Laser Guitar

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ABSTRACT

Our senior design project the “Laser Guitar” attempts to create a new innovative instrument which can be played like a guitar, where the strings are lasers. This is done using communication between two sensing systems, one which determines which note to play, called our “Fretting” system, and the other which determines when to play each note, our “Strumming” system. All detection is done by photodiodes operating in photoconductive mode so that they act as light dependent current sources. The current is run through resistors in series and a voltage divider is used to return information to the MCU. This process will be described in greater detail throughout the paper.

I. OBJECTIVES

The motivation for this project is to develop an instrument with new, unique features that uses the knowledge we have gained from our studies at the University of Central Florida (UCF). The laser harp and optical theremin have been seen many times to implement lasers as a replacement for strings in an instrument, however to our knowledge this has never been done with a guitar. Guitars are one of the most popular instruments in the western world; however, learning the guitar is a struggle for many beginners due to the fact that it can be physically painful to play guitar strings with your bare hands over a period of time. This inspired us to design an instrument which can be played like a guitar without the physical drawbacks that an acoustic instrument normally causes. By using lasers as the strings, the goal of our project is to remove the painful process that normally comes with learning the guitar as a beginner and creating an instrument that feels and plays like an acoustic guitar.

II. REQUIERMENTS

The design of our instrument will result in a stringless guitar that uses laser light as the strings. The user requirements include the size and feel of the instrument, and general eye safety for the user. Initially, our idea was to make an instrument that feels natural to play, the size should be no longer than that of a bass guitar, and with spacing between frets that is reasonably small so that the user can play comfortably. Eye safety will be accounted for by using nothing more powerful than a class 3R laser with proper eyewear included if necessary. We must ensure that the correct notes are being played based on which laser is being blocked by the user's finger, and the returned intensity signals the microcontroller to play a certain note. This note will be stored and played when the corresponding string is strummed on the strumming set of strings. To do this, two separate sets of laser systems will be designed.

The first is a strumming system. This system simply tells the microcontroller to play a note when the beam is interrupted. A stretch goal of the system would be to determine the volume and sustain of the note played based on the velocity of the strums. The second system is the fretting fretting system. This system uses a series of photodiodes in conjunction with a laser diode to determine what note will be played by the strumming system. The photodiodes will be placed along the neck of the guitar in parallel, so they carry the same voltage and vary in current values. They will be reverse biased so that they act in photoconductive mode, which means they act as current sources which increase in current as the amount of light incident on the diode increases. The voltage will be read by running this current through resistors in series and performing a voltage divider using our MCU to determine the voltage at each diode. When this voltage is high, it means a high amount of current is running to the resistors, telling the MCU our diode is on and returning a digital signal of 1. When the beam is interrupted, a digital signal of 0 is read by the MCU and a sound is played for each string that is interrupted.

The fretboard works in a similar way to the strumming system but uses analog readings rather than digital readings. This is because the reflected light off the users fingers only resulted in a small change of voltage, making digital readings inconsistent. These photodiodes operated in photoconductive mode are used once again to act as light dependent current sources, however this time it is implemented across an array of photodiodes along the fretboard of the guitar. The amount of light incident on each diode can be controlled by the user by interrupting the laser beam that is fired across the fretboard. In terms of project requirements, this means we need to have a system which can fire a laser beam in a controlled area of space and collect any light reflected by the user's finger. This requires many photodiodes as one will be used at each fret for each string. The MCU needed to account for each of the photodiodes that are used in our project, and have enough pins and a fast enough clock speed so that the act of playing the instrument feels natural to the player, and the system should be able to work under settings of various lightings.

III. COMPONENTS

A. Microcontroller:

The microcontroller we selected is the Arduino ATmega2560. This microcontroller offers 54 I/O pins with 16 analog inputs. The 16 analog inputs are connected to a 16-channel analog to digital converter making them ideal for use with our laser strings. The total amount of 100 pins is more than enough to provide that all four strings with four photodiodes will have a usable input, while still accounting for our power supply and any other unaccounted-for inputs. The ATmega2560 is also very power efficient, drawing only 500 microamps when running in active mode at 1 megahertz and 1.8 volts. This power efficiency improves even more when the device is in sleep mode, drawing just 0.1 microamps. The ATmega2560 offers a clock speed of 16MHz at 4.5V-5.5V, which is fast enough to provide sufficient processing for a natural feeling experience. The ATmega2560 is programmable with a language specific to Arduino which is based on C and C++ programming, which should ensure that picking up the language will not be a challenge for our software team. The price is currently listed as $15.99 on Amazon, which is reasonably cheap for the amount of features this microcontroller provides.

