HU 3910 Practicum: Chameleon

Scott Barton
Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609
sdbarton@wpi.edu

Ben Draper
Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 0169
bjdraper@wpi.edu

Kyle Mikolajczyk
Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 0169
kjmikolajczyk@wpi.edu

Tom Nurse
Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 0169
tjnurse@wpi.edu

Daniel Santamaria
Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 0169
dsantamariahopki@wpi.edu

ABSTRACT

The goal of the project was to utilize Spiropyran, a color changing silicone-like polymer developed in collaboration with MIT and Duke University. To achieve this, we developed a string instrument that executes an autonomous tuning sequence and uses an actuated harpsichord plectrum to play specific notes. The Spiropyran polymer was incorporated into the anchorpoint, sandwiched between two plates, so that the stress-induced color changing property could be activated as the string tightens or loosens to play different notes.

1. INTRODUCTION

1.1 Motivation

One of our motivations for this project is to incorporate the color changing polymer recently developed by Duke and MIT as a way to visually and/or musically enhance the system. This polymer alters its color when varying levels of tension are applied to it. We planned to implement this polymer into an anchor point or bridge for the strings. For visual appeal, we also pondered creating a chameleon representation that changed it's color depending on the note being played. The polymer needs to be exposed to a certain wavelength of light in order to have the color reset to its default state, so we planned on adding LEDs to reset the color of the polymer.

1.2 Purpose

Our general purpose is to be able to autonomously play a composition in a way that is visually appealing by incorporating Spiropyran. The instrument should be capable of self tuning and seamless string pitch variation. The color of the Spiropyran must also change depending on pitch and automatically reset with exposure to light.

2. BACKGROUND

2.1 Prior Art

After spending time researching different instruments and designs that would help with designing Chameleon, key features, advantages, and disadvantages were explored for each. A key takeaway for each instrument was determined as well.

2.1.1 Sound Of Color (Myles De Bastion)[1]

2.1.1.1 Key Features

Colors, luminosity, and patterns directly correspond to frequency and dynamics.

2.1.1.2 Advantages

Allow for the visualization of sound which is traditionally only taken in audibly. This can be beneficial to the hearing impaired, such as the creator of this project. Allows for an enhanced sensory experience for both the abled and hard of hearing.

2.1.1.3 Disadvantages

Visuals could take away from audio. Sometimes a direct correlation from sound to light doesn't make for an artistic visual, but can create strobing/unorganized effect (during a guitar solo for example)

2.1.1.4 Takeaway

Visuals are good for both the performer and audience, but a balance needs to be found between the sound and the visuals so that neither takes away from the other.

2.1.2 Xylophone Light - Sound Of Color (Hyo Shin Bae)[2]

2.1.2.1 Key Features

A musical machine that takes colors inorder to produce a musical and visual experience through sound and light. This device operates by reading RGB values and thus translating that to sound and light. The colors are equated to a specific musical note with the exception of the color purple which tells the machine to change instruments.

2.1.2.2 Advantages

Can enhance the sensory experience to disabled, deaf, and hard of hearing population.

2.1.2.3 Disadvantages

Primarily seems to be a novelty, simply converting color to music and light.

2.1.2.4 Takeaway

Colorful visuals are well received, the instrument is a novelty and would be better received if it did more

2.1.3 A Harpsichord That Plays Itself (Malcolm Messiter)[3]

2.1.3.1 Key Features

Individual solenoids for pushing each key which was bolted down on a polycarbonate sheet. Furthermore, each solenoid had felt padding as to not damage the system, similar to the design of the standard harpsichord plucking design. Also, they 3D printed new mechanisms as the old ones aged over time.

Figure 1: A Harpsichord That Plays Itself

2.1.3.2 Advantages

They used a fully functional Harpsichord and instead of modifying how it works, they placed the solenoids above the keys, which would play like a human would do. Thus, it was advantageous to use what was already there and just add on top.

2.1.3.3 Disadvantages

Many, many solenoids. They needed one for each key, which we do not want to do. Optimally we can do different things, have fewer strings and change the tension for different pitches. This should save money and reduce the amount of problems, as 61 solenoids is bound to have some issues with a few.

2.1.3.4 Takeaway

Although our project will not be using a harpsichord already made but instead have the same plucking mechanism, this helps us further realize the potential for using variable strings with solenoids as to not have too many parts.

