

# Design and Implementation of a Raspberry Pi-Based Laser Harp

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## ABSTRACT

This report shows how the laser harp was built step by step. First, it gives a brief introduction of the STEM background in the UK and lists out the key issues in engineering. Then it presents the aim of attracting young pupils to study engineering and lists the objectives of the laser harp project. Secondly, previous work, including two styles of laser harp and designs related to laser harp is carefully reviewed and analyzed. Thirdly, the design of the harp in this project, which uses button circuits, a Raspberry Pi-based system structure as the hardware, and Python and Sonic Pi based programmes as software, is shown. Fourthly, the results are presented and discussed, and then the challenges encountered during the project are analyzed. Finally, a conclusion is provided, summarising how the laser harp achieves the aims and most objectives and then points out possible improvements for the future.

## KEYWORDS

Laser harp; STEM education; Raspberry Pi; Circuit design; Python programming; Sonic Pi; Interactive musical instrument

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## 1. INTRODUCTION

This chapter describes the background and emphasizes the importance of UK STEM (Science, Technology, Engineering and Mathematics) education. Also, several key factors that discourage young girls and boys from choosing to study or work in engineering (or more broadly, STEM), are highlighted. Finally, an explanation of the purpose of the project and the significance of our work is given.

### 1.1. STEM in UK

STEM is a well-known abbreviation that is used to refer to the fields of science, technology, engineering, and maths in educational environments, which aims to educate and train the engineers and scientists of the future [1].

In recent years, STEM education has seen an abundance of growth in the UK, with a surge in a curriculum that focuses on providing students with a complete learning platform that teaches skills directly related to real-world applications. This skill set provides a foundation that is necessary for many organizations in a variety of sectors including aviation, healthcare, and many more. Hence, gaining a grasp on these skills through education is becoming increasingly important for students [2].

The development of STEM education has seen rapid growth across the globe due to an array of solutions it can provide across a range of fields. Due to the fact most sectors are reliant on the STEM fields, advances in STEM can indirectly boost the economy [2]. Regarding the UK's economy,

engineering alone makes up for 25% of the added gross value, whilst manufactured goods account for 50% of British exports [3, 4].

STEM plays a significant role in the engineering workforce in the UK. Numbers estimate that there are around 30 million people employed in the UK, 5.8 million of which work in STEM-based jobs, accounting for roughly 20% of the total workforce. Due to constant innovation, new technology is always emerging, and this trend is expected to continue upwards in the coming years, driving STEM to become one of the largest employers across the globe [2].

However, the number of people committing to a career in STEM cannot keep up with this demand [3]. Due to significant developments across each STEM discipline, new career opportunities are appearing all the time. In recent years, many workforces around the world are suffering from a shortage of capable STEM workers. Hence, the demand for qualified students is ever-growing, however, the number of students pursuing a career in STEM is dropping rapidly [2].

## **1.2. Key Issues in Engineering**

Although most reports claim that engineering is vital to the well-being and economic development of the country, the UK is facing an engineering skills crisis. Evidence suggested that the following key factors are influencing young students.

### **1.2.1. Lack of awareness**

One factor which can determine a young person's choice to pursue a career in engineering is their existing knowledge and perception of the profession. However, unfortunately, many young people's awareness of engineering is severely lacking. Around half (47%) of 11 to 19-year-olds stated they had very little or no knowledge of what engineers do. An even bigger issue is that this knowledge is often based on preconceived misconceptions, such as engineering being too complicated, it's dirty, and a job exclusively for men. These ideas are inaccurate but are a clear factor that discourages girls or some ethnic minority groups from pursuing a career in engineering [5].

### **1.2.2. Self-doubt**

Young people have lots of doubt in their ability, and hence doubt their chance of success in STEM. Most believe that STEM should be reserved for those who are considered to be extraordinarily clever, which often discourages individuals who do not feel confident in their academic ability. Among 16 to year olds in the UK, it was reported that 62% of them feel STEM subjects such as science or maths were harder than non-STEM subjects [5].

### **1.2.3. Underrepresented Groups**

The number of women and ethnic minorities currently in apprenticeships relating to engineering is still drastically low [5]. It has been discovered that men have a higher chance of pursuing education or a career in the fields of engineering, science or maths, whilst women tend to choose to pursue positions in humanities, arts, and education-related fields. Subsequently, there is a large imbalance between genders in scientific and humanistic fields [6, 7]. The subject preference of each gender is prevalent even at a secondary level, with previous research establishing that the gender difference in secondary- education subject choice is a strong predictor for the decisions related to the field of study in post-secondary education [5, 8, 9].

## **1.3. Project Aim**

Under such circumstances, our project aims to provide an exciting exhibit. It could be showcased at science fairs or taken into schools to encourage students to engage in STEM subjects. Although more and more measures are taken to encourage young students to choose engineering-related subjects, it remains a huge challenge for society, considering that science, technology, and engineering are regarded as the backbones of future economic growth.

One potential solution is through interactive learning, a teaching method that helps students improve critical thinking skills, which are essential to the development of analytical reasoning. Through exposure to open-ended questions, children are forced to use imagination and logic to make decisions and solve problems, rather than just regurgitating information. Furthermore, through interactive learning, children learn how to work as a team to complete tasks, a skill that is vital to modern-day workplaces which orientate around team-based structure [10].