B. Laser Diodes:

After looking into each of our options for laser diodes, and taking into account the photodiode we selected, we chose to go with the GeeBat Mini 650nm. These laser diodes were not only the most readily available, as with Prime shipping they could be shipped overnight with Amazon, but they were also the cheapest and smallest of the laser diodes we looked into. The downside is that the maximum output power is only 5mW, however this actually helps us with keeping our device from becoming too bright and staying within our safety constraints. Because we ended up selecting the Vishay BPW34 photodiodes, the GeeBat Minis were also the best option due to the wavelength being closest to the Vishay's peak wavelength. This helped us achieve a clearer signal and make the software design easier for our software team. Another factor that we took into consideration is the size of the laser diode. Because the GeeBat Mini 650nm was the smallest option available, we were more inclined to pick this device. This was confirmed when we decided we wanted to use the body of a ukulele rather than the standard or bass guitar body, as this was the smallest body we had to choose from. Other options of wavelengths would require more expensive and harder to find options for photodiodes in most cases, so we decided to go with the 650nm option, where related components were found abundantly for cheaper.

C. Photodiodes:

The Vishay BPW34 is a PIN photodiode offered on Amazon in groups of 10 for just $7.99. The data sheet of the BPW34 lists the device as having a dark current ranging from 2-30nA, and a reverse light current of 40-50µA. By using a voltage divider with resistors on the order of 10-50kΩ, this would allow us to easily draw enough voltage to send a signal to our MCU given enough light incident on the photodiode. The rise time and the fall time of this photodiode are both 100ns. The spectral range of the Vishay BPW34 is from 410-1100nm, with a spectral sensitivity of roughly 70% at the wavelength of 660nm, meaning they were highly compatible with our laser diodes.

D. Voltage Regulator:

The voltage regulator used is the Texas Instruments LM2596 Simple Switcher. There are three set output versions for 3.3-V, 5-V and 12-V, as well as an adjustable version. Our design requires 3.3-V and 5-V versions for the photodiodes and laser diodes, respectively. With two battery cells in series giving 7.2-V, our case is a buck regulator. The design for the PCB will use two capacitors, inductor and diode. With an output current of up to 3-A and a package of TO-220, it suits our needed specifications. Another consideration is the use with individual battery cells, since efficiency is a key requirement for our overall design. Previously in our design, we implemented a regulator with a SOT-23-5 package that overheated quite quickly, which caused us to rethink our design for better heat dissipation. The parts selection for each component was followed and recommended in the datasheet, which followed our designs voltage and current specifications. Design wise with the component selection, the switching frequency of 150-kHz will require smaller size components. Unlike the design for the previously selected regulator, MCP1630, the number of components required is now smaller since we are using a fixed output. With a smaller junction-to-ambient and junction-to-case thermal resistance of 52°C/W, the heat dissipation is greatly improved over the >200°C/W with higher currents. This new design maintains the regulated output for out systems and is kept cool over a long period of use.

IV. IMPLEMENTATION

When implementing our design, we must consider both the hardware and software. By understanding how the hardware will function based on the code of the software, we can implement the necessary functionalities to implement in the software.

