Expressive Laser Harp

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***Abstract* — We have designed and constructed a MIDI instrument that uses lasers and photoresistors to simulate the strings of a harp. Infrared distance sensors detect the distance at which the laser strings are blocked and control the attack velocity of the notes that are sent from the laser harp to external devices. This distance sensing adds a layer of expressiveness to the instrument that would otherwise sound dull and would be less exciting to play.**

***Index Terms* — Diode Lasers, Photodetectors, Infrared Sensors, Musical Instrument Digital Interfaces, Microcontrollers**

I. Introduction

The harp is one of the oldest stringed musical instruments in human history and has been a part of musical performance for millennia, even still being played commonly today. In the latter half of the 20th century, the advent of the synthesizer led to a boom in the invention of new musical technologies. Alongside this musical revolution, the laser was being developed as a new method of light emission. During the 1970's, many famous rock groups began to incorporate laser lighting displays into their live performances, creating a fantastic visual component to their shows. Shortly after these laser shows were reaching their peak popularity, the laser harp, which triggers synthesizer notes by blocking laser beams, was invented as a new way for performers to interact with their lighting displays.

The laser harp is an instrument that uses lasers to simulate the strings of a traditional harp. When the laser beams are blocked, they trigger an external synthesizer to play notes corresponding to the strings of the harp. Traditionally, these harps are intended to create a grand display, with laser beams pointing to the sky, but we intend to bring the same technology to a smaller module making it portable.

Our laser harp consists of a rectangular frame with vertically pointing lasers aligned across the top of the frame, with photoresistors at the bottom to detect when the corresponding laser is blocked. These lasers are assigned to notes that are sent via Musical Instrument Digital Interface (MIDI) to control external synthesizers and samplers. To add another layer of expression, the laser harp can also detect the distance that the lasers are blocked by the user, and this information is also sent via MIDI as Control Change (CC) messages, to control parameters such as attack velocity or timbre.

Fig. 1. Framed Laser Harp

II. Musical Interface MIDI

In order to develop a product that can be used in conjunction with existing electronic music hardware, a key element we needed to implement is Musical Instrument Digital Interface, or MIDI. MIDI is the software standard for controlling electronic instruments, and has been since the early 1980's. MIDI has been used in practically every synthesizer, drum-machine, and sampler since it was introduced, and is a necessity for any controller or electronic instrument. MIDI can be transmitted using a standard 5-pin DIN connector cable, as well as USB interface with a computer. Both of these were implemented into our design in order to maximize compatibility with other musical devices, and to allow us to control a wide range of instruments with one device.

Our device has a MIDI input, MIDI output, and a USB connection that can send and receive MIDI data.
MIDI messages are made of 8-bit words (bytes) transmitted by serial communication at a rate of 31.25 kbps. This is a standard based on early microcontrollers which operated at 1 MHz. The first bit identifies the byte as a status byte or a data byte (1 for status bytes, 0 for data bytes), and the following 7 bits contain the value that corresponds to note numbers, velocity, and many other possible parameters. The words also include a start and stop bit to aid in frame synchronization, so each message requires 10 bits to transmit. The Status bytes are sent first to indicate to the receiving device how to process the following Data bytes.

The 7-bit word allows for a range of values from 0 to 127, which allows for note information exceeding the number of keys on a traditional grand piano. These MIDI notes can be used to control a variety of parameters in an external instrument but are generally used to control pitch. These note messages are split up into two types: Note-On and Note-Off. As they might sound, they tell the synthesizer when to start playing a note, and when to stop playing the note based on when the key is pressed and then lifted, respectively.

III. Light Source

The strings of an optical harp differ fundamentally from the strings of a typical harp. There would be parallel beams of light acting as the strings, which would be detected. The "strings" in this case would be created most likely from the radiation of a laser. Small laser diodes would act perfectly in this case as the light source for these strings. The strings could also have different colors to distinguish the different strings. This could be done by using a different laser for each note, or by using a different laser at the start of each octave, which would be one every seven strings. We needed to consider our budgetary restraints when choosing different colored laser diodes because they do become costly. We also had to consider the amount of power that they require, for now we are using low power with current 5mA laser diodes.