2.1.4 Musical Kinetic Shape (Ismet Handzic Et. Al)[4]

2.1.4.1 Key Features

The research team experimented with adjusting the tension of a string using a kinetic shape and derived a mathematical model for understanding how the shape affects the string's dynamics.

2.1.4.2 Advantages

Can be plucked or bowed to play and was able to successfully produce various frequencies.

2.1.4.3 Disadvantages

Slight variations in the sound existed as a result of possible slippage or misalignment of the shape

2.1.4.4 Takeaway

Researchers from the University of South Florida have demonstrated that a variable tension string instrument can be created simply by using a kinetic shape. This fractal-like shape has a mathematical relationship with the frequencies it produces. By repositioning the shape the tension can be increased or decreased. The team linked a stepper motor with a movable platform that was covered with sandpaper to more finely control the adjustments to the shape. In the end, while the team was able to successfully produce various frequencies within a recognizable range, they did encounter some difficulty with the occasional slipping at the shape-platform contact point. Regardless, the instrument they developed does work and can be played by plucking or bowing the string.

2.1.5 Stari: A Self Tuning Auto-monochord Robotic Instrument (Shawn Trail Et. Al)[5]

2.1.5.1 Key Features

This self-tuning string instrument has a tuning apparatus which uses a stepper-motor driven guitar tuning mechanism. It also uses a passive single coil electro-magnetic guitar pickup and a standard guitar pick on a servo motor.

2.1.5.2 Advantages

Very similar to our planned instrument. Uses a guitar tuning mechanism to prevent backdrive and a stepper motor to make accurate fine adjustments.

2.1.5.3 Disadvantages

The team had some trouble with noise when using the pickup they chose (recommended looking into optical sensors instead).

2.1.5.4 Takeaway

A team of computer scientists from the University of Victoria have developed STARI (Self-Tuning Auto-monochord Robotic Instrument), which is a self-tuning string instrument that uses a stepper-motor driven guitar tuning mechanism to adjust the string's tension. The team focused on how to use feedback from their sensors to tune the string and since they encountered some system noise when using an electro-magnetic pickup, they suggested using an optical sensor to detect string vibrations.

2.1.6 Assistive Individual Guitar String Plucker (Jia Cheng Zhou et. al)[6]

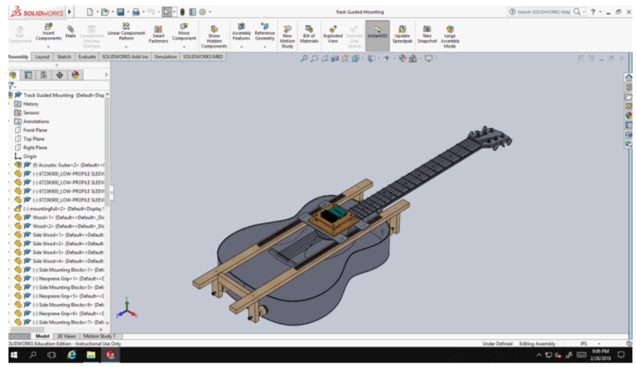

Figure 2: Assistive Individual Guitar String Plucker CAD Design

2.1.6.1 Key Features

This was designed to help people who cannot pluck their guitar without assistance. This mechanism uses a very similar version of the harpsichord plucker that we were considering.

2.1.6.2 Advantages

Horizontal plectrum. This is key as this shows the proof of concept is not only feasible but works as intended.

2.1.6.3 Disadvantages

Issues with the device were that two strings cannot be plucked at the same time and if one of the push buttons were held correctly when one string that is needed is being used, that it will be sent to another string that can perform the same pitch in real-time.

2.1.6.4 Takeaway

If we use horizontal plectrums, we should plan ahead for issues that will arise when notes are requested to be played; that they are sent to both a free string and a string that can play the requested pitch quickly. Also, for simplicity, the solution to the tuning is to have defined pitch ranges for each string.

2.1.7 Drone Guitar (Moritz Simon Geist)[7]

2.1.7.1 Key Features

Guitar pic strapped to DC motor plucks strings. Modified nut, adding metal cylinder, used to increase string sustain.