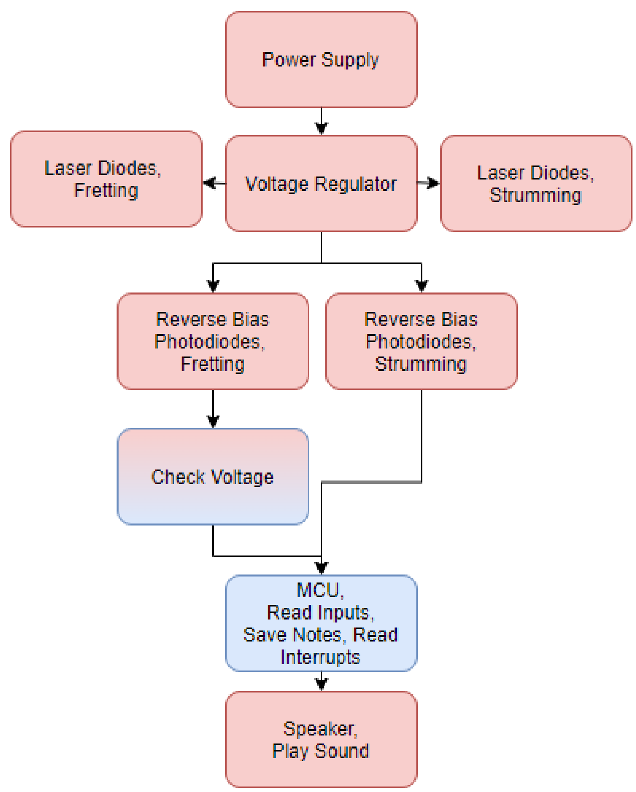

Fig. 1. A Hardware Block Diagram

The goal of the hardware implementation is to allow the microcontroller to detect which string is being played, and where it is being fretted to determine what note to play. To do this, two sets of lasers will emulate one string on a guitar. We will call these sets the "fretting" sets and "strumming" sets. The strumming set of strings will be placed at the head of the guitar and will operate by detecting when the laser is interrupted. If a strumming laser is interrupted, then the note determined by the corresponding fretting laser will be played. The fretting laser system will operate by detecting the amount of light reflected off the user's finger back to the photodiodes which will read the intensity of reflected light. Each fret will have its own photodiode, which will return a 1 to the MCU when the voltage is high, meaning the fret is being held down and reflecting light to the photodiodes. The photodiodes which are not reading any reflected light will return a low voltage, or value 0 to the MCU. This information will be used to save which note should be played by the speaker. The entire system will be powered by a lithium ion battery connected to a voltage regulator, which will power the laser diodes and provide a reverse bias to the photodiodes. The figure below provides a hardware schematic for our Fretting system. This schematic shows all four strings, each with three photodiodes connected to two resistors and a capacitor. While our initial design only called for the two resistors to perform the voltage divider, in practice our MCU was unable to make consistent readings with a direct connection from the resistors to the MCU. After doing some research we found that the device we were initially testing with had a small internal capacitance which allowed for more consistent voltage readings. We then tested this on our own using 10µF capacitors and found that this solved any problems we had been running into. All four strings are powered by a single power supply, which runs 3.3V across each of the photodiodes. The photodiodes were placed such that they were reverse biased, and the pin outs on the far right end of the PCB connected to the node where the voltage was changing with respect to the light incident on the photodiodes. These pinouts were later connected to the MCU and used to make analog reading which would determine how much light was present at each of the 12 photodiodes on the fretboard. If this value was greater than 1V, the diode was considered "ON", and if the value was less than 1V, the diode was considered "OFF". Using a range of values and an analog reading as opposed to digital readings allowed us to use lower power lasers to meet our eye safety standards.

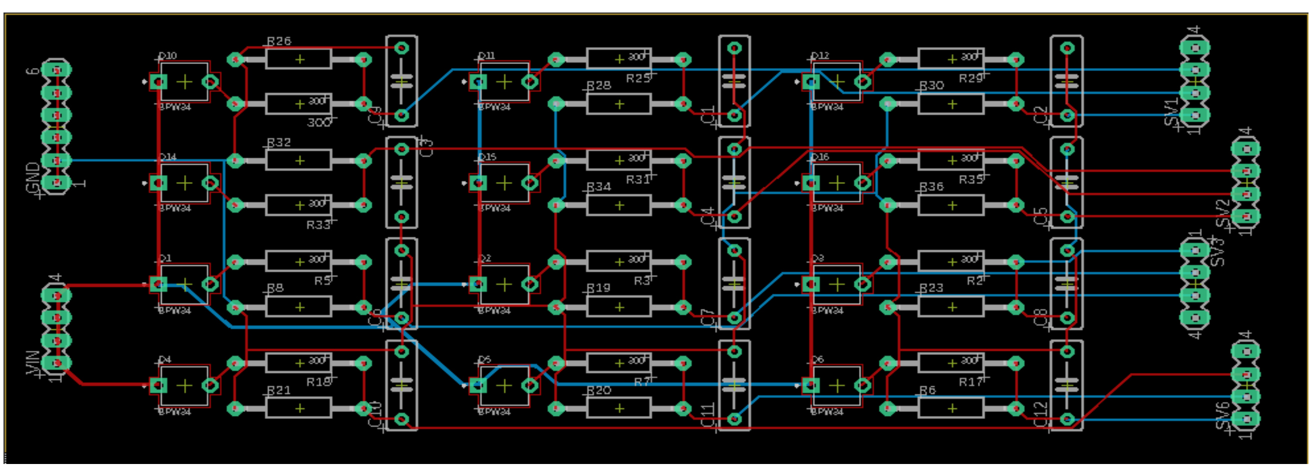

Figure 2. Fretboard PCB Schematic

The dimensions of the PCB shown in Figure 2 are 2" x 5", which fits nicely as the fretboard for a smaller design, so we opted to base our design on a ukulele rather than a traditional guitar. The strumming system involved a similar PCB, but with only four photodiodes as that was all that was necessary for the four strings. The laser is shined directly onto the photodiodes in this case, so the voltage was around 3.6V when the diodes were on, and 0.7V when they were off. Because of this large disparity in values, the strumming system used digital inputs instead of the analog inputs which were used in our fretting system, which helped to improve the performance of the device. The schematic for the strumming PCB is shown in Figure 3 below.

