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Hands-on Engineering Experience, a Liberal Arts Case

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Abstract

Our project was a part of the 2019 Cornell College Summer Research Institute (CSRI), where Cornell College students and faculty work in close collaboration on a research project for eight weeks during summer. The program includes one faculty member and one or two students per each research topic. As the educational goals of the program, we expect our students to commit to the eight-week timeline, and we hope to get them ready for their future workplace and give them some ideas of the graduate school experience. They practice to learn how a research project is done from the literature review to the built, and we hope to encourage them to be independent thinkers. To satisfy the educational goals of the program, the students were given the flexibility to lead the project in the direction they wished, and the supervisor provided a guiding hand, emulating a graduate-level research work. In addition, the students presented their work for their peers and public audience multiple times during the project that helped them with their presentation skills. We chose the project based on the students' background and passion and with having their degree, general engineering, in mind. Students at Cornell College are heavily involved in artistic and athletic activities. The students involved in this project had recently taken the engineering circuits course and have a musical knowledge background. The technical goal of the project was to construct a gesture-controlled piano that could recognize the distance from an object to the sensor and translate it into musical notes. The idea came from an open-source project designed by Andy Grove. The students built upon the open-source project and expand its capabilities. They added new features to the initial design, including the ability to switch between notes and chords, additional instrument voicings, an LCD screen, a shutdown command, and a custom-made enclosure. The students wish to see variations of this project implemented in hospitals, nursing homes, and schools so that no matter the stage of life or the physical capability, such as weak muscle issues or joint-related disabilities, the user enjoys playing the piano. We also hope this project will reflect the power of engineering in a liberal arts education through the combination of multiple disciplines, experiences, skills, and interests.

1. Introduction

The Cornell College engineering major, established in 2013, focuses on general engineering and prepares students with the knowledge they need for entering into the workforce or graduate studies. The engineering major is working towards ABET accreditation. We had our first site visit in September 2019. Engineering has five graduates so far, and it is a fast-growing interest on campus. As a liberal arts college, Cornell not only strives to have students excel in their chosen fields of study but to make them well-rounded individuals who are curious about many topics. This goal means engineering students are involved in a variety of activities such as music and athletics, which allow them to pull on various interests and skills. The emphasis in our program is on hands-on learning experiences and on providing our students with real-life challenges. Each course at Cornell is taught over an eighteen-day period, and the students only take one course at a time. Cornell's One Course At A Time allows students to foster experiential learning in the classes, which enables students to work on engineering projects in and outside of the classroom with no time and space restrictions.

Our project was a part of the 2019 Cornell College Summer Research Institute (CSRI), where students and faculty work in close collaboration on a research project over the summer. Cornel College funds this program. Each group includes one faculty member and one or two students per each research topic. The goal is to familiarize undergraduate students with conducting a research project from the literature review to finish. Students have to present a midterm and a final presentation, and different workshops are offered to students on research ethics, the job market, fellowship programs at Cornell, and applying to graduate school. Students also attend a TED talk session where faculty talk about their current research interests.

1.1. *Choosing the Project:*

Based on the background and interest of the students our team looked for different projects and we came across the project designed by Andy Grove on instructables.com. It is an open-source project called "Ultrasonic Pi Piano with Gesture Controls!" [1] We treated this opportunity as a tinkering challenge. Grove's project is a gesture-controlled piano that uses ultrasonic sensors to determine the distance and to generate corresponding notes to each length. The goal was to have a student-led project that not only tests their recently gained knowledge in programming and circuitry but also their passion and knowledge for fine arts, especially music theory. In this project the previous knowledge of the students in computer science (Python programming), circuitry, material science, and music were utilized. They designed and built an enclosure for the piano. They chose the material for the enclosure, considering budget and structural restrictions.

2. Technical Aspects *Students' section*

2.1. *Different musical instruments:*

Clearly, there is an interest in nonconventional musical instruments [2], [3]. The most famous one is the no touching Theremin (see section 2.6 for more details). There are various types of organs such as the one that strikes stalactites tuned to different pitches, the Zadar sea organ that utilizes the sea waves and tubes to generate music, and the organ that uses combustion and explosion to play music [4]. There are flute-like instruments that use the power of water or wind to play, such as Hydraulophone and Aeolus [5], [6]. Theremin is a musical instrument that uses a variety of modified solid-state Tesla coils to produce musical notes. Kangaroo Pouch Tone uses rolls of paper and a series of oscillators to generate sound [7].

Our project is a step towards making something fun and different and using our engineering skills along the way. Our instrument is portable; it is easy and inexpensive to make, which makes it different from the devices mentioned above.