2.1.7.2 Advantages
Simplicity of design, easy to use and program.

2.1.7.3 Disadvantages
Only useful for single note drones, must manually adjust pitch, cannot dampen strings.

2.1.7.4 Takeaway
Harpsichord plucking mechanism is a better design, gives more control over the sound produced (damping). We might opt for a modified nut as well as over an extended amount of time, a double pluck occasionally occurred. We will have to consider this issue as well with our machine. When a string is being used it cannot be used for another note and thus will have to wait. A good way around this issue besides having strings be adjustable in real- time, is to have multiple strings that are identical that can then be adjusted as needed. It may also be beneficial to have software that "dispatches" each note.

3. DESIGN SPECIFICATIONS AND REQUIREMENTS

Before setting out to build Chameleon, we established a few key design specifications and requirements with regard to the instrument's musical characteristics, visual attractiveness and autonomy.

3.1 Specifications

With respect to the instrument's musical characteristics, we focused primarily on the timbre, selection of producible pitches, note speed, and articulation and dynamics. We decided that we wanted to develop a string instrument which produces its sound by plucking as opposed to tapping or bowing. This would ideally go hand-in-hand with our next requirement which was the ability to play longer sustained notes as well as short accented notes. When it comes to note speed, we planned to have the ability to play prestissimo, meaning we could reach speeds of at least 200 BPM, in order to meet or perhaps even exceed human ability.

Chameleon also needed to be able to produce pitches with a high level of accuracy. Ideally, we wanted to see fundamental frequencies tuned to within ± 5 Hertz (Hz) as any difference within that range would be difficult enough to perceive. Furthermore, we designed Chameleon to have a wide range of notes it could play. At the bare minimum, Chameleon should be able to play 2 full octaves.

As for the visual aspect, we designed the physical structure of the instrument in such a way that would showcase the instrument's moving parts. We also wanted to highlight changes in string tension by designing Chameleon around the use of Spiropyran, a color changing polymer developed in collaboration between MIT and Duke University. As the changes in string tension will be difficult to perceive visually, the Spiropyran would offer a way to make these changes more visible.

With respect to autonomy, the instrument needed to be capable of playing pieces without human interaction and have the ability to re-tune itself. While it doesn't necessarily need to tune the string in real-time, we aim to have it tuned within a timeframe of just a few seconds.

3.2 Design

All of the CAD for our project was done in Fusion360. As seen in *Figure 3*, the frame of our module is made using aluminum 8020 extrusions bound together using 3D printed corner brackets and braces. These were resources we had at our disposal and could easily withstand the tensions of the string. The motor mount was designed to hold our brushless motor horizontally and couple with a guitar tuning peg that is rotated 90 degrees from its traditional orientation. A brushless motor was chosen over a brushed motor because brushless motors are quieter and thus would produce less background noise. Our original design called for a stepper motor, however we found that it could not provide enough torque. Directly above the motor mount is a custom concave bearing that serves the same purpose as a guitar nut would. Within this bearing are two 608zz bearings so that it can rotate smoothly as the string changes tension and therefore not build up friction; lengthening the lifespan of the string. The middle of the frame has a custom mount that allows for our electromagnetic pickup to be roughly one quarter inch below the string. The anchor point is designed to be mounted against upright aluminum extrusions. The front plate of the anchor point is fixed and clear so that a slice of Spiropyran can be inserted behind it and the polymer can be seen changing color. Behind the spiropyran is a second opaque plate that the string is strung through. As the string is tightened, the back plate is pulled forward against the clear plate and squeezes the Spiropyran, activating it's color changing property.

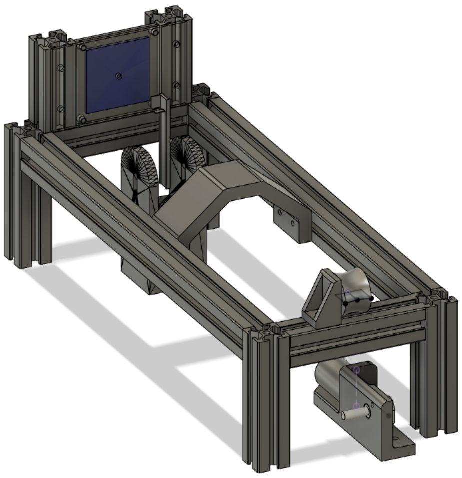

Figure 3: Chameleon Module CAD Render (Front View)

The solenoid is mounted in a box with guide rails so that the plunger of the solenoid is prevented from rotating and the harpsichord plectrum is always facing the string. A pull solenoid is used with a spring so that the plucking is done when the solenoid releases its hold; causing the plectrum to quickly rise and strike the string. The sound resonates until the solenoid is activated again, pulling the plunger and resting the felt pad on the string to dampen it. Small pieces of foam were also added to the top of the mount and the base of the plunger to reduce noise.

