Laser Musical Instrument

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***Abstract* — The objective of this project is to create a laser musical instrument that is new and novel. The laser beams will act as strings for the instrument. When a beam is interrupted by an object the reflected light is detected by photodiodes. Based on the intensity of the reflected light the pitch will then be determined for the note to be played. The laser instrument is intended to provide a new and entertaining way of approaching musical creativity at a reasonable price.**

***Index terms* — diode lasers, music, operational amplifiers, photodetector, photodiodes, pulse width modulation, switched mode power supplies.**

I. INTRODUCTION

Music has universally been known as a way for humans to creatively express themselves in many ways. As the times change so too have music trends and the instruments that are used to create music. The creativity of music goes beyond just the sounds that are being produced. The creativity also comes the instruments, methods of integration, and the presentation of creating music. With advancements in technology instruments are no longer just strings being plucked and struck or tubes to pass air through. Instruments have evolved to much more sophisticated mediums to produce sounds. In recent developments some instruments even require zero physical contact by the user.

Having the opportunity to work with the College of Optics and Photonics, we decided to engage in this multi-disciplinary project that fused music and technology in a new way. Using lasers as the interactive medium to produce the sound have been seen before with hobbyists and professional concerts [1]. However, their laser instruments are either too bulky or expensive to be used practically. This is because they use a single note for a laser beam or use a laser projector and image recognition techniques, respectively.

Our project proposes a new form of constructing a laser instrument by compacting multiple notes in a beam and using amplitude detection with photodiodes. The instrument must be light-weight, portable, and capable of producing multiple pitches to play a song.

II. LASER DETECTION SYSTEM

The detection system starts with a laser beam being incident onto an alpha detector. This detector determines whether the beam has been interrupted. When the user interacts with the beam, an interruption occurs, and the alpha detector will send a signal to the microprocessor to activate the sound for that particular beam. At the bottom of the instrument the beta detectors will collect the reflections of light off the interrupting medium and determine which pitch will be played based on the amount of reflections received.

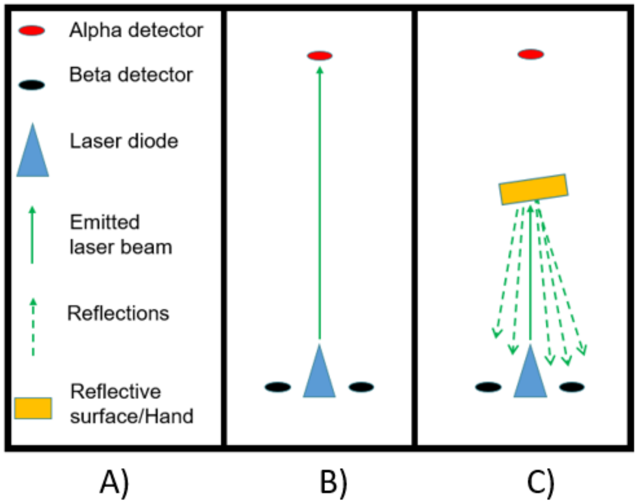

Figure 1: Figure 1: Laser Detection System. A) Legend of icons. B) Emitted laser beam is on the alpha detector so the beam is "off". C) Laser beam is interrupted so the beam is "on".

A. Alpha Detector

The alpha detection is based on the interruption of the user with the laser beam. It will tell the microprocessor which beam should emit sound and play the range of notes that are assigned to the beam. In previous sections of this report, it was determined that photoresistors will act as the alpha detector to sense the interruption. As seen in figure 1B, when the beam is not interrupted, the beam will be incident on the photoresistor. The incoming light causes the resistance of the photoresistor to be low and act closely to a short in a circuit that emits a small voltage signal. This will tell the system that the beam is off, and no notes should play from this beam. When the user interrupts the beams, as is the case in figure 1C, the photoresistor is no longer receiving an optical stimulus. As a consequence of this, the resistance of the photodetector will largely increase and will cause a large voltage signal to be emitted to the microprocessor. This large voltage signal would tell the microprocessor to play any notes that are a result of the interruption of the particular beam. The processing speed of this optical switch should be fast enough, a few milliseconds, to appear seamless to the user. The alpha detectors also prevent cross-over interactions from other beam If another beam is interrupted and the reflections become incident to the uninterrupted beta detectors, then the system will see if the alpha detector