2.2. *Human Computer Interaction:*

The initial forms of human-computer interaction were primitive primary means of communicating binary to the computer such as punch cards or paper with circles either left empty or filled in with a pen [8]. Mouse and keyboard were the next steps. These days as computers became more prevalent in our modern-day lives, creating a more efficient and effective means for interacting with computers is necessary. Some modern forms of human-computer interactions include touchpads, gaming consoles, Kinect for Windows, voice search, leap motion, and even brain-computer interfaces [7]-[12]. The methods developed also became increasingly specialized to accommodate various specialties in computing. As HCI becomes further intertwined with our lives, more effective and natural ways must be developed to utilize computers fully. Hand gesturing is a method of communication that has been with humans since the dawn of communication. As such, hand gestures offer a more natural and effective means for interacting with computers. As the method of our choice, we need a sensor to see and interpret various hand gestures.

2.3. *Sensor:*

Gesture control methods with computers have usually utilized video sensors sometimes with the addition of infrared sensors to clear the picture. Our project looked at the effectiveness of ultrasonic sensors as a cost-effective means for gesture control and HCI. We chose HRS-204 ultrasonic sensors, which operate when an electric current causes a quartz crystal to oscillate, creating an ultrasonic wave. This wave then bounces off of an object such as the user's hand and returns to the sensor, see Figure 1. Using the speed of sound, the distance is calculated, and our python program converts this distance into a note. We must admit that ultrasonic sensors are not as good at precise position measurements as other sensors such as vision-based or infrared sensors. However, ultrasonic sensors are inexpensive and have no limitation on colors or patterns and can handle both short-distance and long-distance measurements.

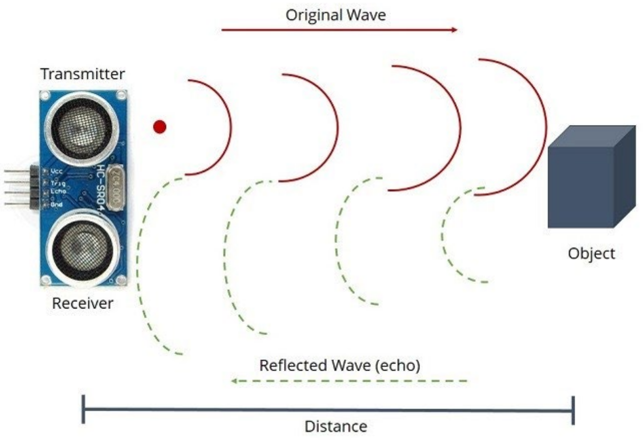

Figure 1- Schematic of ultrasonic sensor operation [13].

2.4. *Raspberry Pi:*

Our project uses a Raspberry Pi, a single-board computer, as the brain of the piano. Raspberry Pi is more than powerful enough to run all of the sensors and displays needed for this project. It is light and portable to ensure mobility for the piano.

2.5. *Python:*

Python is a high-level programming language that is friendly to beginners. We used it to receive ultrasonic sensor data, to figure out what pitch needed to be played, and then to format an output that is sent to Fluidsynth, a music synthesizer program using a Linux terminal. Fluidsynth would produce the correct note or another command, such as a change in the instrument.

2.6. *Practice projects:*

We started the process by first conducting some basic experiments with Raspberry Pi, creating simple projects such as a flashing light and a soundboard, Figure 2. These projects gave us a basic grasp of how Raspberry Pi and its GUI function, and how python connects to Raspberry Pi.

We then tested our array for ultrasonic sensors by building a basic Theremin found on Raspberry Pi official website [14]. Theremin is one of the first musical instruments that is played with no physical touch. It was buils by Léon Theremin, in 1928 [15]. Executing the project was quite easy and it includes only the control of the note, so we expanded upon it by adding ultrasonic sensor to provide volume control for our instrument, see Figure 3.

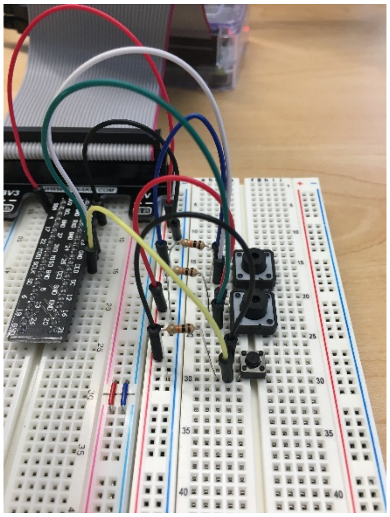

Figure 2- Sound board.