Figure 4: Final Design of Solenoid with Plectrum

As for the electronics, the solenoid was controlled through the use of a simple transistor circuit which can be seen in *Figure 5*. This was driven by an Arduino Uno which handled converting the MIDI note messages. The electromagnetic pickup was connected to an ADS1115 Analog-to-Digital converter (ADC) to amplify the signal and send the result to a Teensy 4.0 over an I2C connection. The Teensy is used to handle all of the digital sound processing necessary to make tuning the instrument possible. For this reason, the brushless motor is also driven by the Teensy. The Uno and the Teensy communicate with each other over a UART serial connection to ensure everything is performed in sync. Full electronic schematics can be found in *Appendix B*.

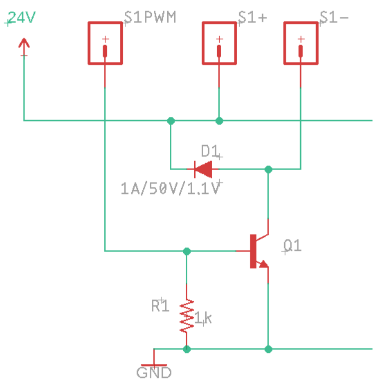

Figure 5: Solenoid Control Circuit Schematic

4. RESULTS AND FINDINGS

4.1 Pickup

We originally planned to use a piezo pickup to detect the pitch of the string. However, the piezo proved to be too sensitive to motor vibration and solenoid actuation. The background noise not only hindered the ability to find a pitch, it output a muddy sound to the amp as well. We opted for magnetic pickups instead which were proven to be more reliable in our testing. When plugging the pickup into the amp, we found that the pickup was generating several harmonics. *Figure 6* shows the captured amp noise.

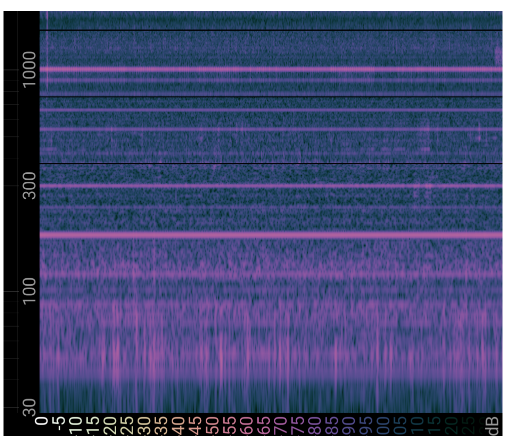

Figure 6: Background amp noise

The 1000 Hz frequency generated by the circuit is well beyond the range of the instrument. Hence why we decided to add a low pass filter to the signal. *Figure 7* shows the filtered signal with most of the higher frequencies attenuated.

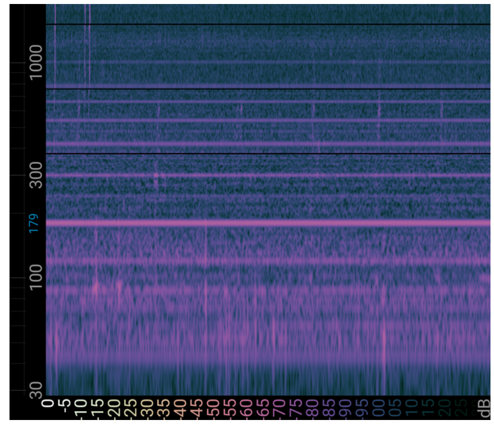

Figure 7: Background amp noise (with filter)

4.2 Pitch Detection

The ads1115 ADC was used to amplify and convert the signal and passed the result to the Teensy over I2C. The default sample rate was set around 128 samples per second, which was insufficient for our application due to the Nyquist frequency. Therefore, the Adafruit ADS1X15 was modified to overclock the sensor. The sample rate was increased to 1030 samples per second. Originally, an autocorrelation algorithm was tested however it wasn't accurate enough. The pitch detection currently uses a Fast Fourier Transform which can approximate the note frequency to ±1 Hz uncertainty with proper filtering.