B. Beta Detectors

The beta detection is the determinant factor in having a range of notes to be played. Photodiodes were chosen to be the beta detectors due to their responsivity and low cost. As seen in figure 18C, once a user interrupts a beam and the alpha detectors enable the sound to be emitted for a beam, the photodiodes would pick up the intensities of light reflecting off the interrupting surface. Different intensities would provide different notes from a range of predetermined notes. We could designate the beta detection to be where the higher intensities of reflections can emit a higher note and lower intensities of reflections can produce a lower note in the range.

C. Lasers

We will be using semiconductor laser diodes in order to produce our laser system. Considering that certain colors are perceived more by the human eye and some colors are easier to produce than others, and are less costly, our group has decided to implement green lasers with red lasers as a back-up source. We also decided to buy the laser diode with its module since it makes electrical installation easier than the bare laser diode itself. We did this because with the module all we do is connect the voltage leads and regulate them with the electrical system as oppose to creating a separate circuit for the laser emission that might not end up being functional.

III. POWER SYSTEM

The power systems requirements where defined by the power demand of the six lasers, the portability of the instrument, and the sensitivity of the sensors and microcontroller. Because of the portability constraint the team was pushed into making the instrument to be powered by batteries. The team did not set any requirements of have a built-in charging feature but wanted to leave the design open enough that the batteries selected would be rechargeable. The substantial current draw of the lasers meant a switching regulator was used. For the power stability need of the MCU and the sensors linear regulators were implemented because of their low voltage levels. The separate linear regulators also added a layer of safety for the MCU and sensors because the regulators will shut down from a reverse voltage or overcurrent. The entire power system was designed so that later additions, such as more lasers, fans, and sensors, could be included without having to redesign or rebuild the power system.

A. Battery

Before selecting a battery, the team considered four different popular battery chemistries, nickel metal hydride, nickel cadmium, lithium-ion, and lithium polymer. All batteries chemistries come in many different package sizes and weights with recharging capabilities. For all the chemistries the team considered they have fairly high energy densities. Having a high energy density was the largest requirement for the battery to be selected for the instrument in order to minimize weight and maximize power and run time. Out of all of the chemistries the team researched lithium-ion stuck out the most for many reasons. First because they have the highest energy density of the four and second because of the recent growth of the chemistry’s popularity.

After selecting the chemistry of the battery, the cell package had to be selected. The team ultimately selected the cylindrical 18650 cell. The cell was selected because of its compact size and because of its popularity and wide use in many commercial electronic applications from laptops to electric cars.

Not all 18650 cells are the same, they have different ratings for capacity and continuous discharge rate. Through research the team discovered that as the capacity of the cell increases the stability, loading capability, and life span decrease [2]. For that reason, the team decided to select a cell that falls somewhere in the middle ground. The final selection of a cell was the Samsung INR18650-30Q with ratings of 3000mAh capacity, 3.7 nominal voltage, and a 15-amp continuous discharge.

To allow for future expansions of the system a three series, two parallel cell arrangement was selected. The three series cell arrangement creates a nominal voltage rating of 11.1 volts, which is high enough to power fans if they were to be added to the system for cooling. The two parallel arrangement means the capacity of the battery bank is twice that of a single cell. This gives the instrument a longer run time. To safely build the battery pack cell holders where soldered together to prevent having to solder directly to the cells as that is dangerous and should never be down without the proper equipment. The cell holders also allow for easy removal of the cells so they can be charged outside of the system. In a future build of the system the battery pack will be redesigned to be permanent to the instrument and allow direct recharging in the system.

B. *Switching Voltage Regulation*

The switching regulator was originally designed using the parameters of eight laser diodes and two cooling fans. This led to overdesigning of the switching regulator but allowed for further additions to the system. Original estimates for the system had an overall current draw of about 3 amps. The team used this estimation to choose the components for the switching regulator. The first design of the system had all of the power being regulated by the switching regulator. Later iterations in the design implemented linear regulators into the system.

