Joule Jugglers: The Accessible Ukulele

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Team Name; ECEN 1400 - 100

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Abstract

With our accessible technology project, we decided to try and solve the problem of accessibility in music. Many instruments require very precise movements and very fine motor control to play. Due to this, there is a large market of people who love music but cannot express themselves due to the fact that they have a motor control disability. They cannot move their hands or fingers precisely enough to express their feelings through an instrument. We decided to change this. With our accessible ukulele, we designed a system in which fine motor control is taken out of the equation. In our design, the user is able to press one of four buttons to play a chord. When the button is pressed several solenoids fire in a coordinated pattern pressing down certain strings to play a chord. The user can then strum the strings playing the ukulele fully acoustically. With four chords provided, it gives the player a new freedom of expression that they never had access to. This project spreads the love of music to many regardless of disability.

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1 Introduction

1.1 Project Overview

A system to hold down chords of a ukulele to ease the process of playing the ukulele. This system will replace the fine motor requirements of traditional play with simple and intuitive buttons. Our buttons may have limited options, but the combination of these options will allow players to perform many popular songs with few or no compromises. Experimentation and timing with chord presses will also be controlled by the user which opens up thousands of options for the music that they create with this system.

1.2 Inspiration/Client

This project is meant to assist those without fine motors skills and amputees. We have not has a specific client in mind throughout this process; as a result, we have made strides to keep the system as open to as many people as possible. The final product could be fine tuned to suit a specific person's needs, but as it stands we have the chosen to create the most ambigious project possible.

2 Project Scope

The **Scope** of our project is to provide an alternative solution to those who do not possess the fine motor control that is needed to play the instrument

2.1 Goals

- Maintain sub-100°F temperatures while playing. This will ensure that the user can freely play the instrument without having to be concerned about the solenoids heating up too much.
- Allow the user to play all their favorite songs for as long as they decide.
- Implement functionality of the ukulele and the solenoids for four different chords.

2.2 Plans to Achieve Goal

In our project, we will achieve our goals through...

- Designing and constructing a base for the ukulele to sit firmly so that when a button is pressed, a corresponding chord can be played accordingly with no issue.
- Using the solenoids to hold down the frets so music can be strummed, as well as our fans to help keep the internal temperature under 100° F
- Utilizing resources such as Professor Piket-May and Tim May. We also plan to use Jonah Spicher and Rylee Beach to help us to overcome any difficulty we may encounter.
- While we may not offer every single chord that can be played on the ukulele, we included the most used ones that allow for the most amount of songs that can be played possible.

2.3 Team Assignments

- Dominic - CAD design, solenoid force testing, manufacture of parts, part assembly assisted in PDR and CDR creation, help to create housing and 3D print any necessary parts.

- Kameron - Coding design, solenoid force testing, part assembly, assisted in PDR and CDR creation, helped create housing, also help assemble the circuit.
- Kaleb - Circuitry, solenoid heat testing, manufacture of parts, assisted in PDR and CDR creation, created a circuit to get the fan working.
- Ryan - Circuitry, solenoid force testing, manufacture of parts, assisted in PDR and CDR creation.

3 Specifications

3.1 Solenoid Housing Unit

The solenoid housing unit is a 3d printed model that houses six solenoids which allow the user to play four different chords on the ukulele. The footprint of the unit is approximately 2.5" x 2.25". All the solenoids are housed in very specific locations on their respective strings and frets.

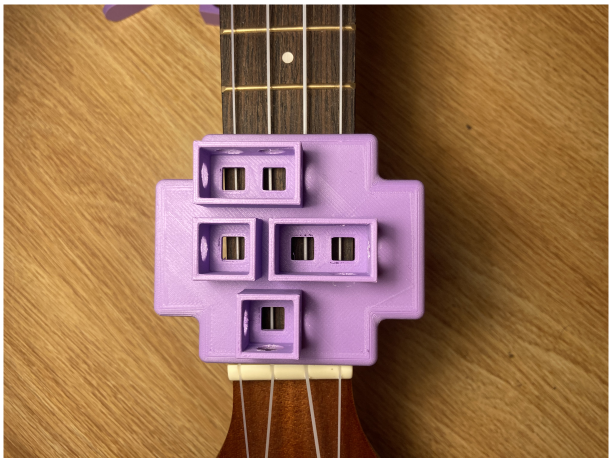

Figure 1: Final Solenoid Housing

3.2 Solenoids

- Manufactured by SparkFun
- Designed for 5V
- 4.5mm Throw
- 11mm x 12 mm x 20.5 mm Body