IV. Laser Detection

To communicate information to the controller there needs to be an interface that detects when the laser light is interfered with. A photodiode is a semiconductor device that converts light into a current, which is generated when photons are absorbed. This absorbed light will generate an electrical signal output that will communicate with the system to fire off musical notes on the harp. There are also photoconductive cells that do not produce electricity but rather change physical properties when subjected to light. A photoresistor is a common type of photoconductive device that changes its electrical resistance to the changes in the intensity of light. The light dependent resistor (LDR) is made from a piece of exposed semiconductor material that changes its resistance, creating electron hole pairs, when light reaches the photocell.

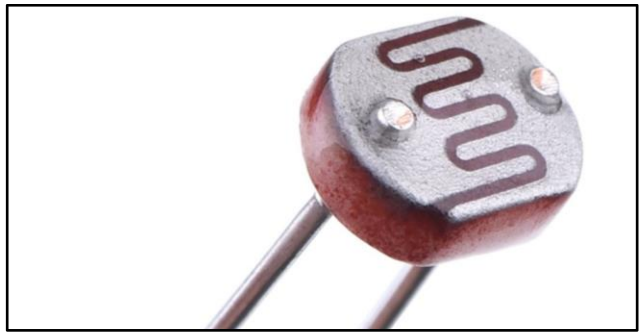

Fig. 2. eBoot Photoresistor

V. Distance Detection

Detecting the distance at which the beam is interrupted can also be implemented in this project using infrared distance sensors to create another dimension of sound. A pulse of infrared light is emitted, and the distance-to-object is determined by the angle of reflection of light returned to the receiver. The process of using the angle of reflection to calculate the distance is known as triangulation. Our goal is for the laser harp to be compact so as to fit on a desk or table, so we will need to select infrared distance sensors that will be accurate within a range of about 10-12 inches. As well, the sensors will need to be small enough that they can be placed alongside the laser diodes, which will be separated by 1.5 inches. If the infrared sensors are too large, we will be forced to increase the size of the laser harp, or reduce the number of strings, so we will need sensors that can be arranged parallel in with the same distance of 1.5 inches between the infrared beams. For this, we opted for the Sharp GP2Y0A41SK0F infrared sensor, seen in the following figure.

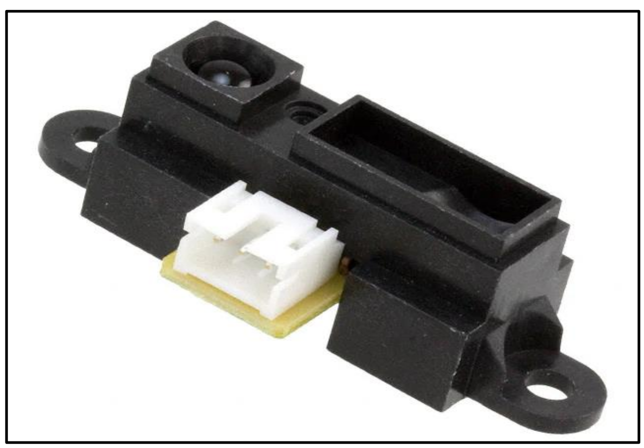

Fig. 3. Sharp GP2Y0A41SK0F infrared sensor

The GP2Y0A41SK0F has a 3-pin connector attached to the board from the manufacturer, but to save space between the parallel infrared sensors, we instead connected the sensors via soldering at the contact points on the back of the PCB attached to the sensor. The three pins on the sensor are supply voltage, output voltage and ground, and the sensor does not require any other components like capacitors or resistors to function properly, so the hardware implementation and connecting the output to the microcontroller and grounding the circuits.

Because the output of the infrared sensors have a continuous, analog output we also needed to ensure that we have a sufficient number of channels in the analog-to-digital converter (ADC). As we intended to have distance sensing implemented for each individual beam, we needed to have 15 channels of analog to digital conversion. Most microcontrollers include a built-in ADC, but not many have so many analog inputs for their ADC. This is a very important factor in our microcontroller selection and project design, as we either needed to find an affordable microcontroller with sufficient analog inputs, or we would have needed to use serial communication to connect a separate analog-to-digital converter to a microcontroller with less inputs, further complicating our design and introducing more points for failure or malfunction. To avoid these problems, we elected to find a microcontroller with the necessary number of analog channels.