The team considered two main switching regulators, the LM2678 and the LM2576. Both regulators are designed by Texas Instruments, have similar footprints, and applications. The team considered both regulators for the reason that both are well documented on and simple to use. Ultimately the team chose to use the LM2678 because of its higher current rating and its much higher efficiency rating. Using the data sheets of both the LM2678 and the LM2576, for our applications values the reported efficiency levels where 84% and 77% respectfully [3][4]. Neither switching regulator had a terrific reported efficiency but 84% was good enough for the team's prototype build. The switching regulator is one component that the team would like to replace with a better option, ideally with a component that has an efficiency over 90%.

The final design for the switching regulator was derived from its data sheet. It comprised of three electrolytic capacitors with one ceramic capacitor for the input voltage. On the output of the switch regulator we used a schottky diode to help maintain the output voltage and sink the high current, an inductor is used to prevent large fluctuations in the current, and after the inductor are two more electrolytic capacitors to smooth out the ripple of the regulator.

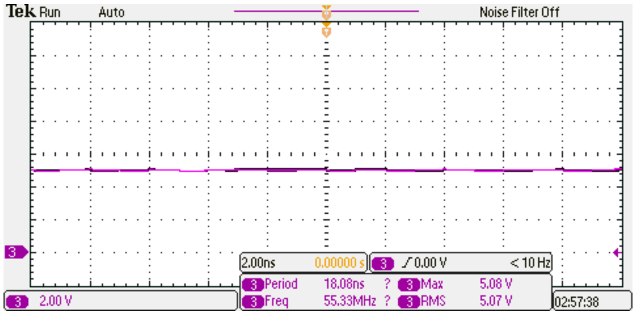

Figure 2: Switching regulator output

From testing of the switching regulator, the team found that's the output ripple of the switching regulator was minimal. Figure 2 shows the output on an oscilloscope at its highest magnification settings. Regardless of the low ripple of the switching regulator the team discovered one major issue with the regulator. The issue that the team discovered was where the voltage would climb up to 5.4 volts. This higher voltage is on the upper limits of the voltage that the MCU can handle. This is the main reason the team moved to add separate dedicated linear regulators into the system.

C. *Linear Voltage Regulation*

Two different linear regulators are included in the system, a five volt and a six-volt regulator. The linear regulators selected in the system are both from the STMicroelectronics L78 family. The MCU and alpha sensors receive power from the five-volt L7805CV regulator, and the beta sensors receive power from the six-volt L7806ABV regulator. Using regulators from the same family made designing the PCB layout easier because both regulators come in the same package and pinout.

Linear regulators where added into the system to increase the voltage stability of the sensors and the MCU. The increase in the voltage stability increases the precision of the sensors and the processing of the MCU. The linear regulators also double as a layer of protection for the sensors and MCU. Both linear regulators have built in protections for reverse voltage and overcurrent which could harm the components.

In testing of the system, the team discovered that the alpha sensors and the MCU should receive the same voltage from the same source. When the alpha sensors where connected to another source the MCU was not always able to detect when a laser was interrupted. We believe this is because of internal comparing circuits in the MCU trying to work with an alien voltage source. Because of this finding both the MCU and alpha sensors are connected to the L7805CV.

The reason for having a six-volt regulator for the beta sensor is to increase its output voltage range. Since the MCU can read up to a five volt signal the rail to rail voltage of the op-amp was set to six volts preventing a voltage greater than five at the output. Using a six-volt regulator in place of a five-volt regulator extended the range of the beta sensors by 0.8 volts. This greater voltage helped to increase the range that the ADC can process with.

The two linear regulators have different characteristics as is given by the ending letters. The six-volt regulator has the ending letters ABV which are supposed to have a narrower swing than a CV counterpart. From our testing of our two regulators our ABV regulator operated well below its six-volt regulated output. The output of all of the six-volt regulators we tested was closer to 5.8 volts which is below their reported minimum output voltage. The CV regulators we tested had a more accurate voltage output. The tested output for our L7805CV was about 5.1 volts. The L7805CV did produce a greater swing especially in the presence of a ripple in the power supply.