Features of a successful exhibit:

Portable. It could be built and transmitted easily.

At a reasonably cost. Schools should be able to afford it.

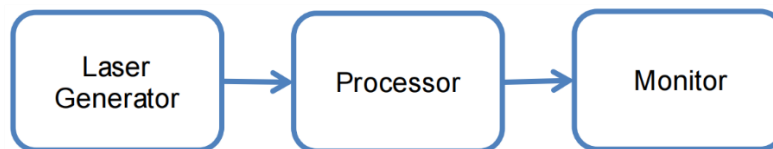
Eye and ear catching, fun, interactive. The exhibit should be attractive.

Gender neutral. It should be able to encourage both young girls and boys.

Educational. It should be able to prompt students to ask questions.

#### 1.4. Laser Harp Project

Our project is based on this concept of interactive learning. The laser harp project aims to provide young girls and boys with a more interactive and fun way to experience engineering and improve their knowledge of the subject, and subsequently encourage them to choose to study engineering.



**Figure 1.** The conceptual diagram of laser harp

As Figure 1 above shows, a laser harp consists of three parts. Lasers work as inputs, as shown on the left side of the figure. The input signal is generated and sent to a processor in the middle. The output signal is then sent from the box to the monitor. The monitor then generates sound and displays graphics and animations as the output.

A laser harp is an electronic instrument that mimics a traditional harp, but rather than plucking strings to generate sound, it uses lasers instead, which can be blocked to produce the desired sound. It is an interactive device that players can play with and learn from. The monitor guides players when to block the specific lasers at the right time and the laser that is blocked will show notes on the monitor to provide feedback to the players. This is the first draft of the laser harp we'd like to design.

#### 1.5. Aims and Objectives

**Aims:** The laser harp project is a joint project designed by another undergraduate student, Bohdan, and me. We both aim to design a laser harp as described above, and we both have our own tasks to complete on this basis. The project is roughly divided into the software part and the hardware part. My job is to mainly focus on the software part from June to September. Bohdan's job is to design the hardware part starting from September.

**Main objectives:**

Agree an architecture design for the operation of a laser harp in collaboration with Bohdan

Main playing mode: generate sound when blocking lasers

Develop games like pong game or guitar hero game...

Add music effects including attack, sustain and using synthesizers

Add settings to provide options for users to change

Additional objectives:

Add menu with settings to provide a better user experience

Provide gesture recognition to navigate the menu or control the harp

Add a distance sensor to the side to have a different kinds of input

These are my objectives from June to September, and they are mostly focused on the software part. The laser harp will work properly if the three main tasks are done. The first task is to generate a sound when blocking lasers, but buttons will be used at first to test whether it's working. They will be replaced with lasers in the end. Secondly, different game modes are designed to add more fun to the design, to give a better overall player experience. Thirdly, some fancy musical effects like vibrato, attack, or release can be added. The next step is to add settings such as the option to adjust difficulty or choose different songs to give a better user experience. At that stage, the laser harp should be working and players can play games with different musical effects with the option to change settings.

Additional objectives include some further improvements after making the basic harp fully functional. Firstly, this includes a menu that allows the game to be paused and have a full overview of the settings that can be added. Secondly, gesture recognition could be added for better navigation of the menu. It is especially interesting when using it with the lasers. At last, a distance sensor could be used to add a new method of interaction.

Bohdan's main objectives:

Design system architecture of the laser harp

Design a specialised board for locally handling laser/speaker pair.

Create a CAD model of the laser harp.

Bohdan's additional objectives:

Build a laser harp with an integer of 12 vertical lasers and potentially 6 horizontal lasers which can be later configured to play other instruments also.

Record and playback melodies/songs.

Add export recordings functionality.

App interaction with plug in USB. [App and communication]

These are Bohdan's objectives start from September, and he will focus mainly on hardware part.

## **1.6. Report Structure**

Section 1 mainly provides an introduction of STEM in the UK and some key issues that are causing fewer young pupils to choose to study engineering. Then a conceptual diagram of the laser harp we would like to design is presented alongside a list of our aims and objectives from a holistic and personal perspective. Finally, the structure of the report is shown for the readers.

Section 2 talks about the design of other devices that are related to the laser harp project. It demonstrates different types of laser harps and analyzes three designs with different methodologies. A comparison is then made between different system structures, hardware parts, and software tools.

Section 3 studies previous designs and draws a sub-conclusion of the final design of the laser harp. Everything the laser harp needs is prepared so that practical work could commence.

Section 4 mainly provides information on the difficulties during programming and the results of the program. Several difficulties are solved through modifications but some are not solved due to time limitations. At last, an analysis is done to fully evaluate the laser harp.

Section 5 gives a conclusion on the laser harp design. It compares the aims and objectives listed in section 1 and discusses the importance of this project. Then it predicts trends and discusses how the project will develop in the future. At last, it elaborates on some thoughts of the designer during the project.

## 2. REVIEW OF PREVIOUS WORK

In this chapter, two styles of laser harp are introduced, and laser harp related projects designed by others are reviewed. The advantages and disadvantages of each design are carefully analyzed and compared.

### 2.1. Framed Style Laser Harps

Framed style laser harps are designed to mimic a traditional harp with strings. The frame has a series of low-powered lasers (normally around 5mW) and photodiodes attached. The number of lasers can range from one or two for a simple harp, to up to 32 or more for harps with more complex software and MIDI hardware [11].



