Design Paper 120 Pages:
Optical Harp

Group 10

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1.0 Executive Summary

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. A diagram of a traditional acoustic harp can be seen in Figure 1.

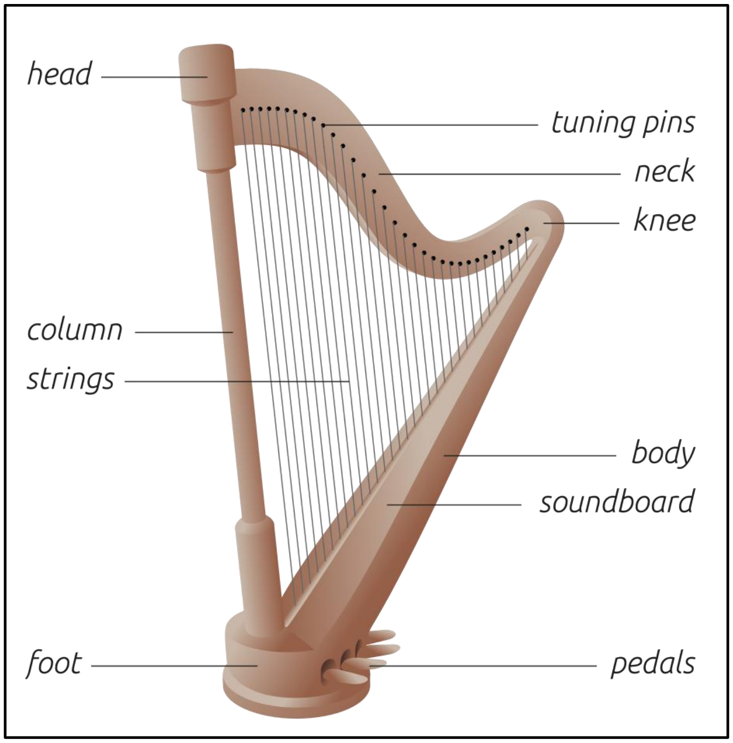


Figure 1 - Acoustic Harp

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. One such performer was Jean-Michel Jarre, who still incorporates the laser harp in his live performances to this day.

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 that can sit on a desk or tabletop. As the world of live music is constantly evolving, more and more artists are beginning to bring their live performances to online streaming platforms, to supplement in-person live shows. A compact laser harp that fits in these artists' home studios or streaming setups could appeal to a wide range of electronic musicians that are looking to introduce new ways of performing and creating music.

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

2.0 Project Description

Our goal is to create a harp that uses light as strings with distance detectors to create more musical depth. The harp will be small enough to move around easily yet large enough to place down and perform. It will use lasers as the strings of light, detection of interference will cause musical notes to play and the depth of interference will change the pitch. Our reasoning for choosing and developing the laser harp, aside from us just wanting to do it just for fun, is because of what it can teach us and what applications we can use as engineers. Throughout most of our major degrees as engineers we practice the theory and physics behind what we are doing, but with this project we can actually learn and fail when creating this harp. Since we are a group composed of two photonics, one electrical, and one computer engineer we are at least proficient in starting and finishing this project. We will then go over the laser harp in as much detail as we can provide in the following sections.

2.1 Project Background

Since the popularization of laser light shows and the invention of the laser harp, lasers have been a vital part of many musicians' live performances. They create a grand display and can allow performers to interact with every aspect of their show, even the visual aspect. However, the rapid growth of live-streaming as a means to communicate with a wider audience has led many artists to opt to perform from the comfort of their own homes, directly to the homes of their fans. Now that these artists are performing in more compact surroundings, often a home studio, many are likely looking for new ways to increase the production value of their performances. This is a great opportunity for a new generation of artists to incorporate the laser harp into their new style of live performance.

While the laser harp is not a new device, it is one that has kept its awe-inspiring nature. However, there has been very little innovation of the instrument in the nearly 50 years since its invention. Generally, the laser harp has been seen as a black box that emits lasers upwards and outwards, creating a grand display. This doesn't fit easily into a home studio, however, and is not appealing to musicians who do most of their work in their home or a studio.

We intend to create a laser harp that carries some of the same visual appeal of its predecessors, but also can fit seamlessly into a home studio. Our laser harp will be more compact than other framed laser harps, and will be designed to be played in the same orientation as the classic frameless style of the 1970s.

Our laser harp will be capable of transposing by semitone or octave, and will have the ability to control parameters like timbre or volume by changing the distance at which the lasers are blocked.

To add another benefit to home performance, the laser harp will be able to be controlled by MIDI. When MIDI notes are sent to the harp, it will turn lasers on and off according to the incoming MIDI note information.

As a part of the early stages of this course, we were tasked with composing a diagram that shows how the various parts of our design interact with each other, as well as how power is supplied to them. These diagrams serve primarily as a guideline for the project as it moves forward throughout the design process, and may not perfectly match the final architecture of the laser harp. These initial design diagrams were created with minimal research as part of the "Divide & Conquer" assignment, and can be seen in figure 2 and 3.

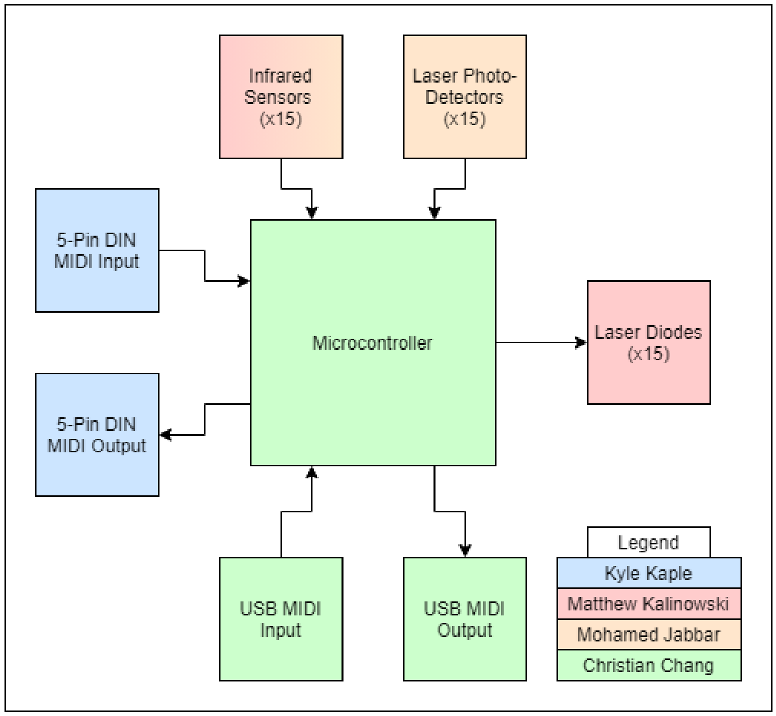


Figure 2 - Electronics Block Diagram

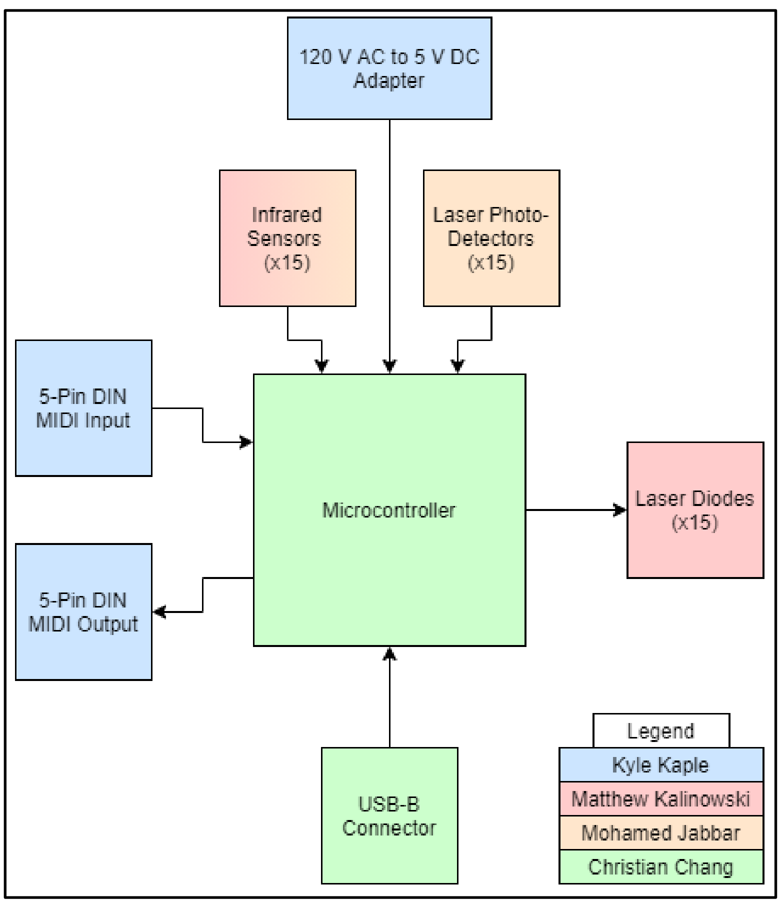


Figure 3 - Power Block Diagram

As stated, these designs were created early in the process, and were done with minimal research, and as such may not reflect the final design. However, they are still arguably one of the most important parts of our design process, as without the rough outline and idea, reaching a final design would be much more difficult. After conducting more in-depth research into relevant technologies and components, we will develop a design schematic for the laser harp.

2.2 Objectives

Our objective for our prototype is to showcase a product that is somewhat functional similar to what we describe in our executive summary. The prototype will exhibit a few lasers that will make contact with a sensor, and when this sensor is blocked or obstructed at a distance it will create an audible beep or musical note. The harp will be small enough to be considered portable yet large enough to be set on a table without support. We plan to make this as cost effective as possible, as it is a college project and everyone has a limited budget. We want the laser harp to be able to create individual notes for each string when the beam path is blocked. When the beam path is blocked for a note the distance of the interception must be determined before a note is relayed. This requires the signal input and the sensor to relay and output with minimal delay so that the harp sounds more natural. The notes will be able to overlap one another just as a regular stringed instrument does. The harp will be able to change a notes tone depending on the distance of interference. A single string will have one note, but because we add distance detection we can determine exactly where the hand intercepts the beam. The height difference between the laser diodes and the LDRs are known and constant and the distance detectors will be placed on the same location as the laser diodes. Since the distance is fixed, all we need to do is create a scale for a note and change the pitch with distance. The basic note will be centered and by moving up and down on that string you can change the pitch to be higher or deeper sounding.

2.3 Motivation

The motivation for this project is to utilize all that we have learned in our time at the University of Central Florida as engineering students. This is one of the few chances we have in our degree programs to work with others on a large-scale group project, and we get to combine the things we have learned from all our various engineering disciplines into one project. The initial motivation came from one of the photonics students, and became accompanied by another phonics student also interested in creating a laser instrument. Being an optics major at CREOL we are familiar with basic laser systems, however they have always been used in a scientific setting. Engineering at school is more research and gaining insight into its theory. For senior design we get to use that theory-based knowledge and use our creativity to combine music and science to create an interactive piece of art.

2.4 Requirements/Specifications

As this design is for an optical harp, there are some requirements to the initial design. Firstly, it should play a note when something blocks the beam. It should do this for at least one octave, which consists of eight notes. The design should detect the distance that the strings are blocked. The design should also have Musical Instrument Digital Interface (MIDI) connectivity. Finally, the design should not cost over $500. Simply blocking the beam to create a note is too simple, we wanted to create an instrument that not only holds an octave but can change the pitch of the note with a slight adjustment in the hand. By allowing the harp to read not only interference but consider depth do we create a more interesting piece of technology. We will build a base that surrounds laser diodes and detectors and encase the depth sensors in the same platform as the laser diodes. Information from the detectors will be sent out to a microcontroller who will allow the electronic signs and measurement data to create a musical note. MIDI is the interface that will change the electronic signal to a musical note, which can be configurable making different scales optional.

The list below summarizes these requirements:

- The harp shall be no greater than 2.5 ft. in width.
- The harp shall be no greater than 1.5 ft. in height.
- The harp shall be no greater than 1 ft. in depth.
- The harp shall have at least 7 laser “strings” that each send a different MIDI note when the beams are blocked.
- The lasers shall have a separation of no less than 1 inches.
- The harp shall be able to send notes within the range from A0 to C8.
- The harp shall detect the distance at which the laser “strings” are blocked and send this information in the form of Control Change (CC) messages.
- The harp shall not cost more than $500 to manufacture.
- The harp shall be able to send and receive MIDI notes and CC messages via a standard 5-pin DIN connector and USB.
- The harp shall be capable of operating on battery power for at least 2 hours when not connected to wall power.

2.5 House of Quality

The following figure contains our house of quality in which we compare the laser harps engineering versus marketing. Each engineering component is compared to multiple marketing components and is marked by its priority and then given an association.

		Quality	Energy Cost	Performance	Ease of Use	Target
		+	-	+	+	
Efficiency	+	⥣	⥥	↑	⥣	>50%
Functionality	+	↑	↑	⥣	⥣	>50%
Weight	-	↑	⥣	↑	↓	<10lbs
Detection	+	⥣	↑	⥣	⥣	<1sec Delay
Polyphony	+	⥣	⥣	⥣	↓	<1sec Delay
Laser Intensity	+	⥣	⥣	↑	⥣	Enough for user to see in a well lit area
Distance Detection	+	⥣	↑	⥣	⥥	>2 Notes per String
Cost	-	↑	↑	↑	⥣	<$100
Engineering (blue) Marketing (green)						

Table 1 - House of Quality

+ : Higher priority
- : Lower priority
↑ : Good association
↓ : Bad association
⥣ : Strong positive association
⥥ : Strong negative association

3.0 Research

In this section we will provide the necessary research that goes into creating the laser harp. The topics covered in this section will include aspects from creating the prototype and where we started to what the full product would look like. In our prototype we started off with playing with components and seeing what worked and what didn't on the bread board, to having our breadboard make a sound, and then linking the beeping sound to MIDI.

3.1 Existing Products and Projects

The laser harp is not a new invention, and has been used for decades in live music to control laser shows and create interactive projections. Many laser harps currently on the market are of the "frameless" variety, which is designed for a stage show where the lasers extend from the ground into the sky.

Figure 4 - Prolight LH1 MK2 frameless laser harp

Figure 4 shows an example of an existing laser harp controller that is currently on the market, and is focused primarily on controlling large stage lasers and lights, but is capable of using MIDI as well to control synthesizers and external instruments. It uses a sensor at the base of the controller to detect when laser beams are blocked by reflection, and sends this information via MIDI or ILDA. This is a commonly used method for commercially available laser harps, as it keeps them compact and portable for live performance, and cuts down on manufacturing and shipping costs. These kinds of laser harps require extra steps of precaution to be taken by the user, as it is possible to accidentally look directly into a laser beam, which can cause temporary or permanent eye damage and vision loss. We are purchasing lower powered red dot laser diodes that are considered to be eye safe. That being said, lasers are still dangerous and nothing should be pointed directly in one's eye path.

Figure 5 - Framed Laser Harp

Figure 5 shows an example of a framed laser harp, which is another option for laser harp design. This design allows for more interesting visual design for the harp, but is often much larger. These kinds of harps generally use photoresistors on the opposite side of the harp from the laser diodes, and these detect when a laser beam is blocked. Framed laser harps also are safer in terms of eye protection, as direct eye exposure to the laser beam is much more difficult. As our laser harp is intended to be used in the home, it is important that we take these safety issues into account when designing the frame.

3.2 Musical Instrument Digital Interface (MIDI)

In order to develop a product that can be used in conjunction with existing electronic music hardware, a key element we need 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 is 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 should be 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 will then have a MIDI input, MIDI output, and a USB connection that can send and receive MIDI data.

MIDI can be sent from one device to multiple devices by connecting each device's MIDI Outputs and Inputs in a daisy-chain organization. To control each device individually, MIDI messages are split into 16 "channels" that can be selected on each device. This allows any combination of up to 16 different MIDI sequences to be sent to any number of synthesizers and samplers.

MIDI messages are made of 8-bit words (bytes) transmitted by serial communication at a rate of 31.25 kbit/s. 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. A condensed list of relevant MIDI messages can be found in Table 2.

Status Byte [nnnn = 0-15 (Channel 1-16)]	**Data Byte(s)**	**Description**
1000nnnn	0kkkkkkk 0vvvvvvv	Note Off event. This message is sent when a note is released (ended). (kkkkkkk) is the key (note) number. (vvvvvvv) is the velocity.
1001nnnn	0kkkkkkk 0vvvvvvv	Note On event. This message is sent when a note is depressed (start). (kkkkkkk) is the key (note) number. (vvvvvvv) is the velocity.
1010nnnn	0kkkkkkk 0vvvvvvv	Polyphonic Key Pressure (Aftertouch). This message is most often sent by pressing down on the key after it "bottoms out". (kkkkkkk) is the key (note) number. (vvvvvvv) is the pressure value.
1011nnnn	0ccccccc 0vvvvvvv	Control Change. This message is sent when a controller value changes. Controllers include devices such as pedals and levers. Controller numbers 120-127 are reserved as "Channel Mode Messages" (below). (ccccccc) is the controller number (0-119). (vvvvvvv) is the controller value (0-127).

Table 2 - MIDI Message Summary

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. The MIDI note values in decimal format and their corresponding musical notes and octaves can be found in Table 3.

		Octave										
		-1	***0***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Note	***C***	0	12	24	36	48	60	72	84	96	108	120
	C#	1	13	25	37	49	61	73	85	97	109	121
	D	2	14	26	38	50	62	74	86	98	110	122
	D#	3	15	27	39	51	63	75	87	99	111	123
	E	4	16	28	40	52	64	76	88	100	112	124
	F	5	17	29	41	53	65	77	89	101	113	125
	F#	6	18	30	42	54	66	78	90	102	114	126
	G	7	19	31	43	55	67	79	91	103	115	127
	G#	8	20	32	44	56	68	80	92	104	116	
	A	9	21	33	45	57	69	81	93	105	117	
	A#	10	22	34	46	58	70	82	94	106	118	
	B	11	23	35	47	59	71	83	95	107	119	

Table 3 - MIDI Note Values

Along with note values, MIDI can be used to send a plethora of other control information to synthesizers and samplers by way of Control Change messages, which follow a similar 10-bit format to the Note On/Off events. In our case, the Control Change messages will be used to send the distance at which the laser beam is blocked to control various parameters via MIDI mapping. A simplified table with relevant MIDI messages, their format, and description can be seen in Table 2.

Ideally, the MIDI OUT connection sources a 5 V source, uses two 220-ohm resistor, and connects a ground wire according to the schematic in Figure 6. The MIDI IN connection will use a 5V source, standard PN-junction diode, two resistors (220-ohm and 280-ohm), a ground wire and an optocoupler. The optocoupler is necessary to prevent an audible ground-loop hum due to the common ground that would otherwise be needed to complete the serial communication.

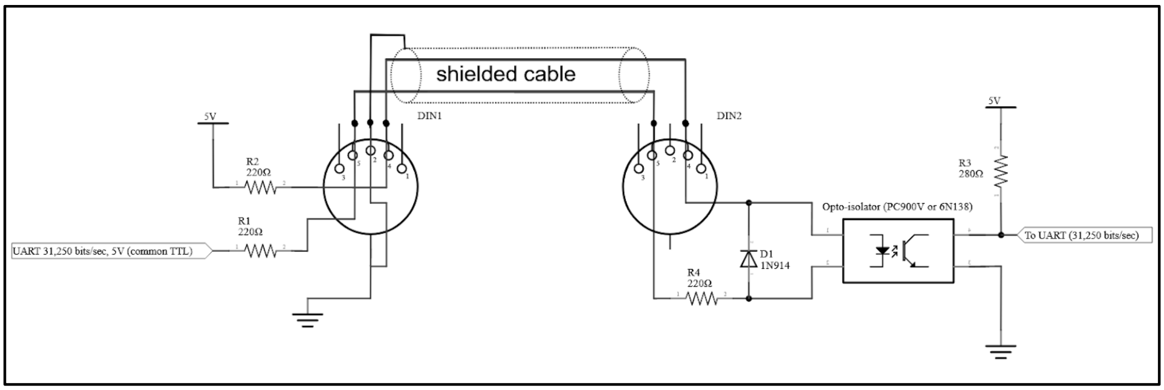


Figure 6 - MIDI Communication Diagram

3.3 Optocoupler

An essential part of the standard MIDI connection for our laser harp is the optocoupler, or optoisolator. The optocoupler is an optical device that uses light to transfer an electrical signal between two isolated circuits, similar to a transformer, but does so on a smaller scale without the use of magnetic fields. This is especially important in audio circuits, where a common ground can cause an audible ground loop hum, which is difficult to remove without purchasing expensive external devices to isolate the devices that are already in use. In the case of our device, the optocoupler serves the purpose of preventing this audible ground loop feedback hum that can come from the MIDI Input, due to what would otherwise be a common ground in the MIDI input. The optocoupler consists of an emitter of light in one circuit, a closed optical channel, and a photosensor of some kind (photoresistor, photodiode, phototransistor) to convert the light into electrical energy on the other end of the channel, without the need for a common ground between the two circuits. An example of a simple DC optocoupler-based circuit can be seen in Figure 7.

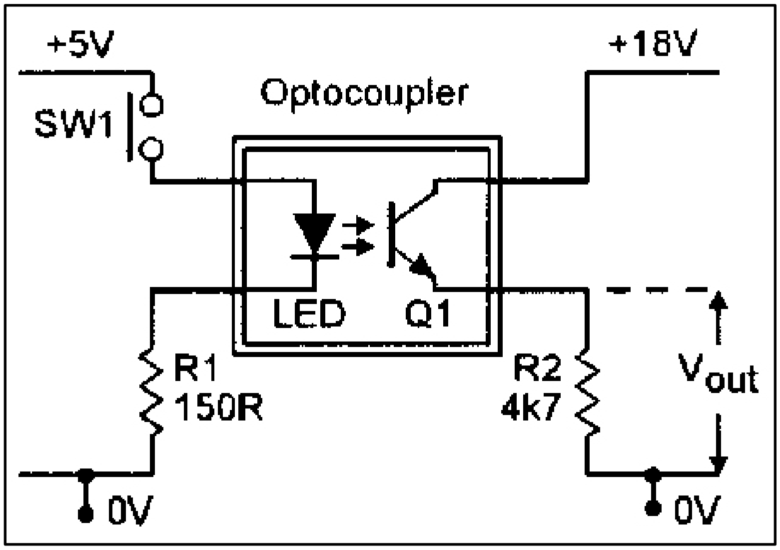


Figure 7 - Basic Optocoupler Circuit

As MIDI is a digital communication protocol with a focus on accurate timing, it is important to select an optocoupler that is capable of fast switching. At the standard baud rate of 31250 bits/s, there is a period of 32 μs of time between individual bit communication, so the optocoupler must be capable of switching between values in significantly less time.

There are a wide variety of optocouplers available for purchase, and it is important for us to select one that can achieve sharp “edges” with a high slew rate. The original MIDI 1.0 specification from the MIDI association specifies a 6N138 optocoupler, and that has been used in MIDI circuits for decades. Another option is the 6N137, which has a CMOS level output, rather than the 5V BJT output of the 6N138. These devices are compared in the following Table 4.

	6N138	**6N137**
Maximum baud rate	100 kBaud/s	10 MBaud/s
Output-type	Darlington BJT	Logic Gate
Pull-up resistor	220 Ω	10 kΩ
Price	$1.86	$1.76

Table 4 - Optocoupler Comparison

Both of these optocoupler options, as well as many other optocouplers on the market, come standard in an 8-pin DIP format, and are very inexpensive, as most manufacturers sell them individually for only a few dollars. As we only need one optocoupler in our device, and they only require a few resistors and a standard 1N4148 diode to operate, the 6N137 should be selected, due to it having a much higher switching speed and Baud Rate, as the price difference is negligible in terms of the entire project cost.

3.4 Musical Scales and Modes

To improve ease-of-use, our laser harp will have a number of preset musical scales that will be automatically assigned to the strings. A musical scale is a set of musical notes ordered by pitch. These scales are used by musicians to write their music in a way that is pleasing to the ear, by choosing notes within a given scale. Many non-keyboard based MIDI-controllers have a “scale mode” that allows the user to only play notes in a chosen scale, essentially ensuring they don’t play a “sour note” that sounds out of place with the rest of the band. There are a near infinite number of possible scales in music, but our laser harp will be focused primarily on the most popular scales used in western music, according to the twelve-tone equal temperament system. Most standard western scales consist of 7 notes per octave, and this is why we chose to include 15 individual notes, allowing the laser harp to play at least two full octaves of most standard scales. Scales generally consist of a set “step order” of intervals between notes, and these can be transposed to different root notes.

Along with the standard scales usually found in western music, there are also different “modes” of these scales, which operate similarly to scales. Modes in western music consist of the same notes as their familiar major or minor scales, but shift the step order to achieve a different tonal character. We will also include these modes in the list of predefined scales, specifically to increase the playability of the laser harp and allow more flexibility for the limited number of strings. A list of these scales and modes with their note intervals can be seen in Table 5, with the step order being indicated by their intervals relative to the major scale, which is ordered as W-W-H-W-W-W-H, where “W” represents a whole step, or two semitones, and “H” represents a half step, or one semitone. The “♭” and “#” indicate flat and sharp notes (accidentals), respectively, based on the major scale.

Scale/Mode	Note Order											
Major (Ionian)	1	2	3	4	5	6	7					
Minor (Aeolian)	1	2	♭3	4	5	♭6	♭7					
Harmonic Minor	1	2	♭3	4	5	♭6	7					
Melodic Minor	1	2	♭3	4	5	6	7					
Major Blues	1	3	4	♭5	5	♭7						
Minor Blues	1	♭3	4	♭5	5	♭7						
Major Pentatonic	1	2	3	5	6							
Minor Pentatonic	1	♭3	4	5	♭7							
Dorian	1	2	♭3	4	5	6	♭7					
Phrygian	1	♭2	♭3	4	5	♭6	♭7					
Lydian	1	2	3	#4	5	6	7					
Mixolydian	1	2	3	4	5	6	♭7					
Locrian	1	♭2	♭3	4	♭5	♭6	♭7					
Chromatic	1	♭2	2	♭3	3	4	♭5	5	♭6	6	♭7	7

Table 5 - Common Western Scales

3.5 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 would have to consider our budgetary restraints when choosing different colored laser diodes because they do become costly. We also have to consider the amount of power that they require, for now we are using low power with current 5mA laser diodes.

3.6 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. After searching through various options, we narrowed down our options to a few infrared sensors, all manufactured by Sharp: The GP2Y0A41SK0F, GP2Y0A51SK0F, and GP2Y0A21YK0F. A comparison of these sensors can be found in table 6.

To communicate information to the controller there needs to be an interface that detects when the laser light is interfered. A photoelectric sensor is a piece of hardware that is used to calculate and determine the distance, absence, or the presence of an object by using a transmitter and receiver. There are several types of photoelectric sensors that we will discuss further to determine which type is best suitable for the project. To have a better idea of what to look for in a detector system we need to have conditions that are met so that we have the best solution for our project.

Minimum conditions required:

- Needs to be easy to adjust and align when necessary.
- The detector needs to be accurate.
- Needs to be able to work with fog and smoke effects.
- The detector must be able to work in all light conditions.
- The detector must be able to work with large distances.
- Must be able to distinguish noise from actual signals.
- There needs to be a fast response time.

	GP2Y0A41SK0F	GP2Y0A51SK0F	GP2Y0A21YK0F
Manufacturer	Sharp	Sharp	Sharp
Sensing Range	1.57” - 11.81”	0.79” - 5.9”	3.93” - 31.49”
Output Type	Analog	Analog	Analog
Supply Voltage	4.5 V - 5.5 V	4.5 V - 5.5 V	4.5 V - 5.5 V
Price per unit	$8.74	$7.53	$10.22
Total Cost (15 sensors)	$131.10	$112.95	$153.30

Table 6 - Infrared Sensor Comparison

From table 6, we can see that the three sensors to be considered are very similar, and so the primary deciding factor in our decision is primarily the sensing range. The GP2Y0A41SK0F is the best of the three infrared sensor options for use in the laser harp. The sensing distance is long enough to give the user accurate control over the distance control, but also not so long that the harp frame would exceed our initial size specifications. The GP2Y0A41SK0F can be seen in figure 8.

