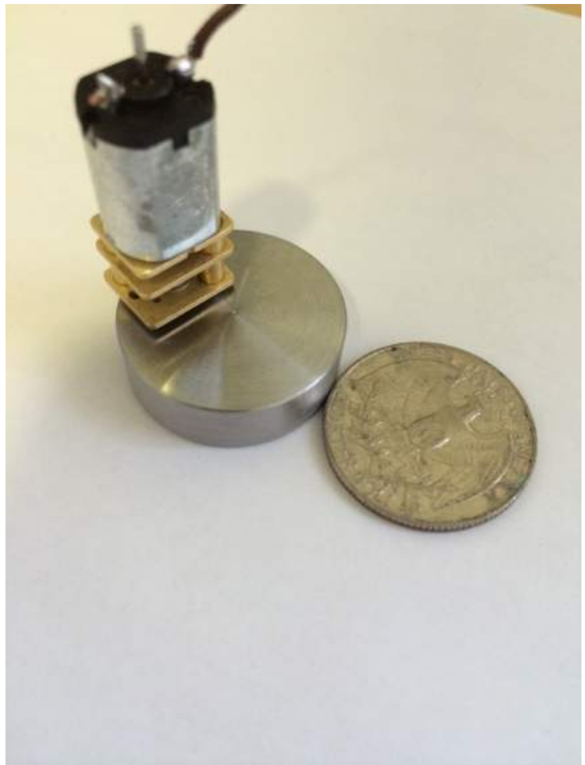

Figure 15: An image of the offset weight required to produce the same amplitude of displacement per mass that the old designed tensegrity produced.

The motors can be controlled using an Arduino library that was made by Pololu and the motor controller. The library allows the controller to be able to set two motors at levels between -127 and 127. The motors are controlled independently and can spin in either direction.

The motors themselves will not produce vibrations. In order to get the tensegrity to vibrate, an offset weight needed to be attached to the unit. In order to produce the same magnitude of vibrations that the old design produced an analysis of the tensegrity weight to amplitude was done. The resulting offset weight can be seen in Figure 15.

6.4 Feedback System

The feedback system of the final design is responsible for taking in data from the other systems and generating a better output. This system has three main components: the IMU, the motor encoder, and a spiking neural network. The inputs to the spiking neural network are the data from the IMU, the data from the motor encoders and the desired frequency. The network takes these values and then produces a new output based on the network's internal weights.

The benefit of using a spiking neural network over other types of neural networks is that the output of the network is not a sigmoid function on every iteration. Rather the network has an aspect of makes the spiking neural network act closer to actual neurons that exist in biological systems.

7 Results and Future Work

The project resulted in a circuit design of a strut for a wireless tensegrity robot that meets the goals of the project. The strut is completely wireless. It has the ability to be controlled and powered without a tether. The price of an individual strut is $177.60 for all the electrical components. While this price is fairly high, not every strut on a robot needs to be the wireless ones. In the old design only 3 of the struts had motors mounted on them. Overall the project is a success, but there are still many things that can be done to improve the design.

7.1 Battery

The strut is able to run for over an hour on one charge of the battery, which accomplishes the goal. But this battery is large and makes the overall size and weight of the tensegrity too big. Future work will be to see if a smaller, lighter battery exists that can replace the current one. If not the project requirements may have to be changed so that that battery will be smaller.

7.2 Spiking Neural Network

While the spiking neural network was created for the Arduino micro there is still a lot of work that needs to be done. The network is not yet interfaced with the IMU and motor encoder. This is the biggest part of the project that still needs to be done. This is a required step before the strut will be fully functional as a closed loop system, currently is is just an open loop system.

In order to do this there needs to be some parsing of the data that will need to be done before it is inputted into the SNN. The SNN is expecting spikes as the input to the system so the IMU data will need to be read in, normalized to a percent duty cycle and then the SNN will run for a certain number of iterations. This means that the IMU will not be polled for data on every iteration of the SNN. A similar process will need to be taken for the information from the motor encoder.

Another major task of the SNN is to figure out how to interpret the output of the system. The network will output a bunch of spikes. The duty cycle of these spikes will need to be analyzed. From this duty cycle a new motor setting can be set.

7.3 Physical Design

Currently the entire design is implemented on a bread board. This obviously is not a tensegrity robot. In order to make this design into a fully functioning robot there needs to be two steps. The first will be to come up with a way to interface all the components. One way to accomplish this will be to just use wires that connect to the pin headers. This is a very temporary way that will allow for easy repairs and modifications. Another idea is to take the layout and design a protoboard for the components to be mounted on. This is a much more permanent solution. The protoboard solution will probably be best for this case because it will secure the components better so they are able to withstand the vibrations of the strut.

Once a solution to connecting the components is reached, a design for the strut can be completed. Currently the best option for doing this will be to take the measurements of the components and design a plastic block to be 3D printed. This will allow for everything to be mounted together. Once there is a physical component that holds together all the parts an analysis of the weight will allow us to pick out the appropriate springs. Then finally the wireless tensegrity will be born.

8 Discussion and Conclusions

Overall the project was a success, the majority of the design work to create a wireless tensegrity robot has been completed. The robot is relatively small and lightweight and can operate for over one hour on a single charge. Once the remaining steps are finished this robot will allow for new research to be completed at Union.

Over the course of the project I have learned many things that I would do differently if I was to do the project again. The first of which is the choice of micro-controller. Overall I think the Arduino Micro limited what I could do. The issue of not having all of the C standard library was something that was frustrating, but easy to overcome. The biggest problem with the Arduino was the amount of memory that it has. Towards the end of the project I started to realized that I am just about out of storage space on the board. This was causing issue like random values from memory being assigned to variables. Another issue I had with the Arduino was that it was not very easy to debug. The only option I really had was to print to the serial monitor, which sometimes did not even function correctly. Choosing something that has better debug modes would be ideal.

Another lesson that I have learned form doing this project is that it can be very hard to work with customers. Over the course of the project several times the exact constraints changed. For example, originally the requirement was that the robot be able to run for an hour on one charge, later in the design process this constraint was made less important in an effort to keep the size and weight down. There were many other examples of initial requirements that later were changed.

Finally, this project showed me the importance of creating a schedule and keeping to it. I found that I was most productive when I set goals for myself and forced myself to reach them. The project got the farthest behind when I let myself push a deadline back.

Even though the project still has a lot of work to be done to make it into a full wireless tensegrity, I am proud of what I accomplished. The project allowed me to learn many lessons about the design process. Hopefully the new wireless tensegrity will be very beneficial to future research at Union.

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