**Figure 2.** Framed style laser harp [12]

Usually, the lasers have a very low power of 5 mW and are red or green, as they are deemed safe for public use by the FDA. As the harp is framed, the style and size can vary a lot, ranging from a box-sized harp to a room-sized fitting, depending on the desired design.

### 2.2. Unframed Style Harps

Unframed style harps are normally made up of three components, a laser projector, controller, and sensor. The first editions of unframed laser harps had these three components contained with a single box. However, more recent laser harps have been designed and built so that the three elements can be positioned independently and connected by cables. The harp uses a single laser beam that is split into an array of beams. This is connected to a computer or synthesizer which generates the subsequent

sound or musical effects. The frameless laser harp design allows players to have a more elaborate method of play. A prime example of this type of harp is the Prolight Laser Harp Controller [11].



**Figure 3.** Prolight laser harp controller [11]

The Prolight Laser Harp Controller is the latest product of this kind available on the market. Through the combination with a laser projector, beautiful beams of light can be generated to form the laser harp. The generation of colourful beams of light rather than strings makes for an amazing sight. It can also be programmed to produce any audio or video output, which includes visual images, sound effects, music, or even pyrotechnics [11].

The laser projector and sensor are positioned so that they are facing each other, and are connected to a control box. The system is incredibly versatile as you can arrange the components in any way you like, and any kind of laser projector can be used, though normally high-powered lasers ranging from 5 to 20W and more are used [11]. The control box is a MIDI controller that sends MIDI signals. Although these unframed harps are more difficult to build than framed harps, their design allows for much freedom and creativity [11].

The array of laser beams is projected into a fan-shaped arrangement. When a blocked laser is detected by the sensor, a signal is sent to the control box, causing a MIDI signal to be sent to a synthesizer, sampler, or computer sound card which results in a particular sound to be played which corresponds to the information received [11].

There are multiple benefits from using high-powered lasers, which include making it easier for sensors to detect when laser beams are interrupted as well as providing an enhanced visual experience for viewers. When operating a laser harp, users normally wear white gloves to improve the sensor's ability in detecting reflected light, to serve as protection from the potential dangers of laser radiation, and to provide a better visual experience for the audience [11].

## **2.3. Some Designs**

Here are some fantastic designs made by others that show the capability of the Raspberry Pi, Arduino and sensors, and how to realize these creative and brilliant ideas.

### **2.3.1. Piano Stairs**

Piano stairs are an interactive and portable musical device that can be fitted to almost any stairwell.

Each step utilizes a light-based “tripwire,” with the light source on one side of the step whilst the photoresistor is fitted on the opposite side. To function, the Arduino receives information from the sensors and transfers it to the Raspberry Pi, resulting in a sound being generated [13].



**Figure 4.** Player interacting with Piano Stairs [13]

The Piano Stairs work by relying on both an Arduino and Raspberry pi, which is a bit wasteful. The author suggested that an Analog to Digital Converter (ADC) and a Pi Cobbler Breakout Board could be used to replace the Arduino. Additionally, the number of analogue pins on the Arduino limits the expansion of the number of stairs, and 6 keys are not even enough for one octave.

However, this Piano Stairs design demonstrates how the Arduino and Raspberry pi work together to deal with input signals and process them. The audio latency is perfect but it can only generate 6 specific sounds. The piano stairs have only one method of interaction, so maybe more games or more sensors could be added to the stairs to make it more creative and more fun. For example, games like avoiding the flashing stairs, or blocking the stairs to play some music. Other sensors such as distance sensors to adjust volume could be added to each step, or pressure sensors could be added on the centre of the stairs to generate special music effects like vibrato or drums. Overall, it has a great design, it's creative and attractive but it could be modified to have better performance and better user experience.

### 2.3.2. Laser Harp with Tah board and Raspberry-Pi

This wooden harp was designed using Laser and Light Dependent Resistors (LDRs) to be able to play music. Six LDRs are connected to a 1K pull-down resistor and a Tah board, and another six 1K resistors to an additional Tah board. One side of the harp has a connector for a 5V adaptor which is used to power the lasers. The lasers are connected in series and fitted to the wooden frame using play dough in the harp's upper cavity. The lasers are aligned along the slit of the central cavity, and the LDRs fitted appropriately. The six analogue pins of the Tah board function as the input from the LDRs. To finish off the design, a Raspberry Pi was connected to run the program [14].