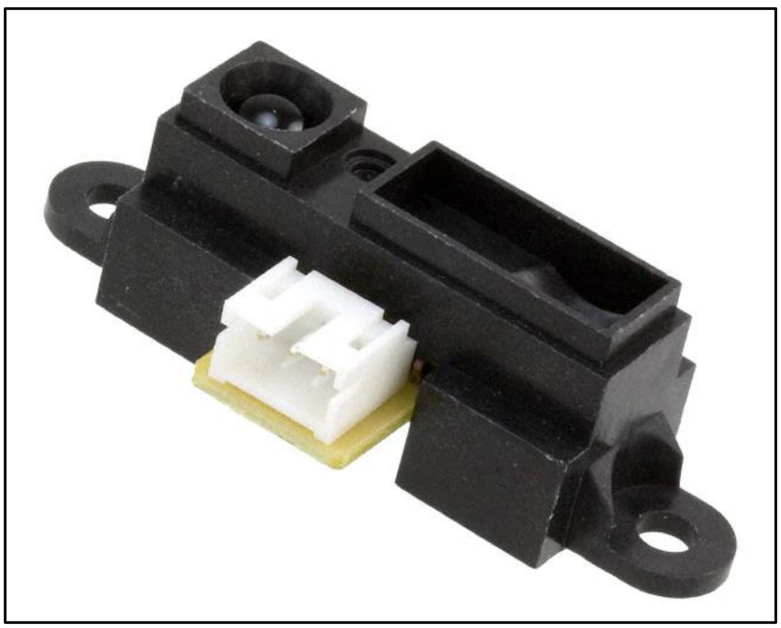


Figure 8 - GP2Y0A41SK0F Infrared Sensor

into the laser harp will be as simple as supplying the sensors with voltage, The GP2Y0A41SK0F has a 3-pin connector attached to the board from the manufacturer, but to save space between the parallel infrared sensors, we will instead connect 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 doesn't 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 will be a continuous, analog output we also will need to ensure that we have a sufficient number of channels in the analog-to-digital converter (ADC). As we intend to have distance sensing implemented for each individual beam, we will need 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 will either need to find an affordable microcontroller with sufficient analog inputs, or we we will need 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.

3.7 Universal Asynchronous Receiver/Transmitter (UART)

According to the MIDI 1.0 Specification, MIDI information is sent via a serial communication protocol known as Universal Asynchronous Receiver/Transmitter (UART). This communication protocol sends information in a sequential fashion, starting with a stop bit, followed by bits of data, and then followed by a stop bit. This communication protocol using one wire is less costly than using multiple wires. The baud rate we will use is defined by the MIDI Standard, and is 32.5 kBaud/s. This is the standard baud rate used by all MIDI devices, so it is essential that we stick to this Baud Rate for both receiving and transmitting MIDI via UART.

We are mainly going to be using UART when we link Arduino to MIDI. As we link the libraries from Arduino Software to the MIDI library, we would have to create a physical link to the hardware to actually produce a musical note. We do this by going into the UART and linking the bits required in the Arduino Software.

3.8 Programing

Depending on what microcontroller we use, the language we will be using will be either ARM, C/C++, or assembly language. When all the components are mounted to the board, we will then communicate with the board via the selected programming language. Since we will be using two octaves, we will have fourteen to fifteen laser strings and each string will have their own respective notes which will be stored by hexadecimal. Depending on how long the user will block the laser will provide a value in which it will track to get a note of a different pitch or velocity. Once the user unblocks the laser the note will resume its off position.

3.8.1 Arduino

For programming the microcontroller we will use the Arduino Software that is compatible with the Arduino Nano or ATmega328P. Also, the Arduino Software is similar to the C language when it comes to getting familiar with it. The Arduino IDE is an open-source language that lets you communicate with the microcontroller by writing code and uploading it to the board. The Arduino IDE supports Windows 7 and above, The Windows app, Linux, and Mac OS X.

For our prototype we used the Arduino Software and created five laser strings and whenever they hit an endpoint it created an audible "beep" to let us know that each string can be used. Once this has been established, we will work with MIDI to move on to the next step of creating musical notes. Since we know that each string will create a beep, we would then need to communicate to MIDI to translate that one beep into a note. Since there are five strings, we would use C, D, E, G, A. These notes will output their respective frequency/wavelength. From there we would be able to hook up a speaker to actually output each note whenever each laser is blocked with their respective note.

In our prototype code that was made in the Arduino Software we created one instance of the laser string and we would use the function analogRead() to check the status of the laser beam and see if it was being blocked or not and would take that status bit and move it along the code to create the audible beep. ldrPin is a variable that was assigned to the designated pin on the board of which the string was attached to. The entire code is on an infinite loop waiting for something to happen, and once something happened and ran through the code it would then again resume its infinite loop status.

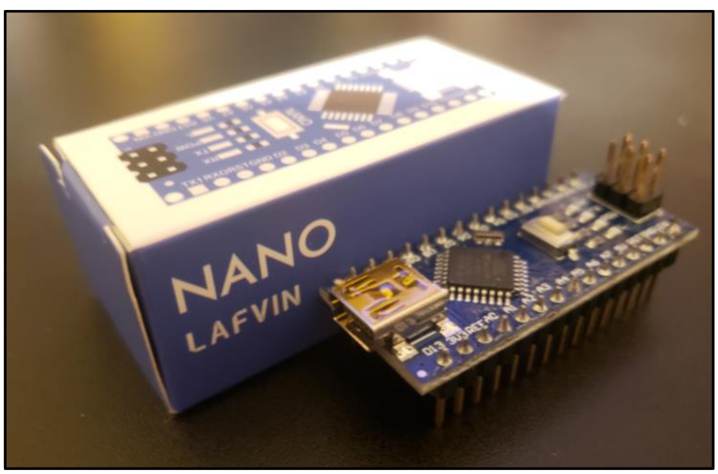


Figure 9 - Photo of Arduino Nano

3.8.2 Arduino Interacting with MIDI

Communication between the Arduino Nano and MIDI software. To run the MIDI software we would need LoopMidi which is a virtual MIDI cable and Hairless MIDI to Serial Bridge. Hairless MIDI to Serial Bridge is what is used to connect the serial devices, which in our case would be our Arduino Nano, which also uses Arduino MIDI Library. From here we can actually test to see if our wirings are correct as well because we can see the data flux exchange between our microcontroller and Hairless MIDI Serial. From here we are able to map the microcontroller to what needs to be played. We would map the five strings; C, D, E, G, and A; to their according values in a chart. By doing this we don't have to map the five strings to what we have listed but could practically change them to whatever we would like.

A function we would like to implement would be for the harp to play a preexisting song and without any user and flash the correct laser string that corresponds to the note in the song. The idea for this is we would need the harp to analyze the song using MIDI and playback the song.

3.9 Arduino Microcontroller

The microcontroller is one of the most important parts of our laser harp design, and without it the device would not be able to perform any of the actions we need it to. The microcontroller will be programmed to interpret the analog signals from the photoresistors and the infrared sensors, and is responsible for sending messages through MIDI by UART to the external device, be it a synthesizer, sampler, or computer.

3.9.1 Tech Specs

For the microcontroller we decided to use Arduino Nano in the prototype. Its tech specifications which consists of no battery and has a Mini-B USB input that can range from seven to twelve volts; It can operate at five volts with clock speeds of sixteen megahertz; Its flash memory has thirty-two kilobytes and two of those bytes are used by the bootloader; The static random-access memory has two kilo-bytes; Has eight analog IN pins; The electrically erasable programmable read-only memory (EEPROM) has one kilo-byte; DC current per I/O pins is forty milliamps for every I/O pin; Digital I/O pins are twenty two and six of them are for the PWM; The pulse-width modulation (PWM) output is six; Power Consumption nineteen milliamps; Printed Circuit Board (PCB) size is eighteen by forty-five millimeters; Weight is seven grams.

3.9.2 Power

The microcontroller is supported by a Mini-B USB with an unregulated, pin thirty, power supply or a pin twenty-seven, five volt regulated external power supply. The highest voltage source is chosen automatically. There are two pins that supply voltage to the components it is attached to. Both the 3V and 5V pin are located on the side with the analog pins.

3.9.3 Memory

The microcontroller has thirty-two kilobytes of memory. Two kilobytes are used for the bootloader. SRAM consists of two kilobytes and EEPROM is one kilobyte of memory.

3.9.4 Input and Output

The microcontroller has fourteen pins that can be used for an input or an output. Which can be accessed and operated at five volts, in code can be accessed via the functions: pinMode(), digitalWrite(), and digitalRead(). Each pin can provide or receive forty milliamps which is the maximum amount it can receive. The pins also have an internal pull-up resistor which is disconnected by default of twenty to fifty kΩ. Some pins may also have alternative functions, specified from their website, which are:

- Serial: 0 (RX) and 1 (TX) are used to receive (RX) and transmit (TX) TTL serial data. The pins are connected via pins of the FTDI USB to TTL serial chip.
- External Interrupts: 2 and 3. These pins can create an interrupt on a low value, rising or falling edge, or change in value. With more details in the attachInterrupt() function.
- PWM: 3, 5, 6, 9, 10 and 11. Has an 8-bit PWM output with the analogWrite() function.
- SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK). These pins support SPI communications which are provided by the hardware and usually aren't included in the Arduino language.
- LED: 13. The microcontroller has a built in LED that is connected to a digital at pin thirteen. When the pin is HIGH value, the LED is on and when the pin is LOW it is off.

The microcontroller has eight analog inputs each can provide ten bits of resolution (i.e. 1024 different values). At default the measurement is five volts and it is also possible to change the upper end of their range using the function analogReference(). Analog pins six and seven cannot be used as digital pins as well. These pins may also have specialized functions, specified from their website, as followed:

- 12C: A4 (SDA) and A5 (SCL). 12C (TWI) a form of support communication can be used by the wire library.

3.9.4.1 Additional Pins

- AREF. Reference voltage for the analog inputs, used with analogReference() function.
- Reset. Brings the line LOW to reset the microcontroller entirely and is used to add a reset button to protect the one on the board.

3.9.5 Communication

The microcontroller can communicate to a numerous number of other systems such as a computer, another Arduino or other microcontrollers. A way to communicate to one of these devices include UART TTL (5V) serial communication using pins 0 (RX) and 1 (TX). The FTDI FT232RL on the board channels this serial communication over USB and the FTDI drivers, which is already included within the Arduino software, provide a virtual com port to software on the computer. The Arduino software has a built-in serial monitor to allow text data to be sent and received by the microcontroller. RX and TX LEDs on the board will flash when data is being transferred via the FTDI chip and USB plugged into the computer excluding pins 0 and 1 which are used for an alternative use for communication. A SoftwareSerial library allows for serial communication on any of the microcontroller's digital pins. The microcontroller also supports I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus. To reference the SPI communication, refer to the ATmega328 datasheet.

3.9.6 Programming

The microcontroller is programmed with Arduino software, which is an open-source IDE. When it comes to programming our project, the Arduino Nano seems to be the perfect fit without going over the limitations of what type of microcontroller we can use. Since the Arduino Nano is a type of breadboard that is small and based off of the ATmega328P; The Arduino UNO is another alternative to the Arduino Nano that is also available to use.

	Nano	Uno
Microcontroller	ATmega328	ATmega328
Operating Voltage	5V	5 V
Flash Memory	32 KB, 2KB for bootloader	32 KB, 0.5 KB for bootloader
SRAM	2KB	2KB
Clock Speed	16 MHz	16 MHz
Analog IN Pins	8	6
EEPROM	1KB	1 KB
DC Current per I/O Pins	40 mA	20 mA
DC Current for 3.3V Pin	-	50 mA
Input Voltage	7-12 V	6-20 V
Digital I/O Pins	22, 6 are PWM	14, 6 for PWM
PWM Output	6	6
Power Consumption	19 mA	-
PCB Size	18x45 mm	68.6x53.4 mm
Weight	7g	25g

Table 7 - Nano vs UNO Microcontroller Comparison

3.9.7 Automatic (Software) Reset

On the microcontroller there is a physical reset button to reset the software of what is uploaded onto the microcontroller. There is an alternative way to reset the board without using this physical button. One example of how to reset the microcontroller is when it is connected to a computer and one of the hardware flow control lines (DTR) of the FT232RL is connected to the reset line via a one hundred nano-farad capacitor. When this is implemented, it will catch on the low end where the line drops and resets the microcontroller. To implement this, you would need to add this code in the Arduino software and upload this onto the microcontroller in the Arduino environment. Also, when this is implemented, the bootloader can have a shorter timeout as the DTR is being lowered and it can run in tandem with the beginning of the upload. When the microcontroller is connected to a computer whether it is Windows, Mac OS X, or Linus every time the board is connected via USB it will reset the software. When this connection to a computer happens in approximately half a second the bootloader is running on the microcontroller. Although when it was programmed, it is set to ignore anything except for the new code being uploaded and catch the first few bytes of data when the microcontroller is connected and opened. As a caution when a sketch is running on the microcontroller it will communicate that it should wait until an opening connection has been established before sending data.

3.9.8 ATmega2560 Microcontroller

This is another microcontroller that we are considering using after our prototype. 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 will be 15 infrared sensors (one per string), the microcontroller we choose will need 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 won't 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

Table 8 - ATmega328 (Arduino Nano) vs ATmega 2560

The ATmega2560 microcontroller, specified from their website, is:

- a low powered 8-bit AVR RISC-based microcontroller
- 256 KB ISP flash memory
- 8 KB SRAM
- 4KB EEPROM
- 86 general Purpose I/O lines

- 32 general purpose working registers
- 100 Pin Count
- Real time counter
- 6 flexible timer/counters with comparable modes
- 16 PWM
- 4 USARTs
- 5 SPI
- I2C
- 4 Input Captures
- 4 CCP
- Byte oriented 2-wire serial interface
- 16-channel 10-bit A/D converter
- JTAG interface for on chip debugging
- Throughput of 16 MIPS at 16 MGHz which operates at 4.5 to 5.5 V
- Timers: 2 x 8-bit and 4 x 16-bit
- Temperature Ranging from -40 to 85 C
- Operating Voltage from 1.8 to 5.5 V

3.10 Light Sources

A variety of light sources exist to be used in our project. We decided pretty early that the light sources should be a laser. This would allow for a straight-line beam for the strings of our optical harp. This section focuses on laser theory to better distinguish it from different light sources.

3.10.1 Lasers

Lasers In this project will be used for the strings to be struck. There are plenty of different types of lasers out there, and many could be suited for a role in this design. They are useful due to their ability to be directed into a small width and intensity of their beams. The fundamental characteristic of a laser is the act of stimulated emission. Stimulated emission occurs when an electron is in an upper energy state collides with a photon of incident power. The result is two photons of incident power. This makes for a coherent, directional, and high-power light source. Below is a figure explaining the action.

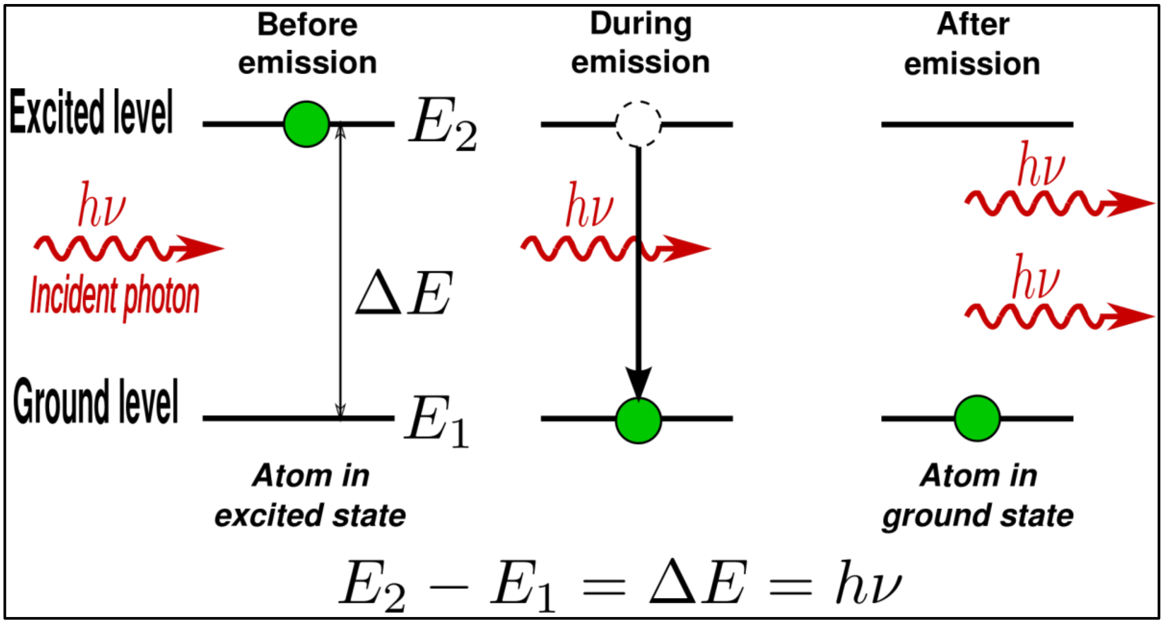


Figure 10 - Stimulated Emission

From the figure, we see that the incident power of hv is directed at an upper state electron of energy E2-E1 = ΔE = hv. This causes two photons of energy hv to be emitted.

Now that the concept of stimulated emission is explained, the concept of a population inversion can be covered. The limit of stimulated emission is by how many electrons are in an upper energy state. For there to be any electron in an upper energy state, there must be some action that brings it there. For normal operation, a material in thermal equilibrium is of a ratio between upper and lower energy levels as given by the following equation.

$$\frac{N_2}{N_1} = \exp\frac{-(E_2 - E_1)}{kT},$$

Figure 11 - Boltzmann Distribution

The distribution is a representation of electrons in an upper state by just the thermal effects in the material. Since the exponential shows that a negative is showing that means that there must be a negative temperature to have a population inversion. This is impossible to obtain in a real environment. Luckily, there are plenty of methods to achieving a population inversion via other methods.

3.10.2 Laser Pumping

The term “pumping” is used when using a laser is the ability to cause a population inversion. To pump the electrons into an upper laser state something other than thermal effects must be used. One method of pumping is via a flashlamp. Another method is via electricity. Another one is via pumping with another laser. There are plenty of other methods for pumping but will not be discussed here as they serve no purpose for the design.

3.10.2.1 Flash Lamp Pumping

A flash lamp uses an electrical current to generate a very hot gas that is bright enough to pump a laser. The photons emitted from the gas come from the blackbody spectrum. Light from the blackbody spectrum is dependent upon the temperature of the gas. Below is a diagram of the spectrum at different temperatures.

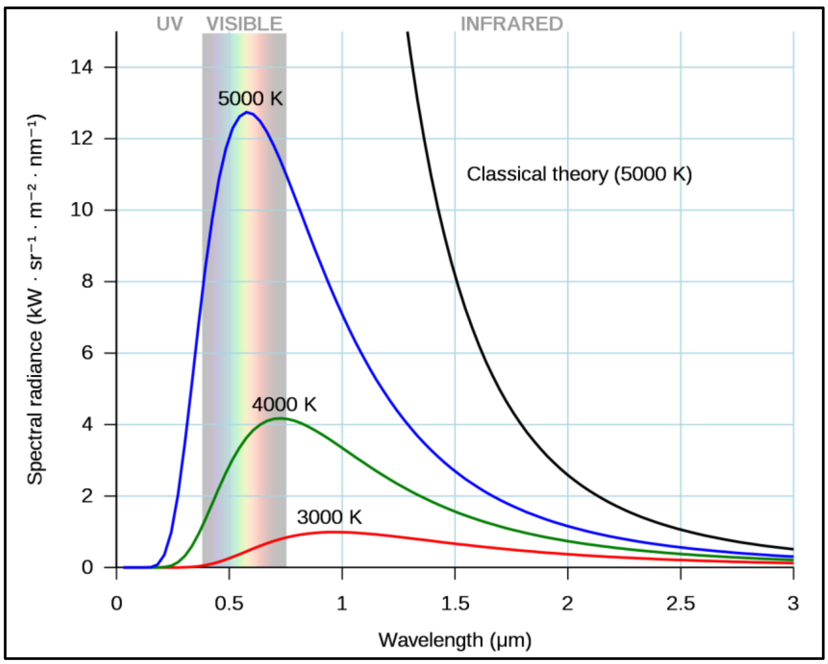


Figure 12 - Blackbody Spectrum at Different Temperatures

From the figure, the hotter the gas, the brighter the spectrum and higher the peak wavelength. These photons emitted by the black body are absorbed by the laser material, causing a population inversion.

3.10.2.2 Electrical Pumping

For some lasers, directly applying electric current into a laser cavity causes a population inversion. By using electricity, the upper state of these lasers is populated, allowing laser action to occur.

3.10.2.3 External Laser Pumping

Lasing by using another laser is common. For these lasers, a higher energy pump beam is used to populate materials that absorb the input laser and radiate at a lower energy level.

3.10.3 Cavity Design

For any laser, there must be a suitable cavity design to cause laser action. A typical cavity features a gain medium, an optical cavity formed by mirrors and lenses, an output coupler, and a pump. For lasing to occur, there must be net gain to the optical brightness of some wavelength that is greater than the input. This means that a light is brighter coming out of the cavity than into the cavity.

A common design of a laser is to use a Fabry-Perot Etalon. A Fabry-Perot etalon is formed by two mirrors of less than one hundred percent reflectance. This allows a beam to be formed in the etalon itself. When a gain medium is placed inside the etalon and pumped beyond an amount for account of loss in the cavity, a laser is formed. Below is an image of a typical laser design.

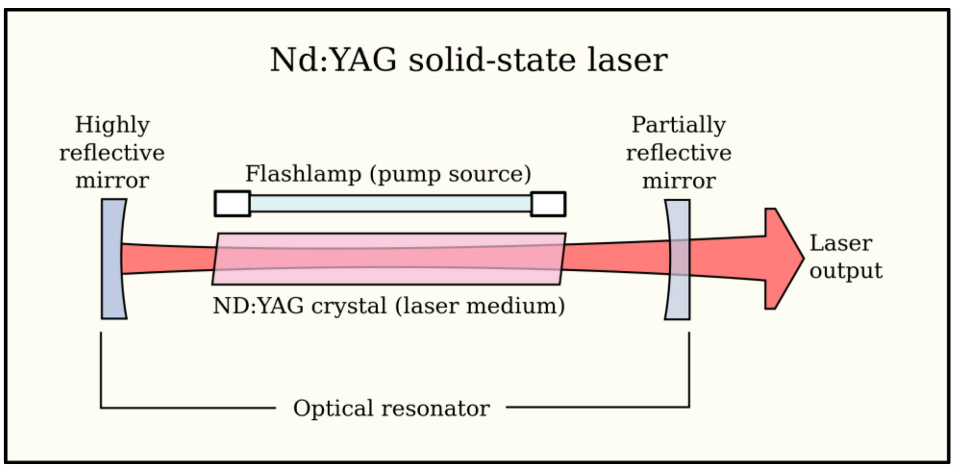


Figure 13 - Typical Nd:YAG laser

The cavity can be formed with two parallel mirrors. This would be an ideal way to make a laser. However, there is a possibility that the design lets light out of the system. One way to correct for this is using curved mirrors such that light is focused back into the center. Shaping the mirrors differently results in different designs. For a typical system, something like that in the figure below would be used.

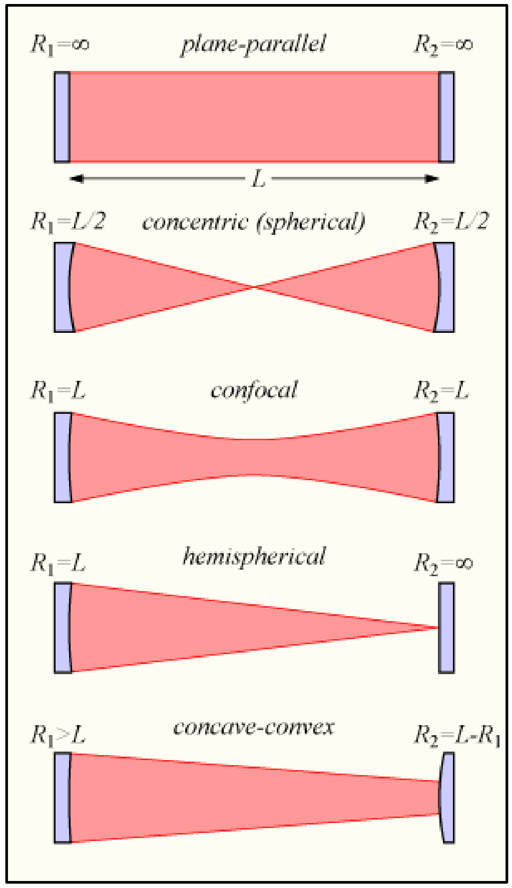


Figure 14 - Laser cavity designs

A typical laser uses high reflectivity mirrors to propagate light through a system.There is a criterion for laser that must be met for a laser to lase.

$$\mathbf{0} < (\mathbf{1} - \boldsymbol{d}/\boldsymbol{R_1})(\mathbf{1} - \boldsymbol{d}/\boldsymbol{R_2}) < \mathbf{1}$$

Figure 15 - Laser Cavity Criterion

In this equation, d is the length of the chamber while R_1 and R_2 are the curvature of the first and second mirror respectively. It can also be the case that lens elements are used as well.

3.10.4 Types of Lasers

There are numerous types of lasers dependent upon the gain medium. There are gas lasers, solid state lasers, diode lasers, and plenty of others that won't be covered in this project. For this paper, we will cover the three types of lasers that we could use.

3.10.4.1 Gas Lasers

Gas lasers use a gain medium of a type of gas. They are useful in giving a high-quality beam for this project. They can range from a low power Helium-Neon gas laser and a high-power CO2 laser. They typically are electrically pumped by an external power supply. Below is a diagram showing a Helium- Neon design.

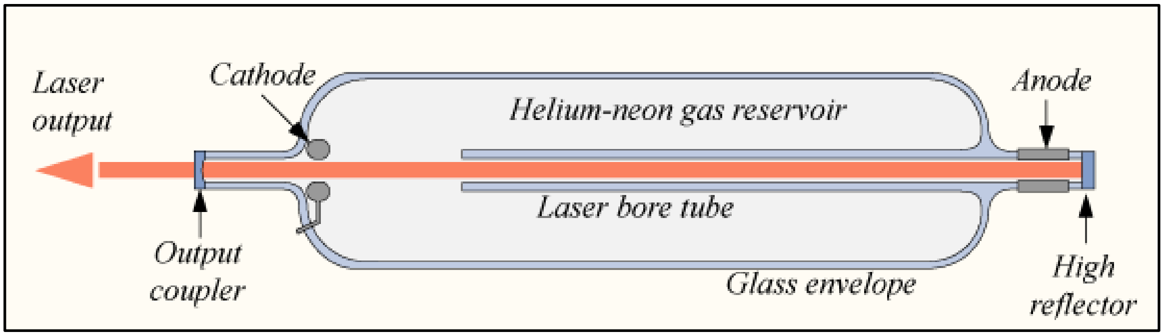


Figure 16 - Helium Neon laser design

3.10.4.2 Solid-State Lasers

Solid-state lasers have a gain material out of a solid. They are useful for high power applications and provide a steady beam. Typical solid-state lasers include Neodymium-doped yttrium aluminum garnet (Nd:YAG), Titanium-doped sapphire, and Ruby laser. The beam produced by a frequency doubled Nd:YAG provides a nice green beam for use. This beam could be useful for indicating between octaves.

3.10.4.3 Semiconductor Lasers

For semiconductor lasers, the laser gain medium is pumped via electrical current stimulating a specific band gap between two different semiconductors. They are useful for this project for their affordability, lasing wavelengths, and efficiency. For a typical semiconductor laser, the materials required are aluminum gallium arsenide.

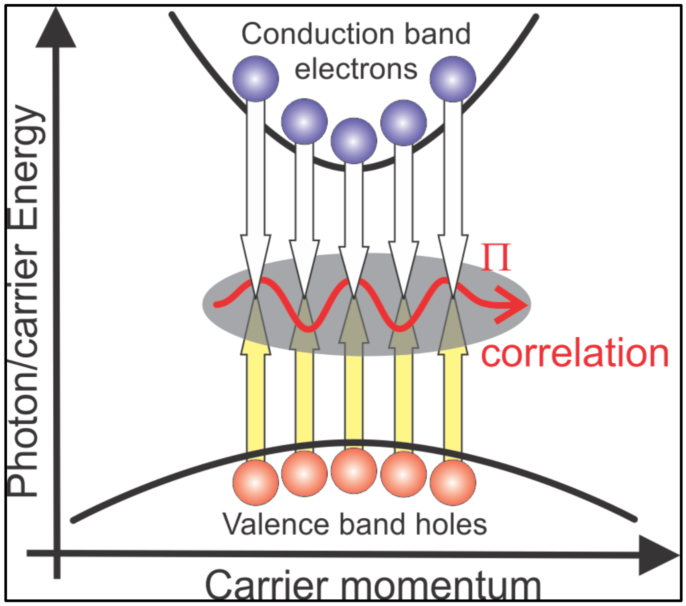


Figure 17 - Semiconductor Valence Band Gap

This band gap, as shown above, between two different regions is what causes the emitted photons. Different band gaps result in different wavelengths of the laser. The cavity for a semiconductor laser is typically a region between two areas with different dopants. A set of mirrors is constructed of two cleanly cleaved ends that have high reflectivity due to Fresnel reflection. The rest of the cavity is given a rough surface so there are no laser feedback mechanisms where there is no output.