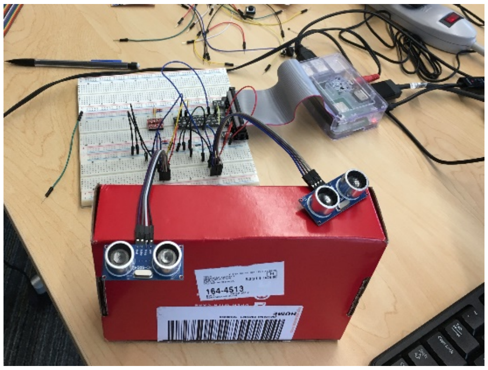

Figure 3- Theremin with added volume sensor.

2.7. *Main project:*

After initial experiments with Raspberry Pi, we began to work on the main project. We started the work by looking through the open-source code and started learning and debugging process going through the code.

After getting the original project to work properly, see Figure 4, our next step was adding further commands and functionality to the piano, each of which would test our programming and electrical engineering skills.

This project was treated as a tinkering problem, and at each step the students thought about how to make the instrument more interesting and easier to use. Based on those they looked for solutions and the software and hardware needs.

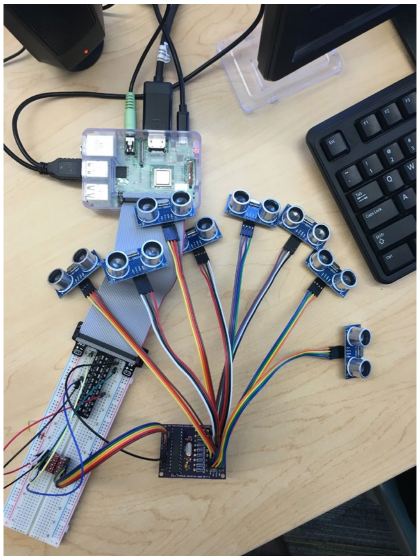

Figure 4- Building the main project, sensors, Raspberry Pie, and bread board

a) Change of instrument: we first added the ability to change the sound of the piano to different instruments such as guitar, drum kit and harp using the voices stored in Fluidsynth and dictionaries in Python. We found these options by looking at the source code for Fluidsynth and trying to access them from the Linux terminal on the Raspberry Pi. By looking at the source code we were able to find part of the note command which we believed would specify the type of instrument used and applied it to the code.

b) Gesture shut off: we then added the ability to shut off the piano using a gesture and Python operating system commands. This command was found through online research into Raspberry Pi terminal commands and was implemented into the code.

c) Display: since the notes correspond to the different distances from each sensor, the location of the note is less tangible than on a standard piano. We wanted to tell the users what note they were playing. As such, we added an LCD that displays to the user the current note and the name of current instrument being played, see Figure 5. The implementation of the LCD screen offered its unique challenges due to the I2C backpack attached to the display. Interfacing this display with the Raspberry Pi proved difficult even with online research. Eventually we earned how to communicate between the two through online tutorials, the Raspberry Pi Cookbook [16], and through trial and error.

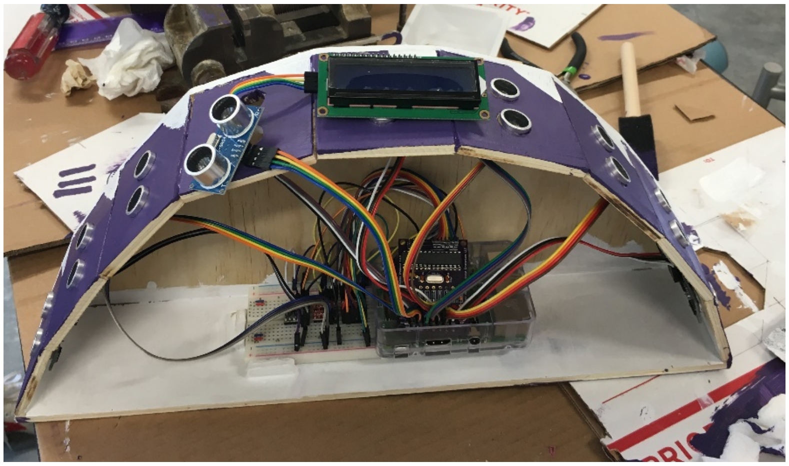

Figure 5- Adding the display.

d) Adding chords: next, we wanted to know what we could add, which would make the piano more musically interesting. We decided to include chords that would add new exciting layers to the instrument. We created a chord gesture where the piano would remember whether each sensor was playing chords or notes. When the gesture was triggered, the piano would then switch the value of the sensors causing Fluidsynth to plays a chord. To generate the chord, the software would take the base distance and calculate the corresponding pitch as if it were to play a normal note. Then the python code will play two more notes with the correct number of half-steps added to play the right chord. Following a C major scale, if a C would typically be played a major chord would also play an E and G, if a D would be played an F and A would be added. This allows any octave to be played with chords or notes and switched in between. The process of creating this command was through brainstorming based off our preexisting knowledge of python. We determined by have an infinite loop checking each sensor for a value the program could determine what each sensor should play. Once we learned how to make each senor remember a value we used our music theory knowledge to know what pitches would need to be played next to create the chord.