### 3. DESIGN AND METHODOLOGY

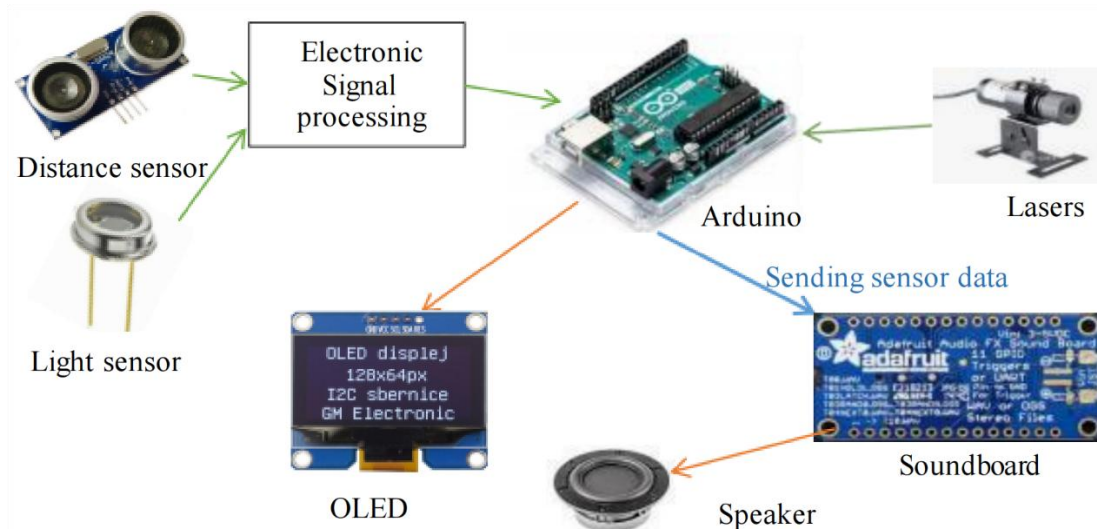
This chapter mainly shows how the hardware and software of laser harp is designed.

#### 3.1. Laser Harp Project Hardware Design

Laser harp its a joint design. Bohdan take majority responsibility for building and testing the architecture and other hardware parts.

Although some of the designs have their deficiencies, they all provide some good ideas and methods in some specific fields. The piano stairs and laser harp with a Tah and Raspberry Pi are limited in the number of notes they can play, but they are interactive and able to generate nice musical effects. The Raspberry Pi with buzzers has a poor set of musical effects and no interactions, but it provides a way to code music and to generate many notes without limit. All of these designs need some game modes to make them more interesting. Other designs that are not listed here were also considered and they inspired many ideas. After more meetings with my partner and professor, the idea of our laser harp was realised and gradually the design of the laser harp came to fruition.

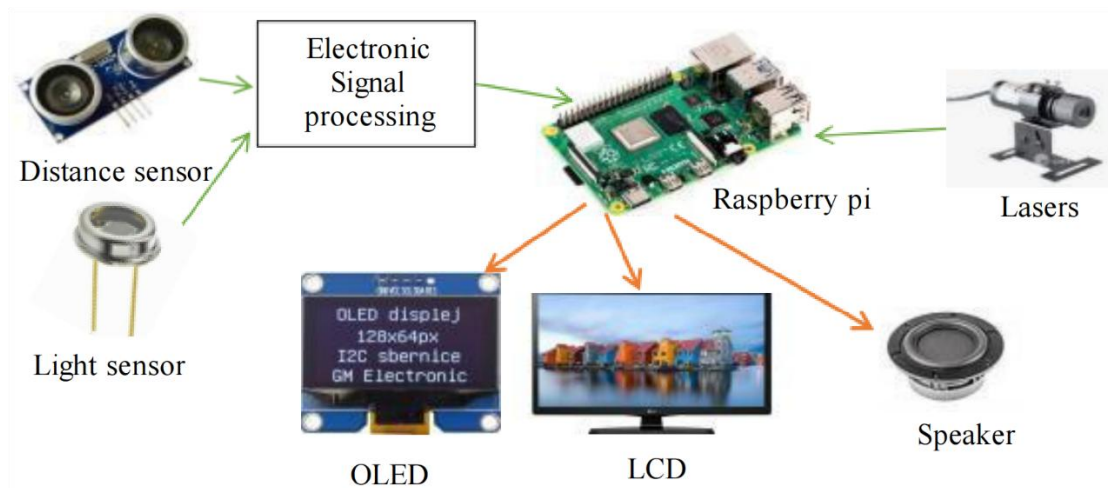
##### 3.1.1. System structure



**Figure 6.** Schematic of laser harp with Arduino

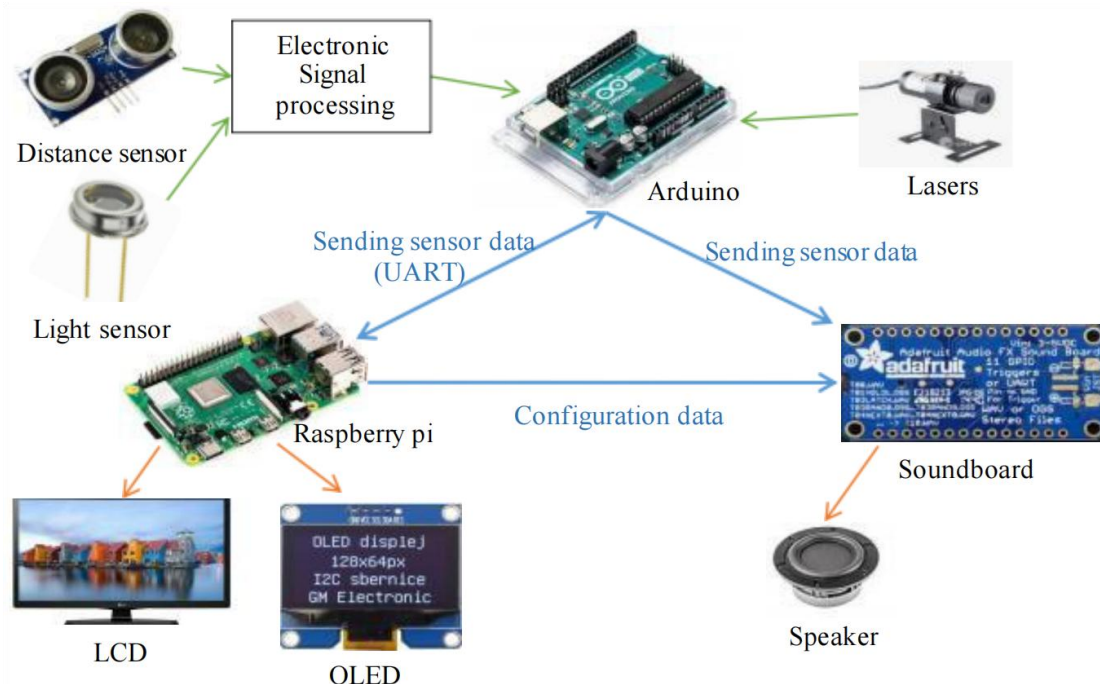
Figure 6 shows the first idea for the potential structure of the laser harp. Sensors send analogue signals to the electronics in the middle for signal processing, and then the signal is sent to the Arduino. Here, the Arduino does what it does best, deals with sensors, and sends the data to the soundboard to play sound. The Arduino could be connected with an OLED to display some simple graphics or texts.