Given the variety of light technologies there must be a comparison between them for selection. Below is a summary of light technologies.

Laser	Solid-State (Nd:YAG)	Gas (Helium Neon)	Semiconductor (InGaP)
Space Used	++	+	+++
Output Power	+++	+	++
Efficiency	++	+	+++
Cost	+	+	+++
Beam Quality	++	+++	++
Safety	+	+	+++

Table 9 - Laser Comparisons

We have decided to use semiconductor lasers as our choice of laser. This is due to its low cost, high efficiency, and very little space used. Diode lasers are typically used in low-cost laser pointers, making them a safe technology. We may also use Solid state lasers for several strings, giving a decent reference point for comparison.

3.10.5 Nonlinear Optics

Nonlinear materials (Typically crystals) are employed to a variety of applications, such as frequency conversion. There are several different types of frequency conversion, including frequency doubling, frequency tripling, and even frequency quadrupling. The most famous case for frequency conversion is for converting the Nd:YAG laser into green physical light. Nd:YAG lasers do not lase at a visible wavelength. However, a frequency doubling crystal will turn the laser radiation visible. The crystal allows the 1.064 um wavelength of the Nd:YAG laser into green 532 nm wavelength light. Below is an example of this action.

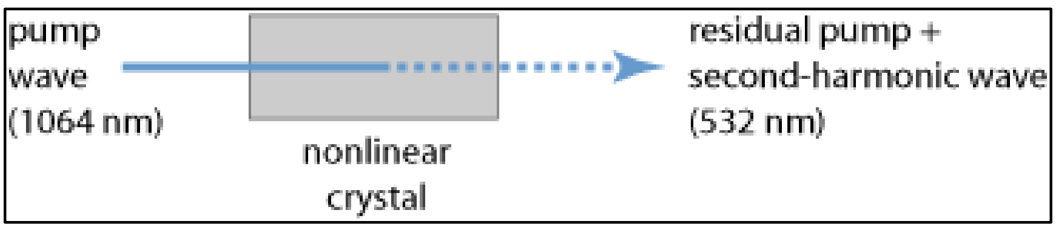


Figure 18 - Frequency Doubling

Some of the original beam will be left over since the material is not one hundred percent efficient. However, the higher input power results in higher efficiency of conversion. This is because the effects are nonlinear. We will be using a Potassium dihydrogen phosphate (KDP) crystal for use with an ND:YAG laser to allow a visible wavelength to be seen. Potassium dihydrogen phosphate is our choice over several other crystals due to high threshold damage and ease of making. The table below shows a comparison between crystals.

Crystal	Potassium dihydrogen phosphate(KDP)	Potassium titanyl phosphate(KTP)	Lithium Niobate
Symmetry	tetragonal	orthorhombic	trigonal
Ease of manufacturing	+++	+	++
Damage threshold	++	+++	+
Efficiency	+	+++	++

Table 10 - Nonlinear Crystal Comparison

3.11 Light Detection Technologies

There are several different ways to convert a beam of light into a signal. The most common one being a photodiode. There are others, such as Avalanche photodetectors as well as photoconductors. These devices change an optical signal into electrical signals.

3.11.1 Photodiode

Photodiodes are made by simply forming a positive- negative junction (PN junction) Photodiodes work on the principle of forming electron hole pairs. When a beam of light impinges on a photodetector, a bunch of electron hole pairs are created. This causes the voltage along the photodetector to lower when placed in negative bias voltage.

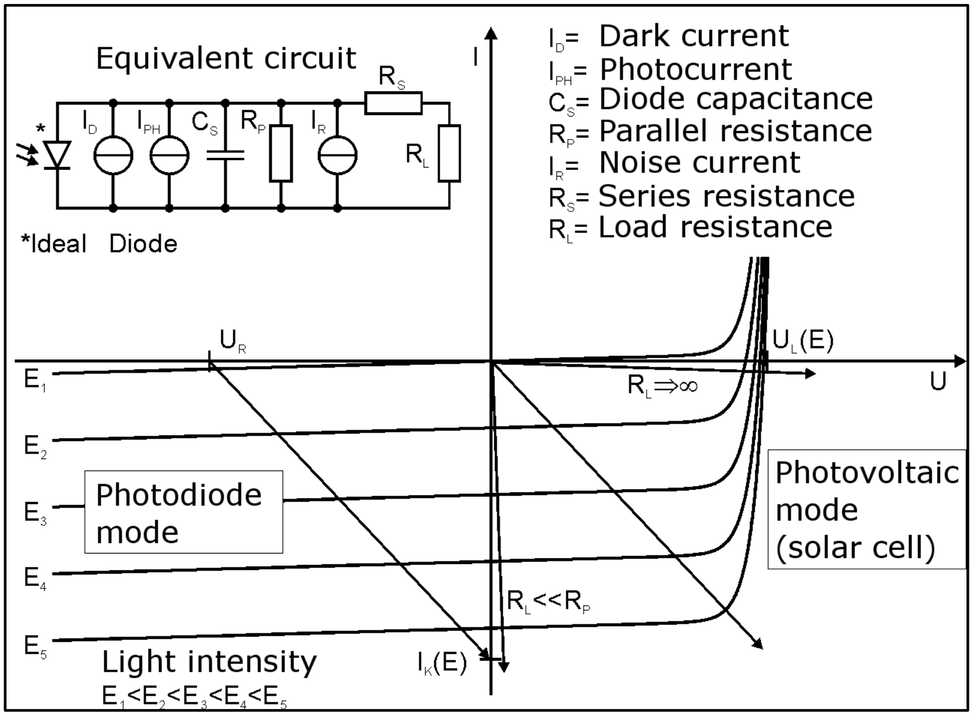


Figure 19 - Photodiode Operation

From the diagram above, different voltage levels across the photodiode result in different currents across the device.

3.11.2 Photoresistor

Photoconductors rely on the principle of using light to change the conductivity of a material. Similar in the case of a photodiode, an electron-hole pair is formed when light impinges on it.

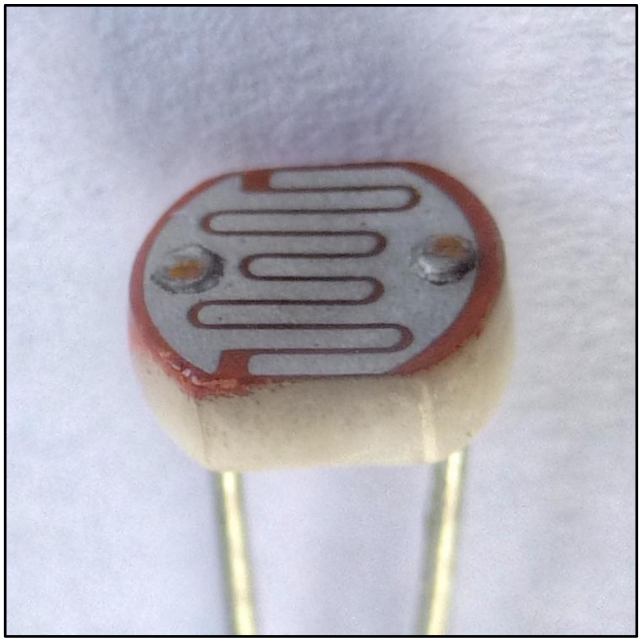


Figure 20 - Photoresistor

Photoresistors are formed to make maximum of the gap between materials. This is so the voltage across the device will change in response to light. Different light filters can be used to allow only a targeted spectrum to impinge on the junction.

Technology	Photodiode	Photoresistor
Cost	++	+++
Efficiency	++	+
Speed	+++	+
Complexity of circuit	++	+++

Table 11 - Comparison of Light Detection Technologies

We have decided to use photoresistors for our project. Photoresistors are easy to use, have low cost, and are fast enough to register when light is blocked by a human finger.

3.11.3 Detection Considerations

The operation of the laser harp is not feasible without the proper detection of interfering with the beams and at a specific distance. The laser diodes provide a means of having a light source to interact with that the detector system can interpret the incoming data. By using a laser as the light source, the detector can convert the electrical energy into a signal that will describe a specific note to the microcontroller that will replay a sound through the MIDI interface. There are several types of detection methods discussed below as well as different types of detectors.

There are several ways to detect the presence of a light source using the phase relation, the change in frequency, or converting light into electrical energy. For this project we thought it best to consider only the components that rely on converting photon energy into electrical impulses. When considering the other methods, they rely too much on small and subtle changes that would be too difficult to interpret. Using electrical amplitudes from the light conversion can be distinguished in the software allowing multiple notes to be played. When considering the light source is a laser diode, we can assume that the note will be present when the beam has been interfered, this brings other considerations into the picture. What type of detector will allow us to use a laser diode as the light source, provide a fast enough response time to send a signal to the MIDI interface, and not cause distortion and noise to other nearby detectors.

3.11.4 Photodetectors

Because we are using a laser as the light source to act as our strings for the laser harp it is mandatory at this point to use a photodetector. The photodetector will capture the light and convert the energy into electrical signals that can be used to communicate with the microcontroller. It is essential that the photodetectors we choose have the proper capabilities to have a working laser harp. There are several areas to consider when choosing a photodetector such as dark current, the noise and sensitivity, as well as the response time. Each of those topics will be briefly discussed before discussing the types of photodetectors and the possible parts that we will consider before choosing a final part.

3.11.5 Dark Current

Dark current is current that is leaking when there is a voltage applied to the photodiode. Dark current causes noise to devices such as photodetectors, we must consider choosing the right detector that does not interfere too much with one another. The dark current causes noise by the electric field being generated by the semiconductor’s electron- hole pairs causing current to flow. This small current is dark current and is significantly more impairing to photodetectors than to the photodiodes. Dark current is also affected by the build material of the photodiode, for example silicon devices tend to have a low dark current. We compare the more common materials with a chart provided by Thor Labs website which considers the materials spectral range and cost shown in figure 21.

Material	Dark Current	Speed	Spectral Range	Cost
Silicon (Si)	Low	High Speed	Visible to NIR	Low
Germanium (Ge)	High	Low Speed	NIR	Low
Gallium Phosphide (GaP)	Low	High Speed	UV to Visible	Moderate
Indium Gallium Arsenide (InGaAs)	Low	High Speed	NIR	Moderate
Indium Arsenide Antimonide (InAsSb)	High	Low Speed	NIR to MIR	High
Extended Range Indium Gallium Arsenide (InGaAs)	High	High Speed	NIR	High
Mercury Cadmium Telluride (MCT, HgCdTe)	High	Low Speed	NIR to MIR	High

Figure 21 - ThorLabs Dark Current Material Comparison

3.11.6 Noise

Noise is any type of interfering signals that are unwanted. In our situation for the laser harp, we are using photodiodes that take in light. Light is a factor that is provided not just by the specified laser diode but by the conditions that the harp is saturated in. there will be testing of the photodiodes signal capability in which to better understand how ambient conditions will affect the performance of the laser harp. There are other possible outcomes for noise in this laser harp given the configuration of providing additional sensors to have a more accurate read on the interfering hands position. Figure 22 below that displays that dark current is amongst the highest cause of noise in a photodetector.

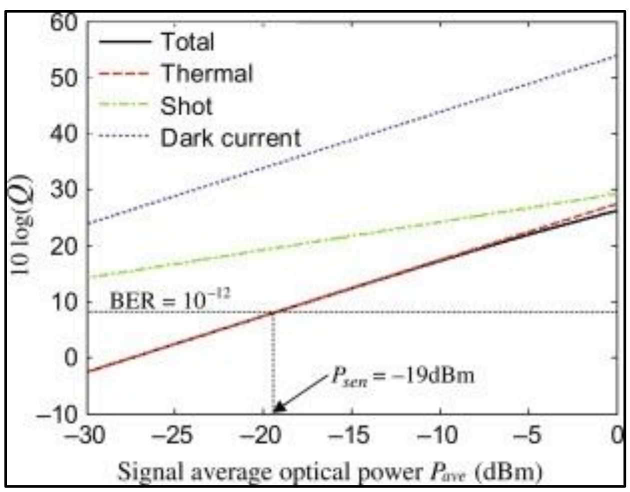


Figure 22 - Dark Current Causes the Most Noise in Photodetectors

3.11.7 Spectral Range

Since we are considering using detectors for both the distance detection and the interference detection it is important, we do not get detectors that will cross talk between one another. If they interfere with one another due to the common spectral detection range it will cause unwanted signals on the laser harp. In order to appropriately accommodate for both detection systems, we must choose two different types of detectors that do not use either the same process or detect the same wavelength. We are using laser diodes that run at 650 nm producing a visible red dot, we must consider that the interference detector must be able to operate at this given wavelength. For the distance detection we must consider an alternative detection method than what we use for the laser diode and it must not operate in the same spectral range causing interference amongst the laser harps strings.

3.11.8 Response time

The laser harp is to be used as a musical instrument and is required to be played as such. This means that there must be little to no lag between the input and the output for it to be played as intended. When deciding a photodetector, we need to be conscious of the response time so that we can relay the signal to the MIDI interface in an appropriate time, this is known as responsiveness.

Responsivity of the photodetector is the ratio of the photocurrent generated by the optical power. The equation below in figure 23 is used to calculate the responsivity using Planck's constant, its frequency, the electric charge, and the quantum efficiency.

$$R = \eta \frac{e}{h\nu}$$

Figure 23 - Responsivity Equation

In considering the responsivity we must also consider the capacitance, as it will also affect the response time. Recall that response time is measured in terms of the resistance and the capacitance forming the basis of the RC charging circuit. when the voltage is applied to a capacitor that is discharged it will charge current up, and when the voltage is reduced the capacitor will discharge its voltage in an opposite direction. The electrical charge of a capacitor is given by figure 24 which reads:

$$Q = C * V$$

Figure 24 - Electrical Charge of a Capacitor

The storage and discharging of the voltage that the capacitor carries requires a certain amount of time known as the time constant (tau). It is necessary to consider the capacitance to better understand the response time for the photodetector. With a lower capacitance the response time is much faster compared to when there is higher capacitance. If you consider that a capacitor stores charge, the less it can store the faster it can release it yielding a lower response time.

3.11.9 Sensor Housing

The photodiodes we choose 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.

3.12 Methods of Detection:

To figure out which detector we want to use for this project we first look at the theory behind what types of optical sensors are currently available. With a basic understanding of the types of detection we can move onto looking at the sensors we will consider. There are several types of photodetectors that could be used, each using a different system of detection yet yielding a similar result.

3.12.1 Through-Beam

This type of set up consists of a transmitter emitting the light directly in the sight of the detector as shown in figure 25. As soon as the beam is blocked the receiver will transmit a signal to the MIDI control and cause a note to be played on the harp. This is the simplest type of configuration, requiring very few parts to create a prototype. In this configuration the emitter and receiver are separated in two units placed on opposite sides of one another, this makes it a very reliable sensing mode. The light will pass directly from the emitter to the receiver and when the beam's path is broken by placing an object in the way the receiver can no longer detect light and relays that signal to the control unit.

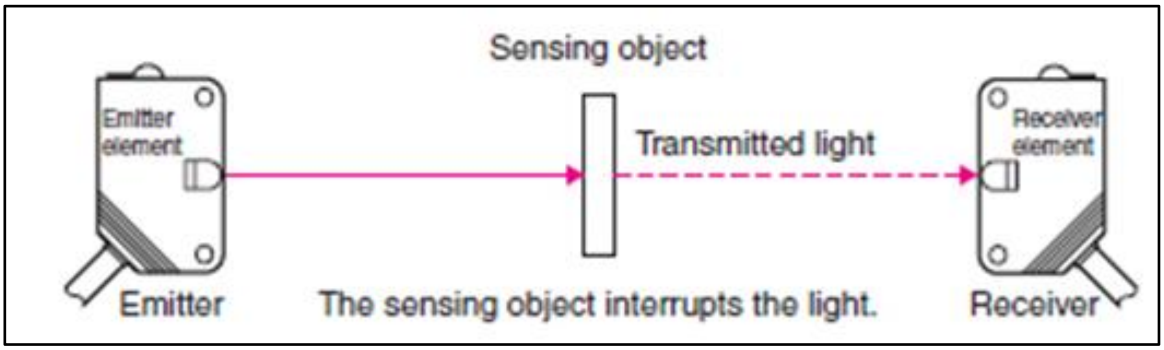


Figure 25 - ThroughBeam Sensor Diagram

A photocell is an example of a through beam style detector that will be considered. Because of its cheap price and it being abundant from any resource, it was used in the primary prototype. There are other methods of detection to consider, but the photocell will be discussed further in the considered sensors section.

3.12.2 Retroreflective

This sensor is different from the previous through beam style because it contains both the emitter and receiver in the same housing compared to the separate components of the through beam design. They work in a similar fashion, there is a beam and once the beam is broken there is an output signal that lets the computer know that it is either interrupted or uninterrupted. In order for the beam to return to the receiver it needs to be reflected by a prism type mirror to create that continuous state of not being interrupted. Once something passes through the detection zone there is no return of light from the emitter to the receiver and so the output changes state, determining there is an object in its path. Below figure 26 can be seen describing the basic structure and operation of a retroreflective sensor.

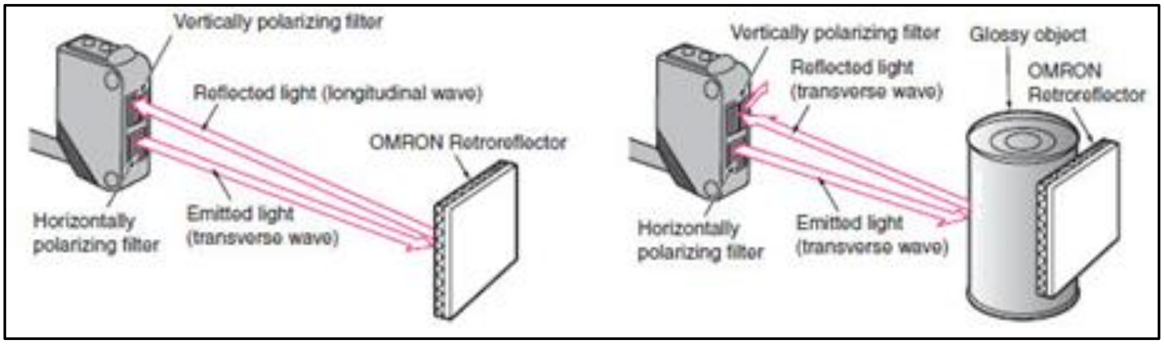


Figure 26 - Retroreflective Sensor Basic Operation Diagram

3.12.3 Diffused

Like retroreflective sensors, diffused sensors emit light and detect the reflected signal in the same housing. Within the housing is both the emitter and receiver however it is designed so that the reflected light off the object can be detected rather than off a mirror specifically designed to send the signal back. What is different about this type of sensor is that as its name describes, the emitted signal is diffused in all directions so that it can fill up an area of detection. Once something enters the area of detection, where light is deflected off an object's surface, a signal can be sent out determining that an object has gotten within its sensing distance. A simple breakdown of how a diffused sensor works shown in figure 27.

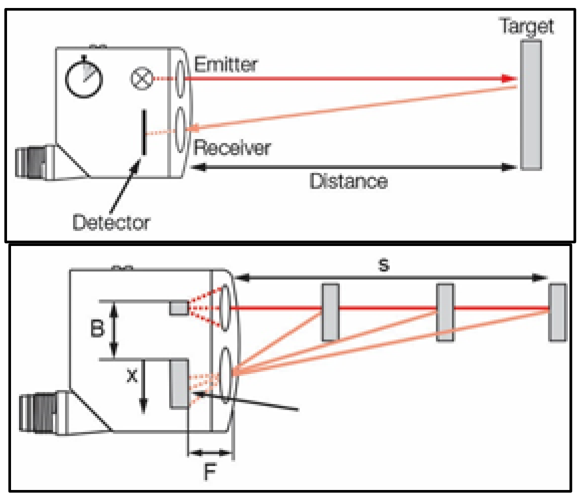


Figure 27 - Diffused Emitter and Receiver Diagram

3.12.4 Comparison of Sensing Modes:

Now that we have discussed the types of sensing modes, we can create a chart that briefly compares their advantages and disadvantages. In considering different types of detectors that operate in different modes it is good to keep in mind parameters such as cost, range, and accuracy shown in table 12 below.

Type	Advantage	Disadvantage
Through- Beam	• Very accurate • Long range • Reliable	• Two- point system (emitter and receiver) • False positives when misaligned
Reflective	• Fairly accurate • Decent sensing range • Reliable	• Two -point system (sensor and reflector) • Costly smaller range than through-beam
Diffuse	• Single point installation • Cheap	• Not as accurate as the reflective or through beam • Time consuming to set up

Table 12 - Comparison of Sensing Modes

3.12.5 Sensors Considered

For the harp to be able to understand when the beam is being interfered and communicate with the PLC, we must use devices that convert photon energy into electrical current to observe its signal. A photodiode is just that, a type of semiconductor device that will convert its photon energy into current allowing communication to electrical devices. Basic principles of how it works is when a photon carrying enough energy reaches the diode, an electron- hole pair will be created. The holes are positively charged ions and the electrons are the negatively charged, and with the depletion regions built- in electric field the positively and negatively charged ions will be moved to the anode and cathode. From the process of the positively and negatively charged ions being distributed a photocurrent is created and that is how communication between the diode and the controller takes place.

Depending on the application there are two types of modes that the diodes can operate in, either photovoltaic mode or photoconductive mode. For photovoltaic systems, the production of current at its junction is due to it being exposed to light operating in forward bias. A diode operating in a photoconductive mode will also take in light energy but will instead use that energy to reduce electrical resistance across the junction making it operate reverse biased. There are several types of detectors that can be considered for this project that either operate in reverse or forward biased modes which are discussed further.

3.12.5.1 Photocell

Also known as LDRs, which are light dependent resistors, are used to specifically detect the level of illumination of the surrounding area, or whatever hits its sensor. It is called an LDR because the resistance will change depending on the amount of light present on the sensor. The working principle of LDRs is that the resistance works off photoconductivity. When there is light present on the surface of the detector, the material conductivity will reduce causing the electrons in the valence band to be energized into the upper conduction band. Due to the light being received onto the detector having a high enough energy to cross the band gap decreasing the resistance. This type of detector is a photoconductive detector because it absorbs the light creating population inversion allowing the electrons to flow into the conduction band allowing the resistance to drop between the two electrodes. A basic component breakdown of the material makeup and the terminals is displayed below in figure 28.

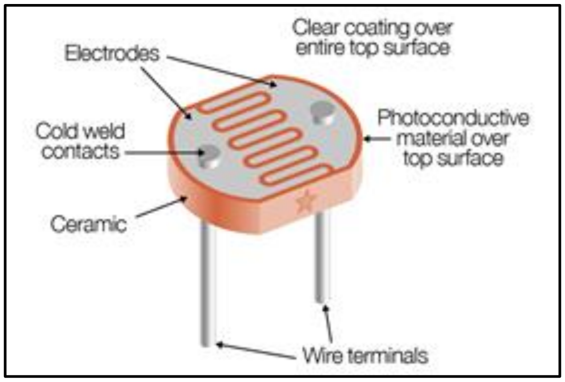


Figure 28 - Photocell with Part Description

LDRs are already widespread in a multitude of products and used as light sensors everywhere. They are low cost and have a simple structure as depicted in the figure. They are commonly used to sense the absence and presence of light and used in security and alarm systems as well as used to control streetlights. This type of detector could work with our project if it meets all the requirements. A basic description of a general LRD is displayed below in table 13.

Size:	Round (5mm)
Price:	< $ 1.00
Resistance Range:	200 kΩ - 10kΩ
Sensitivity Range:	400nm – 600 nm
Power supply:	> 100V, > 1mA

Table 13 - Photocell Specs

3.12.5.2 Retroreflector

The seco- larm E-931 wall mounted photoelectric beam sensor, as shown in figure 29, is available to purchase online and has a long range. This system is much too large for a portable laser harp however we can consider using only the detector sensor and outsource the retroreflector. When looking at the data provided in table 14 we can see that each component weighs too much and requires a larger power supply than the rest of the components we plan to use.

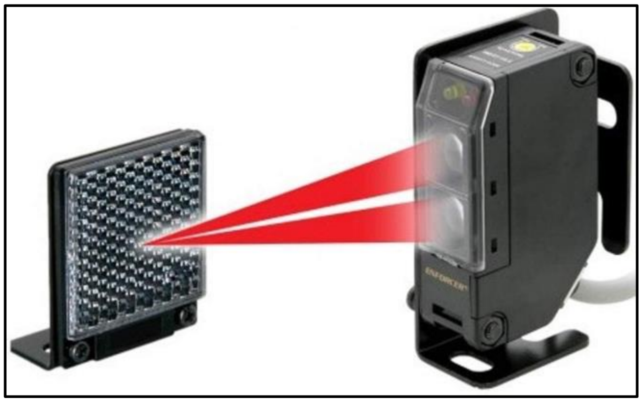


Figure 29 - Retroreflector Detection

Size	5.75 x 3.5 x 2 inches
Weight	0.7 pounds
Sensing range	0.1-11m
Current draw	20mA@12VDC, 10mA @ 24VDC
Response time	10ms
Source	IR LED

Table 14 - Retroreflector Sensing Specifications

Through the considerations of the detection methods and the systems overall configuration we decide it is the best route to use LDRs as the detector. From experience with the basic Arduino prototype, we believe that the LDRs are the best choice considering price, weight, configurations, and the lack of modifications. By choosing an LDR over a retroreflector system we lessen the weight and lower the number of parts. Not only that, but quality retroreflectors are also costly compared to basic electronic components.

3.12.6 Distance Tracking

To add another dimension of sound to the harp, we want to be able to change the pitch depending on the location of the interference. This requires additional sensors which will be discussed further in detail for comparison. There are an abundant variety of distance detection mechanisms however there are three that should be considered for this project. Ultrasonic sensors are used in robotics but are commonly used for automation and motion sensing. The second consideration for tracking the distance of where the hand interferes with the beam are IR proximity sensors. These are relatively cheap and are easy to configure to a microcontroller, making it a less risky choice to be considered. Another possible consideration would be LIDAR, which uses a laser to calculate the distance using its return time

3.12.6.1 Ultrasonic Sensor

An ultrasonic sensor is an instrument that can measure the distance of an object by using sound waves at a frequency above the human hearing range. The sensor shown in figure 30 uses a transducer to emit and receive ultrasonic pulses which relay information about and objects distance. Ultrasonic sensors use a single transducer to emit a pulse and receive the echo which gives enough information to calculate the distance of the object. The time of fight is used to determine the distance an object is by dividing the time of flight by the speed of sound. The longer the time of flight when the pulse is emitted, the further the distance of the object is allowing us to control the pitch of the laser hard using distance.

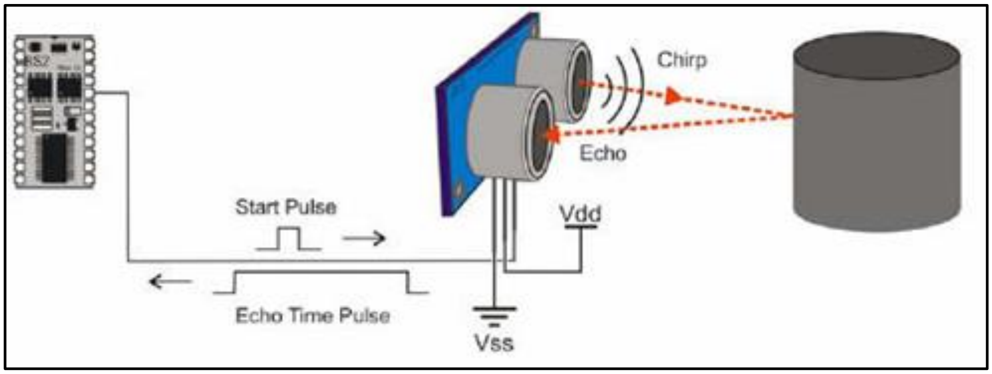


Figure 30 - Ultrasonic Sensor Diagram

One of the possible issues we need to be aware of is interference when multiple modules are connected near each other. If there is cross talk or any type of interference giving false positives, the harp will emit sounds that the user did not intend to create. It is possible for cross talk to occur because the ultrasonic sensors transmit sound waves toward the target and the reflected waves return to the receiver. If there are returning signals from a multiple ultrasonic sensor, we need to ensure that there are delays in the processing software to account for any false signals or somehow be able to differentiate the signals. Some advantages and disadvantages of using this system is discussed in table 15.