VI. SENSOR HOUSING

The photoresistors we chose will need to be encased in some sort of darken casing to better protect the detectors from ambient light. We have discussed that ambient light is the highest factor in noise, we must block out any oncoming light that could alter the detectors performance. The photodiode that is chosen will be tested on its performance in multiple settings including indoor lighting, outdoor, and with direct light on it. We must be able to know the exact ranges of detection to have the microcontroller process the data and send the proper signals to the MIDI interface. We will consider different materials in the testing process and relay the final details at the final build.

We must also consider the housing situation for the distance detectors, so that they too do not interact with any other unwanted signals. There are many detectors that come in housings already to be purchased, however for testing purposes we will use basic components and purchase similar products in the final configuration. For the case of distance detectors, we must consider that there are two components next to each other so it must not take up that much space to fit all the parts in the laser harp housing. The dimensions of individual components for electronics such as photodetectors and other distance detectors, however when you begin to purchase parts from distributors, they become bulky with plastic casings. Something we want to do is limit the amount of wasteful space used on the laser harps casing because this harp is meant to be portable, the smaller the better.

VII. ATMEGA2560 MICROCONTROLLER

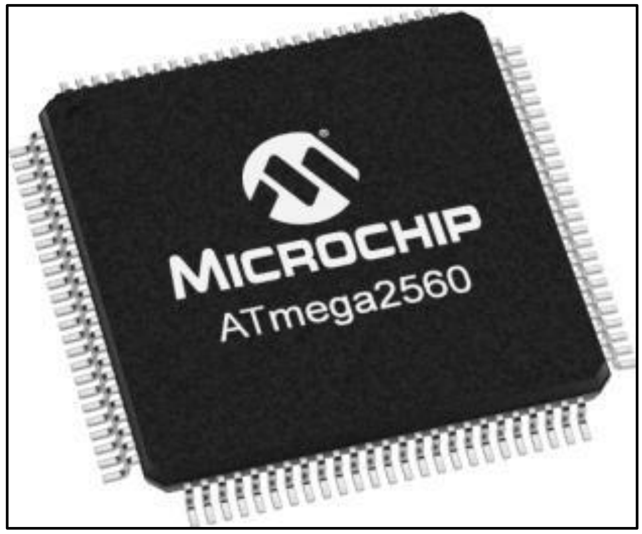

Fig. 4. Atmel ATmega2560 microcontroller

The microcontroller that we chose to control the many parts of the laser harp was the Atmel ATmega2560. In our early tests we had used an ATmega328, and in the following table we show the differences between the two microcontrollers. It can also be shown that the difference between the two is very significant due to the ATmega2560 being a lot larger. While the ATmega328 is fully capable of performing all of the processing duties of the laser harp, it does not have sufficient input/output pins to facilitate the combination of photodetectors and infrared sensors necessary for the laser harp. Because there are 15 infrared sensors (one per string), the microcontroller we chose needed to have at least 15 channels of analog-to-digital conversion, while the ATmega328 only has 6 analog channels. The ATmega2560 is a larger microcontroller that is also programmable via the Arduino IDE, but it comes in a 100-pin format, allowing for 16 channels of analog-to-digital conversion and 86 general purpose I/O lines for digital input/output. The ATmega2560 is also powered by a 5V supply voltage, just like at ATmega328, which means we did not need a step-down/step-up voltage conversion to properly power it.

Microcontroller	ATmega328	ATmega2560
Operating Voltage	5V	1.8 to 5.5V
Flash Memory	32 KB, 2KB for bootloader	256 KB
SRAM	2KB	8192 bytes
Clock Speed	16 MHz	16 MIPS/DMIPS
EEPROM	1KB	4096 bytes
Digital I/O Pins	22, 6 are PWM	100
PWM Output	6	16 PWM

Fig. 5. ATmega328 (Arduino Nano) vs ATmega 2560

VII. Serial-to-USB Conversion

In our design plan, there will be two ways to connect the laser harp to external devices. One of these is the 5-pin DIN connector, which has a simple UART line connecting the laser harp to an external synthesizer or sampler. The other is USB, which is slightly more complicated in terms of physical connections. Whereas UART can be transmitted using a single line of data, USB uses two data lines, labeled as Data+ and Data-. As well, USB connectors require a 5 V power supply and a ground connection.