The problem with this structure is that we may need an additional soundboard since the Arduino does not have an internal soundboard. Arduino is not a good choice for developing in the future as well. More complex games and fun are not suitable for this structure.



**Figure 7.** Schematic of laser harp with a Raspberry pi

The second version of the potential structure, shown in Figure 7, is more innovative than the previous one. Only one Raspberry Pi is used, which simplifies the structure. The Raspberry Pi will receive the signal, process it, and then send it to the display and speakers. This structure is better because it has lots of potential for development. Also, all sensors, actuators, and output devices are connected directly to the processor which makes the data transmission time shorter than before. The Raspberry Pi could be programmed with Python to develop a more intricate level of games, which is the best solution. It can also be connected with an LCD which makes it a better option as well. After much discussion, this structure was decided upon to be used in the laser harp project.



**Figure 8.** Schematic of laser harp with both a Raspberry pi and Arduino

Figure 8 shows the structure using both a Raspberry Pi and Arduino. The Arduino collects data from sensors and lasers, the data is then sent to the Raspberry Pi for further display or to the soundboard to play sounds. The Raspberry Pi receives the signals and presents nice graphics on the displays. This is a hybrid version of the project, each processor should be able to perform better in their own field. It is a backup option for the second proposed structure. If the latency or the second system structure is not acceptable, then this hybrid version could be tested to see whether there are any improvements in delay.

### 3.1.2. Processor

**Table 1.** Comparison of Arduino UNO and Raspberry pi 4B [19]

	Arduino UNO	Raspberry pi 4B
Category	Microcontroller	Full computer
Language	C, C++	Python, Linux
OS	-	Raspbian, Linux
Clock speed	16MHz	1.2GHz
Good at	Interfacing Sensors and controlling LEDs and Motors	Developing software applications
Task	Single task	Multiple task
Price	\$23	\$35
Pins	14 digital I/O pins	40 GPIO pins
Add-ons	Arduino Shields	HAT expansion boards
Logic-level	5V	3.3V
Power	USB port from PC	5V 3A USB Power Adapter
Internet	Modules or shields	Easily connect to WIFI
Wireless connection	Not on board	Bluetooth and WIFI



**Figure 9.** Arduino UNO vs Raspberry pi 4B

As Table 1 shows above, the Arduino UNO and Raspberry Pi 4B can both complete laser harp tasks, but still, they have a lot of differences.

The Raspberry Pi is a computer that has a better programming language for larger projects, and it has an operating system that makes it easier to handle tasks and make improvements afterwards. It is very good at multitasking and has 40 GPIO which is enough for the laser harp. More importantly, it can be connected to WIFI and Bluetooth which allows for greater room for improvements.

The Arduino UNO is only a microcontroller and has a more basic programming language. The processor is not as good as the Raspberry Pi's and it is only good at interfacing sensors and controlling LEDs. Normally, it's also only good at doing a single task repeatedly and has difficulty connecting to WIFI.

In the laser harp project, we'd like the laser harp to play sound and show graphics at the same time. The shorter the delay, the better the experience it provides. It's always better to have some interesting games while playing with lasers rather than just turning on LEDs. Thus, a more comprehensive programming language is needed to build a platform for further improvements. When the laser harp is designed and built successfully, apps on smartphones can be designed to control the harp through WIFI. So overall, the Raspberry Pi 4B is the best processor for the laser harp.

### 3.1.3. Light sensor

Photodiodes are used to detect the changing of light and it will output an analogue signal to the electronics and then to a processor for future processing.