Advantages	Disadvantages
• Multiple interface options • Works well in dim lighting • Low power consumption • Not affected by color or transparency	• Limited range • Low resolution and refresh rate • Not good with fast moving objects

Table 15 - Ultrasonic Comparison

The cuisimax HC- SR04 displayed in figure 31 is an ultrasonic distance measuring tool designed to be used on an arduino system. Requires a typical 5VDC and has a static current less than 2mA, this module sends out 40khz square waves and automatically detects whether a signal is returned. Table 16 shows that this could be a possible detector since it meets certain conditions such as distance detection and the correct voltage.

Figure 31 - Cuismax HC-SR04 Ultrasonic Sensor Distance Measuring Module

Voltage	5 VDC
Static current	>2mA
Sensor angle	No more than 15 degrees
Detection distance	2cm-450cm
High precision	Up to 0.3cm
Brand	Cusimax

Table 16 - Cuismax HC-SR04 Ultrasonic Sensor Specifications

3.12.6.2 IR sensor

Short for infrared, the IR proximity sensor detects the distance of an object by emitting a beam of light. This light is captured by the receiver which detects the presence of the reflected infrared light. It operates in a similar fashion to the ultrasonic sensors, but instead of emitting sound waves, IR is transmitted. The main composition of the detector is an LED that emits infrared light and a detector where it can receive the reflection signal. The components themselves cannot determine the distance or presence of an object; they need to be integrated into a circuit with software. The two separate components are displayed below in figure 32 displaying the clear LED to be the emitter and the darker one to be the receiver.

Figure 32 - IR Components

There are several premade circuit configurations available on the market that can be easily integrated into the circuit we design. All of the preconfigured sensors come with three pins for input power, output signal pin, and ground pins to communicate with the system. Creating a circuit that controls the individual emitter and receiver is also an option. There are many schematics available to get a better understanding of how the detector works. In this section we will compare two different premade circuits shown in figure 33 and figure 34 to compare multiple units to better have an idea of what is best to use by comparing the advantages in table 17.

Advantages	Disadvantages
• Contactless detection • Light or dark uses • Line of sight communication • Can detect soft objects	• Requires line of sight for communications • Performance alters with distance • Affected by environmental conditions

Table 17 - Infrared Sensor Comparison

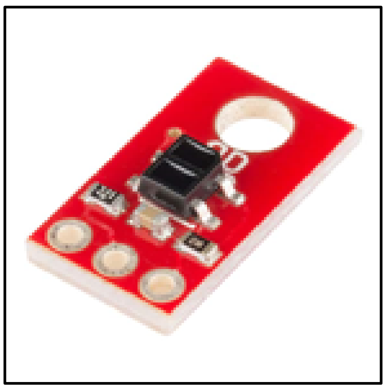


Figure 33 - Sparkfun Electronics IR Detector

Price	2.95
Manufacture	Sparkfun electronics
Product number	ROB-09454

Interface	Digital
Voltage	5V
Current	25mA
Sensing distance	>5cm

Table 18 - Sparkfun Electronics IR Emitter Specifications

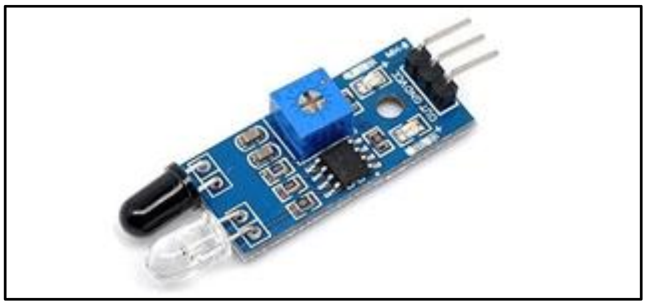


Figure 34 - HiLetgo IR Board

Price	7.99
Manufacturer	HiLetgo
Dimensions	5.5 x 3.5 x 1.25 inches
Voltage	3.3- 5 VDC

Sensing distance	2-30cm

Table 19 - HiLetGo IR Board Specifications

When comparing the two different infrared detectors in table 18 and table 19 that are being considered it is clear that they both share many similarities in the design. Although HiLetgo is larger than the Sparkfun, it provides a far greater reach in terms of distance sensing capabilities. For this project our laser harp is too large to use a detector that only measures a few cm. The last detection method for distance considered is lidar discussed below, then a final decision on what component we believe is best suited for this project.

3.12.6.3 LIDAR

One of the more complex sensors to consider is LiDAR, or light detection and ranging, which uses a laser to measure the distance as opposed to ultrasonic. Laser distance sensors emit a beam of light that can be either infrared, visible, or ultraviolet, which then bounces back to a receiver where the circuit can process the information and calculate the distance. The way laser-based distance sensors measure distance is by triangulation, using the time it takes for light to travel from emitter to receiver as shown in figure 35. It uses its time of flight to calculate the return signal using the common factor that light moves at a constant speed using the equation shown in figure 36. By observing the time, it takes for the reflected beam to return allows the unit to calculate the distance the target is. Lidar is used more recently for 3-D imaging of the wilderness or self-driving vehicles. The technology is very precise because it uses lasers which have very little beam divergence allowing data points to form a point cloud. This point cloud system will enable the user to create a three-dimensional structure of the objects at hand. In order to use a lidar system we would need a complex computational system that can handle real time data flow while the harp is being played. Furthermore, we would have to test out and work with a prototype to see if this best suit our needs. A table discussing the advantages and disadvantages is shown below in table 20.

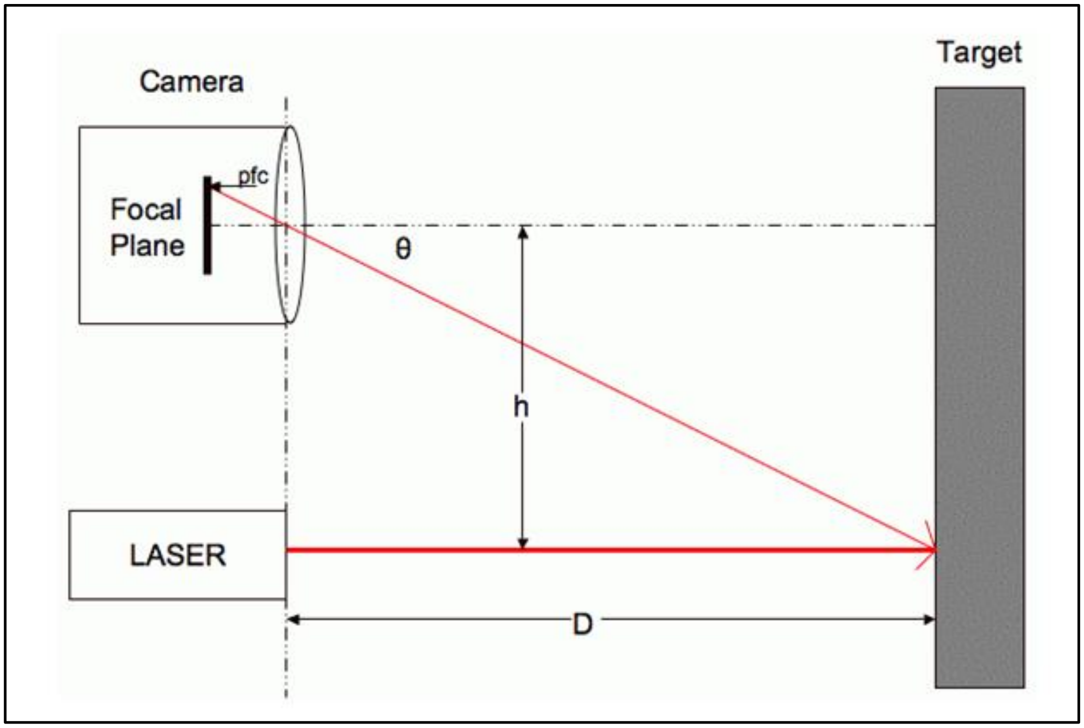


Figure 35 - Lidar Triangulation

$$D = \frac{h}{\tan\theta}$$

Figure 36 - Distance Calculation

Advantage	Disadvantages
• High range • High accuracy • Fast update speed • Good for small object detection • Day or night time use	• Costly • Can be dangerous • More complex

Table 20 - LIDAR Comparison

The VL53L0X from ST microelectronics shown in figure 37 is a time of flight ranging system integrated into a single compact module. It precisely measures how long it takes for emitted pulses of infrared light to reach the nearest object and reflected to the detector. Because of its small form factor, it is a self-contained lidar system. The sensor can report up to distances of around six and a half feet with 1mm resolution, however its actual resolution is dependent on its ambient conditions. More details on the components manufacturers specifications can be viewed in table 21.

Figure 37 - VL53L0X Time-of-Flight Laser Distance Sensor Breakout Module

Manufacturer	ST microelectronics
Part number	VL53L0x
Voltage output	2.8v

Voltage input	2.6-5.5 volts
Price	6.98
Range	Up to 2m

Table 21 - Time of Flight Distance Sensor Specifications

3.13 Battery

In this section we are discussing the varieties of viable batteries we can use to make the laser harp portable, instead of having it stationary and plugged into the wall. We are trying to search for a five-volt rechargeable battery so that we can make it a more convenient product. If we had disposable batteries, it would inconvenience the user, so a rechargeable one is the right choice. All that is really required for the rechargeable battery is the charging cable itself and it will be a type of USB that you are likely to find, if it should ever go missing.

3.13.1 Lithium-ion

In a lithium-ion battery, lithium ions move from a negative electrode through an electrolyte to the positive electrode during discharge and back when charging (Lithium-Ion Battery). The lithium-ion battery uses an intercalated lithium compound at the positive electrode as seen in Figure 38, which is a reversible insertion of an ion into materials with layered structures, and a graphite at the negative electrode as seen in Figure 39 (Lithium-Ion Battery).

The procedure for charging lithium-ion cells is carried out by: constant current phase, which is a direct current that doesn’t change intensity with time until each cell is full; balance phase, which is the reduction of the charging current with each cell at the same level state of charge; constant voltage, which is when the charger applies a voltage equal to the maximum cell voltage times the number of cells in series to the battery as the current declines towards zero.

As a standard all batteries they start to discharge at some point seen in Figure 40. With this battery the rate of discharge is 1.5% to 2% per month of the total charge.

Some factors to consider is that the rate of discharge increases as the temperature increases.

This battery has a high energy density and low self-discharge. A con that comes with this battery is that it can be a safety hazard since the elements used in the lithium-ion battery are flammable, if it is damaged or charged the wrong way the conclusion will result in either a fire or an explosion.

The battery life is determined by stress factors like how many times it has been charged/discharged, Figure 41, temperature, discharge current, charge current, and state of charge ranges.

In Figure 42 we see that this is diffusion and it's because of the change of electrolyte concentration. The negative sign means that they are flowing from a high to low concentration.

There are multiple versions of a lithium-ion battery:

- Lithium polymer with a polymer gel as an electrolyte and lithium cobalt oxide ($LiCoO_2$) as a cathode. High energy density and possible safety risks
- Lithium iron phosphate ($LiFePO_4$). Low energy density, lasts longer, and less likely to catch fire or explode.
- Lithium manganese oxide ($LiMn_2O_4$, Li_2MnO_3, LMO). Low energy density, lasts longer, and less likely to catch fire or explode.
- Lithium nickel manganese cobalt oxide ($LiNiMnCoO_2$, NMC). Low energy density, lasts longer, and less likely to catch fire or explode.

$$\mathrm{CoO_2 + Li^+ + e^- \rightleftharpoons LiCoO_2}$$

Figure 38 - Positive Electrode in the Lithium Cobalt Oxide Substrate

$$\mathrm{LiC_6 \rightleftharpoons C_6 + Li^+ + e^-}$$

Figure 39 - Negative Electrode Half Reaction for Graphite

$$\mathrm{LiC_6 + CoO_2 \rightleftharpoons C_6 + LiCoO_2}$$

Figure 40 - Full Discharging Reaction

$$\mathrm{Li^+ + e^- + LiCoO_2 \longrightarrow Li_2O + CoO}$$

Figure 41 - Over Discharging Supersaturates Lithium Cobalt Oxide Resulting in Lithium Oxide

$$\frac{\partial c}{\partial t} = -\frac{D}{\varepsilon}\frac{\partial^2 c}{\partial x^2}.$$

*Figure 42 - Diffusion, where c is the Concentration, t is Time, x is the Distance, D is the Diffusion Coefficient for the Lithium Ion (7.5 * 10^{-10} m^2/s), ε is the Porosity of the Electrolyte (0.724) (Lithium-Ion Battery)*

3.13.2 Lead-acid

The lead acid battery is the oldest type of rechargeable battery we are considering using. It is able to supply high surge currents which means the power to weight ratio was significantly large. Along with its power to weight ratio, the energy to weight ratio and energy to volume ratio were also pretty low. All these factors would keep the cost of the lead acid battery low (Lead-Acid Battery).

A larger form factor of the lead acid battery would be useful for storing more power. While in a charging state, pure lead on the negative side, Figure 43, and lead oxide (PbO_2) on the positive side, Figure 44 (Lead-Acid Battery). The electrical energy that is produced when the battery is discharged is when water (H_2O) molecules form hydrogen ions (H^+) and oxygen ion (O^{2-}) from the lead oxide (Lead-Acid Battery). We can see that in Figure 45 that when you combine Figure 43 and Figure 44 equations you will get the total reaction when the energy is released.

$$\mathrm{Pb(s) + HSO_4^-(aq) \rightarrow PbSO_4(s) + H^+(aq) + 2e^-}$$

Figure 43 - Negative Plate Reaction

$$PbO_2(s) + HSO_4^-(aq) + 3H^+(aq) + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l)$$

Figure 44 - Positive Plate Reaction

$$Pb(s) + PbO_2(s) + 2H_2SO_4(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)\ E^\circ_{cell} = 2.05\ \mathrm{V}$$

Figure 45 - Total Reaction

When the battery discharges both the positive and negative plates become lead sulfate ($PbSO_4$) and then become water as the electrolyte dissolves its sulfuric acid (H_2SO_4) (Lead-Acid Battery). When in a charging state the negative plates become lead (Pb), the positive plate becomes lead dioxide (PbO_2), and the aqueous solution of sulfuric acid (H_2SO_4(aq)) becomes a higher concentration (Lead-Acid Battery). When overcharging the aqueous solution generates oxygen and hydrogen gas that may escape the battery.

A safety concern would be from internal explosion, the reason being stated in the last paragraph is when the oxygen and hydrogen gases escape from the top vents of the battery, but if the vents don't open properly then the gas will constantly build up and become very flammable. A typical occurrence for the vents to not open properly would be from debris or dirt buildup. Another safety concern that could also lead to an explosion is if the cells in the battery short circuit during a time when the oxygen and hydrogen gasses are being built up.

3.13.3 Nickel-cadmium (NiCad)

We were also considering using a nickel-cadmium battery. Nickel-cadmium batteries have a discharge, Figure 46 and Figure 47, of 1.2 volts and slowly decline at the end of the discharge (Nickel-Cadmium battery). The net discharge, Figure 48, is the combination of Figure 46 and Figure 47, in which after the battery has been released of its energy. These batteries have a good life cycle and good performance when temperatures are at a low. Compared to the Lead acid battery the Nickel cadmium battery costs more and has a high self-discharge rate.

When charging the Nickel cadmium battery, it's ideal to charge at temperatures of -20C to 45C, because when it approaches full charge, the temperature will rise to 45C to 50C (Nickel-Cadmium battery). The discharge rate, Figure 48, of the battery will be about 10% per month at 20C and 20% per month if the temperature is too high (Nickel-Cadmium battery). When the battery is being rapidly charged, discharged, or overcharged it will release oxygen and hydrogen gases, Figure 47, but will recombine back into water, unless the battery has reached its maximum gas valve. In this case it will just lose some gas and slowly render the battery less useful.

$$\mathrm{Cd} + 2\mathrm{OH}^- \rightarrow \mathrm{Cd(OH)}_2 + 2\mathrm{e}^-$$

Figure 46 - Cadmium Electrode during Discharge

$$2\mathrm{NiO(OH)} + 2\mathrm{H_2O} + 2\mathrm{e}^- \rightarrow 2\mathrm{Ni(OH)}_2 + 2\mathrm{OH}^-$$

Figure 47 - Nickel Oxide Electrode Reaction

$$2\mathrm{NiO(OH)} + \mathrm{Cd} + 2\mathrm{H_2O} \rightarrow 2\mathrm{Ni(OH)}_2 + \mathrm{Cd(OH)}_2$$

Figure 48 - Total Reaction during Discharge

3.13.3 Nickel-zinc (NiZn)

The Nickel Zinc battery is very similar to the Nickel Cadmium battery except that it has a higher voltage. This battery compared to the other batteries listed doesn't use elements that are difficult to recycle, whereas this battery has common natural elements. As seen in Figure 49 and Figure 50, the Zinc Hydroxide on the negative terminal can be combined or recreated when discharging or recharging. The same can be said in Figure 51 except there is Nickel Oxide hydroxide and water on the positive electrolyte. With the negative and positive electrodes combined you will get the overall reaction Figure 52 but also could be the same thing for the parasitic reaction, Figure 53, in which an extra element is added and removed.

This battery is the safest of all the batteries listed here because there are no flammable components or organic electrolytes (Nickel-Zinc Battery). These batteries are designed to have a high-power density and low temperature discharging performance and can be discharged to nearly zero.

$$\mathrm{Zn} + 4\ \mathrm{OH}^- \rightleftharpoons \mathrm{Zn(OH)}_4^{2-} + 2\mathrm{e}^-\ (E^0 = -1.2\ \mathrm{V/SHE})$$

Figure 49 - Negative Electrode

$$Zn(OH)_4^{2-} \rightleftharpoons Zn(OH)_2 + 2OH^-$$
$$Zn(OH)_2 \rightleftharpoons ZnO + H_2O$$

Figure 50 - Potassium Hydroxide Electrolyte

$$2\ NiO(OH) + 2\ H_2O + 2\ e^- \rightleftharpoons 2\ Ni(OH)_2 + 2\ OH^-\ (E^0 = +0.50\ V/SHE)$$

Figure 51 - Positive Electrode

$$\mathbf{Zn + 2\ NiO(OH) + H_2O \rightleftharpoons ZnO + 2\ Ni(OH)_2}$$

Figure 52 - Overall Reaction

$$Zn + 2\ H_2O \rightarrow Zn(OH)_2 + H_2$$

Figure 53 - Parasitic Reaction

3.13.4 Nickel-Metal Hydride (NiMH)

The Nickel Metal Hydride battery has a similar chemical reaction compared to the Nickel Cadmium cell (NiCd) by using nickel oxide hydroxide at the positive electrode, Figure 55. The only difference is the negative electrode, Figure 54, where this battery uses a hydrogen absorbing alloy instead of cadmium.

$$H_2O + M + e^- \rightleftharpoons OH^- + MH$$

Figure 54 - Negative Electrode Reaction

$$Ni(OH)_2 + OH^- \rightleftharpoons NiO(OH) + H_2O + e^-$$

Figure 55 - Positive Electrode Reaction

When charging the Nickel metal hydride battery, it will range from 1.4 to 1.6 volts per cell (Nickel-Metal Hydride). The discharge averages 1.25 volts per cell (Nickel-Metal Hydride). Also, as all batteries the self-discharge is quite high compared to the nickel cadmium battery where temperature also is factored in it as well. 5 to 20% discharge on the first day and 0.5% to 4% per day and so forth, assuming room temperature is 45C (Nickel-Metal Hydride).

The safety precautions when using this battery isn't so extreme compared to the other safeties in other batteries. This battery contains a resettable fuse, a bimetallic strip, which is used to protect against overcurrent faults. This fuse will open if the current or the temperature gets too high. When overcharging this battery and/or additional heat and pop the cap of the cell and discontinuing the charging process. Also, in this process the extra heat in the battery will create hydrogen gas which can also lead to the cap popping as well, Figure 56.

$$(2\,H_2 + O_2 \xrightarrow{\text{catalyst}} 2\,H_2O)$$

Figure 56 - Gasses Produced and a Catalyst Produced by Over Charging

3.13.5 Alkaline

The Alkaline battery is a hybrid between the zinc metal battery and the manganese dioxide battery. The name alkaline comes from the alkaline electrolyte in the potassium hydroxide. The negative electrode is zinc and the positive electrode, as seen in Figure 57, is manganese dioxide (MnO_2). The alkaline electrolyte of the potassium hydroxide does not part take in the reaction on the zinc and manganese dioxide aspect during discharge. The alkaline electrolyte of the potassium hydroxide remains since there are equal parts of OH^- used and created. When the positive and negative electrolytes are combined, they produce the overall reaction for the energy stored, Figure 58.

$$Zn_{(s)} + 2OH^-_{(aq)} \rightarrow ZnO_{(s)} + H_2O_{(l)} + 2e^- \ [E_{oxidation}{}^\circ = +1.28\ V]$$
$$2MnO_{2(s)} + H_2O_{(l)} + 2e^- \rightarrow Mn_2O_{3(s)} + 2OH^-_{(aq)} \ [E_{reduction}{}^\circ = +0.15\ V]$$

Figure 57 - Half Reactions from Positive and Negative Electrolytes

$$Zn_{(s)} + 2MnO_{2(s)} \rightleftharpoons ZnO_{(s)} + Mn_2O_{3(s)} \ [e^\circ = +1.43\ V]$$

Figure 58 - Overall Reaction

When recharging the battery, a complication may occur such as a rupture of hazardous liquid. These leaks can cause potassium hydroxide which can cause irritation to respiratory, eye and skin irritation (Alkaline Battery). The leak will combine with carbon dioxide in the air and form a crystal-like structure that can cause the surrounding area to rust or corrode and could potentially ruin the product (Alkaline Battery).

3.13.6 Battery Comparison

Below is a table summarizing the different batteries we were considering.

Type	Lithium Ion	Lead-acid	NiCad	NiMH	Alkaline
Energy	+++	+	+	++	+
Safety	++	+++	++	+	+++
Lifetime	+++	++	+	++	+
Cost	+	+++	+	++	+++

Table 22 - Battery comparison

Below is a summary of the battery technologies that we considered for use in the laser harp.

Figure 59 - INIU Battery Pack

Manufacturer	INIU
Part number	B07CZDXDG8
Type	Li-Ion
Voltage	5 V
Capacity	100000mAh
Price	$17.99

Table 23 - INIU Lithium-Ion Battery Specifications

Figure 60 - Duracell AA Battery

Manufacturer	Duracell
Part number	OPT1500B12PRT
Type	Alkaline
Voltage	1.5 V
Capacity	2000mAh
Price	$10.48

Table 24 - Duracell AA Battery Specifications

Figure 61 - PKCELL NiCad Battery

Manufacturer	PKCELL
Part number	B088CTMBH6
Type	Nickel-Cadmium
Voltage	1.2 V
Capacity	7000mAh
Price	$7.79

Table 25 - PKCELL NiCad Battery Specifications

Figure 62 - Minetown AA Battery

Manufacturer	Minetown
Part number	B07V3JQS1Z
Type	Nickel-Metal Hydride
Voltage	1.2 V
Capacity	1300mAh
Price	$14.59

Table 26 - Minetown AA Battery Specifications

From our comparison it is clear to us that the INIU 5V Li-Ion battery is best for our use. It provides more power than the other batteries and is to USB specifications. This means it can provide a standard of 5 volts to our devices, which is what we need.

3.14 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 Baud rate only needs to be 32.5 kBaud/s, 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 is summarized in the following table.

	FT232R	CH340E
Manufacturer	FTDI	LZQ
Supply Voltage	3.3V - 5.25V	3.3V or 5V
Baud Range	300 baud - 3 Mbaud	50 bps - 2Mbps
Duplex	Full	Full
USB compatibility	2.0	2.0
Price	$4.50 (sold individually)	$4.95 (pack of 10)

Table 27 - Serial-to-USB Converter Comparison

From the table, it can be seen that the two serial-to-USB chips compared are functionally very similar. They both are capable of the Baud rate that we are after for MIDI communication, and both support full-duplex transmission so that we can easily facilitate our laser harp’s USB connection with a single USB connection to a computer. Neither require an external crystal for clock generation, and are rather simple to implement. Because of this, either chip would fulfill the needs of our project.

Based on these considerations, we chose to use the CH340E, primarily due to the lower per-unit cost. This 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.

3.15 Voltage Regulator

An essential part of any electrical engineering project utilizing a noisy power supply is a voltage regulator. These simple and inexpensive devices take a noisy DC voltage input and convert it into a more solid DC voltage. This is very important in digital devices that require constant voltage for power supply and input, especially when the devices receive power from wall power, as spikes in voltage can cause damage to electrical components.

There are two main types of voltage regulators that are used today: Switching and Linear. In the following sections, we will compare these types of regulators, and after deciding which type of regulator we will use, we will compare a few specific voltage regulators that we will consider using in our laser harp design.

3.15.1 Linear Regulators

Linear voltage regulators use a linear component to regulate the voltage at the output of the device. Linear regulators are generally simpler to implement into circuits, as they often only require an input capacitor and an output capacitor to operate properly. They also have very low noise when compared to switching regulators, which suffer from switching noise. However, they are less efficient and can generate a large amount of heat. As linear regulators are powered by linear components, this heat is proportional to the difference between the input and output voltage, and can be calculated according to the following equation.

$$\boxed{P = VI}$$

Figure 63 - Power Dissipated Through Linear Voltage Regulator ($V = V_{in} - V_{out}$)

This heat can be minimized to an acceptable level by minimizing the difference between the input voltage and the output voltage. If we were to use a linear regulator in our device, we would need to select an input voltage that is still close to the desired output voltage of 5V we need for our microcontroller and other components.

3.15.2 Switching Regulators

Switching regulators use a switching component, like a MOSFET, to a pulsed voltage that is turned into a DC voltage using resistors, capacitors, and inductors. Because of this switching method of voltage regulation, switching regulators are very efficient devices that generate very little heat. This could be beneficial to our laser harp, as we intend to include battery power as an optional power source to aid in mobility. Switching regulators are also capable of boosting the input voltage, as well as bucking it like in a linear regulator. However, switching regulators require more external parts, which will increase the size and complexity of our PCB. As well, the conversion creates a much noisier output voltage, which can be a problem for digital devices, and an even bigger problem for a device that uses analog inputs from sensors, like our infrared sensors. In our laser harp, accurate readings from the infrared sensors are very important for musical expression, so noisy voltage regulation might cause too much of a problem for the laser harp's distance sensing subsystem.

3.15.3 Voltage Regulator Type Comparison

Now that we have compared the two types of voltage regulators, we will need to compare the pros and cons of the two and decide which will be more suitable for the laser harp. The major points of comparison between linear and switching regulators are summarized in the following table.

	Linear	Switching
Operation Modes	Step-Down	Step-Up/Step-Down
Heat generation	High	Low
Noise level	Low	High
Circuit complexity	Low	High

Table 28 - Linear vs. Switching Regulator Comparison

After careful consideration, we chose to utilize a linear regulator in our laser harp design. The primary reason for this decision is the noise level at the output of switching regulators. In our laser harp, accuracy of the infrared sensors is a very important feature, and we need to ensure that we don't sacrifice that accuracy for voltage regulation.

3.15.4 Linear Voltage Regulator Selection

Because we will be using a linear voltage regulator, we will need to be sure to include a heatsink in our design in order to prevent damage to other components from the heat dissipation in the voltage regulator. As well, we will need a voltage regulator that outputs 5 volts DC, and will need to have an input voltage to the regulator that is more than 5 V, with a difference low enough that heat dissipated through the regulator is not enough to cause damage to the circuit or other components. Because of this, a low dropout voltage will be ideal, as this will allow us to minimize the difference between input and output voltage, and thus decreasing the power dissipation. There are thousands of linear voltage regulators on the market that we could purchase, but we selected three to compare that appear to come close to what we are looking for. These linear regulators are compared in the following table.

	L7805	LP3855	LM1117
Manufacturer	STMicroelectronics	Texas Instruments	Texas Instruments
Maximum Input Voltage	35 V	7 V	15 V
Output Current	1.5 A	1.5 A	800 mA
Maximum Dropout Voltage	2 V @ 1 A	0.435 V @ 1.5 A	1.2 V @ 800mA
Price	$0.50	$4.90	$1.10

Table 29 - Comparison between Linear Regulators

From the information we gathered in this table, it can be seen that the LP3855 is the closest regulator to what we are looking for. Though it is the most expensive of the 3, it is still very inexpensive when compared to the entire budget of the project. The LP3855 can be found in multiple formats, but the TO-220 format will be the ideal choice for us, as this housing has a standard heatsink that can be purchased alongside it and attached with a simple screw. This, combined with the already very low dropout voltage, makes the LP3855 the ideal choice for our design.

3.16 Polyphony

Polyphony is the combination of parts or notes to create a melody and harmonize with each other. We plan on playing a full song when demonstrating the laser harp and polyphony plays a big part in this. To do this we would need to have the lasers constantly on and listening to a signal and have the microcontroller know that laser strings can be pulled simultaneously.