Since MIDI is a UART communication protocol, we will need to transmit UART through USB, which requires an extra step of serial-to-USB conversion. As well, we will need to send and receive data via this USB connection, so a full-duplex converter will be ideal. This part will not need to be very expensive, as it will only be converting one UART Rx and one UART Tx line to USB, and because of the MIDI standard the serial rate only needs to be 32.5 kbps, which is well within the range that most serial-to-USB converters are designed to operate at. With these considerations in mind, we compared a few serial-to-USB converter chips that might suit our needs, and the comparison between them.

Based on these considerations, we chose to use the CH340E, primarily due to the lower per-unit cost. The CH340E is a very common USB-to-Serial Converter chip and is used in many Atmel-based development boards and the like to allow for USB connectivity. The low per-unit cost also allows us to have backup chips in case there are problems during testing. The CH340E will give us a simple method to implement our USB connection that will expand the functionality and compatibility of our laser harp.

IX. Lithium-ion battery

We decided to go with a lithium-ion battery that was a rechargeable battery so that we can make it a more convenient product. Something that needs a charging cable, and it will be a type of USB that you are likely to find, if it should ever go missing. The reason why we chose a lithium-ion battery is because it has a high energy density and low self-discharge. The specific battery we chose was sold by TalentCell, and has 12V output and 6000 mAh capacity, which means plenty of battery life for our laser harp, which has relatively low power consumption. This battery also uses a DC5521 connector to recharge and supply power, so we can connect it to the same external power input that we connect a standard AC-DC adapter to.

Fig. 6. TalentCell Rechargeable Lithium-Ion Battery

X. Printed Circuit Board (PCB)

In the final design of this project, we decided to use KiCad to handle and design our PCB. The reason why we went with KiCad was because it was already accessible for us and free to use. We designed two PCBs, one was designed to house the light-dependent resistors for laser detection, and the other was our main board which would be populated with the various chips and ICs discussed earlier, as well as taking connections from the LDR boards and IR sensors. The layouts of the two PCBs can be seen in the following figures.