### 3.1.4. Distance sensor

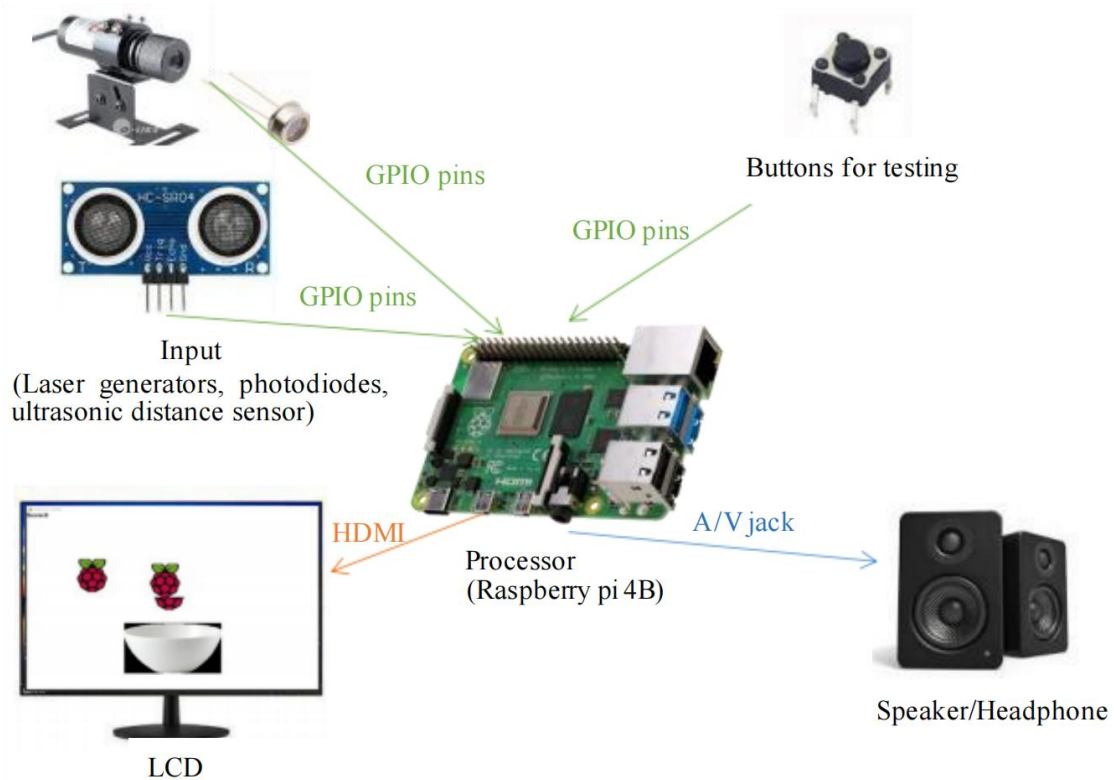
The HC-SR04 Ultrasonic Distance Sensor can send high-frequency sound waves towards the target object and calculate the time taken for the wave to return and determine the distance. It won't be affected by the target's colour or transparency, and it can work under low light circumstances. However, its range is from 2 cm to 4 m, and it has a low refresh rate at 40 Hz, so the hand must be slow and close enough to detect.



**Figure 10.** HC-SR04 ultrasonic distance sensor

### 3.1.5. Final hardware design

Finally, Figure 11 shows the final structure and components of the laser harp.



**Figure 11.** Basic schematic of the laser harp

Ideally, 24 laser generators and 24 photodiodes are placed on the upper and lower ends in a one-to-one correspondence with a 2cm interval between each of them. The 2 cm interval was chosen as it is a little bit wider than a single finger, so the player won't block two lasers at the same time with one finger. The ultrasonic distance sensor is placed on one side of the laser harp, so a player can use one hand to control the distance if needed. In the first phase, 8 buttons are used to simulate the lasers and photodiodes, they will be replaced in the end after modification. The Raspberry Pi 4B was chosen for the processor. Python and Sonic Pi are used for programming. Pi will send the signal to the monitor

through an HDMI cable and this will send the audio signal to the speaker or headphone through an AV jack if the monitor does not have a speaker. The monitor and speaker will display graphics and generate sounds to let the players understand what they are doing and give them instructions to have more fun.

## **3.2. Laser Harp Project Software Design**

This chapter will mainly demonstrate the key practical software design process during the project. It will list and explain the process and principle of the programming section.

### **3.2.1. Python**

After the hardware is ready, it's time to choose the right language to programme the project. Python was chosen as the programming language due to its capabilities as an object-orientated, and highly functional language. Also, Python is an ideal language for programming due to its simplicity and readability. Another benefit of Python is that programs can be written in fewer lines of code compared to alternative languages such as C/C++ or Java trying to achieve the same goal [21, 22].

### **3.2.2. Sonic Pi**

Sonic Pi is an open source programming platform which is used to produce music through a live coding experience [23]. It can generate better sounds by live coding, which is done by typing text into the Sonic Pi server. It can change the frequency of musical effects of sounds by using different synthesizers, and it can play multiple threads containing different sounds at the same time. Sonic Pi can be connected to Python through code or package so that the script will be able to send messages to Sonic Pi to generate sounds [23].

## **3.3. Chapter Summary**

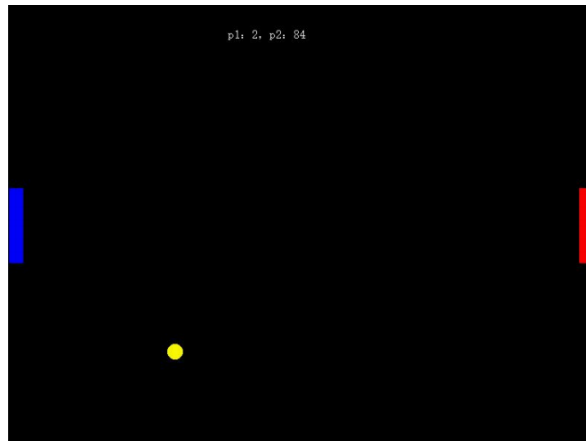
This chapter shows how the laser harp is designed from the hardware to software step by step. Laser generators, photodiodes, and ultrasonic distance sensors are used as inputs, buttons are used for testing and they are all connected via GPIO pins. The LCD is connected through an HDMI cable and headphones are connected through an A/V jack. Python and Sonic Pi are the two pieces of software for programming and generating beautiful sound. Finally, the laser harp is designed, built, and it's now ready for programming and testing.