3.17 Display screen

It would benefit the user greatly if there were a display of some kind that will allow the user to know what scale they are on when playing. The screen would assist the user in changing the scale, running through basic hardware tests, and allow the user to communicate with the harp's settings directly. We need the display to be fairly small so that it can be mounted on the base of the frame next to push buttons to control the options. There are two types of screens that can be considered for this project, liquid crystal displays (LCDs) or another option being the organic light emitting diode (OLED). Both options will be considered and the price points and quality will be compared further below.

3.17.1 LCD vs. OLED

A liquid crystal display is commonly used for small projects such as Arduino and raspberry pi because of its low cost. LCD displays use a backlight that uses cold cathode fluorescent tubes or LEDs to create the light housing m multiple layers of components. When compared to the OLED display which requires no backlight or as many parts but are more expensive. Some things to consider before purchasing a display are the sizes and the power consumed by each display. LCDs are much thicker than the OLEDs because of the number of components required for the backlighting. Because OLEDs do not require a backlight, they will have a display that does not get as bright as the LCD will. Since the laser harp will not be in outdoor conditions, we do not need to have the display be extremely bright. OLED gives a richer color because the black pixels are off when not used whereas there is light leakage from LCD displays that make the blacks look faded rather than dark. OLED also has a better viewing angle compared to LCD; the picture quality does not fade when you look off center. LCD displays have that back light panel making it bulkier than OLED, because OLED has those self-illuminating pixels rather than a whole backplate of LEDs. It would be good to consider both types of displays and we will investigate manufactures after displaying some basic parameters of the two screen types as shown below in table 30.

Parameter	LCD	OLED
Response time	Around 1 ms	Up to 1,000 times faster
Cost	$5- $20, affordable	$10-$50, more expensive

Viewing angle	Limited to 50 degrees	Higher range, 80 degrees
Viewing contrast	Light bleeds in	Darkest blacks
Thickness	More components, larger	Thinner
Power consumption	Has backlight to power	Requires no backlight
Contrast	Noticeable	Much better
Voltage	3.3-5 volts	3.3-5 volts

Table 30 - LCD and OLED Parameter Comparison

3.17.2 Display Options Considered

There are two display options shown below in figure 64 which were found online. The screens are both priced affordably from the manufacturer meaning we can have free range in the final decision since price point is no longer a factor. The Frieda OLED display is 1 inch in all directions and if we needed a bigger display, we could always upgrade. The LCD panel is made by HiLetgo and is a longer display that measures roughly four inches across giving more legible script to read. Some manufacturers specifications can be viewed below in table 31.

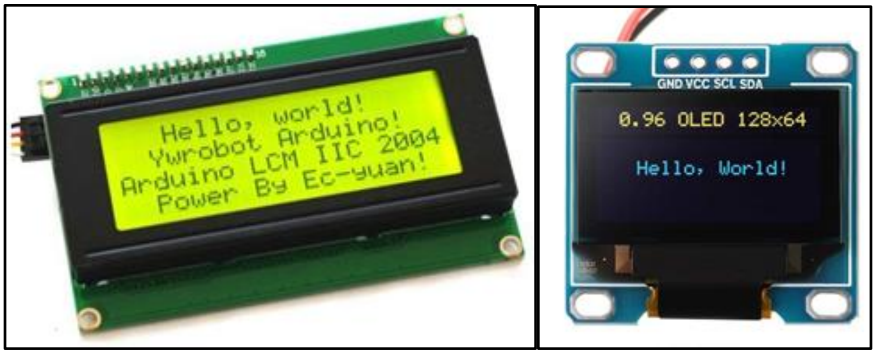


Figure 64 - LCD and OLED Purchase Display Option

Specification	Frieda OLED	HiLetgo LCD
Size	0.96 inch	60mm x 99 mm
Supply voltage	3.3-5V	5 V
Backlight	Yes	No
Text display	2 rows of yellow 6 rows of blue	Yellow background with black text

Table 31 - LCD and OLED Manufacturer Specification Comparison

The OLED panel is much nicer than the LCD, we want the laser harp to be visually pleasing at all levels including instructions and settings menus. The OLED is chosen because of its vibrant color display while not having to power a backlight the entire time. Because the pixels only illuminate when they are active it will consume less power and consume less current than the LCD display.

3.18 Parts Selection Summary

In the previous sections, various technologies and components were discussed and explored. This section will summarize the parts that were selected for use in the laser harp, as well as their cost. The laser diodes, photoresistors, and optocoupler are very low-cost components, and as such will not have a large effect on the budget of our project. The most expensive part we had to select was the infrared sensor, of which we need 15. A tabular summary of the major component selections can be found in the following table.

	Selected Part	Price per unit	Quantity needed	Total Cost
Laser Diode	HiLetgo 5 mW 650 nm	$0.39	15 (10/pack)	$12.98
Photodetector	eBoot Photoresistor	$0.16	15 (30/pack)	$4.95
Infrared Sensor	Sharp GP2Y0A41SK0F	$8.74	15	$131.10
Optocoupler	Vishay 6N137	$1.78	1	$1.78
Microcontroller	Atmel ATmega2560	$11.99	1	$11.99
Serial-to-USB Converter	CH340E	$0.50	1 (10/pack)	$4.95
Voltage Regulator	Texas Instruments LP3855	$4.90	1	$4.90
Display	Frieda	$4.00	1	$4.00

Table 32 - Component Selection Summary

This table summarizes the costs of major components that will be used to realize our laser harp design in the second semester of the Senior Design class. These components all come together to less than $200, which is well within our means, as the project will be completely self-funded. Aside from the costs of these components, there are other important costs we will need to consider when we begin to develop and construct our physical prototype. For one, we will have to design and manufacture a PCB, as well as assembling and mounting components onto that PCB. Another cost consideration we will have is the cost of the frame of the laser harp, including both materials and manufacturing. These will be discussed and expanded upon in later sections of this report.

4.0 Prototype Software Design Detail

In this section we will explain how we will plan on executing the laser harp on a software level.

4.1 Microcontroller Flow Chart

The flow chart in figure 65 displays the execution we plan on doing for the microcontroller interacting with the hardware. As displayed, we have a constant loop with five different detectors, each detector checks to see if their own laser has been blocked. When one, more or all have been blocked they will emit their own distinguishable note and once they are no longer blocked, they will resume their original state of constantly waiting for a blockage. This is one dimension of musical notes that the harp will be able to perform, the latter is discussed further below.

The critical feature we plan on is the ranging detection via infrared sensors which we will connect via UART and we can communicate with the sensor. The infrared sensors detect location via time of travel of a returning signal from the original location. We will set up parameters which we will denote each set parameter based on how the musical note will be played, such as if you have one laser string if you pluck it at different heights or distances it will play a different version of the note.

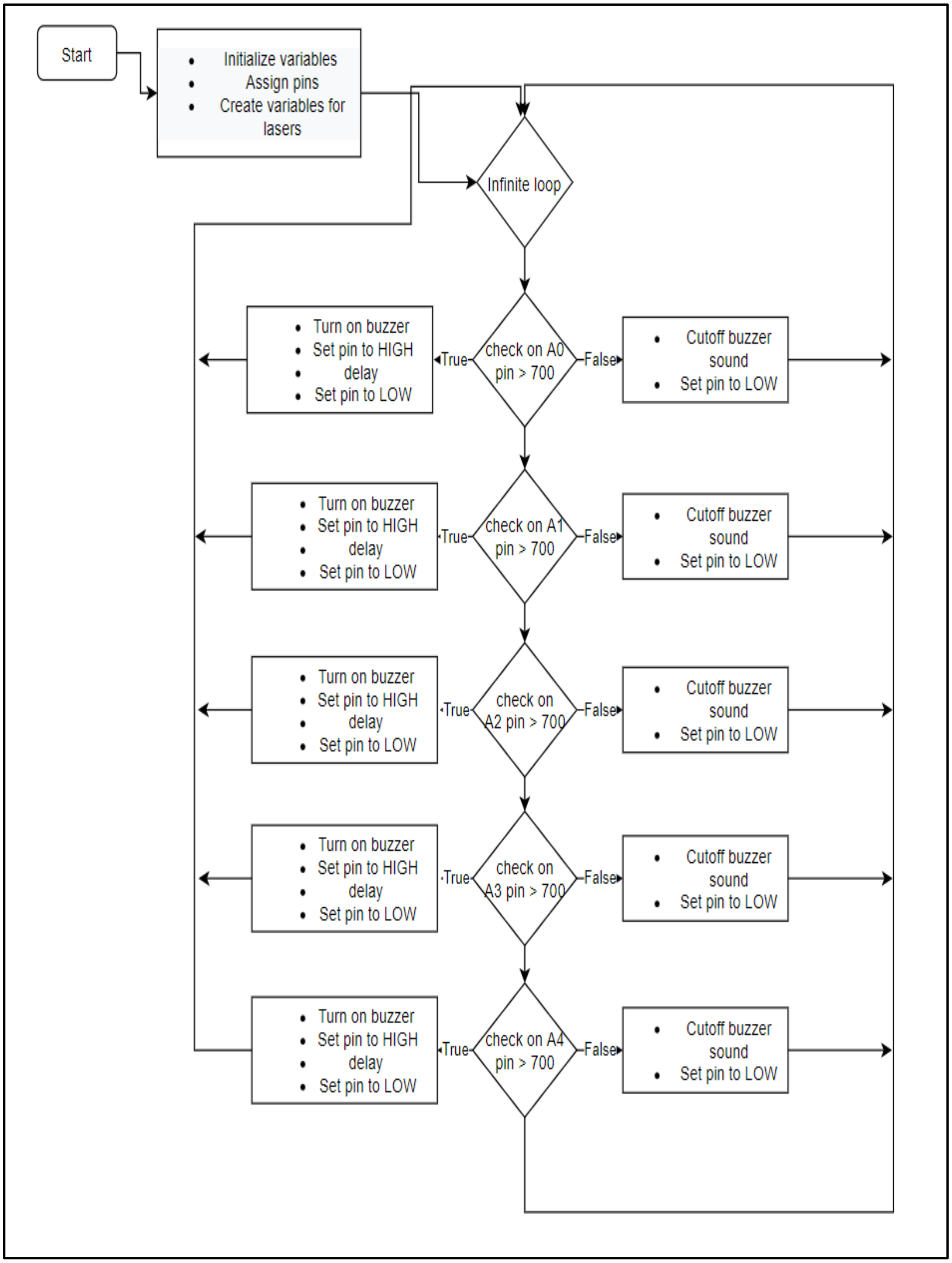


Figure 65 - Arduino Microcontroller Flow Chart

5.0 Prototype Operation

Below are some of the basic functions used in the arduino code.

5.1 Arduino Functions Used

To control the arduino one must use commands. A reference to the arduino website allows us to learn basic commands to control the arduino allowing us to play a laser harp.

Setup() – The setup function in the Arduino language is one of the first functions used in the program. It is used to initialize all the variables in the program as well as the pin modes and libraries. When you turn on the device, aka initialize the Arduino, the setup function will run a single time.

Loop() – the loop function from the Arduino library is critical for the continuation of the harps constant reading data and responding. The loop function literally cycles back the code continuously until a set condition ends the program. In our case the loop will run continuously until the systems power is switched off. The loop function houses the main part of the program, for it will call other functions from the loop function itself. We want to continually read the analog data of the IR sensors and the LDRs so we must constantly be looping back to play continuous notes.
Pinmode() - has two input fields one is for the selection of the physical pin on the board and the other is the mode which can range from an Input, an Output or even trigger with a digital pin and will react when the resistor pulls up.

Tone() - has two inputs, one that allows you to choose the pin you want and the other will generate a square wave of a specific frequency on a pin. The square wave is sent to the speaker that relays a sound. Because it is a square wave the tone does not change in pitch, it is just a constant note with no ability to interact with it. That is why we plan to add distance detectors, so that we can alter the pitch of a note while playing it.

Notone() - one input that chooses a pin and then the function will end the square wave when activated by tone(). This creates no sound on the speaker and is needed to end the current generated tones.

Analogread() - takes in the input of the component and reads the value from the specified pin. This takes information from the LDR and reads the value that it currently has. If the value falls below a certain threshold a tone will be emitted. This is critical for the laser harp, without the ability to detect if the strings are blocked there would be no musical notes being played. The analog data received by the microcontroller is used to determine the distance from which the hand intercepts the beam as well. The data must be refreshed constantly in order to have a playable harp, it is critical to have this function work properly.

Digitalwrite() - has two input fields one that choose the pin and the other allows the user to set the value of the digital pin to HIGH or LOW. Depending on how the pin is set will determine the output of the pinmode. If it is set to OUTPUT the voltage will be set to 5V for HIGH and 0V for LOW.

5.2 Prototype

We temporarily have a functional prototype that performs half the functions that are required from our laser harp. Currently the prototype has the functionality of playing musical notes when the laser diodes path is intercepted, blocking the beam from reaching the photodetector. The beam comes from the laser diodes that are fed constant power so that they are always active. With the path of the beam being blocked, the LDRs can react quickly enough to relay a signal to the microcontroller. There needs to be implementation of the second part of the prototype, which is where the beam is blocked. Measuring out the distance will allow for a higher range of musical notes and sounds. The intention for the prototype is to use infrared LED emitters and receivers to calculate the time it takes for the signal to return. It uses an arduino micro as the microcontroller communicating the received data from the LDRs and creating signals for the speaker. Each laser diode is equipped with its own specific note, creating a basic melody of sounds when you run your hand across the detectors. One of the issues we ran into when using solely the arduino is the lack of musical choices. The Basic speaker and arduino software are only equipped to make simple tones, however we plan on making the notes much more realistic and comprehensive. The electronic signals will go to a MIDI interface which can translate the electronic data into a recognizable musical note. With the interference of multiple laser strings, you will hear all the strings interrupted play. What's more is that the design requires a depth detector in order to add more control over musical performance. By adding a second layer of music settings we create a harp that has more functionality allowing the player to create more complex tunes.

6.0 Related Standards and Realistic Design Constraints

This section will describe and discuss the impacts of various engineering standards and design constraints that will impact the design and construction of the laser harp.

6.1 Related Standards

Standards are a vital aspect of engineering design. For our laser harp, there are a few well established standards that we will adhere to. These standards are outlined in the following sections, and the impact of the standards on the design, both positive and negative will be accounted for. There are a plethora of organizations that derive and verify standards at all levels. Local, national, and global organizations and associations can all be sources for standards information, and these standards and the organizations that maintain them will be outlined in the following sections.

6.1.1 Software Standard - Musical Instrument Digital Interface (MIDI)

Musical Instrument Digital Interface (MIDI) is the standard for communication between electronic instruments, lighting controllers, and various other devices relating to live performance. The details of the standard have been maintained by the MIDI Manufacturers Association, “which was officially established as a California nonprofit, 501(c)6 trade organization) in 1985 with the goal to expand, promote, and protect MIDI technology for the benefit of artists and musicians around the world.” [XX] According to the MIDI 1.0 specification, “MIDI, the Musical Instrument Digital Interface, was established as a hardware and software specification which would make it possible to exchange information (musical notes, program changes, expression control, etc.) between different musical instruments or other devices such as sequencers, computers, lighting controllers, mixers, etc.” [XX] This is a very important standard to adhere to, as the MIDI standard has been implemented as the sole method of controlling electronic instruments for decades. By implementing MIDI into our laser harp, we can ensure that it is compatible with nearly any electronic instrument on the market, new and old.

6.1.2 Design Impact of MIDI Software Standard

The use of this specification will allow our laser harp to communicate easily with any external devices simply by connecting one standard cable. MIDI is a digital communication protocol and specifies the baud rate, so the MIDI spec informs us on how we will divide the clock of the microcontroller and how to program our device to interpret inputs, both analog and digital. MIDI is limited to 127 different notes that can be transmitted, but this limitation will have little impact on our design, as a traditional grand piano has only 88 notes, so no external devices will realistically be impacted.

6.1.3 Hardware Standard - 5-Pin DIN Connection

In order to interface with hardware synthesizers and samplers without complicated modification, we can apply the standard 5-Pin DIN connector that is used in most electronic instruments. The 5-pin DIN connector has 5 pins, but two of the pins are used to supply phantom power to devices like microphones, so we will only need to use 3 of the 5 pins in our connectors. This design involves the use of an optocoupler at the input of the device to negate a ground loop hum and noisy inputs, as well as a few resistors. The traditional design of the connection uses a 5 V supply to facilitate the serial communication, but can also be adjusted to tolerate a 3.3 V input by changing the resistor values.

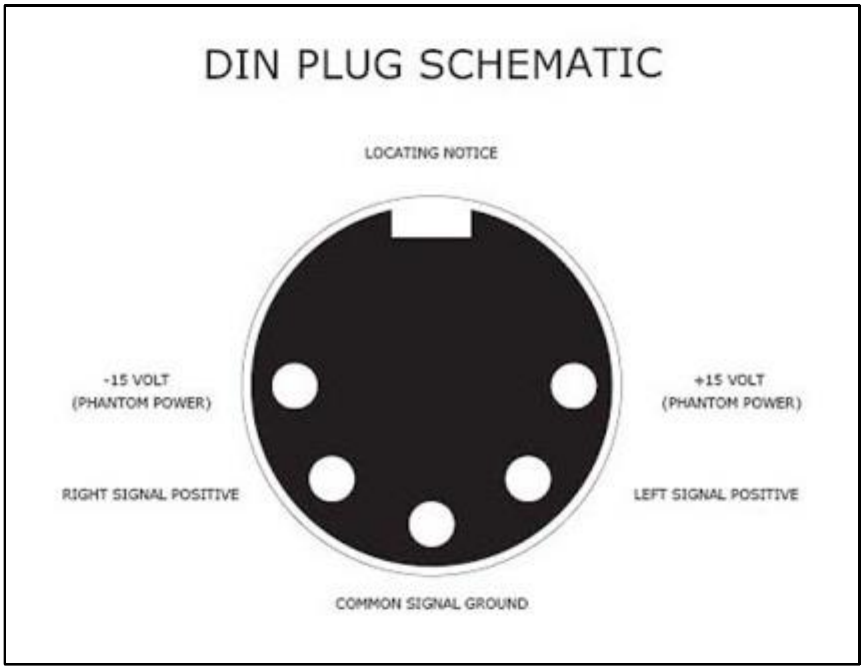


Figure 66 - MIDI 5-pin DIN Connector

6.1.4 Design Impact of 5-Pin DIN Connection Standard

The implementation of the 5-Pin DIN connector primarily impacts the power supply design decisions of our device. As the connection requires either a 5 V or 3.3 V power supply, we will want to select components that can operate at this voltage, such as the microcontroller unit. This will also affect our PCB design and the design of the case, as we will need to allow for connections to both 5-Pin input and output.

6.1.5 Hardware Standard - Universal Serial Bus (USB)

We are incorporating two types of Universal Serial Buses (USB) and they are the Mini-B and the USB-A. USB-A goes in a power source or into the computer while USB Mini-B goes into the microcontroller. Both of which are used to power our harp and upload our software onto the microcontroller.

6.1.6 Design Impact of USB connection

We are limited to how both USB-A and USB Mini-B are capable of doing. USB-A and USB Mini-B have a V_BUS which can be used up to five volts, Negative Data, Positive Data, and a Ground. But the USB Mini-B has a special feature which is the ID or On-The-Go ID which distinguishes between the A-plug or Host which goes to the ground and the B-plug or Device which isn't connected.

6.1.7 Software Standard - Arduino Software

The Arduino software was the IDE that we used to program the microcontroller. The IDE is an open software that can be used on multiple systems ranging from variants of Windows, Linux, and Mac operating systems. The IDE is very similar to the C language just with added inputs and outputs that need to be added to communicate with the microcontroller.

6.1.8 Design Impact of Arduino Software

When it came to the design impact of the Arduino Software in relation to the microcontroller, we had two options which were the Arduino Nano and the Arduino UNO. Both were perfect for what we needed to do but there was only one clear choice for us. It was the Arduino Nano. The reason being was it had a smaller form factor, light weight, and had more pins than the UNO. Not to mention we had a Nano laying around but it didn’t stop us from buying and trying both.

6.2 Realistic Design Constraints

As all projects when designing one there will arise some problems, either it be software, hardware or the dynamic of the group. When constructing the laser harp, we had to take some extra precautions since we are dealing with lasers. So, whenever we had to work on the harp everyone had to wear a set of eye protection to prevent any injury of the sorts without impacting the time frames, we prior to starting designated. We wanted this harp to be large enough to retain a certain set of notes while making it small enough to move around easily.

6.2.1 Economic and Time Constraints

Economic Constraints are very important in the realization of our design, and they can impact what materials we use, what parts we choose, as well as the overall scope of our design. Our project is not sponsored by any outside organization or company, and so it will be funded solely by us, the students designing and building it. Because of this, we need to be careful to prevent our design from incorporating too many expensive technologies or manufacturing processes that might prevent us from realizing our goal. This economic limitation is further affected by the ongoing COVID-19 pandemic, which has negatively impacted our individual sources of income. Because of this, we also will need to carefully consider the components we choose to ensure that we will not waste our limited budget on parts that do not see use after the testing phase.

Aside from Economic Constraints, we also have to account for Time Constraints, which can have a large impact on how we design our device and how we plan our testing, prototyping, and finalization. As our design is part of our Senior Design project, we have a strict schedule of major deadlines, such as the final report and a final presentation, and these are the primary factors in our time management and planning. The research and design phase of the project is to be completed by December 8th, when the Final Design Document is due at the end of the Fall 2020 semester. After that, we will begin construction and testing of the prototype in the following months during the Spring 2020 semester. The final product will need to be operational at the end of the Spring 2020 semester, when we will present the project to a panel of professors and professionals to demonstrate the functionality of the laser harp. To ensure that we are able to meet these deadlines, it is imperative that the group stays connected throughout the development process. We will have regularly scheduled weekly meetings with all members of the group to discuss any developments that we have made, as well as ones that need to be made.

6.2.2 Environmental, Social, and Political Constraints

Our Environmental Constraints, is the living location of where we were based, were fairly normal since we are all Florida residents and we can travel to one location pretty easily. We would typically travel to one of our members' apartments because it was like a central meeting point and they had all the tools that we needed. The build process will likely occur separately in multiple locations due to the continual social distancing recommendations. The build will mostly occur at the Tecport warehouse or we will design and purchase parts remotely.

Our Social Constraints, is the way we all felt towards each other, are also pretty normal, none of us would lash out in anger, stress or any other negative emotion. We were all courteous to each other and asked about each other's concerns pertaining to the project if it impeded our completion. We also would voice each other's concerns or listen to them based on what we thought about designing our project.

Our Political Constraints, is how we set up our roles in the project, are very basic because we didn’t delegate any roles to anyone. We just took the roles that pertained to our majors like the Photonics Majors took over researching photonics related articles and choosing the types of lasers to use, the Computer Engineer would code up what was necessary, and the Electrical would work on the Electrical components of the breadboards and test out what was needed. Since all our majors had a base of electronics, we would all help each other out in those departments if one needed help.

6.2.3 Ethical, Health, and Safety Constraints

As we started this semester during the COVID-19 Pandemic still going on Ethical, Health and Safety Constraints are severely impacted due to this. Holding in-person design meetings was made much more difficult due to social distancing recommendations from the CDC and this limited how efficiently we were able to prototype and design the laser harp. In general, face to face contact has occurred once to display the prototype and discuss further improvements. Following all safety precautions, remaining several feet away from each other makes it difficult to work together in a room and more so on a single project.

The Ethical Constraints, where our moral standards are placed, were pretty standard human needs; we tried to make sure we could meet and work on the project when everyone had the time to, such as after work, school, or at leisurely times. Whenever we planned on working on the project, we would ask each other if it was within our means of doing so, so that there wouldn’t be any conflict.

The Health Constraints, which was how our general wellbeing, were more standard than what we did because of the COVID-19 Pandemic so we would wear masks whenever we had met up to work on the project. We all remained several feet from one another and discussed while wearing proper protective equipment. Nobody ever came across a cold or the virus or showed symptoms itself even though some of us dealt with coming in contact with numerous people a day.

Safety Constraints which were pretty similar as the Health Constraints but with added protection like wearing eye protection since we dealt with the use of lasers and the use of safety gloves when it comes to soldering the electrical components. As well, lasers can cause temporary or permanent damage to eyes when viewed directly, so it is important for us to design a device that limits the possibility of a user from accidentally being blinded by the lasers. This can be accounted for by designing a frame that blocks the lasers at the top, so that the user cannot place their head in such a way that the laser points directly at their eyes.

6.2.4 Manufacturing and Sustainability Constraints

The manufacturing constraints of this project are primarily impacted by the COVID-19 pandemic. Because of social distancing guidelines and restrictions from UCF and local government, the manufacturing options that would normally be available to us through UCF are limited, and some outright restricted. When designing, we have to account for what can actually be manufactured, given our resources. For example, we initially considered using some sort of metal for the frame of the laser harp, but realized quickly that manufacturing using metal would not be feasible.

Sustainability constraints are based around the impact of our design on the natural environment. As our design does not involve any disposable parts (such as batteries), there is little concern of environmental waste from the laser harp. As well, the materials we choose to use to build the laser harp will affect sustainability.

7.0 Hardware Design Overview

The hardware in our design are all of the parts that supply power to the laser harp, as well as controlling the functionality of the laser harp. This section contains information pertaining to the hardware design necessary for the laser harp.

7.1 Initial Design Architectures and Related Diagrams

After conducting further research into the components and technologies that will be used in designing the laser harp, we were able to develop a more accurate diagram of the various data and power supply connections in our design. The ATMega2560 microcontroller is the central device in the laser harp, and from there the various subsystems, such as laser creation/detection, distance sensing, and Input/Output are connected to the microcontroller. This general design architecture can be seen in Figure 67.

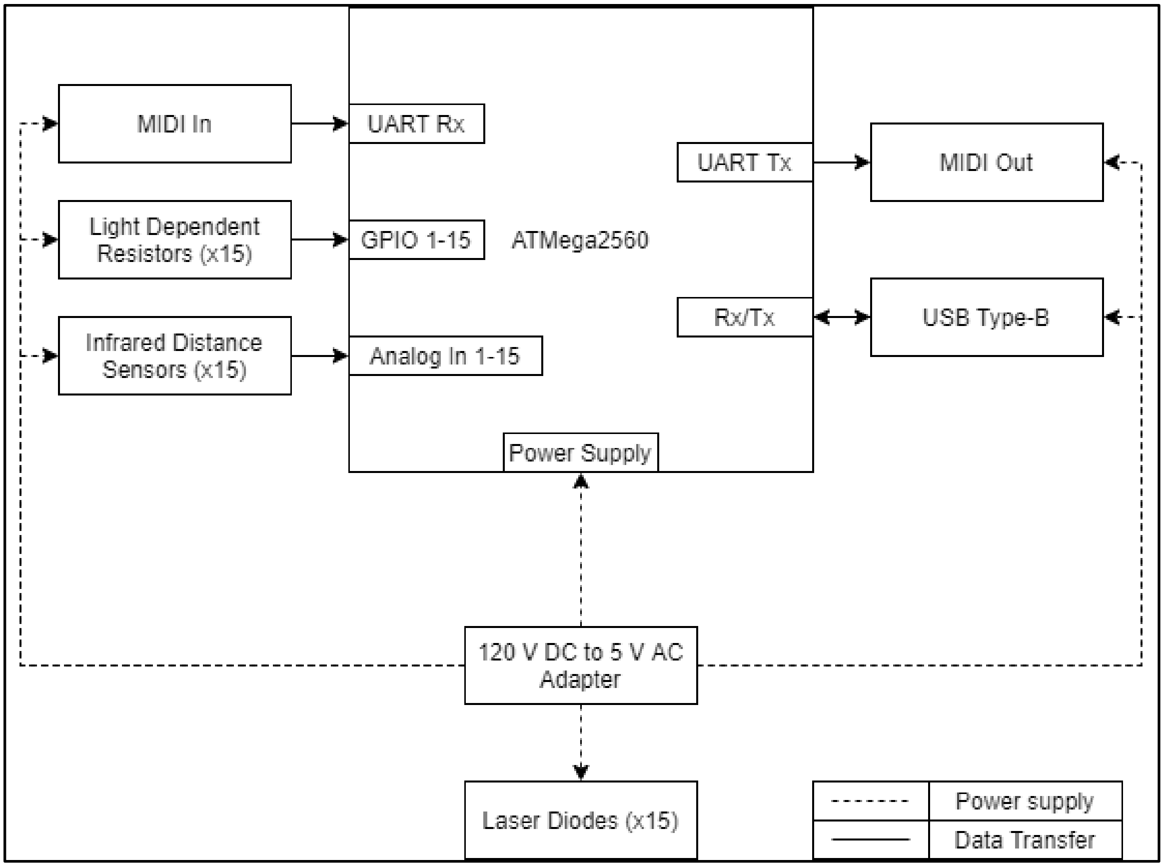


Figure 67 - Block Diagram of Design Architecture

As can be seen in Figure 67, all of the data connections are run through the microcontroller, and most of the individual circuits are isolated from each other. This is important, as it allows us to design all of the individual subsystems of the laser harp while having minimal impact on the other subsystems. All of the electrical circuits, including the microcontroller are designed to use a 5-volt power supply, which removes a need for any step-down or step-up conversion and helps to simplify the design.