4.3 Structural Design

The moment arm produced by the string tension was pulling the 3D printed plate forward, so we designed additional 3D printed brackets to reinforce the plaque.

The plectrum also struggled to pluck notes lower than 80 Hz due to the fact that there was not enough tension on the string. This simply means that Chameleon cannot play notes lower than 80 Hz. Additionally, the plectrum was cut to match the plucking height of the string, thus reducing wobbling and making plucking more accurate.

Furthermore, the acrylic base was not sturdy enough to hold the hardware, so we used a wooden slab as a base instead.

RECOMMENDATIONS AND CONCLUSIONS

Throughout the process of creating Chameleon, we encountered a few obstacles that hindered our progress, and which should be taken into account in future iterations of the instrument. Originally, we planned on having a 3-dimensional abstract structure with multiple strings traveling in abstract ways to emphasize the novelty of our project, but ultimately, we only had enough time to construct and test a single rectangular module. We also relied too heavily on parts that were being shipped to us which got delayed in their arrival. This resulted in a loss of precious and already limited prototyping time.

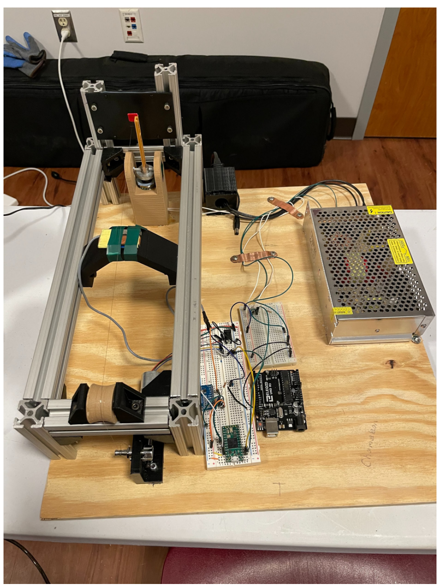

Figure 8: One Completed Chameleon Module

Another conclusion we came to toward the end of our project timeline was that structural integrity of the system needs to be given particular attention during the design process. One aspect of necessary structural integrity that we overlooked was what would be necessary for a base of the module. We planned for how the overall frame of the module would come together, but planned on just using whatever materials we had on hand for a base which ended up being a thin plastic sheet. Due largely to the tension in the string pulling up on the motor base, we ended up snapping the base multiple times and ended up resorting to a piece of wood. We also overlooked the structural integrity of our anchor point. Two vertical aluminum extrusion pillars were used to support our anchor point. Our mistake was using corner brackets to secure them to a perpendicular extrusion located beneath them, as it created an axis of rotation located at the bottom of the pillar. This along with the pillars acting as a moment arm due to the tension of the string caused our anchor point to rotate forward. We resolved this issue by making braces for the pillars, but we recommend designing a more robust solution to this issue in the future; one that would eliminate the anchor point from acting as a moment arm all together.

For future iterations of this project, we recommend the following. First, we recommend finding a way to emphasize the Spiropyran a bit more in the visual experience of the instrument. We achieved our primary goal as we did find a way to utilize the Spiropyran and display its color changing properties, but ideally it should be the focal point of the entire system as it's the primary source of novelty in the instrument. Additionally, we recommend that real time tuning be implemented in the instrument. We did not have the ability to delve into advanced digital sound processing so real time tuning was not explored as part of our project. In the end, our system was built so that a tuning sequence could be run before playing any composition. Notes could be played using predetermined tension values, correlating to different frequencies which the microprocessor could find in a lookup table. However, this method falters over time due to the string's changing characteristics, humidity, temperature, etc. Many of these issues would be resolved with real time tuning during composition.

REFERENCES

[1]Janda, A. (2018, November 15). The Color of Sound. https://www.vrtxmag.com/articles/the-color-of-sound/

[2]Bae, H. (2015, December 07). Xylophone Light - Sound of Color Arduino Project 1. https://vimeo.com/143098574

[3]Szczys, M. (2012, October 19). A Harpsichord That Plays Itself. https://hackaday.com/2012/10/19/a-harpsichord-that-plays-itself/

[4]Handžić, I., & Reed, K. B. (2014). The musical kinetic shape: A variable tension string instrument. *Applied Acoustics, 85*, 143-149. https://doi.org/10.1016/j.apacoust.2014.04.010