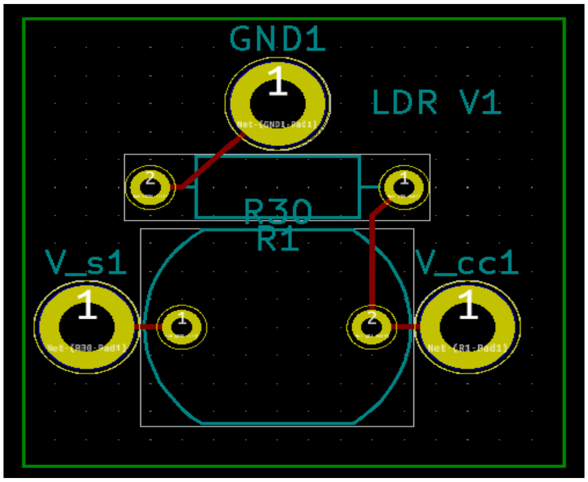

Fig. 7. PCB view of LDR sensor

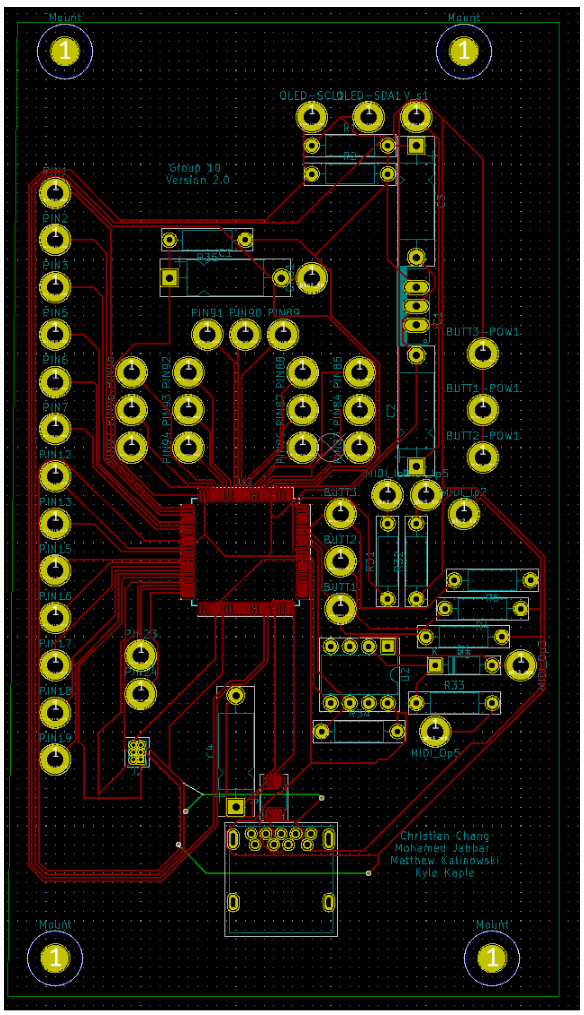

Fig. 8. PCB view of the main board

Once the schematics of the PCBs were done, we would need to carry on to the next phase which is to assemble the PCB in KiCad, Figure X and Figure X. In this view the program would show all the components not connected. We would now need to connect all the components in a way so that the wires do not intersect each other, while also making sure all components are connected carefully according to the schematics.

Finally, when we check that all the components are connected, we need to make sure that the 3D model of the board is what you want the PCB to look like ideally. From here we would need to search for a manufacturer in which we chose JLCPCB as mentioned previously and send them the created Gerber and drl files so they will be able to print out our PCB to be exactly what was created in the PCB view. Schematics for the LDR PCB and the main PCB can be seen in the following figures.