The following sections will describe each of the individual subsystems of our design in greater detail, as well as how they interact with each other and external devices.

7.2 First Subsystem - Laser Diodes and Photoresistors

The first subsystem of the laser harp relates to the laser diodes and photoresistors that are used to simulate harp strings. There are 15 individual laser diodes that are situated at the base of the frame of the laser harp, which project beams of light from the bottom of the frame to the top bar. These lasers are separated by 1.5 inches to allow for proper spacing and playability for the user. Along the top are photoresistors which are aligned to be opposite the laser diodes. When the lasers are pointed directly at the photoresistors, their resistance is very low. When the beams are blocked by a hand or some other object, the resistance of the photoresistors increases. These two states of high and low resistance are necessary for the microcontroller to receive as logical high and low values, which can then be used to determine when to send MIDI Note On or Note Off messages to an external device.

To test this functionality, we constructed a breadboard test circuit using 5 laser diodes, 5 photoresistors, and a buzzer connected to an Arduino Nano. This breadboard test circuit is shown in the figure below.

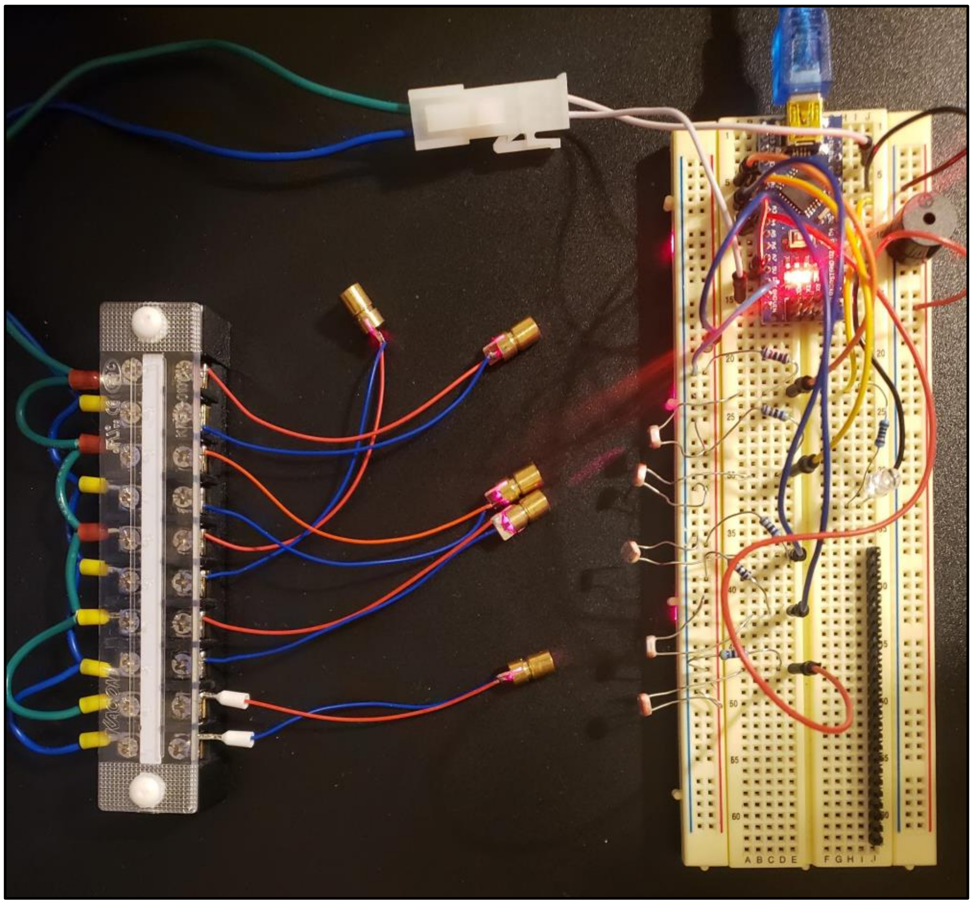


Figure 68 - Breadboard Test Circuit for LDRs and Laser Diodes

In the test scenario, we assembled the basic components that were bought with the budget in mind using spare wiring to connect the laser diodes together. From the image above you can see that the arduino is powered on allowing the laser diodes to lase in the direction of the photodetector. Because of budget constraints and it being our initial attempt, we did not secure the laser beams so that they are pointing at a fixed position. On the breadboard there are photodetectors that are meant to be aligned with each laser diode. The photodetectors are connected to individual pins on the arduino to relay information about each specific detector. The initial set up was equipped with a speaker and with the software the tone of each laser string played a different sound. The functionality of this initial prototype worked accordingly, when the beam is blocked a tone is emitted from the speaker.

In our full-scale design, this will be implemented with 15 laser beams and photodetectors instead of the tested 5. The general functionality will be the same, but the laser diodes will be aligned so that they are focused on the photoresistors at all times. The photoresistors will be connected to the microcontroller in an array of voltage divider circuits, which will allow the 5-volt supply voltage to flow to the microcontroller's digital GPIO pins only when the lasers are blocked, as the resistance of the photoresistors will increase to maximum when the lasers are blocked. Connecting the photoresistors in this manner, rather than directly into the analog/digital converting input pins allows us to use the analog/digital converter for the infrared distance sensors instead. This is preferable for our design, as the distance sensor data needs to be converted into 7-bit values for use as MIDI CC control values, whereas the photodetectors only need to be read as a simple on/off state change.

7.3 Second Subsystem - Distance Sensors

There are several distance sensors mentioned in this paper, but for the initial prototype we purchased infrared emitters and receivers, primarily due to their low cost. The purpose of knowing the distance of where the beam is blocked is how the laser harp will be able to hold so many notes. If it were just one note per string, we would require a very large device, making it impractical to play and move around. We want to make a more portable system which requires it to be somewhat compact in the sense that you can easily move it from place to place. For that reason, knowing the distance from where the beam is blocked allows for more notes or sounds in the same string. With the software we can break up distance into an array of notes and depending on the height of the intercepting hand will determine the final sound. This distance information can be sent via MIDI as Control Change (CC) messages that can be mapped to various parameters on external devices, such as timbre or volume.

The distance sensors, of which there will be at least 7, will be aligned in a similar manner to the laser diodes on the frame of the laser harp, with 1.5 inches of separation between the centers of the infrared sensor beams' emitters. The infrared sensors will be supplied with the same 5-volt DC source, and they will share a common ground. The output voltage of each infrared sensor will be connected to one of the 16 analog-to-digital converter pins, allowing the microcontroller to read the output voltage of each infrared sensor individually.

7.4 Third Subsystem - I/O

As the laser harp is intended to interface with external devices, like synthesizers and samplers, it is important that we include a variety of I/O options to maximize functionality and compatibility. The first two of these are the standard MIDI 5-pin DIN connectors, which are each connected to the rest of the circuit by 3 terminals to facilitate UART communication with external devices. For the UART communication, the baud rate will be set to 32.5 kBaud/s, which is the standard baud rate used in all MIDI communication. The MIDI Input and Output will be connected according to the MIDI standard schematic in Figure 2, but the originally specified 6N138 optocoupler will be replaced with the faster 6N137 optocoupler. The 220 Ω resistor connected to the optocoupler will be swapped with a 10k Ω resistor to facilitate the component change. The optocoupler will be supplied with 5 volts at pin 8, and pin 6 of the optocoupler will be connected at pin 63 of the microcontroller, which will be configured as a UART receiver. The MIDI Output will also be connected according to the MIDI standard schematic in figure 2, and pin 2 of the 5-pin DIN connector will be connected by a 220 Ω resistor to pin 64 of the microcontroller, which will be configured as a UART transmitter. As well, we will include a USB-A connector to be used to connect to a computer via USB to send and receive MIDI messages.

8.0 Software Design Overview

To properly control and utilize all of the components of the laser harp, we will need to write a program that will take in the inputs of the laser detectors, infrared sensors, and buttons and control those to create a MIDI output. For this, we used the Arduino IDE, mainly because of its wealth of third-party libraries that greatly simplify our programming, and the ease of uploading sketches during prototyping.

8.1 Software Design Flowchart

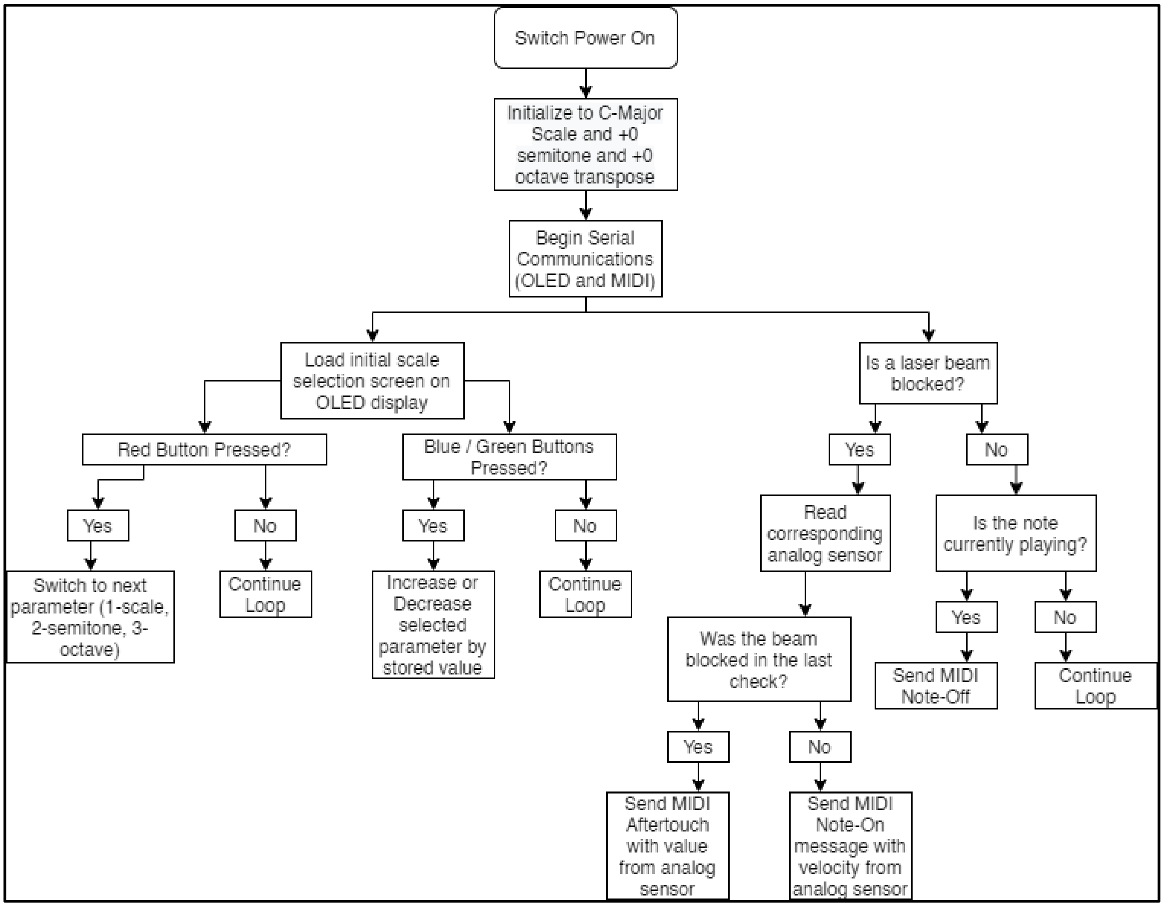


Figure 69 - Software Design Flowchart

Figure 69 shows a simplified version of the general structure of our main code for the laser harp. Outside of initializing upon startup, the whole program runs within an infinite loop, which checks for inputs from the laser detectors and buttons, and uses these to send MIDI notes to external devices and to control which notes are played. The OLED display is controlled by a set of integers that correspond to the parameter being changed, and values for the scale, semitone transposition, and octave transposition. Whenever the loop resets, it checks these values and sends the corresponding characters to the display to indicate what the user is controlling, and what value is currently selected. The laser detection and infrared is a relatively small section of the code, but is repeated 15 times, one time per string. There are individual versions of each value needed to properly process the inputs and send the correct notes. Because the clock speed of the microcontroller is significantly faster than the data transfer rate used by MIDI, which is significantly faster than a human input, there is no need to multiplex the sensors or laser detectors, and this greatly simplifies the program's structure.

8.2 Libraries

In order to simplify our programming load, we included a few external libraries in our code. Particularly, we used a MIDI library, which consolidates the MIDI protocols into simple, multivariable function calls. As well, for the OLED display we included a library for our SSD1306 OLED that easily converts character strings into bitmaps that are easily printed on the display buffer. These two libraries are key to the simplicity of our code and program.

9.0 Project Prototype Construction Plan

In this section we will describe the initial plan and design that we will use to construct our initial prototype. We will also discuss various PCB suppliers that we considered for the development of our prototype PCB.

9.1 Schematics

The following figures are the electrical design schematics that we plan to use to develop and test our prototype. The schematics were created according to the hardware design described in the Hardware Design Overview. The following table can be used as a legend to interpret the component labels in the schematics.

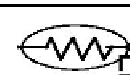
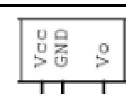
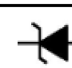
Component Label	Corresponding Component	Component Symbol
LDR	Light-Dependent Resistor	
IR	Infrared Sensor (GP2Y0A41SK0F)	
LD	Laser Diode	

Table 33 - Schematic Legend

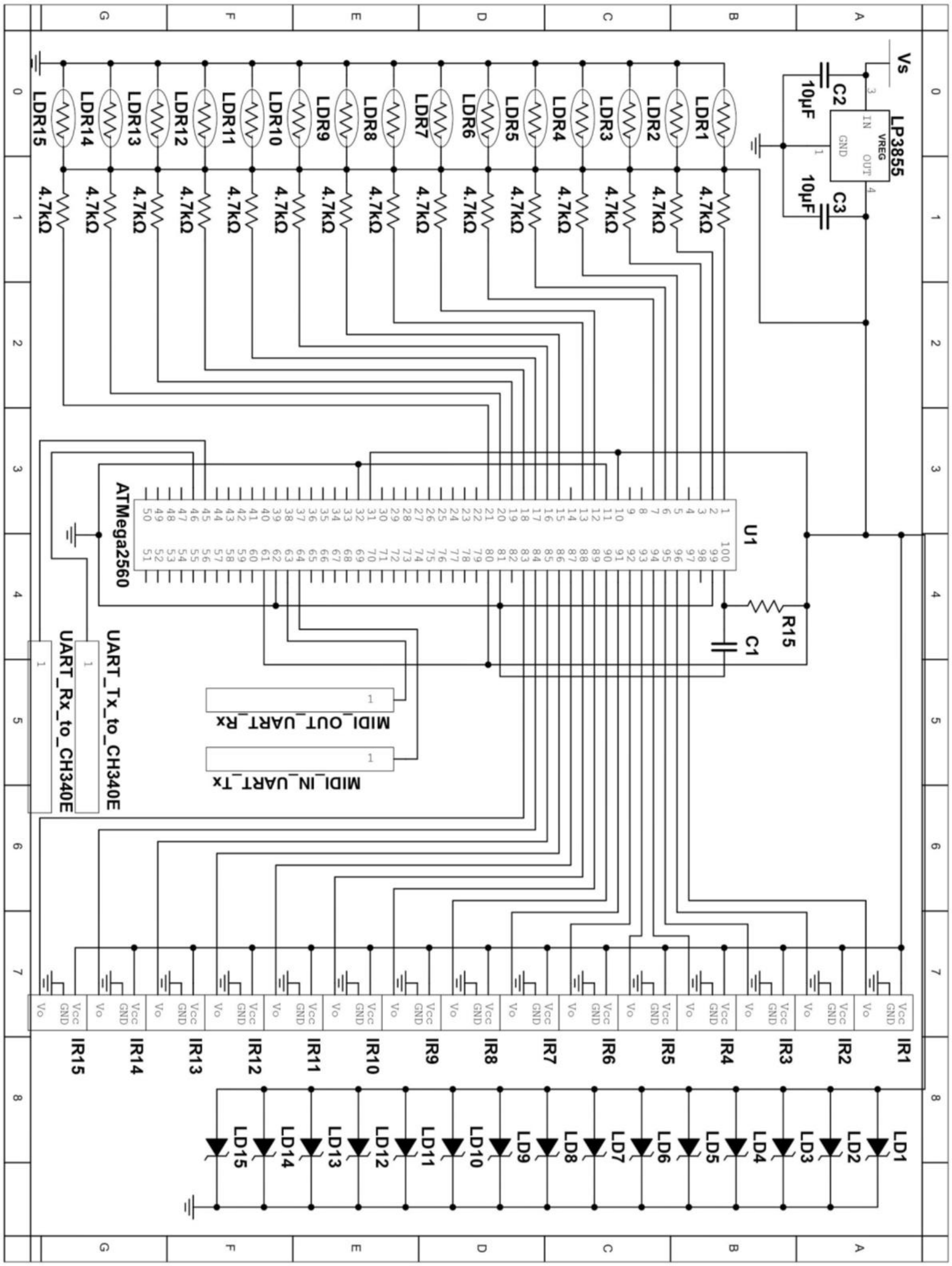


Figure 70a - Design Schematic of Microcontroller, Laser Diodes, Laser Detection, and Infrared Distance Sensor Subsystems

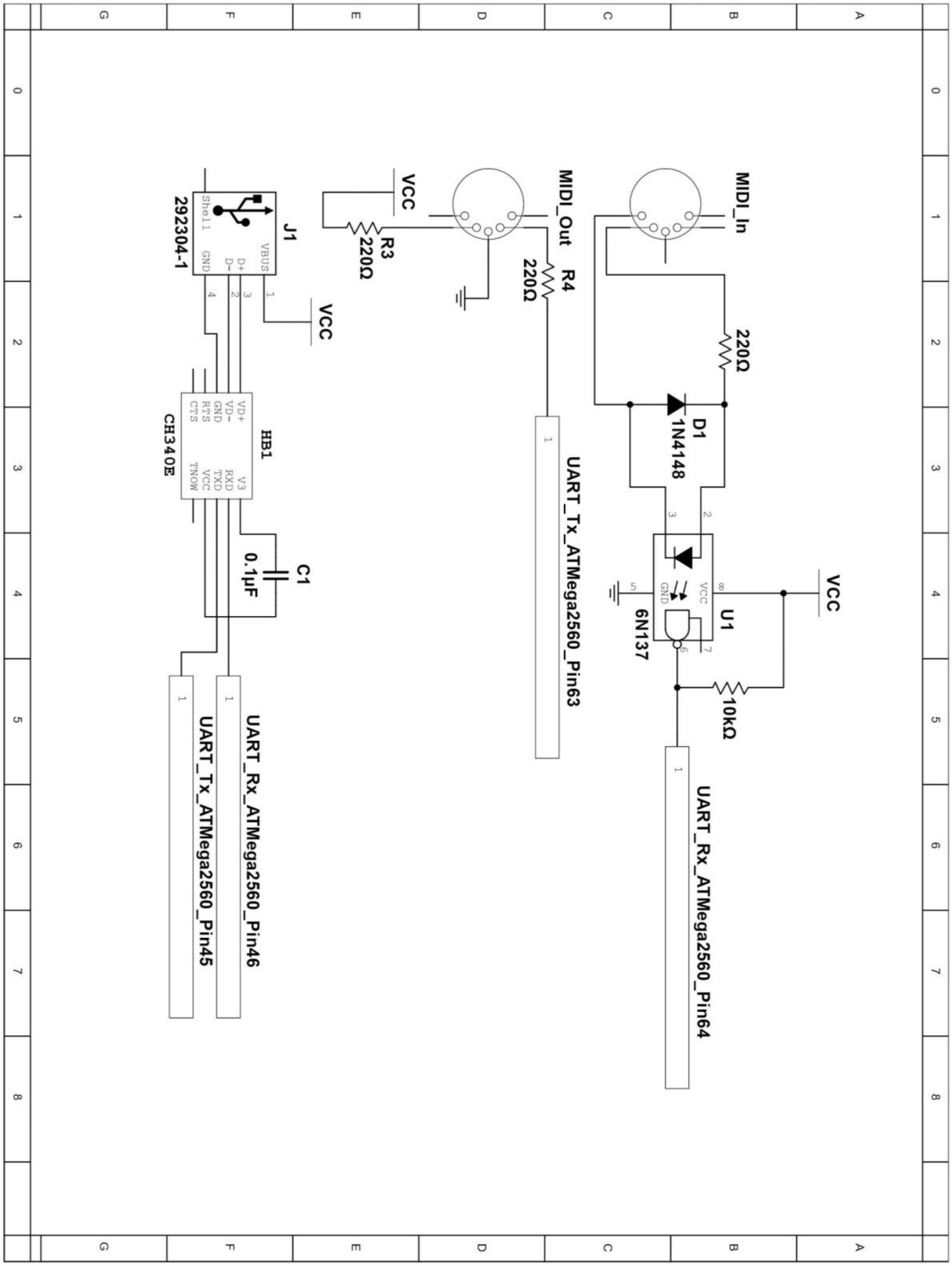


Figure 70b - Design Schematic of MIDI Input/Output Subsystem

9.2 PCB Vendor and Assembly

In order to fully realize our design and to satisfy the requirements of our senior design project, we will need to design and produce a PCB to use in our final prototype. While we are permitted to conduct breadboard tests and use direct wiring to test our components and circuitry, we will still eventually need to transfer those components onto a printed PCB. None of our group members have experience with PCB design or PCB manufacturing, but we do have a wealth of resources online and can also receive help from our Senior Design professors with PCB design.

To fulfill this requirement, we will need to select a PCB manufacturer and supplier that can satisfy our needs, while conforming to our budgetary restraints. Luckily, the whole process of designing and ordering a PCB can be conducted completely online, so this part of our project will not likely be affected directly by the COVID-19 pandemic, although we will need to account for possible shipping delays caused by the increased load on shipping and delivery companies. As such, we will need to order our PCB as soon as possible, to ensure that we are able to construct and test our prototype in time to make any necessary adjustments or calibrations before our final presentation.

There are a wide variety of PCB manufacturers to choose from, and their pricing can depend on a variety of factors, such as the surface material, number of layers, board size, and many more. In order to attempt to narrow down our choices, we will compare a few quotes from 3 manufacturers that are popular with online hobbyists that are able to do low-quantity runs for our project. These prices were sourced from pcbshopper.com, and were based on a 5” x 10” 2-layer PCB with a thickness of 1.6 mm. This information is collected in the following table.

	JLCPCB	ALLPCB	Elecrow
Location	China	China	China
Minimum quantity	5	5	5
Price per Board (minimum run)	$2.66/each	$4.44/each	$6.75/each
Standard Shipping Time	27 days	32 days	27 days
Fastest Shipping Time	6 days	6 days	11 days
Total w/ fastest shipping rate	$36.84	$48.58	$63.91

Table 34 - Comparison of PCB Manufacturers.

From the information gathered in the table, it is clear that JLCPCB is the most cost-effective choice of manufacturer, and also allows for the quickest turnaround if we need to have the PCB shipped quickly. JLCPCB also offers PCB assembly services with surface mount components and comes well reviewed from electrical hobbyists and engineering students alike, so they will likely be our choice for PCB manufacturing and assembly.

While JLCPCB will be able to provide us with PCB assembly services, we will also need to solder many of the components that will not be mounted directly on the PCB ourselves, such as the MIDI and USB connectors and the laser diodes. One of our group members has some experience with soldering connectors and similar components, so we will likely be able to handle whatever other part assembly is necessary after the surface mount components ourselves in order to save on costs.

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 the light-dependent resistor or LDR, Figure 71 and our main board which would handle the MCU and the other things, such as power, strings, buttons, etc, Figure 74.

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 72 and Figure 75. 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 you checked 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, Figure 73 and Figure 76. 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.