IV. EMBEDDED SOFTWARE

The main purpose of the embedded software is to assign an audible pitch on the intensity of the reflections of light collected by the beta detectors. To do so a microcontroller receives electrical signals from the alpha detectors to detect which beam was broken. With each alpha detector having a predetermined range of pitches, the beta detectors will then determine which pitch of the range will be played for that particular beam. Based on the how much reflections were collected the microcontroller assigns in real-time a note to the output speakers.

A. Microcontroller

The requirements for the microcontroller were that it needs to be able to receive both analog and digital inputs, process those inputs to determine the correct note to play, and then actually play the note and send it to an output. Since the device will be powered using batteries, low current consumption is another consideration. Also, since each beam will use two I/O pins, having enough pins as well as support for external interrupts are other features to look for. The final requirement is for the MCU to be able to generate an output signal at specific frequencies. These output signals can be either sine waves or square waves.

The Atmel AVR family of microcontrollers were considered because they fit all of these requirements. Ultimately, the ATMega2560 was chosen because it has a high clock speed of 16 MHz, support for six external interrupts, 54 digital pins, 16 analog pins, and draws approximately 40 mA when running in active mode.

B. Software Overview

The actual software is written in Wiring, which is a dialect of standard C++, and has three main parts:

1. Setup
2. Loop
3. Interrupt Service Routine (ISR)

The setup function is always the first function that the program calls after powering on or after a reset. This is where the I/O pins, hardware timer, and interrupts are all configured and enabled. The loop function is the main part of the program. It is a continuous loop and contains the program's core algorithm. Most of the functions that the program calls are called from the loop function. This is where the notes are played and also where the MCU would go to sleep. An ISR is called whenever an interrupt occurs. Each interrupt vector has its own ISR which contains whatever the device needs to do before going back to the loop function. For this project, there will be one ISR for the hardware timer and one for each beam. The beam ISRs are attached to the digital input pins and are triggered whenever the voltage on those pins change. The pin on which the voltage changed tells the MCU which beam has been broken, and therefore which range of notes it can play. When the beam is broken a flag will be set, the timer will be enabled, and an initial read will be taken from the ADC to decide which note to start with. The timer ISR is called when it counts from the value specified in the TCNTx register to the value in the OCRxA register. When the interrupt is triggered the MCU will check which beam is broken based on the flags and take the arithmetic mean of four reads from the appropriate channel of the ADC to determine the note that needs to be played. In this project, the timer is configured to create a 100 ms delay so there will be a timer interrupt every 100 milliseconds.

Since the ATMega2560 is an 8-bit microcontroller, it is possible for errors to arise when performing comparisons on 16-bit values with interrupts enabled. This is because the MCU can only compare 8 bits at a time, and unexpected behavior can occur if an interrupt is triggered after the first byte is compared but before the second byte is compared. These potential problems can be solved by using the ATOMIC_BLOCK macro to temporarily disable interrupts, but since the comparisons are performed immediately after the timer ISR finishes, it would be easier to perform the comparisons inside the timer ISR and store the necessary values in an 8-bit variable since interrupts are disabled automatically inside an ISR.

The MCU itself was programmed using ICSP. This allows the chip to be programmed while it is installed on the PCB, which allows for testing the system when it is fully assembled without having to assemble another PCB or remove the old MCU and reprogram it if the software is found to contain errors. The PCB uses a six-pin header to receive the programs. The pins used are as follows:

1. Master In, Slave Out (MISO): Serial line for sending data from the master to the slave.
2. VCC: 5V supply voltage.
3. Serial Clock (SCK): Clock signal generated by the master that is used to synchronize the data transmission both to and from the master.
4. Master Out, Slave In (MOSI): Serial line for sending data from the slave to the master.
5. RESET: Connected to the MCU's reset pin and can trigger a reset if its voltage is equal to ground.
6. GND: Connects to the devices ground.

C. Functions

Using wiring with the ATMega2560 MCU and the Arduino IDE allows the software to use the built-in Arduino functions. Some of these functions are analogRead, attachInterrupt, tone, and noTone. These functions are described in more detail below.

The analogRead function takes one argument, which is the analog input to read the value from. This function provides a high-level interface to the MCU's ADC. Each analog pin is connected to one of the 16 channels on the 10-bit ADC, meaning that the function will return a value between 0 and 1023. These values will be used to determine which note to play.