3.3 Microprocessor - ELEGOO Mega

- Manufactured by ELEGOO
- 5V or 3.3V

- 54 Digital I/O Pins and 16 Analog Pins

3.4 Buttons

- Manufactured by SparkFun
- 100 mm x 72 mm (Diameter x Height)
- 100 grams

4 Design Iteration

4.1 Initial Design Ideas

When first getting the idea for the project we took inspiration from several beginner guitar gadgets such as the EZ fret and Beginner Chord. We also took inspiration from the game Guitar Hero. All of these devices allowed the user to play a full chord on an instrument with the press of a button.

Figure 2: Beginner Chord Guitar Product

Figure 3: EZ Fret Guitar Product

Figure 4: Guitar Hero Controller

We were inspired by these gadgets and wanted to apply the idea of playing chords at the press of a button using solenoids. Our team came up with the idea to place several solenoids across the neck of the ukulele that would be activated by different buttons. When a button was pressed several solenoids would fire off, fretting a chord, then the user could strum all four strings allowing them to play the chord. The solenoids would be taking the fine motor skills required to play the ukulele, out of the equation.

4.2 Prototyping and Design Loop

There were many challenges that we faced when prototyping different versions of this project. These challenges included finding the right solenoids, finalizing our housing, and organizing circuitry. First the solenoids. Originally we ordered a 5V solenoid online. We opted for this solenoid due to its affordable price and small size. However, when testing the solenoid we found that it did not have the force required to press the string down when running on 5V. After that, we started exploring other solenoid options. We opted for a 12V solenoid. In testing, we found that this solenoid had more than enough force to push down the string but there were two downsides. The solenoid was very expensive at over 20 a unit and it was very big. This would have made it nearly impossible to fit multiple on the neck of the ukulele.

Figure 5: 12V Solenoid in Comparison to the Ukulele

After this, we tried one more idea which was over-driving the 5V solenoid. We ran 9V through it and then it had the force required to press the string down. We decided to over-drive the 5V solenoids for our final design because it allowed us to press down the strings and have small solenoids that fit on the neck. However, because we were over-driving them they got very hot. This forced us to do heat dissipation in the form of a CPU fan over the solenoids to keep them as cool as possible.

Next, was the difficulty faced with housing. We went through several different housing iterations before finally perfecting the one. In the end, we ended up with a strong design that is detachable via Velcro, and allows all the solenoids to fit in their correct places.

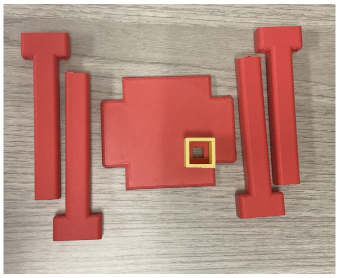

Figure 6: First Housing Model with Weak Legs

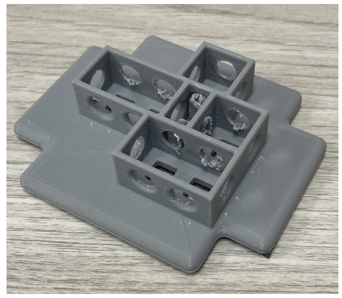

Figure 7: Second Housing Model with Incorrect Solenoid Placement

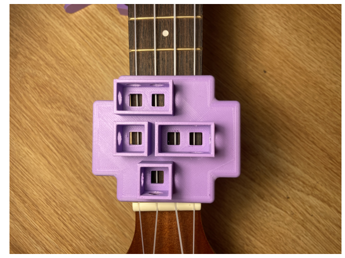

Figure 8: Final Housing Model

Finally, the difficulty with organizing wiring. The wiring for this project while simple in theory, became an issue when every single solenoid needed to be connected to its respective transistor. After that the transistor then had two other ports; one going to the microcontroller, and the other going to the ground. When doing the wiring we needed to keep organization of each wire so we did not have any short circuits. All the wiring and electronics were placed in the button and electronics housing box.