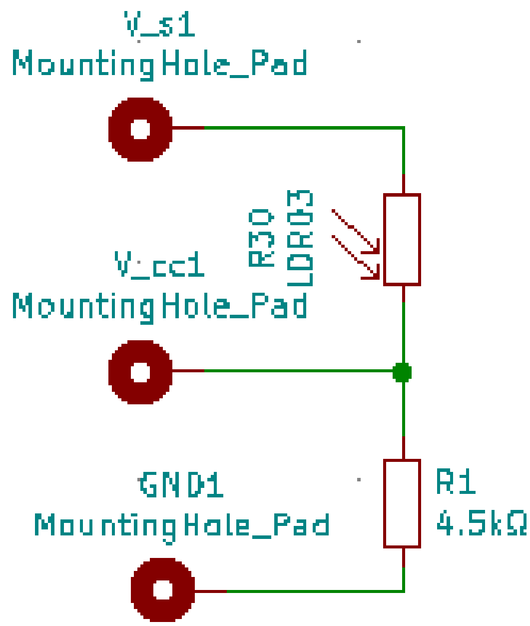


Figure 71 - Schematic of the LDR in KiCad

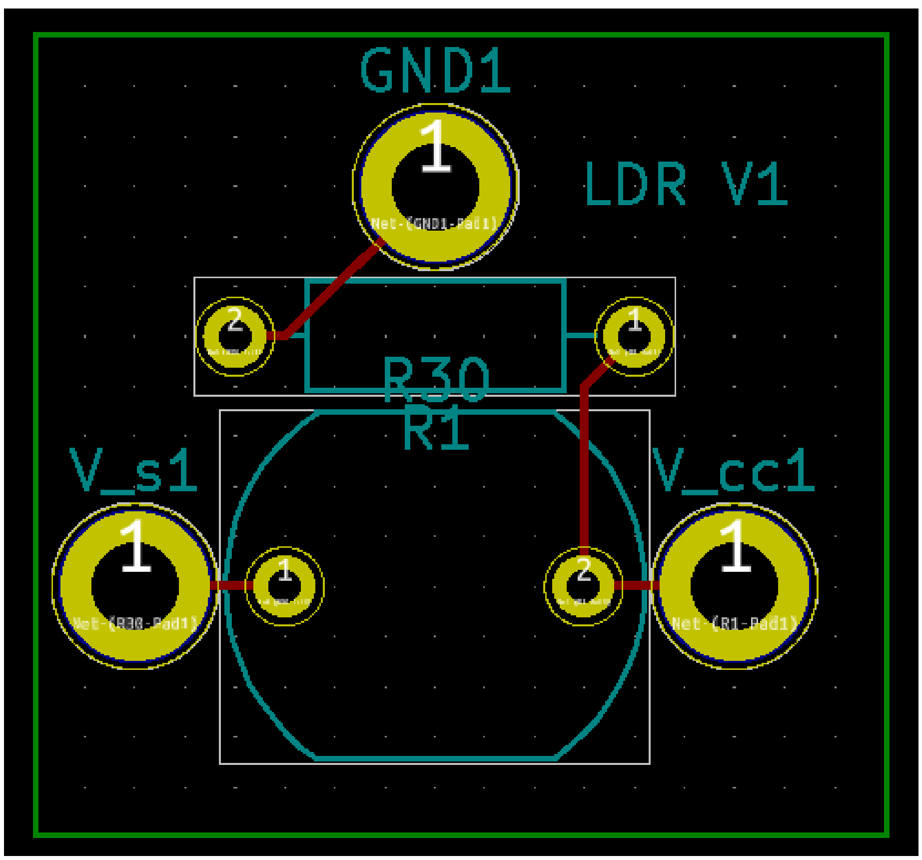


Figure 72 - PCB view of the LDR

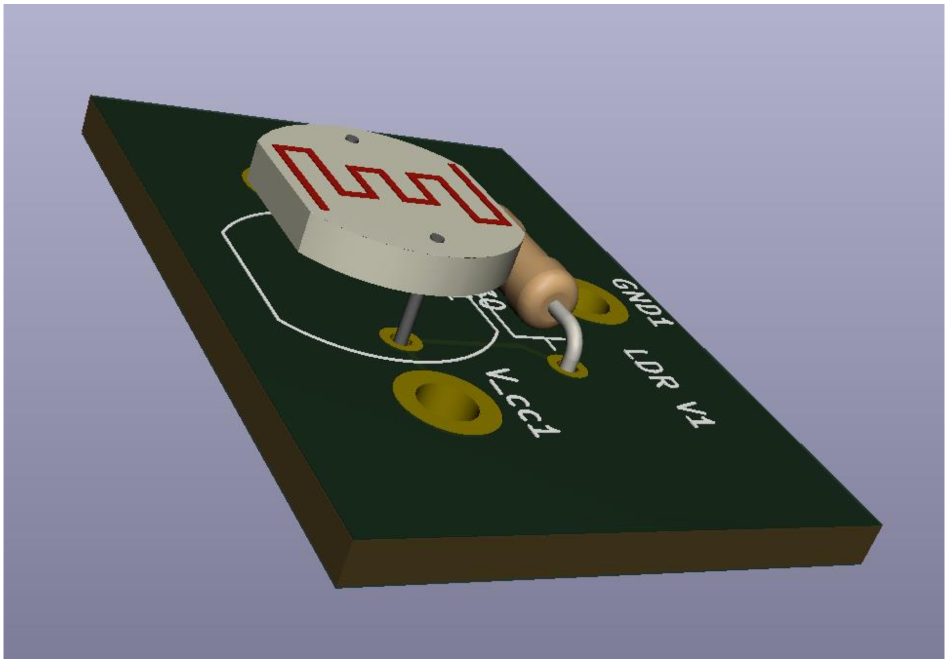


Figure 73 - 3D view of the LDR

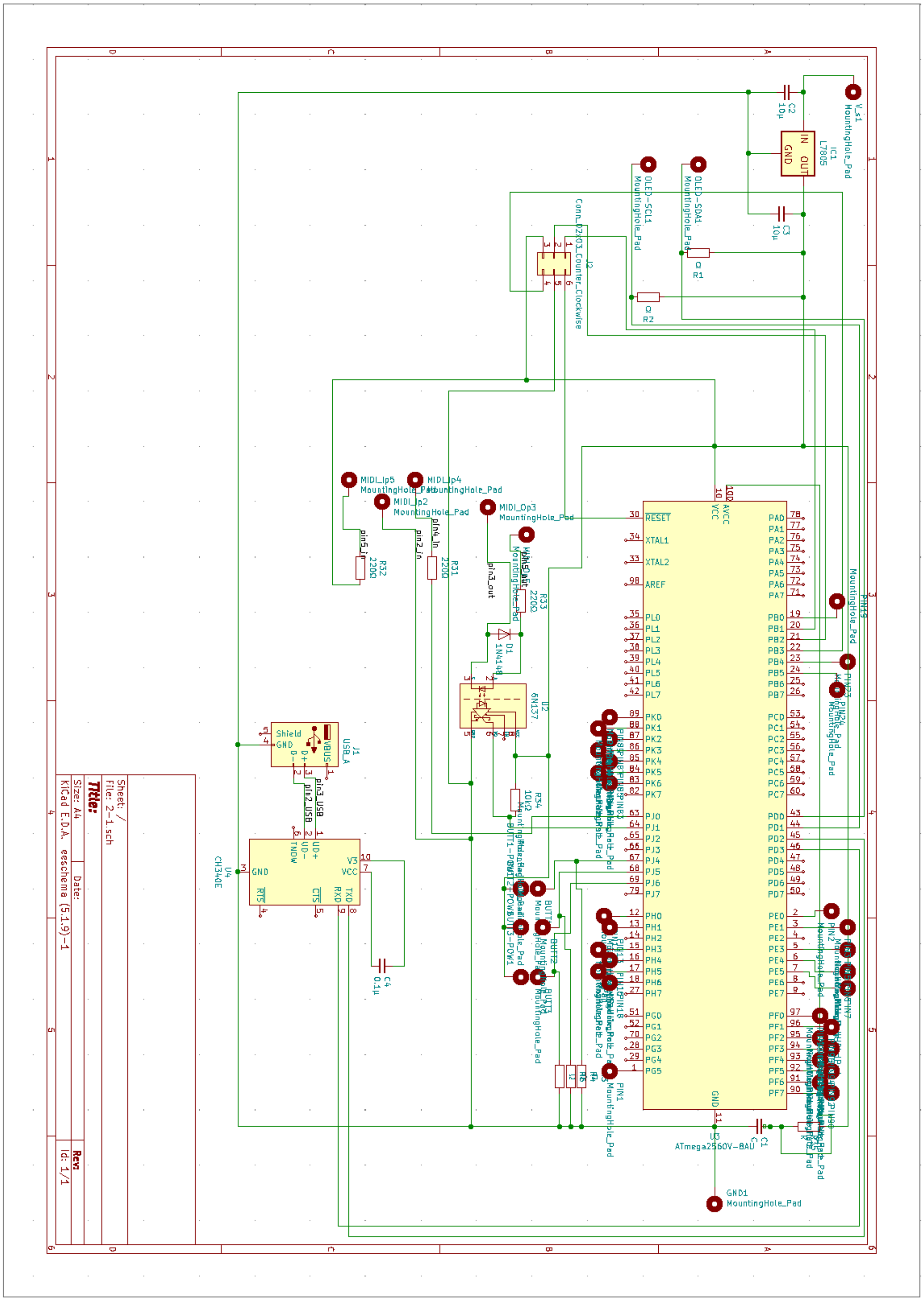


Figure 74 - Schematic of Figure 69 and Figure 70 in KiCad

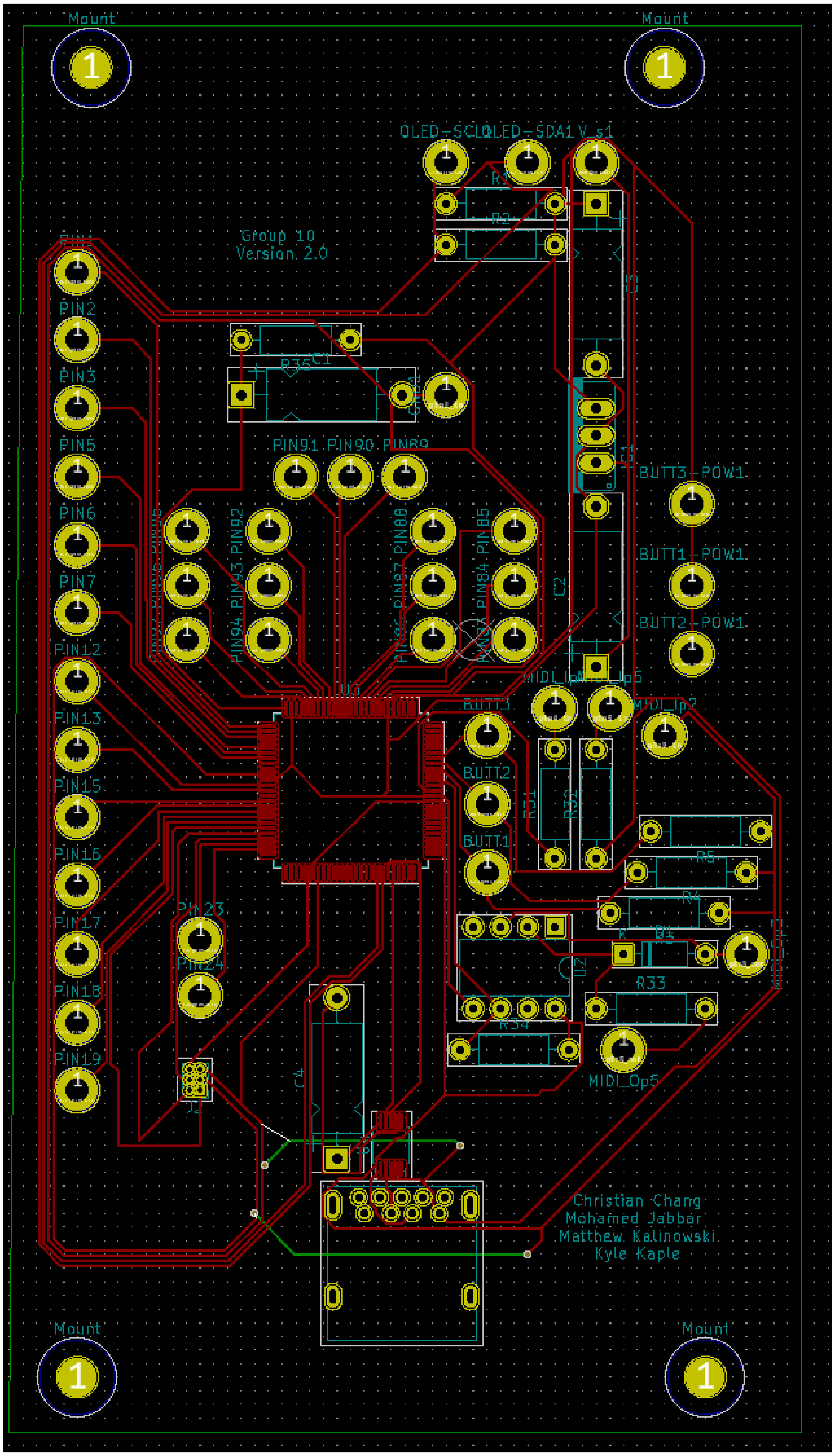


Figure 75 - PCB view of the main board

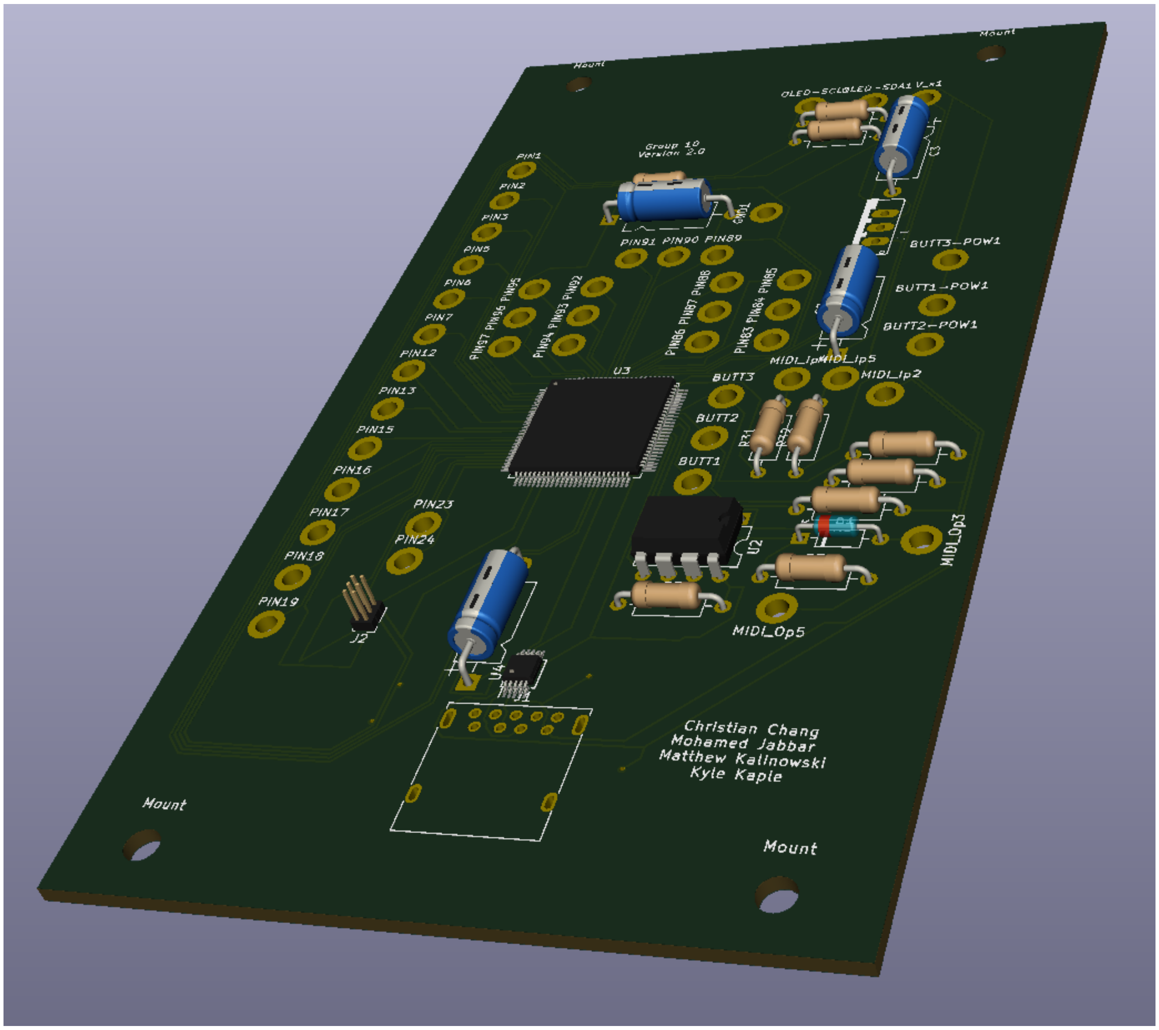


Figure 76 - 3D view of the main board

9.3 Facilities and Equipment

In this section we will explain the facilities and equipment that we used to construct the laser harp.

9.3.1 Facilities

In this section we include the types of facilities we used when designing and creating the laser harp. Because UCF facilities are mostly closed or limited in capacity due to the COVID-19 outbreak, we have been forced to build at home. Tecport Optics allows us to use their facility and equipment to build the laser harp. They are a high vacuum chamber manufacturer providing us with basic tools to build the device. They have provided us with the freedom to use their equipment such as angle grinders, soldering stations, electronic components and wiring, and even welding equipment. Though most UCF labs have been closed, the UCF

Senior Design lab is also available by appointment, so we may perform some testing there as well.

9.3.2 Equipment

In this section we include the equipment used to create the laser harp. Some items that we included when assembling the laser harp were: an assortment of electrical components (resistors, capacitors, inductors, photoresistor (LDR), diodes, etc), oscilloscope, functions generator, Arduino Nano microcontroller, multimeter, computer for research, and breadboard. At the beginning of the semester, UCF supplied our group with a portable oscilloscope and function generator from Digilent. As of now the basic prototype uses basic molex connectors to supply power to the unit as shown in figure 77, however we will more than likely need a soldering iron to make permanent connections.

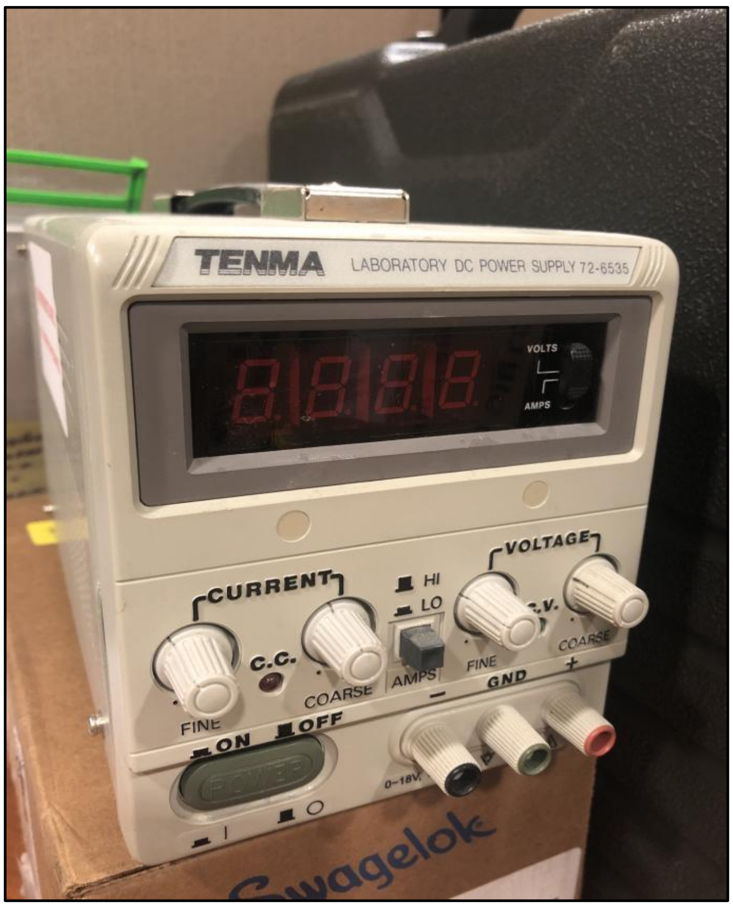


Figure 77 - Power Supply

10.0 Prototype Testing Plan

Once the initial full-scale prototype has been constructed, it is important that we perform tests to verify the functionality of the laser harp. We will need to verify that the lasers turn on and are aligned, the infrared sensors are operational, and that MIDI Note On/Note Off, as well as MIDI Control Change messages can be sent by playing the laser harp as intended. If any of these subsystems are not functioning properly or at all, we will need to adjust or calibrate them so that they do function as intended.

To test and verify the functionality of the laser harp, we will follow the steps outlined in this section. During all testing and use, the technician/user should wear laser protection glasses, and should always be very careful to avoid any direct exposure from the laser beam. While the laser beams in the laser harp are perfectly safe to touch and look at from an indirect angle, they can cause retinal damage if they point directly at one's eyes, so it is very important for the technician/user to take the necessary precautions to prevent any injury.

10.1 Power and Laser Beam Tests

The following steps will describe the method we will use to verify that the laser harp's power and laser beam systems are functioning as intended. Information on how we tested individual components to semi functional prototyping will be discussed below.

10.1.1 Laser Diode Testing

1. Ensure that all laser diodes function properly by using a laboratory power supply.
2. The laser diodes are 3.3 volts that carry a current of 20mA.
3. Using alligator clips to attach the positive and ground wire to the power supply unit.
4. Increase the voltage to the manufacturer's specified voltage level to begin lasing.
5. Using a digital multimeter, connect the two cables in between the diode and the grounding of the power supply unit to measure the current.
6. The current at the specified manufacturer's recommended voltage should be around 20mA.
7. If the current is below the laser diode will not lase, and should be replaced by a spare diode.

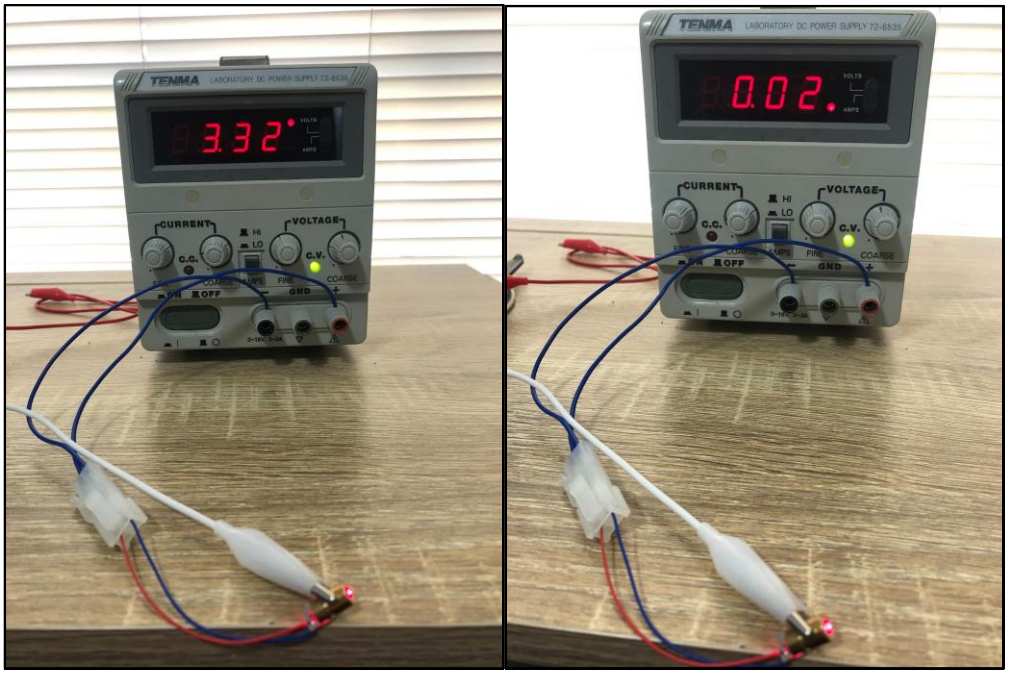


Figure 78 - Voltage and Current Testing on a Laser Diode with a Laboratory Power Supply Unit

As shown in figure 78, testing the individual diodes is a necessary step before connecting them any further. For temporary prototyping and testing purposes all connections will temporarily be molex connectors or ferrules that are crimped. The final connections will be provided by a cable that houses enough individual wires that can be connected to each individual part and soldered to a single connector. Before moving onto connecting the laser diodes together in parallel we must ensure all work properly.

10.1.2 Photoresistor testing

Light dependent resistors can be tested very easily using a digital multimeter. The resistance of a light dependent resistor changes with the intensity of light shining on the receiving cell. When high intensity light shines on the LDR the resistance will be low, roughly 500 ohms and at darkness the resistance will increase to roughly 200k ohms. Before using the LDRs we want to verify the resistivity in different light settings in order to better understand the parameters necessary to include in the program. A basic diagram of how to connect the digital multimeter is shown in figure 73.

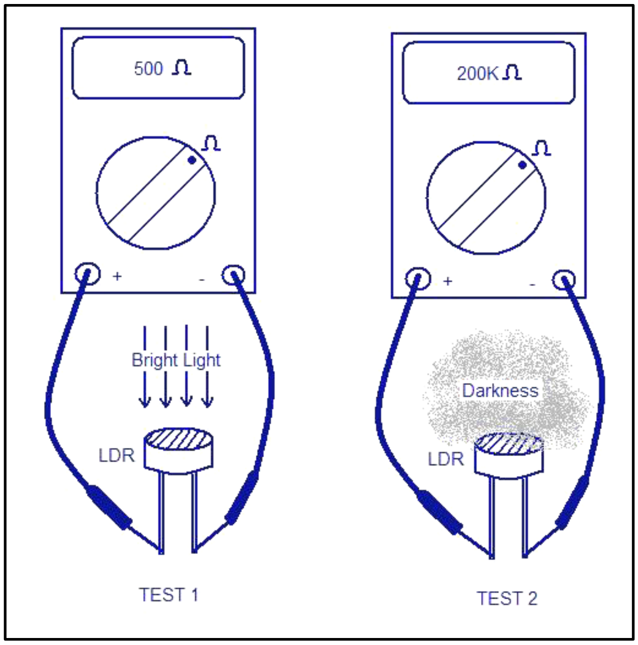


Figure 79 - How to Connect a DMM to an LDR

Test 1: LDR with laser as light source

In this test we will use a laser as the source in order to determine the resistivity of the LDRs.

1. Get a digital multimeter and turn it to the ohms setting.
2. Connect the two wires to the two pins on the LDR.
3. Connect a laser diode to a power supply as previously instructed in the laser diode testing section.
4. Ensure that the laser diode is properly aligned and in safe conditions to use before turning on the power supply unit.
5. While wearing protective eyewear turn on the power supply unit and observe the resistivity.
6. The resistivity for a laser diode at 3.3V is 1.2k as shown in figure 80.

Figure 80 - Using Laser Diode as Light Source Measuring Resistance

Test 2: LDR with no light source

We need to now determine the resistivity when there is no light on the detector. Using the same LDR we will remove the laser diode light source and observe the resistivity.

1. Rather than have a light source, turn off the power supply unit to measure the resistivity.
2. The LDR was covered by a finger so that no ambient light interfered with it.
3. The digital multimeter read 154.5k as shown in figure 81

Figure 81 - Covering the LDR to Show Max resistance

We have some basic parameters for how our system will be set up, with using the laser diodes as the emitter, however me must consider interference of detection since it is mobile. Because it can be brought to any location, we have to consider that there are different light settings and we should take some simple measurements to see what type of light will interfere enough to cause the harp to not perform flawlessly as intended as shown in table 35.

Test 3: Other light source resistance data

Light source	Resistance (Ohms)
Indoor lighting	12.9k
Outdoor lighting direct	0.3k
Outdoor lighting indirect	2.46k
Flashlight	1.5k

Table 35 - LDR Resistance in Various Lighting Conditions

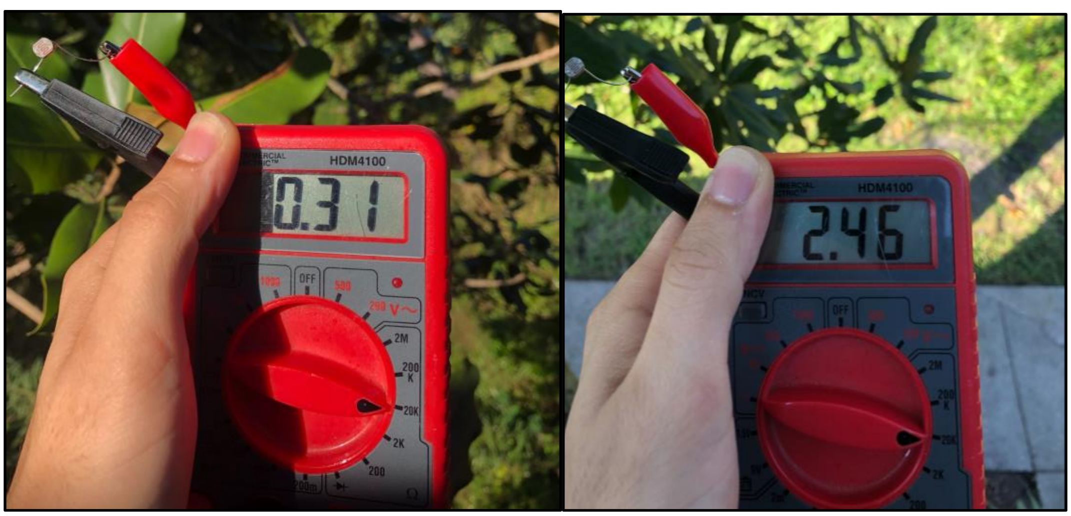


Figure 82 - Outside LDR Testing in Direct and Indirect Sunlight

It was necessary to find the resistivity using the laser diode in order to better set the software parameters but even more useful to know how other light settings affect the LDR. When using the LDR indoor with lighting the laser diode still has less resistivity and the microcontroller will be able to tell the difference between noise and the true signal. However as shown in figure 82, in direct sunlight the LDR reached a point lower in resistivity than it did with the laser diode at its specified voltage configuration. The LDRs will be on the base of the harp design and this is in direct view of the sunlight if taken outdoors, we conclude that the harp should be played indoors unless its night time for this reason.

10.1.3 Single String Testing

Before we begin to connect multiple diodes together and mount them on a frame, we need to ensure that a single laser string will operate appropriately when integrating the detector. We have already found the resistance for the detector when using a laser diode so we can implement that into the arduino code for testing. Besides a laser diode we will need either a speaker or a LED to indicate that the detector has changed states from HIGH to LOW.

1. Using the arduino micro, connect the micro usb cable into the unit and a power supply. The power supply can either be directly to a computer using USB to micro-USB, or use a laboratory power supply unit.
2. The laser diode and the detector need to be mounted so that the beam is always on the detector. Ensure that the laser diodes are properly mounted and do not move around causing it to hit someone's eye. Wear eye protection before powering on the unit.
3. We must connect the LDR to a breadboard and place one end to the Arduino’s analog pin as well as connected to a resistor which is connected to the 3.3v pin.
4. Using basic arduino code scavenged from the internet we manage to initialize the Arduino and get a response. Figure 83 displays the positions setup for the detector configuration.

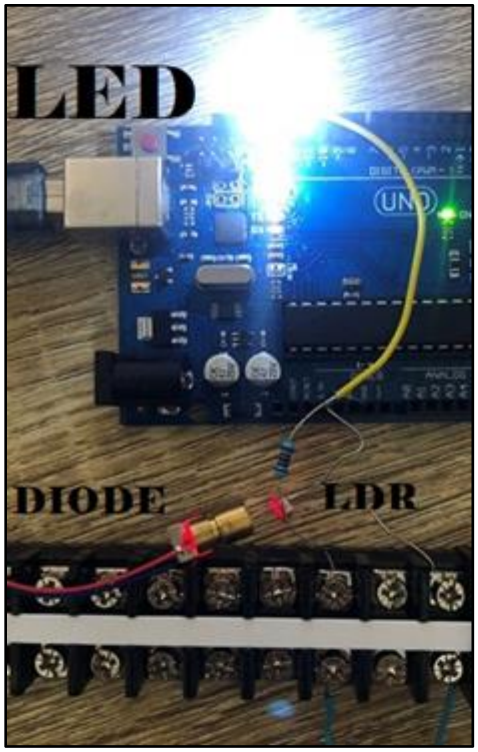


Figure 83 - Single String Testing Prototype

10.1.4 Multibeam testing

Now that we have a single laser string working, we can add additional lasers and diodes to begin configuring the entire setup. Once we have a multibeam set up working properly we can move onto the next part of the project which is distance detection.

1. Using a terminal block, we can connect the power and grounds of the laser diodes together so that we only need two pins to turn on and off the laser diodes. They could all be powered individually, which we considered, so that we can control each laser diode and possibly have them switching between on and off as they are intercepted.
2. Connect the power supply unit to the laser diode terminal block that contains several laser diodes. Before ignition be sure to wear protective equipment.
3. Ensure that the laser diodes are all working properly and note the current and voltage readings for the system.
4. Now that the lasers have been assembled, we need to add additional detectors for the remaining laser diodes.
5. Configure the same setup as done in the single beam testing procedures on a breadboard.
6. Ensure that the laser diodes are facing the LDRs and are fixed in position so that they do not move around while testing the system.
7. With the power now on, the lasers should all be on a detector and no sound or signal will be present.