The attachInterrupt function takes three arguments which specify the interrupt number of the desired digital pin, the ISR, and the interrupt mode. The first argument is the pin's interrupt number, not its pin number. Since they are different, the interrupt number can be obtained by using the digitalPinToInterrupt function. The ISR used as the second argument is the function that gets called when the interrupt occurs. Just like any other ISR for the ATMega2560, this function must be of type void, take no arguments, and return nothing. The third argument is used to determine when to trigger the interrupt. There are four predefined constants that can be used, which are

- LOW: The interrupt triggers when the pin goes low.
- CHANGE: The interrupt triggers when the pin value changes.
- RISING: The interrupt triggers when the pin transitions from low to high.
- FALLING: The interrupt triggers when the pin transitions from high to low.

The tone function generates a square wave with a 50% duty cycle at a specified frequency on the specified digital output pin. The third argument is optional and gives the desired duration of the signal in milliseconds. If the function is called with only the first two arguments, then the signal will be generated until the noTone function is called. A limitation of this function is that it can only be used to generate one note at a time.The noTone function is used to kill the note being generated on the specified pin by the tone function. This function is called whenever a new note needs to be played or the currently active beam is no longer broken.

While not a built-in function, another set of functions used are playBeamx, where x is the beam number. Each instance of the Beam class gets its own playBeam function, which is an ISR that gets called whenever the voltage on its associated digital input pin changes. These functions are not members of the Beam class, however, because they needed to be used as an argument for the attachInterrupt function, and they would have needed to be declared as static in the class, which would have complicated the implementation of the system.

D. Classes

Only one class called Beam is used. The Beam class contains everything necessary to control the system and consists of four members:

- Note: A volatile 8-bit unsigned integer used for determining if the beam is active. It is set to zero when an instance of the class is created and is toggled between 0 and 1 in the playBeam function associated to it.
- freqReads[4]: An array of four 16-bit integers that are the values of four consecutive reads from the ADC. These values are averaged and stored in freq.
- Freq: A volatile 16-bit signed integer that holds the average of the values in freqReads that is used to determine which note to play. Its value is set to –1 when the beam is inactive.
- Difference: A volatile 8-bit integer that is used as a workaround to create atomic conditionals in the loop function.

V. FRAME

The housing of our components is a wooden rectangular cuboid with a hollow center to act as the playing field for the instrument. As seen in figure 2 the entire frame is roughly 2 feet wide, 2 feet tall, and 4 inches of depth. This allows the instrument to be portable enough to carry around without much difficulty and be able to play on a table. Having a play field with 16 inches tall and 21 inches wide enables the accommodation of all six laser diodes with approximately three inches of separation between each laser beam, and a broad space of interaction with the laser beams. This means that a user is able to comfortably interrupt a single beam with the middle of their palm without accidently interrupting another beam.

Wood was chosen as the material to use due to its low cost, lightweight, ease of sculpting, and appeal. The batteries and main PCB (which includes the MCU) is placed on the vertical side of the frame for ease of access when troubleshooting. The laser diodes, beta detectors, and the PCBs to support them are placed on the bottom part of the frame since the lasers will be emitting from the bottom to the top. Connections will be made from the bottom PCBs to the main PCBs. The alpha detectors are placed at the top of the frame where they are positioned to be incident to the laser beams.

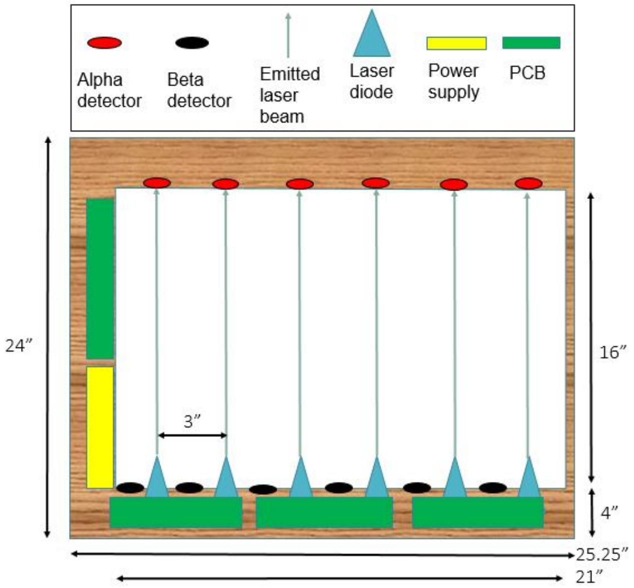

Figure 3: Housing frame for the Laser Musical Instrument.