## **4. RESULTS AND ANALYSIS**

This chapter describes how the code works by using a phase-by-phase flow diagram. It also shows some technical difficulties faced during the programming and design stages. It describes different ways the problems could be solved. Finally, it shows the results of the work and analyzes the advantages and disadvantages of the final piece of work by using photos of the GUI, and games.

### **4.1. Before Project**

Since I'm a beginner in programming with Python and Raspberry Pi, I started by programming two sample games and managed to learn the foundations of programming and how to properly use functions, lists etc.

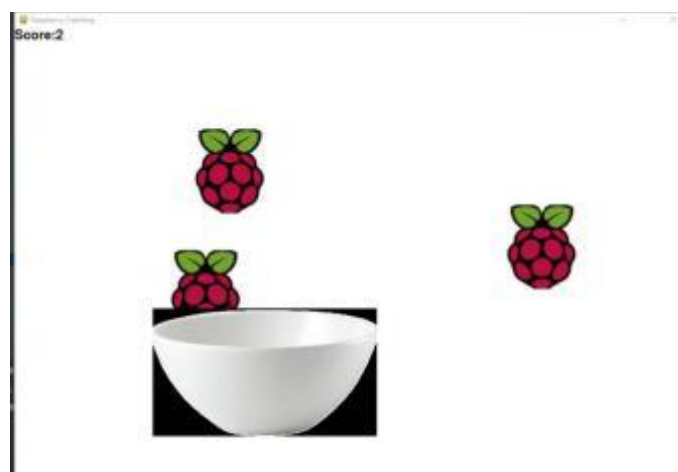


**Figure 12.** Pong game with turtle package [20]

Figure 12, shown above, is a screenshot of a Pong game designed using Python and Turtle package. A ball rolls from one side to another and changes directions when it hits the edge of the screen or the blocks which are controlled by players. The score is updated and shown above if one player failed to block the ball, then the ball is relocated to the centre of the screen to start a new round.

It uses definition to describe the movement of the ball, draw the ball, and block it by using coordinates and shape which are the basic functions in Turtle package. It uses `game.onkey` to listen to the keyboard and the mouse, and then it reacts according to the pressed keys. Turtle package is simple to use and is capable of designing simple games and drawing some simple graphics, but it cannot load large images and it does not have many useful functions to make the game more interesting. So the Turtle package game only taught me how to use certain functions and the structure of the game. It provided me with a conceptual diagram of what programmed games should look like and how designers change parameters and add logic to them.

Next, after much research on better programming packages in Python, I discovered the Pygame package which is a really suitable package for the laser harp project. Pygame is capable of writing games with animations and has a more complex logic in it. It can draw items, show graphics and play music effects as well [24]. More importantly, it has many built-in functions and lots of instructions, so there is no need to start again from scratch.