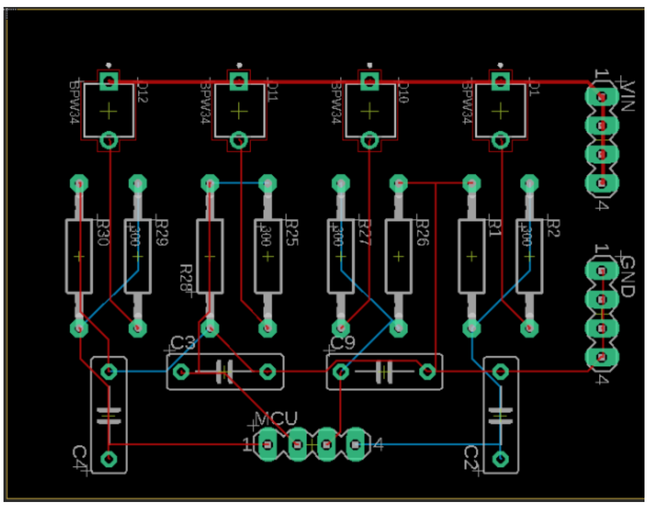

Figure 3 Schematic for the strumming PCB.

The two systems are required to communicate with each other for our design to work as we initially intended. This was done using our MCU, the ATmega2560, which brought the entire project together. Now we will investigate the software implementation, which describes how the two systems communicate with each other, and how we achieved our goal of four notes of polyphony.

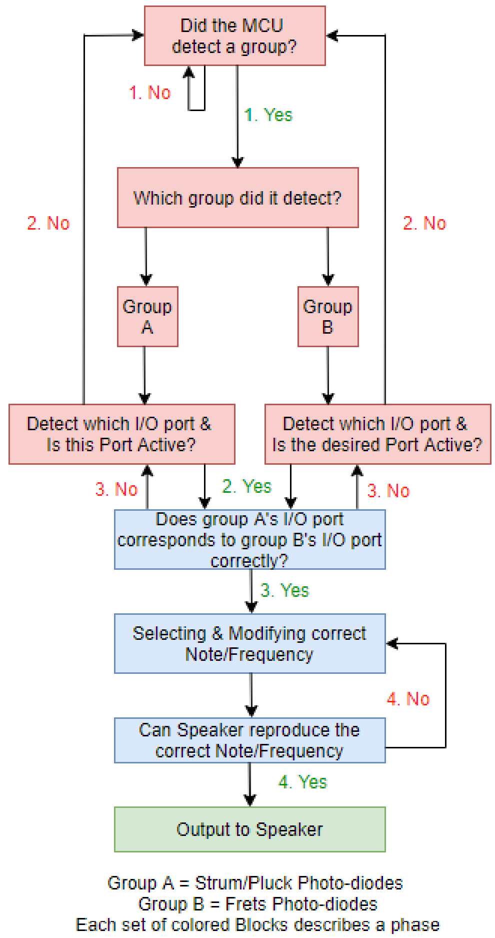

Figure 4. A Flow Chart for software implementation. This is within the MCU.

The goal of the software implementation of the project is to produce the correct frequency/pitch according to the laser intensity when another laser is strummed/plucked. When reading the laser from the sensors, there are two lasers to record and analyze. The first laser is the strum/pluck from the "strumming" set, and the second laser is the fret "fretting" set. Both laser detections will need its own algorithm to process because they are two different systems of lasers. By reading the laser intensity, we can sign a frequency/pitch. When the laser is strummed/plucked, we can use this reading as a trigger to play the frequency/pitch to the speaker. Fig 4. shows the logic behind this implementation.