4.3 Final Design Elements

In our final design, we have three main pieces. These are the solenoid housing, the ukulele housing, and the electronics housing. Starting with the ukulele housing. We have several clips and stands that hold the ukulele in place allowing the user to strum without any harm. The fan and solenoid housing legs are also on the ukulele housing board. Next, we have the solenoid housing. The solenoid housing is 3d printed and fits perfectly over the strings. It attaches via Velcro to its legs on the ukulele housing. We did this so the ukulele does not have to be permanently attached to the project. Finally, we have the electronics housing. The electronics housing is a laser-cut acrylic box that houses all of our buttons, wiring, and the microcontroller. There is a port in the back that allows the wires to power, the solenoids, and the fan to reach their destinations.

(Insert Pic of final project here)

4.4 Risk Mitigation During Design

Our main risk mitigation throughout our project was our heat dissipation. Our main concern for the project is that the solenoids would become too hot and become unsafe. To avoid this we have a CPU fan blowing on all the solenoids while they are running keeping them cool and safe to touch.

(insert pic of fan housing)

5 Electrical Design

The purpose of the circuit is to activate the desired solenoids as their corresponding button is pressed.

5.1 Circuit Description

When a button is pressed, a switch is toggled, sending a signal to the microprocessor. After that signal is processed, a signal is send to the correct transistors, toggling the corresponding solenoids. The fan receives a constant current.