8. Intercept the beam path of every laser diode and ensure that the LDR reacts as intended. Interfering with each diode should cause the resistivity in the LDRs to increase significantly when blocked allowing the microcontroller to use that data and register a change in its state being HIGH or LOW.
9. In this circuit we implemented a two-pin speaker unit designed for arduino so that we can have an auditory signal.
10. By using the speaker, we can distinguish different notes as we specify a different note for each diode. Programming the arduino to make different sounds on the speaker is done by changing the tone() function parameters.

During the multibeam testing it became apparent that having the laser diodes and the receivers spaced too close together will cause false triggers for unwanted strings. In order to solve this issue, we need to consider how much space is required for each string to be comfortably played without interfering with the remaining notes. If we space them out too far the portable laser harp becomes bulky and longer than intended. When building the frame of the harp we will have to consider how large the gaps are between diodes, and must remember that we are also putting a second set of detectors on the same platform. We must consider left over space as well in the case of further modifications or upgrades.

10.2 IR Emitter and Receiver Testing

Before we integrate the IR detector, we need to better understand the parameters at which they function. In order to do that we are starting with an emitter and a receiver as separate components with no electrical configuration like the spark all in one component.

Test 1: Detect distances

1. Using a breadboard connect the IR emitter to a resistor which is connected to a 3.3v power supply from the arduino nano microcontroller.
2. The IR receiver will be connected in series with the emitter.
3. Using another resistor at the end of the receiver we connect the end of the circuit to the analog input on the arduino.
4. Using sample code generated from the arduino website we were able to interact with the circuit and come up with some basic data of the simple IR configuration.

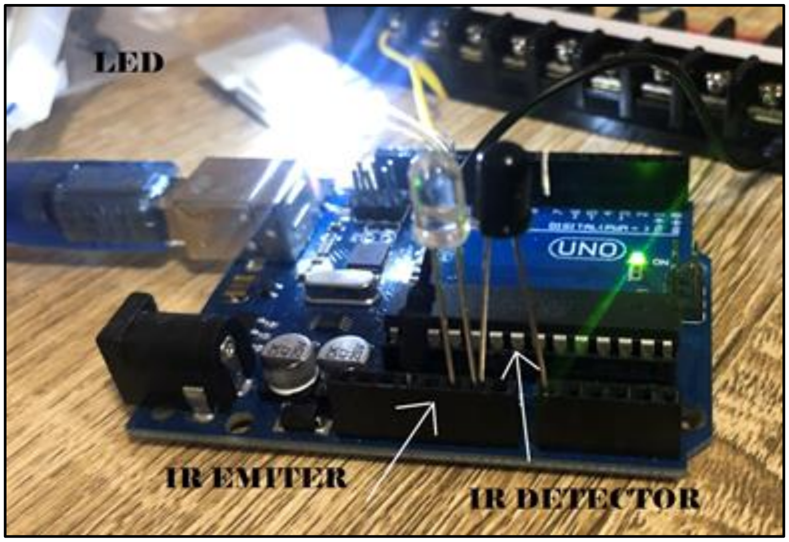


Figure 84 - IR Detection Circuit Testing

Shown in figure 84 is the first trial for distance detection, and we will consider using the sharp IR proximity sensor in future prototypes to have more accuracy and consistency with the ranging as shown in figure 85. The operation of a premade circuit with an in-house detection system is similar to having the two separate emitters and detector, only we have to do a little more in regard to the actual programming. Having worked with the data and how fast it refreshes on the screen it might be better to integrate a small LCD or OLED panel on the system to view information on the device itself rather than data be on a laptop. We could integrate the sharp IR proximity sensor with the display so that it shows the distance detected in a more pleasant and readable form, otherwise you are bombarded with a plethora of data.

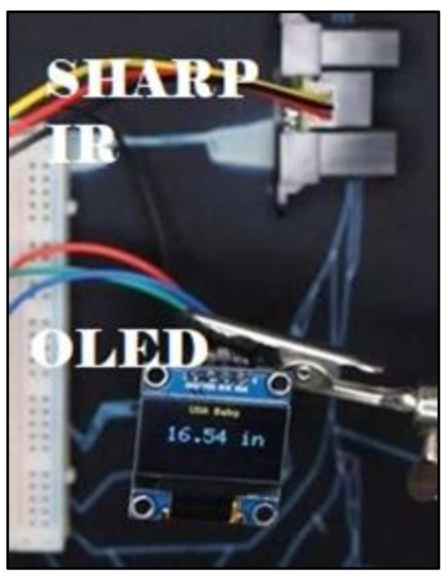


Figure 85 - Sharp IR Proximity with Display

10.2.1 IR Integration into Single String Testing

The next step in creating the laser harp we designed is to integrate the distance detection with the photodetection as shown in figure 86.

1. From previous testing done on the individual components we can combine the breadboards together by running the harp on the same microcontroller program.
2. Combining the two breadboards that hold the distance detection section and the lasers with LDRs we use the power from the Arduinos micro-USB port.
3. The challenging part was configuring the software, arduino is not a standard language learned in school. In order for the harp to display a note we need to ensure that the distance is detected before the LDR sends a signal for the sound to be made.
4. Below is a testing circuit displaying the prototype of a single string integration with both detection types

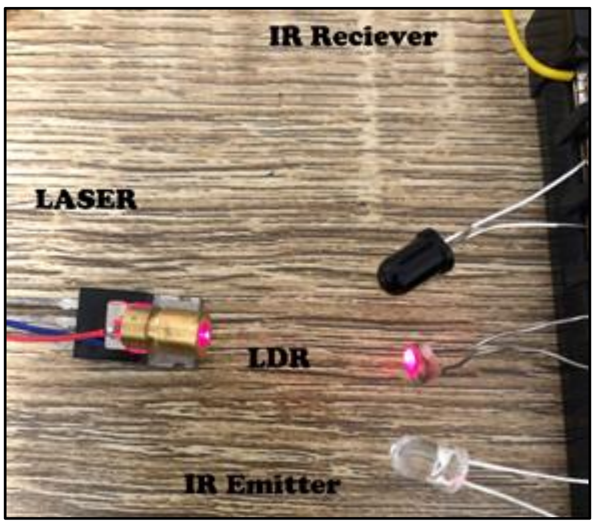


Figure 86 - Integration of Distance Detection with Interruption Detection

More testing needs to be done to appropriately calibrate the detection for distance. We must design a more secure mount that will enable the reading to be more stable. In the image described above we attempted to separate the emitter with the receiver and place the photodetector in the middle. This was an attempt to find the best placement for detection and performing more tests is required before a final design placement is implemented. We need to consider there are several more lasers and detectors to be mounted on a single unit, we must consider spacing and find a balance without sacrificing functionality. If the IR receivers are too close together there could be interference amongst neighboring detectors.

10.2.2 IR Integration Into Multi String Testing

Now that there is a working prototype for a single string laser harp that can alter the notes pitch with distance, we can add multiple strings and begin testing it. After the prototyping is done there will be a more standard section describing how to test the full-scale laser harp for full functionality.

1. Using the same set up as the single string integration testing, we will add additional lasers and detectors to the system.
2. Because we are sharing the same Arduino to run the same program, we must alter the pin selection.
3. Verify that the alterations made to the program are clear of errors and upload the new alterations to the Arduino.
4. Using a pencil because of its thin form factor and easy to control, slide the pencil into the path of each beam at the same height to ensure that the base notes are all working.
5. We can then change the height of interference for each string to test if it properly registers distance.

Some problems we ran into during simple testing was that there was a lot of interference. something needs to be done to control the angle at which the distance detection is limited to. If it is free to observe returning signals from any direction it easily interacts with other incoming signals. Adding a form of protection around it will limit the incoming reflections that cause unwanted interruptions in the program.

10.3 Final Assembly Hardware Testing

Now that we have tested individual components and have integrated the two detector sections into a single unit, we can set up a standard hardware test. This test is required to ensure that the final product has full functionality when it comes to the hardware, the MIDI testing will be specified in the next section. Although we are still prototyping the final configuration, it should be identical in testing hardware.

1. Ensure that you are wearing protective eyewear before the laser diodes are fed power.
2. The hardware should already be aligned so that the diodes are all facing the LDRs and the distance detectors are on the same platform as the diodes facing the LDRs. If the system is not secure, do so to better protect yourself and others from eye damage.

3. With the laser diodes powered on, ensure that all diodes are aligned perfectly onto the center of the LDR.
4. As previously tested in the individual string testing section, begin to interfere with the laser diodes strings one at a time. The scale should be tested from either direction, but every string will have an either deeper or higher note. No two strings should have the same note.
5. Once you have interfered with the laser diodes at the same distance for all strings it is required to check each individual string and ensure that the distance detection does not interfere with one another.
6. Starting at the lowest section of each string, make your way up and listen for the notes to change pitch as the distance between the detector and your hand increases.

10.4 MIDI Output Testing

The following steps will describe the method we will use to verify that the laser harp's MIDI Output system is functioning properly, and will require the use of a MIDI interface connected to a computer with a Digital Audio Workstation (DAW) to record MIDI input. This method is ideal from a testing perspective, as we will have a visualized set of data in the form of a MIDI file that will allow us to directly identify which beams and/or detectors may not be working as intended. Along with note information, the MIDI file will also contain the MIDI CC data that should come from the infrared distance sensors, allowing us to verify the functionality of the distance sensing subsystem, as well.

1. Once the laser beams are on and aligned properly connect a male 5-pin DIN cable to the MIDI Output of the laser harp, and connect the other end to the input to the input of a MIDI interface device that is connected to a computer with a DAW program installed and set up to record MIDI input.
2. The laser harp strings will be configured by default to correspond to the notes of the C Major scale, from C3 to C5. The laser harp's default MIDI Channel is Channel 1.
3. In the DAW program of your choice, create a MIDI track with the laser harp set as the MIDI Input on Channel 1.
4. Press record on the DAW
5. Begin blocking the beams with a finger, starting from the lowest note on the left side of the laser harp, and moving to the highest note at the right side. Be careful not to skip or repeat a note, as the MIDI file will be used to verify that the notes the laser harp is transmitting are correct, both in pitch and order. This test should be performed along with the DAW's built-in metronome, and the beams should be blocked and released along with the

metronome. This will help to verify that there is no discernible delay at the laser harp's output, as the DAW will indicate not only what notes were played, but also *when* the notes were played.

6. To test the semitone transpose functions, press the semitone transpose up button and repeat step 8, again verifying that the notes are being transmitted as expected.
7. Repeat step 9 until the semitone transpose reaches its limit at +12 semitones, equivalent to one octave. Then follow the same procedure, but this time transpose down from 0 semitones to -12 semitones, again verifying that the notes are transmitted in the proper order and intervals.
8. Press the transpose reset button to return the laser harp to its default transpose setting.
9. To test the octave transpose functions, press the octave transpose up button and repeat step 8, again verifying that the notes are being transmitted as expected.
10. Repeat step 11 until the octave transpose reaches its limit at +3 octaves. Then follow the same procedure, this time transposing down from 0 octaves to -3 octaves, verifying that the notes being transmitted are in the proper order and intervals.
11. Press the transpose reset button to return the laser harp to its default transpose setting.

11.0 Case Design

The laser harp cannot be made with electronics and lasers alone. A case should be used to house the electrical components and laser diodes. For the design of the case, it must be sturdy enough to hold the components as well as be affordable for the final design. As the harp is intended to be used in a home studio environment, the case should also have an attractive design, and should be built to a size that can fit easily on a desk or table top. The first possible design we considered was to model our laser harp after a real acoustic harp. An example of a laser harp designed after an acoustic harp is shown in figure 87.

Figure 87 - Traditional Acoustic Harp Design/Layout

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 must 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 opted to model our harp frame after classic synthesizers, like the ARP 2600 shown in figure 88.

Figure 88 - ARP 2600

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 table top, 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 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. A rough 3D model of an initial frame design can be seen in figure 83.

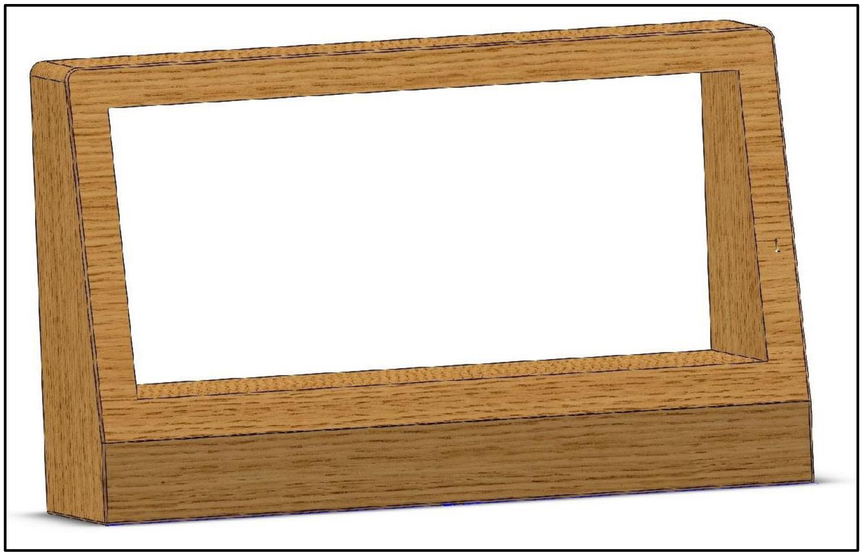


Figure 89 - Initial Frame Design

The frame design in figure 89 was our first attempt at a frame design the cutout on the inside allows for 15 vertically aligned lasers, separated horizontally by 1.5 inches to ensure that the user can block each laser beam without blocking any adjacent beams. There will be photodetectors at the top of the frame opposite the laser diodes that will detect when the beams are blocked. There is a slight angle on the front face of the frame, which slightly increases visibility for a user that does not have the laser harp situated directly in their eye-line. As well, controls for transposition and scale selection can be attached to the front of the harp, to allow immediate, hands-on control over important parameters. Due to constraints in our manufacturing capabilities and budget, we opted for a different frame design.

Figure 90 - Final Frame Design

Figure 90 shows the frame design that we ended up choosing to go with. It is constructed with two parallel planes of wood, with a 29.5” x 14” cutout in each to allow space for the lasers to be accessed. They are held together by metal screws and bolts affixed to the 4 corners of each, and are separated by 3". At the bottom of the frame is a piece of wood affixed to the back panel with machine screws and a ½" square dowel, and this is where the laser detection boards are placed. They are mounted with 3D-printed plastic standoffs which the boards slide snugly into, allowing space for the wires coming from the boards to connect to the main board within the bottom of the frame. On the top of the frame, the laser diodes and infrared sensors are mounted, with 2 inch spacing between the centers of the laser beams, which the infrared sensors are aligned directly next to. Both the laser diodes and infrared sensors are mounted with their beams pointing downward, and the laser diodes are directed to the laser detection boards. This allows the user to affect the distance sensors simply by blocking the corresponding laser diode, without having to worry about whether or not they are blocking both the laser diode and the infrared sensor. The right side of the frame has the connectors for the MIDI, as well as power switches to switch the power to the laser diodes and the main board. Next to these connectors and switches on the front of the frame is the OLED display the buttons that make up the user interface of the harp, allowing the user to control the scale and transposition of the notes played.

11.1 Frame Materials

In the following sections we will consider various materials for use in the construction of our laser harp frame. There are all kinds of materials we could use, but we chose four to compare: Wood, Steel, Aluminum, and Plastic.

11.1.1 Wood

Wood is a great working material. It is lightweight, relatively simple to work with, and affordable. Using it would also draw much appeal to regular harpists, since harps are typically made of wood. Wood was a major part of the visual design during the early days of synthesizers, such as the Moog Model D, and generally is a material used in home furniture due to its looks. It can easily be gathered at a hardware store and we have the tools necessary to produce a harp figure.

11.1.2 Steel

Steel as a material is very sturdy and heavyweight, which in some applications can be a positive. A well-built steel instrument can give a feeling of quality that users often appreciate. We have a portable welding equipment needed to piece together steel parts so that the harp has seamless edges, and no nuts and bolts will show. However, steel is much more difficult to work with, and the weight could be a problem for users who might want to move their laser harp. As well, steel is prone to rust from oxidation, and this can be problematic for a device that is meant to be a fixture in a home studio.

11.1.3 Aluminum

Aluminum is an alternative to steel as a metal material. It is more lightweight and is able to hold a large amount of stress, but has many of the same problems of manufacturability that steel does. While it is a good, relatively rust-proof alternative to steel, it is also an expensive option, and may not be ideal.

11.1.4 Plastic

Plastic is another ideal working material. It is lightweight, easy to work with, can be any number of colors (including clear), and is very affordable. However, plastic is not as aesthetically pleasing as other materials like wood, and as such may not appeal to those looking for a laser harp that is also attractive to look at.

From the options above we have four materials suitable for construction of the base. Below is a table with their comparisons.

Material	Wood	Steel	Aluminum	Plastic
Strength	++	+++	+++	+
Machinability	+++	++	++	+++
Weathering	++	++	+++	+++
Weight	+++	+	++	+++
Cost	+++	++	+	+++

Table 41 - Materials Comparisons

For our use, wood seems to be the ideal candidate. Below is the piece of wood we will acquire.

Figure 91 - 18mm Thick Plywood

Below are the specifications for the wood:

Manufacturer	Home Depot
Part number	3/4 in. Category x 4 ft. x 8 ft.
Type	Plywood
Dimensions	3/4 x 4’ x 8’
Price	$45.98

Table 42 - Plywood Specifications

11.2 Mounting

In order to properly align the laser beams of the harp, we had to devise a method of mounting the lasers that would keep the lasers as consistently straight as possible. Initially, we had attempted to use a thin piece of pegboard to fit the laser diodes snugly. While this did hold the lasers, the beams were not very well aligned, and was not a solution that would stand the test of time. After some deliberation and testing, we decided to implement a 3D-printed laser mounting solution. The final laser mount design we chose can be seen in figures 92 and 93.

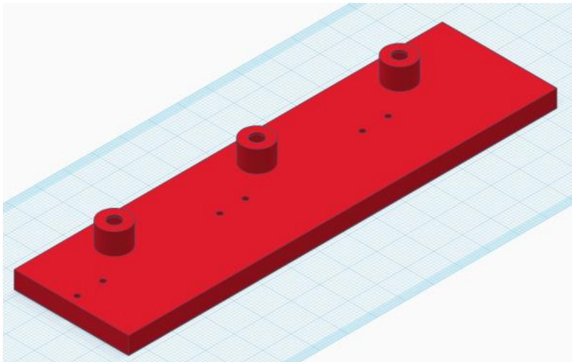


Figure 92 - Laser Mount ¾ bottom view

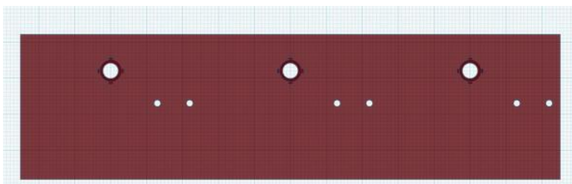


Figure 92 - Laser Mount top view

These laser mounts are designed such that the laser diodes are placed snugly in the top holes and slide in, with the infrared distance sensors fastened on the other side, with their receivers directly aligned with the laser diodes. Once mounted, these greatly improved the alignment of the laser diodes, and allowed us to place the laser detection boards at the bottom of the frame with enough spacing between the laser beams to be played comfortably.

12.0 Personnel

In this section we will give our own input about various topics concerning the laser harp. Such things will include our personal thoughts and actions that went into developing and creating it. We discuss the major contributions that we each provide for this project.

12.1 Project Team Content

Since we all come from different majors: two in Photonics Science and Engineering, one in Electrical Engineering, and one in Computer Engineering, we all had different jobs that needed to be done.

As the Computer Engineer, Christian Chang I contributed toward the development of the software and the electrical aspects of the project. To be more precise I worked closely on how to set up the Arduino microcontroller and the interactions between MIDI and the microcontroller. When it came to working on part of the electrical part of the project, I only prospected the electrical engineer and double checked their work.

As the Electrical Engineer, Kyle Kaple, I contributed to the preliminary research into optocouplers, as well as the MIDI connectors and MIDI communication via software. I also am the one who did most of the research into the musical aspects of the laser harp, and have a history and knowledge of the musical side of the laser harp. As well, I am already very familiar with MIDI operation as a consumer, as I have experience with using electronic instruments. I was responsible for designing the electrical schematics and circuit diagrams, as well as software design and programming.

As one of the Photonics Science and Engineers I, Matthew Nicholas Kalinowski contributed the original idea of the project to my classmates. I formed the group around my idea and we were set. I had the components for senior design sent to my place and created a small workbench for prototyping. I was tasked with providing the semiconductor lasers for the project, as well as anything that produces light. I had the group form at my place so we could at least know each other even during the COVID-19. From there we set out to complete a functioning prototype. Eventually leading to finishing this paper.

As one the other Photonics Science and Engineer I, Mohamed Jabbar, contributed by doing research on the photodetectors that will enable the laser harp to function. The research involved determining what detector best fits our needs while being conscious of the budgetary constraints. From the initial idea I purchased some basic components and assembled a simple yet functional prototype that emits different sounds when laser beams block the LRDs. I will continue to build prototypes with different distance sensors and determine which components will make it to the final design.

12.2 Consultants

When it came to talking to someone who knew what they were doing in our fields we had a vast number of Doctors and Professors at our disposal. Since this is Senior Design, there were three professors who could answer our questions when it came to deciding if a product or component was right for us. They were Dr. Lei Wei, Dr. Samuel Richie, and Dr. David J. Hagan.

12.3 Suppliers

The majority of the components have been purchased through online retailer:

- Amazon for components
- The LDRs were supplied by eBoot.
- The laser diodes were supplied by HiLetgo
- The IR emitter and receiver were supplied by Cylewet
- JLCPCB was used to order the PCB

We were also supplied a digital oscilloscope and function generator from National instruments. We have also equipped ourselves with a laboratory DC power supply.

13.0 Administrative Content

This section contains content pertaining to costs and deadlines for our project. The budget discussion will include a bill of materials based on our initial schematics and construction plan. The Milestone Discussion will contain a list of important deadlines and due dates that we will base our goals around, as well as other deadlines and due dates that we had to choose for ourselves to keep the project moving forward.

13.1 Budget and Finance Discussion

Because the laser harp is a project with no outside sponsors, we will need to ensure that the components we choose do not exceed our own financial restrictions. As we are college students with no external funding, we decided that the final design of the laser harp is to be no more than $500. This allows us to split the costs of the components between each of the four members of our group for a per-member cost of $125. This includes the microcontroller, infrared sensors, laser diodes, photoresistors, optocoupler, serial-to-USB converter, voltage regulator, and PCB. The bill of materials we created based on our parts selection earlier in the report does not include costs of resistors, capacitors, and other common electrical components which can be acquired at a very low cost. A table of the estimated costs and final budget can be found in the following table.

Bill of Materials			
	Price per Unit	Quantity	Cost
HiLetgo 5 mW 650 nm Laser Diodes	$0.39	15 (10/pack)	$12.98
eBoot Photoresistors	$0.16	15 (30/pack)	$4.95
Sharp GP2Y0A41SK0F Infrared Distance Sensor	$8.74	15	$131.10
Vishay 6N137 Optocoupler	$1.78	1	$1.78
Frieda 0.96 Inch OLED Module	$4.00	1	$4.00
Atmel ATmega2560 Microcontroller	$11.99	1	$11.99
CH340E Serial-to-USB Converter	$0.50	1 (10/pack)	$4.95
Texas Instruments LP3855 Voltage Regulator	$4.90	1	$4.90
PCB (from JLCPCB)	$2.66	1 (5 minimum purchase)	$13.30
Frieda OLED	$4.90	1	$4.90
Lumber (for case construction)	$45.98	1	$45.98
Total			**$240.83**

Table 36 - Bill of Materials

As the bill of materials shows, our design is projected to end up with a cost lower than our initial expectation. This is great for our design, as it leaves room for improvement, as well as margin for error.

13.2 Milestone Discussion

Our project has a predefined timeline based primarily around a few specific due dates for assignments and drafts of the design document. A table with these due dates, as well as a few other deadlines that we had to set for ourselves can be found in the following table.

Project Milestones	
Form Group/Idea	August 27, 2020
Test Lab Equipment	September 7, 2020
Divide & Conquer 1.0 Document	September 18, 2020
60 Page Design Draft Due	November 13, 2020
Initial Design Draft Review (w/ Dr. Samuel Richie	November 18th, 2020
Begin Purchasing Components	Mid-November, 2020
100 Page Design Draft Due	November 27, 2020
Final Design Document Due	December 4, 2020
Assemble Prototype	January - February 2021
Test Prototype/Design Adjustment	February - March 2021
Final Prototype Testing	March - April 2021
Submit Final Documentation	Late April 2021
Final Presentation	Late April 2021

Table 37 - Project Milestones

14.0 Parts

With all things considered we have gone ahead and bought some basic parts in order to assemble a semi functional prototype. In order to build a basic model of a laser harp we purchased a set of 650 nm laser diodes that emit a red hue powered by 5V. Using an arduino nano and a laptop as the initial power supply to the unit, which will distribute power directly to the laser diodes as well as the other components. The laser diodes were assembled together in parallel, sharing the same power supply and ground node. The laser diodes do not require to be controlled so it retains power at all times and is grounded separately from the remainder of the components. The next component for the basic prototype we considered were the LDRs that are approximately 5mm, which is a large enough size for the laser diodes beam to fit within the space.

14.1 Laser Diode Product Description

Below in table 38 is a description of the manufacturer specification for the laser diodes we plan to use.

Output Power	5 mW
Wavelength	650 nm
Working Voltage	5 V
Operating Current	Under 20mA
Laser Shape	Dot
Working Temperature	-10 C to +40 C
Housing Material	High quality

Dimensions	6.5 x 18mm
Connections	Blue- Negative pole Red- Positive pole
Price	$5.99

Table 38 - Laser Diode Description

In order to build a laser harp, we need lasers. Since we are making a simple prototype, we are being conscious of our budget and purchasing the cheapest diodes.

14.2 Photoresistor (LDR) Part Description

Below in table 39 we describe the manufacturer specifications given for a specifical photoresistor.

Model	5539
Maximum voltage (VDC)	150
Maximum power consumption (mW)	100
Ambient Temperature (C)	-30C - +70C
Spectral Peak (nm)	540

Bright resistance (k Ohm)	50-100
Dark resistance (M ohms)	5
Performance features	Coated with epoxy Small volume Quick response Good spectrum
Range of Applications	Photoelectric control Indoor light control Alarm Industrial control Light control
Price	$4.95

Table 39 - Photoresistor Description

Based on budget and the range of applications described we decided it was good to purchase these LDRs for initial prototyping. They are simple to use and incorporate into an Arduino, where we were able to assemble a working detector. The LDRs react fast enough to detect when hand movement comes across the path of the diode. This was just an initial test; we will consider other options mentioned in the research section.

14.3 Infrared Emitter and Detector Part Description

Table 40 below describes the part specification provided by the manufacturer.

Diameter	5 mm
Wavelength	940 nm
Receiving angle	40 degrees
Voltage	1.1 – 1.4
Transmitting and receiving distance	7-8 m
Max power	70 mW
Max forward current	30 mA
Maximum reverse voltage	5 V
Maximum pulse current peak	75 mA
Price	$5.39

Table 40 - *Infrared Emitter and Detector Part Description*

Although the other components are important, the IR sensors can make the project a lot more interesting by creating another layer of depth. With just blocking the beam from the path of the photodetector it will limit us to a few simple notes. Because the distance between the detector and the diode are fixed, we can create a scale to add more notes within one string. By measuring the distance between the two we can create a note with different pitches allowing the user to be more creative when performing on the laser harp. Again, price was a consideration for the initial attempt. There will be further investigation on distance detection in order to determine what is the best fit for this project.

15.0 History of the Project

The idea of an optical harp came to Matthew Kalinowski early into the fall 2020 semester. The idea was to create sound using a harp with laser strings. Over the course of the first week, a team was put together to design this project. After consideration from several professors, the idea was deemed a proper project with the additional idea of tracking hand position. This would allow the optical harp to be closer to an actual harp, which makes different sounds based on where a string is plucked. Within weeks, a model of the design was created and tested. It lacked distance sensing, but was nonetheless a powerful example for future use. The group would come together one fateful night to discuss the nature of the design and help each other understand the project. With the class quizzes finished it was time for the group to work on a sixty-page rough draft of the final project.

16.0 Project Summary and Conclusion

To conclude, we designed and constructed a laser harp using laser diodes, photoresistors, and infrared distance sensors. The laser harp is controlled with an Atmel ATMega2560 Microcontroller, and is capable of utilizing wall power as well as the option of battery power. After our testing and troubleshooting, we are able to successfully create a laser harp which is capable of sending MIDI notes within preset scales, and with distance-based velocity and aftertouch.

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