[5]Trail, S., Tzanetakis, G., Jenkins, L., Cheng, M., Macconnell, D., & Driessen, P. (2013). STARI: A self tuning auto-monochord robotic instrument. 2013 IEEE Pacific Rim Conference on Communications, Computers and Signal Processing (PACRIM). https://doi.org/10.1109/pacrim.2013.6625511

[6]Kouninis, A., Zhou, J., Dube, L., & Eaton, M. (2018, September 10). Assistive Technology Individual Guitar String Plucker. https://digitalcommons.wpi.edu/mqp-all/1387/

[7]Geist, M. (2020, December 08). Making Techno with Robots - Behind the Scenes!. https://www.youtube.com/watch?v=zL3wJpk0OVo

APPENDIX A: Bill of Materials (BOM) Per Module

Item	Source	Description	Cost ($)	Quantity
Guitar String	Amazon	Basic universal guitar strings for the desired note range	0.82	1*
Tuning Pegs	Amazon	Basic universal guitar tuning pegs for tuning the Chameleon	7.99	1*
1:45 Brushless Motor w/encoder	Amazon	FIT0441 1:45 Brushless Motor w/encoder	20.00	1*
Spiropyran	MIT/Duke	Color changing Spiropyran supplied by Duke University	N/A	1*
Solenoid	Ledex	Tubular Solenoid 1/2' x 1/2" Pull model 189015	14.38	1*
Spring	Home Depot	Spring that fits snuggly around the 0.5” diameter rod	0.89	1*
Plectrum	Zuckermann Harpsichords	Zuckermann Harpsichords plectrum that can be cut down to size with adjustable felt	15.00	1* (Pack)
PETG Filament	Amazon	0.5 KG of filament for use in a 3D printer for various parts, collars, and brackets	15.00	1*
ADS1115 16-Bit ADC	Adafruit	An analog to digital converter (an ADC) and signal amplifier	15.00	1
Pickup	MGB	Basic electro-magnetic guitar pickup rated ~3k. Singular pickup with a low profile and dimensions of 1.7" x .96" with a thickness	8.00	1*

		of .23”		
Arduino Uno	Amazon	Microcontroller that is very common and has many libraries and projects readily available.	12.98	1
24V 10A Power Supply	Amazon	A 24V 10A power supply that can handle many solenoids at once	20.99	1
Teensy 4.0	Amazon	Microcontroller that can handle the signal processing for tuning. Teensy 4.0 with headers is great for a breadboard	29.03	1
AD/20 Aluminum Extrusion	McMaster-Carr	AD/20 Aluminum Extrusion T-Slotted Framing rails	17.68	1* (6ft)
Wire	Amazon	Various gauges for circuitry.	5.00	1
2N2222A Transistor	Mouser	Amplifier Transistor	1.00	1*
Resistor (1 kΩ)	Mouser	A 1 kΩ resistor rated for at least 5V	0.30	1*
Diode	Mouser	A diode rated for at least 24V	0.30	1*
Capacitor (0.1μF)	Mouser	A 0.1μF capacitor rated for at least 5V	0.30	1*
Resistor (30 kΩ)	Mouser	A 30 kΩ resistor rated for at least 5V	0.30	1*
Breadboard	Amazon	ELEGOO Point Solderless Prototype Breadboard	9.99	1 3-pack
Total			194.87	

* Denotes the quantity for these items would be the amount of modules times the quantity