Given that the microcontroller is at the root of our project and will ultimately be a key factor, our software selections were decided upon once the microcontroller was picked out. The microcontroller selected was the ATmega2560, which is most found on the Arduino Mega 2560 microcontroller board. Our software selection is solely geared around this device and thus the programming language that will be used is Arduino's native language. This language was not in our programming languages research for the sole reason that it is derived from C/C++ and all C/C++ code will work in Arduino for the most part. The developers on the team are familiar with C/C++ and therefore, makes the Arduino language a good fit as a new language will not have to be learned. The Arduino language will give us the benefits that come with the C language such as memory management and bit manipulation, while also allowing us to incorporate C++ programming paradigm such as Object-Oriented Programming.
By understanding the hardware components needed for our project, it allowed us to consider important design factors to advance the software design process. The factors to consider ameliorating the software design process are programming paradigms, and design patterns. Both the programming paradigms and the design patterns should be considered because this will help keep the design within the requirement specification while minimizing impediments.

Upon completion of the software and hardware design, all that was left was to design a housing that meets our requirements for size, weight, and portability. Since we decided on a design based on a ukulele, we thought it would be a good idea to strip a real ukulele of its strings, hollow it out and place the electronics on the inside. We ordered a cheap, twenty-dollar ukulele from Amazon, and were easily able to remove any unnecessary parts of the ukulele. The fretboard was also removed, so we could replace it with our own fretboard which housed our PCB. Laser mounts were attached to the head and the neck of the ukulele, and the PCBs were slid in to custom 3D printed mounts that suited our needs perfectly. The result was a device that met all of our specifications for size, weight and portability, and the final design is shown in Figure 5 below.

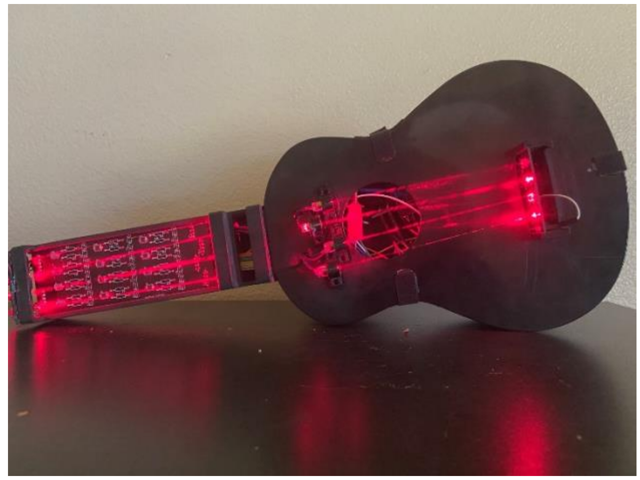

Figure 5. The Laser Guitar

V. ROADBLOCKS

As with most large-scale group projects, we did face some challenges along the road to completing the laser guitar. First and most notably, we were working in the summer and fall semesters of the year 2020, at the peak of the coronavirus pandemic. Life was not normal for anyone at this time, and in the context of our project this made many things much more challenging. First, we had no access to labs on UCF campus for the entire summer semester. Thankfully, we received a package from UCF containing a digital oscilloscope and breadboard set, however this was still very limited as compared to the tools available in previous semesters. Due to the pandemic, shipping times from third parties were often extended, and some places were understocked as sales for everyone have been down in 2020. This became an issue for us when ordering our laser mounts, as only six were available when we needed eight for our project. We found there were times when we could not make any progress until we received certain parts, and due to the extended shipping times, this resulted in a large roadblock in our progress. Finally, coronavirus caused many people to move back home – including two of our group members. For the entire first semester, all of our work was done from home, and it wasn't until the Fall semester that we ever got to work together in person. Beyond the roadblocks presented due to the pandemic, the project went relatively smoothly. The housing was a bit of an issue since the ukulele was too small to fit all of our electrical components, but this was solved by putting the batteries on the back of the guitar rather than on the inside of the guitar to save space on the interior. There were some stretch goals we weren't able to achieve, such as playing custom sounds polyphonically, adjusting the volume, and including more frets than we originally intended, but the overall fundamental goals of our project were all achieved.

VI. CONCLUSION

In the end, we were able to achieve our goals of designing an instrument based on a guitar with lasers replacing the strings. The device met our engineering requirements of low response time, laser eye safety, portability, and polyphonic software design. We are also well within our initial budget, as most of the supplies used in our project were far cheaper than we initially anticipated. This semester was especially challenging due to COVID-19 restrictions making travel and working as a group far more difficult than it has been in the past. Thankfully, our group was able to come together and design something we are proud of. We are happy with the progress we made, and we look forward to future projects taking inspiration and combining music and engineering for fun and innovative projects.

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