e) Dynamic control: finally, we added one extra sensor and used the gain function in Fluidsynth to include control volume to our piano. Early on in scouring the code for how to manipulate the notes we found a command which would alter the volume of the note. Using what was learned through creating the chord command we were able to an additional sensor which would keep track of volume.

f) Setting the zero distance: to make the piano accessible to anyone of any age, we added a set max distance feature to the piano, which averages the distance of the first and last sensor, so both children and adults can use the same instrument. This idea was implemented by our preexisting knowledge of python and knowing we could average repeated measurements of a sensor to determine a single measurement thus creating a set max range.

g) Enclosure: after we accomplished our programming goals, we switched to focusing on the enclosure for the piano. We started to build with cardboard to test enclosure designs. At first, we used a sheet of cardboard with the sensors in a row similar to a standard piano; however, this design provided problems as the user's hand would trigger multiple sensors. Since each sensor emits ultrasonic waves in a cone, we began bending the cardboard so the cones would be pointed off at different angles. Through various trials and errors of angles and distances, we settled on our final design with a more prominent arch but still with straight lines to show the user how to keep their hand parallel to the sensor for the best performance. A method that was explored to reduce sensor interference was adding a cone around each sensor to bounce the waves upwards, but the effect was almost negligible and, as such, was not included in the final design. After we had a prototype we were satisfied with, we conducted a material choice analysis to determine the material for the final product. The final decision was between wood and 3D printed plastic. While 3D printed plastic was an enticing material due to its longevity, professional look, and portability, ultimately wood was chosen. Wood is more cost-effective and forgiving to mistakes. For a 3D printer, a CAD program has to be changed every time something needed to be altered, and it makes the manufacturing process longer. We started constructing the final product using Cornell's engineering machine shop. Design properties that we wanted to have were a door to access the electronics in case of any maintenance is needed, and the door had to have a space that let us access power, HDMI port, and Audio when the door is closed. We wanted a clean decorative design to look nice for performance. The final product is light, portable, and sturdy, obtaining all of our goals for the enclosure, see figures 6 and 7.

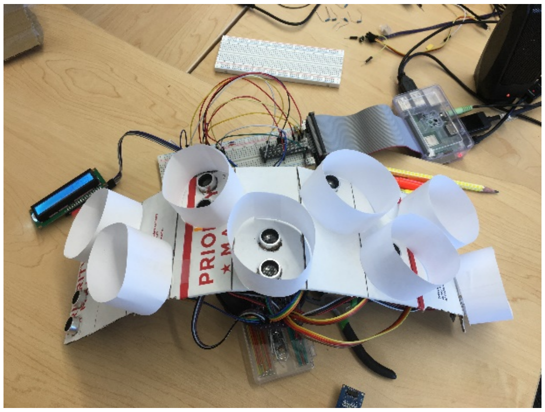

Figure 6- Attempting different designs for the enclosure

Figure 7- The enclosure almost done.

3. Conclusions and Future Work

3.1. *Educational goals of the project:*

I tried my best to make it student-led research, and not to micromanage the project and let the students decide about each step. I did my best to utilize the students' multidimensional knowledge to perform an interdisciplinary project. The students worked in a team of two, which was a great experience to build their teamwork skills. They participated in the events arranged by the CSRI program, including workshops and talks. They presented two oral midterm and final presentations, and they had interviews with the local newspaper, these interactions increased their relationship and presentation skills. The students designed and built the enclosure that contributed to their construction skills and the sense of decision-making. In the end, this project provided an enjoyable summer experience for the students.

3.2. *Technical goals of the project:*

We were successful in the construction of our fully functioning gesture-controlled piano with all the basic features as in Grove's project, and we added more options to the design to make it more interesting. Further advancements we would like to make to this project would be the addition of increased methods for musical articulation light projection onto hands to give users additional input on correct note placement, different types of scales and chords, and the possibility of more advanced control methods such as leap motion. One option we thought about is placing each note on each sensor instead of the current design that each sensor corresponds to an octave. This way, we believe it will be easier for the user to play a simple song with the instrument. Right now, the distance from the sensor dictates the note, and it takes a while for the user to get used to it. Through this project, we have explored the use of ultrasonic sensors as a means of HCI and hope our research inspires further research into this method of HCI. Also, we hope this project will show the power of engineering using the liberal arts combining multiple disciplines, experiences, skills, and interests to create projects which are exciting and to apply engineering to help others. We would love to see devices like ours implemented in hospitals, nursing homes, and schools so that no matter the physical capability or stage of life the user is currently at, the user can still create music.

Acknowledgment

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