5.2 Circuits and Components

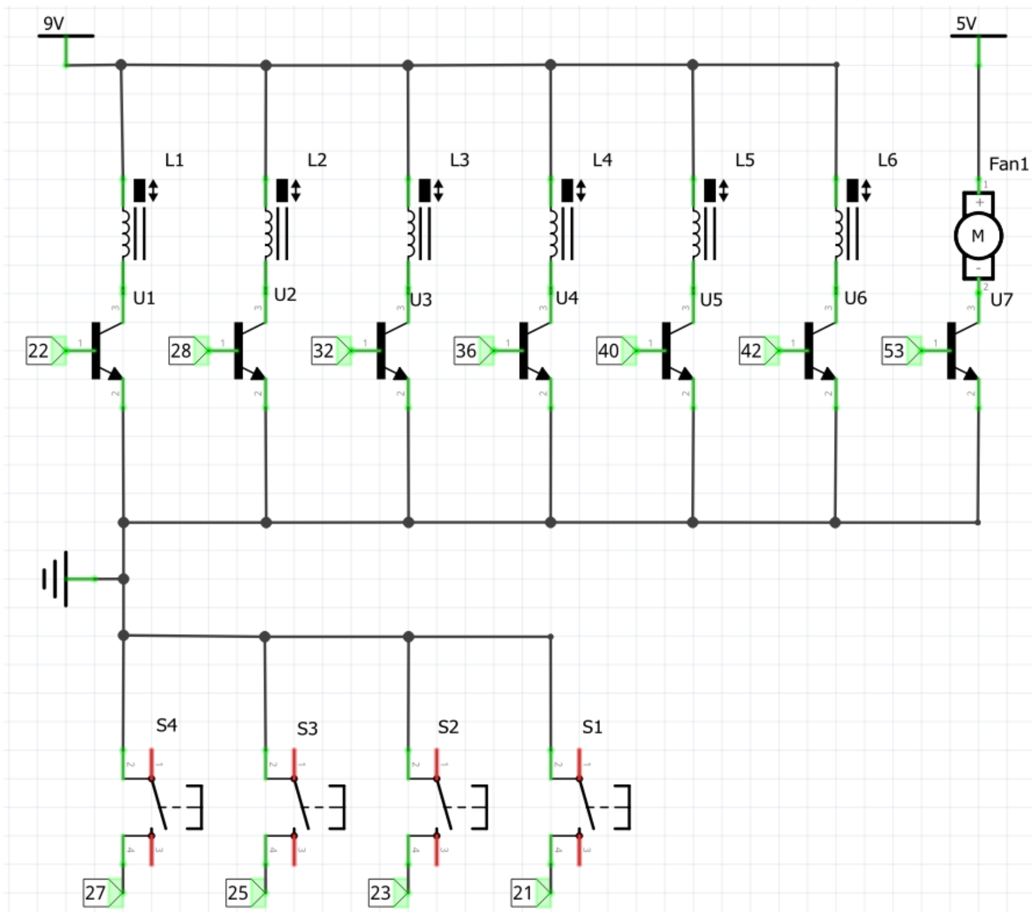

Figure 9: Circuit Diagram

6 Software Design

Our code has two important elements: a loop, that continually checks for button inputs (shown in the block diagram below), and a switch statements that triggers solenoids based on which button was pressed. In keeping with our goal of simplicity, there are only four options that correspond to four chords in our code. The result is a lean chunk of code, that handles all of our logic with as little processing time as possible. Having an Arduino mega as our controller helps the code build and run recursively much faster than an Arduino Uno might, not that you would be able to tell the difference in real time.

6.1 Block diagram

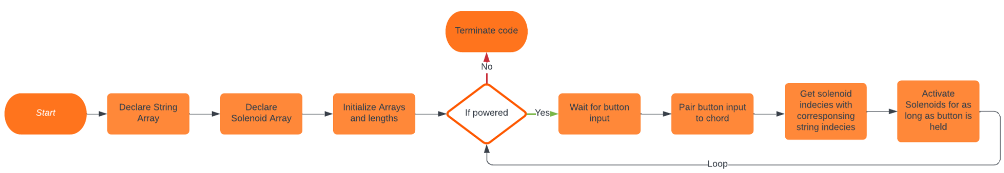

Figure 10: Software Flow Chart

6.2 Programming issues

One challenge has been finding the ideal way to trigger the fan. Our two goals were to limit the amount of time that the fan is on, while getting enough airflow to cool the solenoids. The balance that we landed on, through testing was having the fan turn on when a solenoid is triggered, and then stay on for a few seconds after.

6.3 Code Location

Link to Github Repository.
Inside our repository, you will find our final version of code, as well as all the resources, graphics, and reports that we have made along the way.

7 Mechanical Design

7.1 Mechanical Components

Our main mechanical components of this project were the solenoid housing, the electronics housing, and the ukulele housing. The entire footprint of the project is roughly 26" x 10" and reaches a maximum height of about 7". Most of our components were 3d printed but we did laser cut the electronics housing box.

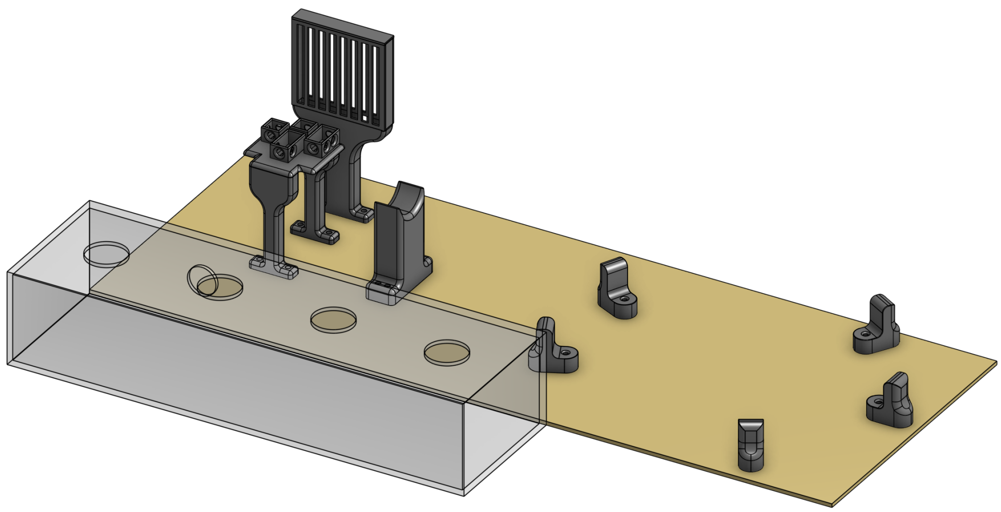

Figure 11: Final CAD Model of Project

7.2 Fabrication and Assembly

Because most of our mechanical components were 3d printed it quickly became a long process. We opted for 3d printing because of the creativity it allowed us to have with our models. However, it was a very slow process as the prints would take up to eight hours. We also had multiple design iterations which required three or four extra prints. However, the parts came out perfect in the end.