VI. SAFETY

When using lasers, it is important to be aware of the safety precautions that are involved.One of which is the amount of output power that the lasers emit. For continuous output of visible wavelengths such as green, the maximum level of exposure is 5 mW [5]. Another concern is having the rated power not being the same as the actual power. This becomes problematic in our design if the actual power is rated to be higher than the rated power as it compromises the safety limits of our project. Stray beams are an issue because of they are beams emitted at an angle from their incident emission causing potential eye harm to someone outside of the intended beam path. Lastly reflections from a highly reflective surface could cause eye damage to the viewer. Unfortunately, our lasers turned out to be emitting a higher output power than what they were rated for. This placed their use in the non-eye-safe region. Attempts were made to decrease the output power via electrical means however the turn-on threshold for the lasers still exceeded the safety limits. Using filters proved to severely decrease our intensity readings causing few, if any, variation in pitch assignation. Laser diode replacements were sought out however due to costs, long delivery times, and the inevitable higher output power of affordable laser diodes than what they are rated for caused us to keep the lasers we acquired. To mitigate these issues a couple of safety measures were implemented. Apertures where installed to the frame to ensure a reliable beam path when the instrument is moved around and prevent stray beams. Safety goggles will be provided for demonstration purposes to ensure the well-being of the user. The inner surfaces of the instrument have been treated with black matte paint to diffuse and minimize the intensity of the reflected beams. Warning signs have been installed to caution the user about the potential danger for eye damage. Instructions on how to prevent eye damage have also been stated such as avoiding direct eye exposure to the laser beam and removing highly reflective personal materials (such as rings or watches) that could cause unwanted reflections.

Ultimately if this were to be developed into a real product, more time and resources would be spent to ensure the lasers are safe to use. Primarily lowering the output power and increasing the sensitivity of the photodiodes to maintain the accuracy of pitch assignation. Other safety measures would be implemented such as an emergency turn-off button and child-locking mechanism.

VII. PRINTED CIRCUIT BOARDS

Due to the size of the system, two PCBs needed to be built. The first board contains the MCU and voltage regulation system, while the second board contains the beta detectors. In the finished system, there would be one main board and three beta boards, with one being used for two beams. The boards were designed in KiCad, which is a free (libre) program and therefore places no limit on the size of boards that can be designed, unlike the free-of-charge versions of other programs that place strict limits on the size or number of layers a board can have. Although KiCad supports up to 64 layers, only two layers were used. In the end, the main board is 130 x 64.75 mm and the beta detector is 105 x 29.75 mm. The main PCB contains the voltage regulation system that receives the 12V input voltage as well as the MCU that receives the input signals from the alpha and beta detectors and generates the note that needs to be played. After receiving the 12V input, the voltage regulation system has three parts. The first part is a 5V switching regulator that that powers the lasers. The second part is a 5V linear regulator to power the MCU. The third part is a 6V linear regulator that powers the op amps that are part of the beta detectors. An audio socket is attached at the upper right corner of the board to enable a standard 3.5mm audio jacket cord to connect the system to a speaker. A reset button has been installed at lower right portion of the board for troubleshooting purposes. Heat sinks were also incorporated for our regulator in order to dissipate the thermal load it exhibited during testing and increase efficiency of use.

The front side of the beta detector board is comprised of two groups of five beta detectors that each correspond to an individual string. The beta detectors are spaced out far enough to where two laser beams can use the same board. This was done for efficiency of cost, space, and installation. The back side of the beta detector board contain an op amp for the beta detectors. The close proximity of the op amp to the beta detectors allows a minimal loss of signals from the detectors before amplification. On this side are also the 5V connections to the lasers and the 6V connections to the op amp.