APPENDIX B: Electrical Schematics

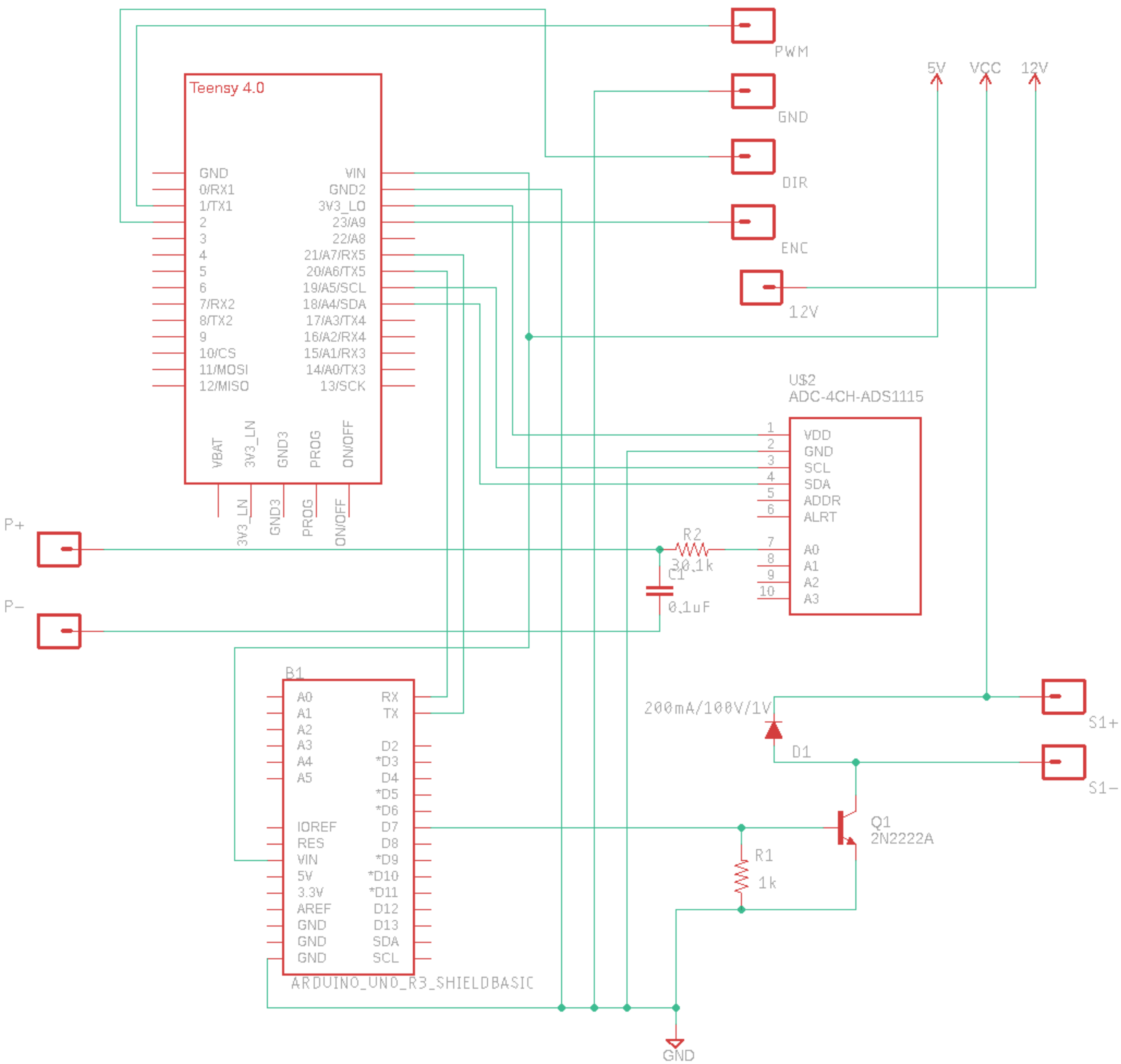

Figure B.1: Schematic of Chameleon's electronics. This assumes only one module.

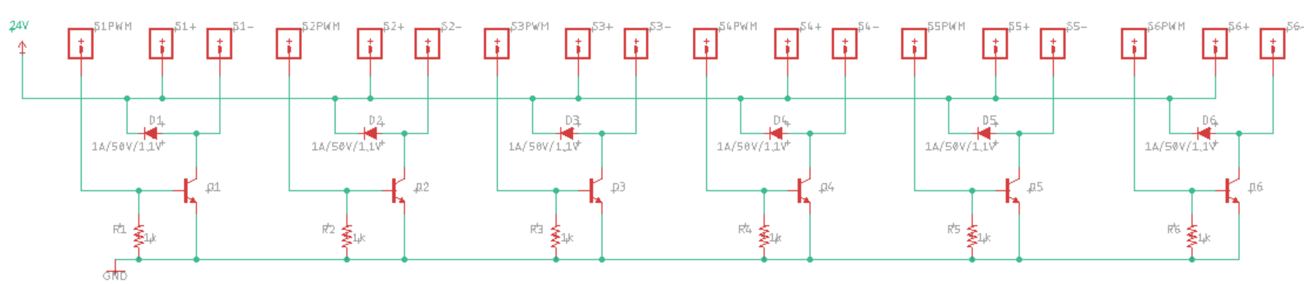

Figure B.2: Solenoid control circuit for six strings