We also laser-cut the electronics housing box. We chose to laser cut the box due to its size and the way we wanted it to look. Laser cutting allowed us to make the box see-through which allows the user to see all of the wiring our team accomplished. Laser cutting was a very fast and easy process.

7.2.1 Tools

Throughout this project, we used tools including but not limited to:

- 3d Printer
- Laser Cutter
- Soldering Iron
- Miter Saw
- Drill
- etc...

8 Testing and Analysis

We feel very confident in our product, and its operation for two main reasons. Firstly, we were impressed by how hot the solenoids were getting. Every single time we tested the solenoid it didn't get any more than 15°F hotter than room temperature when used in normal play. The second reason why we are confident is through all the different playing and testing that we have done, it has been extremely reliable in holding down the frets that needed to be played when we needed them and releasing the fret when we didn't need it.

8.1 Electrical Testing

Circuit works by interpreting the press of a button, and then through our code transforming the input into linear motion by the solenoid which presses down the fret and allows for the user to play a chord.

8.1.1 Qualitative Analysis

We feel very confident in the project as a whole and feel that we will be ready to present our project at expo. We may need to figure out a better way of wiring the project, but overall we feel confident in what we have done and are excited to watch our project be on display for other to interact and engage with.

8.1.2 Quantitative Analysis

Founds that solenoids tend to get hot when held down for more than 45 seconds consistently. With a fan, it only gets to about 10°F more when consistently held down. This, along with the safety precaution built into our code, will allow for the solenoids to run cool and consistently while the user is playing.

Seconds Activated	Temp (No Fan)	Temp (With Fan)
0	72.34	74.71
22.5	75.55	79.99
45	87.02	85.26
67.5	95.22	89.66
90	103.70	93.17

Figure 12: Our Testing data of how hot the Solenoids actually got.

8.2 Mechanical Testing

8.2.1 Qualitative Analysis

The ukulele sits well in the housing when paired with a wedge we created to help the ukulele fit in snug into the brackets. Solenoids are also glued down into housing to prevent them from moving.

8.2.2 Quantitative Analysis

Solenoid was on target every single time that we tried it. We feel confident that the solenoids will hit the corresponding frets as necessary and as needed.

8.3 Overall Results of Testing

We are pleased with how the solenoids performed, and overall are excited to see exactly how the project works when used in the real world, and how the project will perform at expo.

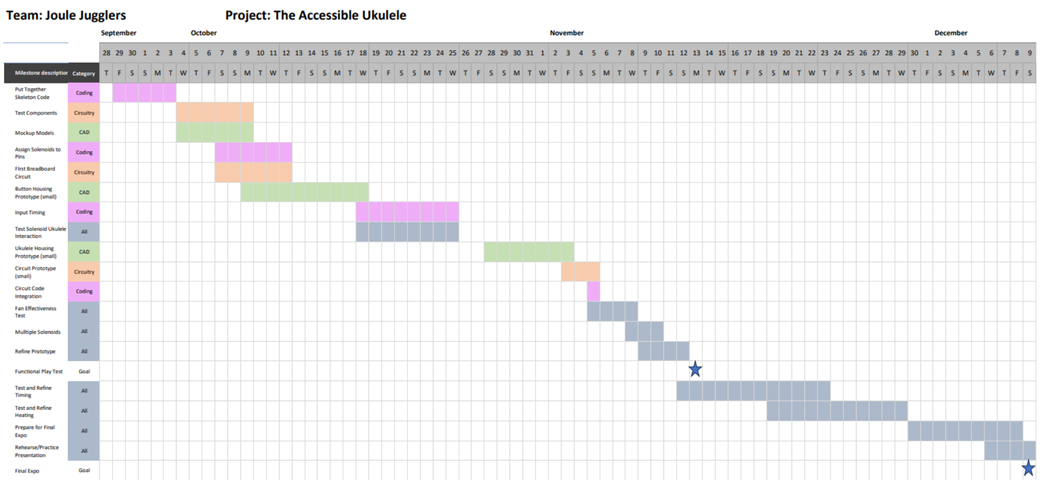

Figure 13: Project Timeline

8.4 Bill of Materials

Quantity & Product	Price per	Total Cost
6 5V Solenoids	$5.50 each	$33.00
6 13.2 x 12.1 mm Copper Heatsinks	$1.95 each	$11.70
6 Transistors	$0.00 each	$0.00
4 Buttons	$12.95 each	$51.80
1 Arduino Mega (Elegoo)	$21.00 each	$21.00
1 30 x 30 mm fan	$3.50 each	$3.50
1 9V DC Power Supply	$14.00 each	$14.00
Total	-	$135.00
Margin	-	$165.00