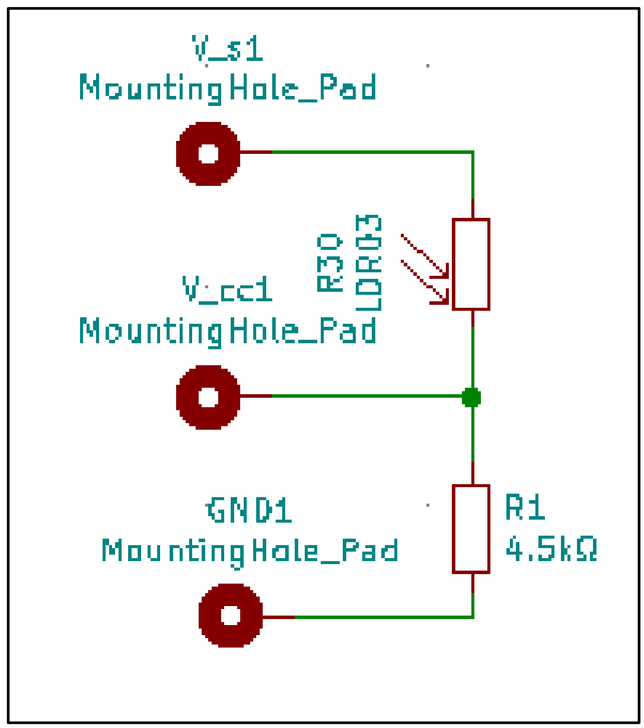

Fig. 9. Schematic view of LDR sensor

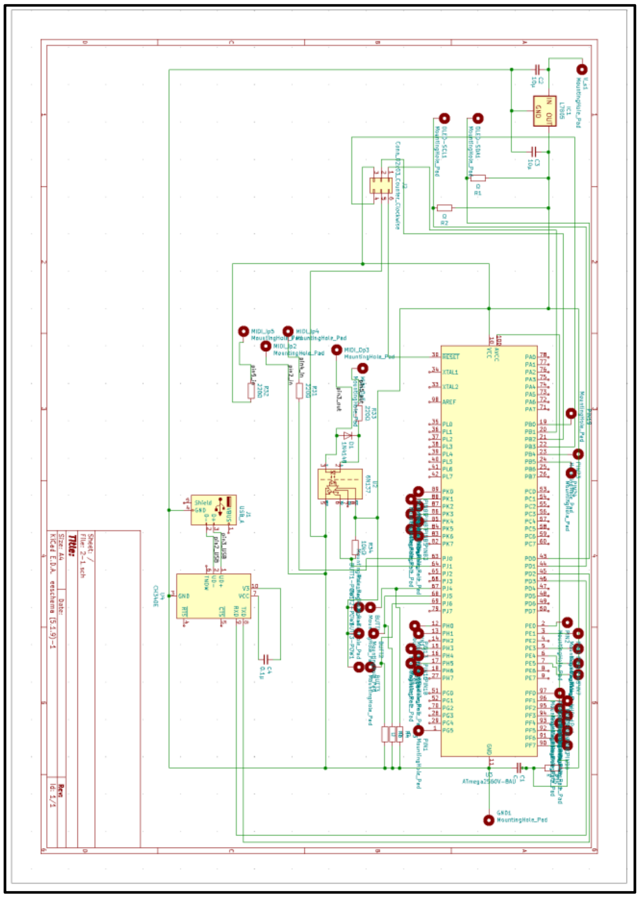

Fig. 10. Schematic view of the main board

XI. Frame Design and Mounting

Regular harps are shaped in a way that is ergonomic for the harpist. This might seem like an ideal choice for our design, however, the muscle memory of a trained harpist will not translate to a laser harp, which has no physical or tactile feedback for the player. Because the user will not have physical feedback from the harp itself, the standard playing position for a harpist would not be beneficial in the case of a laser harp. Instead, the case needed to be designed such that the user can see the laser beams so that they can choose which laser to block by sight, rather than touch. Acoustic harps also tend to be very large and are not as suitable for a smaller home studio or tabletop use. As such, the traditional shape of an acoustic harp will serve little purpose to the benefit of the user. Instead, we chose to take inspiration for our harp frame design after classic synthesizers, like the ARP 2600.

Fig. 11. ARP 2600 Synthesizer

The ARP 2600 is a classic synthesizer with a unique, tall-standing shape. Rather than lying flat across a table or stand, the ARP 2600 stands on a tabletop, with controls clearly visible from the front. This type of layout, also common in many modular synthesizer systems, allows the user to have a full view of the parameters they are controlling. This sort of layout is much preferable for a laser harp, because the strings of the laser harp need to be seen easily. As such, it makes much more sense to have the strings laid out horizontally in front of the user, so they can easily see which note they are playing. This type of framed design would also be beneficial from a safety standpoint, as it prevents the user from pointing a laser directly at their eye, protecting them from accidental eye damage.

Inside of the top of the frame, the laser diodes are mounted in a horizontal line with 2 inches between their centers, pointing vertically downward. The infrared sensors are aligned such that the infrared detector is in front of the laser diode. This alignment allows the user to easily control the velocity of the note played while blocking the laser beam, without having to locate the infrared sensor. In order to aid in alignment of the laser diodes, we designed 3D-printed plastic mounts, which attach to the inside top of the frame, and allow for a snug fit for the laser diodes to be placed into, with holes premade to fasten the infrared sensors in place. Their design can be seen in the following figures.

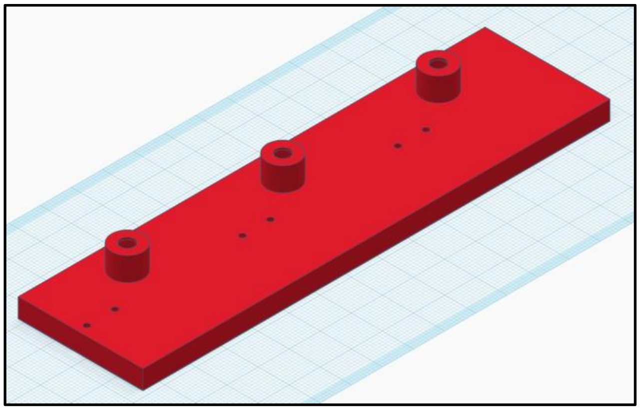

Fig. 12. 3D-Printed Laser Mount (3/4 view)