VIII. PROTOTYPING

In order to test the functionality of the instrument, several testing procedures were made to ensure success in the project. One of which was the breadboard testing of the instrument. To do so a single string was constructed and tested for range detection of notes. This allowed us to troubleshoot any coding, electrical, and optics issues that arose. We were also able to test out how mist would increase the visibility of the laser beams to aid the user in playing the instrument. Once a reliable single string was achieved, two strings were made in order to test how well replicating the string would work. Issues of signal cross-overs, interruption sequences, and pitch allocation were addressed. Finally, when the frame was assembled all six laser beams were installed along with their respective alpha and beta detectors. They were tested for reliability of readings from the detectors, proper alignment, distribution of power to the beams, portability, signal cross-overs, operation over different lighting conditions, and pitch fidelity. It was found that the instrument works best under dark to dim conditions as the detectors receive less noise from the ambient light.

Using different interrupting mediums such as black tape, paper towels, Styrofoam, tissue paper, sandpaper, and a white glove enabled us to see the different responses we would be able to achieve. When using the hand only the result would usually be that most of the pitch would be achievable with the most extreme pitches not being attainable. Wearing a white glove enabled the higher pitches to be reach while the lowest note would be harder to achieve. We believe that this is due to a greater level of reflection for the glove than the bare hand. Black tape was useful in achieving the lower notes while struggling to get the higher notes. Sandpaper enabled us to test the dispersive effects of rough surfaces and how they effected the reading in our detectors. We found that although it was producing reliable notes when it was close to the lasers and detectors, the further away the rough surface was the less light we were able to detect to the point were detection was almost indistinguishable at about half-way through the playing range. The most balanced interrupting medium that we found was a white paper towel. Using it would normally enable us to attain all pitches and at a reasonable amount of spacing in between each pitch transition. With more time we would be able to create a musical pick that the user could use to reliably play all the pitches in the instrument.

IX. CONCLUSIONS

The project has been an incredible experience for the team. Working together towards a common goal, maintaining constant communication, writing technical reports, and troubleshooting problems has helped us develop professionally. Being able to tackle such a unique project that we came up with and design it into reality has a milestone for our engineering careers.

If given more time and resources, we would have implement more features to improve the project. One of which is creating a software that is capable of receiving the input light and creating a continuous gradient of pitches as the collection of light varies instead of having discrete levels of pitches. An array of different laser colors with appropriate wavelength-sensitivity beta detectors could be used for aesthetic appeal and a mist diffuser would be built into the frame to enable the user to see the beams without needing external diffusing materials. Additional safety measures as stated previously would be incorporated. Bluetooth connection to a remote speaker or electronic device (such as a phone) would be an excellent way to project the sound of the instrument without the use of cables. The ability to change the note tuning for each laser, replicate the feel of playing a real string instrument, and replicate the sound decay that naturally occurs when a string is plucked would be some of the stretch goals we see could be worked upon.

One of the biggest achievements of the project is being able to have an input light into the system and have it give an audio output. Seeing how a visible beam can produce an audible note made us believe that the project is more feasible than we ever could have imagined. It also gives us a sense of confidence that we know we are heading in the right track and it was only a matter of improving upon our results to finally obtain our laser musical instrument.

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BIOGRAPHIES

Joshua Cates is a senior at the University of Central Florida and will graduate in Spring 2019 with a bachelor's degree in electrical engineering. After graduation, he plans to enroll in graduate school at UCF to pursue a master's degree starting in Fall 2019. He has made the Dean's List three times, most recently in Fall 2018. His interests include mathematics, electronics design, and software development.

David Guacaneme is a Photonic Science and Engineering student graduating Spring 2019. He currently interns at L-3 Technologies and has done research in creating holographic gratings for mode shaping with PTR glass under Dr. Glebov and Dr. Divliansky. Among his achievements, he has been a finalist for the Order of Pegasus. His plans include working in industry before going back to school for graduate studies.

Lucas Sweet is a senior at the University of Central Florida perusing a bachelor's degree in Electrical Engineering. He has been the president of the IEEE PES student chapter. His plans after graduation are to work for a consulting or utility company working with distributed energy resource management and control. His goals include obtaining a professional engineering license and in the long term he would like to return to academia to peruse a PhD in power system management.

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