Figure 14: Bill of Materials

9 Conclusion

Stringed instruments bring great joy to many who are musically inclined, but the finger dexterity that holding chords requires restricts the medium far too much. While hoping to broaden the range of individuals who are capable of playing stringed instruments, we still have immense respect for the instrument's physical form. To this end, we have set out from the beginning to create a project that complements the ukulele's traditional form, rather than supplementing it. It has also become clear to use through working with solenoids, that much of the complexity of holding chords should be hidden by simple, easy to use, buttons that represent chords; in this way, our target market can focus on timing their strums and experimenting with chord combinations.

9.1 Summary

Every bit of our project, housing included is centered around our solenoids. Measurements for all of our housing units are based strictly on what is required by our solenoids. Our wires all run to the solenoids, or to an adjacent component. As such, most of our technical and design goals and solutions have been for the sake of fitting our optimizing our solenoids. By seeing this solenoids as fingers we have worked on every level to set up the equivalent of what it would traditionally be to play a stringed instrument. We feel that we have succeeded in creating an alternate way to play an instrument without changing the instrument in any way or 'dumbing-down' the process.

9.1.1 Technical Summary

Our project uses the plungers attached to solenoids, along with high current to create enough tension in ukulele strings to mimic human touch. Our circuit starts by drawing voltage from our Arduino mega, and then listens for input from out buttons, which are also wired to our micro controller. On a button's press, a circuit with a transistor sends enough current to our solenoids to create magnetic fields that push our solenoids plunger into the ukulele's string. These solenoids can be active simultaneously, but they do generate a significant amount of heat; we use a fan to disperse these heat. The fan's activation is tied into button inputs, where if a button is being held, the fan will also be on.

9.1.2 Design TakeAways

Our design has had to evolve quite a bit over the course of this project to account for our solenoids. The two constraints that solenoids bring is that they are often large, or in our case, they are small but produce a potentially dangerous amount of heat. In looking at our project it is immediately clear, that much attention went into making housing that fits the solenoids perfectly, and leaves space for a mounted fan on the side. In conjunction with this, it has been our goal from the start to avoid modifying the ukulele in any way, which is why all of the housing units can be moved and reconfigured.

9.1.3 Teamwork TakeAways

Our team has worked very well together from the onset of this project. Communication has been key, and we have kept in contact with updates and ideas nearly every day this semester. For most of us, this is the first time contributing to a team where there is not a weakest link, and instead there is one continuous chain of responsibility, where work is shared equally. We are very lucky to have personalities similar enough to allow for instant understanding, but different enough to allow for creativity.

9.2 Future Work

As mentioned in the design takeaways, our solenoids have been the crux of our project, and have required majority of our attention and budget for a cohesive simple final product. Our future work would then include adding more solenoids, which allows for more chords. In our current set up, we could only afford to test two solenoids, and order a total of six. In the future, it would be great to find a solenoid that has better heat dissipation and then order dozens to allow for more creativity in the player. There are also additional avenues for heat dissipation that we had neither the time nor the budget to explore, like heat syncs, which could make our product even safer. On that note, holding the chords of an instrument is only 1/2 of the experience, we could now endeavor to use a motor system to replace the manual strumming.

Now that we have the foundations of what it takes to achieve a hands free string press on a small stringed instrument, it would be interesting to experiment with other stringed instruments. From a technical perspective, a bass guitar is very similar to a ukulele in all but size, and the same housing and solenoid arrangement could transfer seamlessly. We could also branch out to more traditional instruments, like the violin, which opens up doors to a second mechanism for mimicking the pizzicato of a violin's bow.