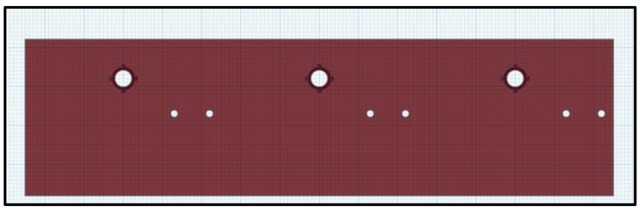

Fig. 13. 3D-Printed Laser Mounts (Top view)

At the bottom of the frame, directly opposite the lasers and infrared emitters are our laser detection PCBs, and these detect when lasers are blocked. Because the laser diodes are not perfectly straight (due to manufacturing inconsistencies and tolerances of the 3D printer), they are mounted individually using 3D printed mounts with notches near the top to fit the PCBs into. These allow space for the wires underneath the laser detection PCBS, as well as allow us to adjust for any individual alignment issues with the laser diodes. A photo example can be found in the following figure.

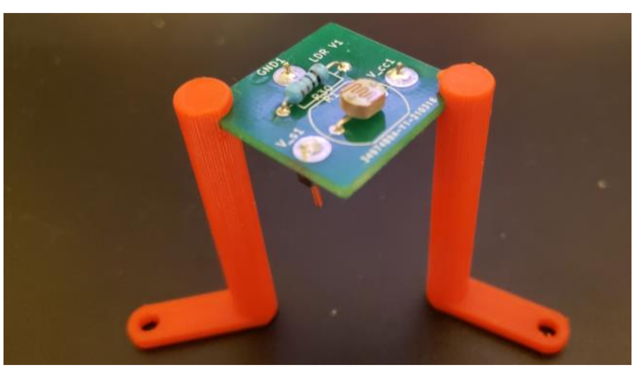

Fig. 14. 3D-Printed Laser Mount (3/4 view)

XII. Conclusion

To conclude, we have designed and constructed a framed laser harp using laser diodes, photoresistors, and infrared distance sensors as the main optical components. It has 15 laser “strings” with the same number of infrared sensors and photoresistors to detect when lasers are blocked and at what distance they are blocked. This information is used by the ATmega2560 microcontroller to send MIDI messages to external devices to play notes corresponding to each string. It has scale-mode selection, semitone transposition, and octave transposition for more sonic flexibility and ease-of-use. It is powered by a lithium-ion battery or an AC-to-DC power adapter and can send MIDI by either a standard 5-pin DIN MIDI cable or USB.

XIII. Biographical Sketches

Fig. 15. Christian Chang

Christian Chang was born and raised in West Palm Beach, Florida. He went to King’s Academy for High School followed by Palm Beach State College. After a few years after he received his General AA, he then went to attend University of Central Florida in pursuit of his bachelor’s in computer engineering. My hobbies include working out, assembling various model kits, reading comics, and playing video games.

Fig. 16. Matthew Kalinowski

Matthew Kalinowski was born and raised in Saint Petersburg, Florida. He attended a STEM oriented high school there where he learned coding, physics, robotics, and basic research skills. He has worked as a laser engineering intern at LaserStar Technologies Corporation, where he characterized lasers and materials for laser processing. He has also worked as an undergraduate research assistant in CREOL, the College of Optics and Photonics, and was co-author of an article featured in Optical Materials Express (OME). His hobbies include working in an optics lab, as well as gaming on his custom built, liquid-cooled workstation.

Fig. 17. Kyle Kaple

Kyle Kaple was born and raised in Destin, Florida. He attended Fort Walton Beach High School and elected to attend the University of Central Florida to pursue a bachelor's degree Electrical Engineering. In his time at UCF he has taken an interest in working with vintage electronic instruments and MIDI, both as a pursuit of passion and scientific curiosity. His hobbies include writing and recording music, videography, and gaming.

Fig. 18. Mohamed Jabbar

Born in Ocala, Florida attended Forest High school introduced to engineering through the EMIT program. While pursuing a degree in photonics and Optical engineering at UCF's CREOL, landed a full-time job as a service technician for high vacuum chambers for thin film optics. The last three years have allowed him to travel internationally while pursuing his degree, gaining valuable technical skills used to create the expressive laser harp. Hobbies include traveling, woodworking, and piloting drones.