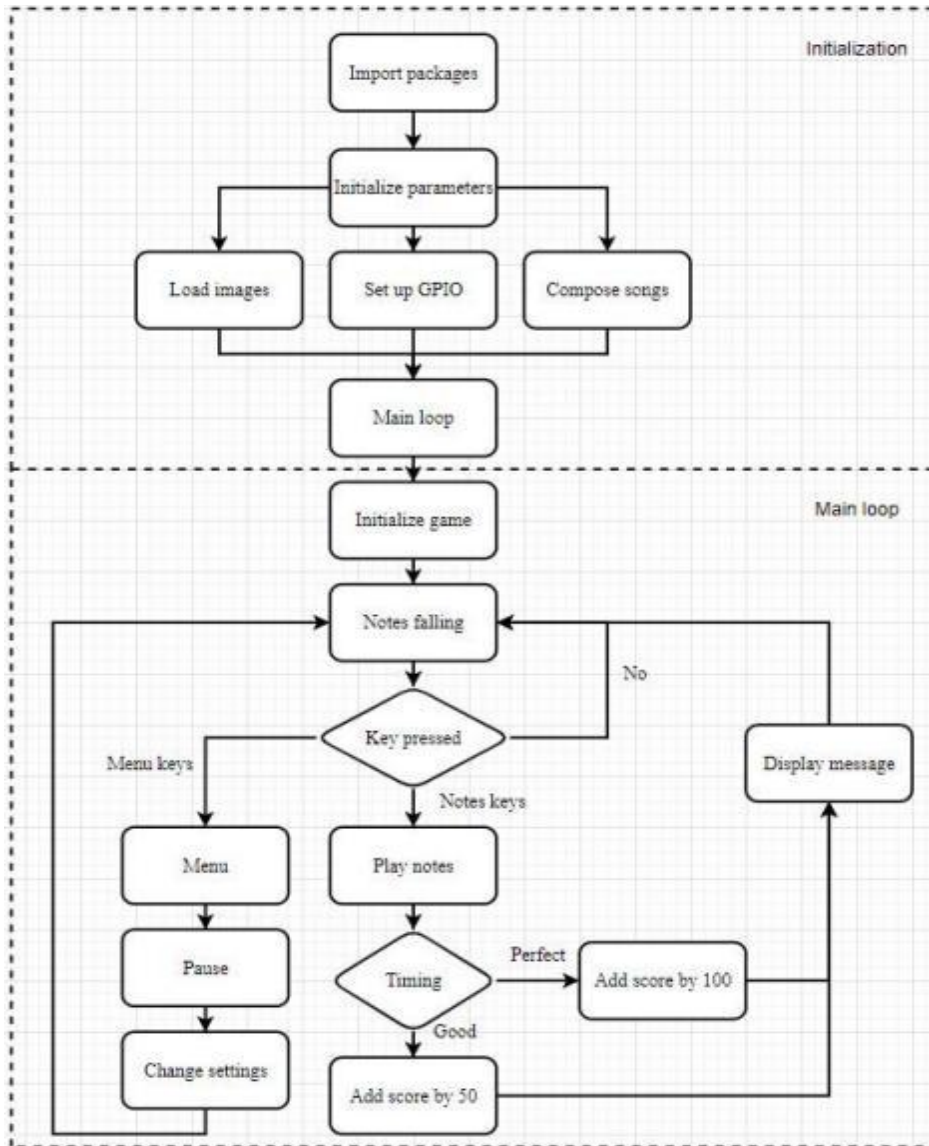


**Figure 13.** Raspberry catching game designed by using Pygame

The objective of this game is to catch raspberries falling from the screen top with a bowl, with the score counting the number of raspberries caught. It is basically a model for Laser Harp Hero. This game allows for a better understanding of the structure needed to design a real game. The most important knowledge gained from this is knowing how to develop the game step by step, put the steps in the right order, and replace the long paragraph of codes with class and def [22, 24]. However, there

are some disadvantages to this programme. For example, the outlook of the bowl needs to be modified, and some raspberries fall outside the screen and the system cannot tell in the same manner as a human whether the raspberry has fallen into the bowl or not. Moreover, this game has only one kind of interaction, which is the mouse. It needs to be improved with more keys to press and more sound effects.

## 4.2. Programming



**Figure 14.** Flow chart of the laser harp programme

Firstly, packages were imported, and the parameters initialized for future use. This included loading the images and setting up the GPIO pins and writing the songs in the music pack. Then the main loop of the code was started. This will control the falling of the notes while at the same time listening to the keys. After keys are pressed, the programme will play the corresponding notes and calculate the score or call out the menu. After this is done, the notes start falling again and await input from the keys.

Line 1~9 imports all the packages that are needed. In this project, 3 packages are imported to build the main game and other packages are used to support testing, control or display. The packages are Pygame, Pygame-menu and Psonic. The Pygame package is used from the start till the end to build the whole project. The Pygame-menu package is for designing menus and was downloaded from

GitHub and modified to suit the project [25]. The Psonic package is for advanced music coding and playing. This package is used to replace the bad sound system Pygame uses. Packages including math, time, random are installed to support testing or to control the time keys are pressed to call out the menu. Pynput package was installed to simulate the input of the keyboard.

Line 20~48 shows the initialization of the parameters. The Pygame system is initialized, background images and notes images are loaded, the clock, falling speed and other parameters are set to their initial value.

Line 50~83 contains the GPIO settings for the button circuits. Users can then interact with the device by using buttons without using a keyboard. Wires are connected and pins are set to the Raspberry Pi.

Line 86~ 112 contains the music pack and the notes corresponding to the songs. Additionally, some menu keys and synthesizers are initialized in this section.

Line 115~ 191 shows the beginning of the design of the main body of the programme. Firstly, some functions are set up to display messages and draw backgrounds on the screen. Secondly, the menu is designed here with the help of the Pygame-menu package. Selectors and buttons are linked to their function, difficulties, songs and synthesizers are written for options in the main game loop.

Line 194~363 defines two GPIO controls, one for controlling the keys and generating corresponding notes' sound, and one for controlling the system when the menu is called out. Gesture recognition is designed here, so users can navigate the menu by pressing the buttons in order. Only the first four buttons are used in gesture recognition, and it could be expanded to 8 when the buttons are replaced by lasers so it's easier for users to block from 1 to 8. Pressing from left to right controls the menu and moves to the next option and pressing from right to left moves to the previous option. Pressing from the middle to both ends moves to the upper option and pressing from both ends to the middle allows movement to the lower option.

Line 366~413 are for pausing the game when the menu is called out. The screen is updated each time and the keys are reset to default. It keeps listening to the buttons until keys are pressed to unpause the game.

Line 416~606 contains the design of the main loop. Line 417~448 includes the parameters that are set to the right value every time the screen refreshes itself. The refresh rate is set and the notes fall at the set falling speed after each refresh. The clock is set up here to achieve gesture recognition and support for testing. Line 450~528 contains the set-up for the keys on the keyboards for testing on the computer. Line 529~602 calculates the scores according to players' performance. If the player presses at the right time when the notes fall over the keys, a message will show 'perfect' and 100 is added to the score and if the player presses a little bit earlier or later, a message will show 'good' and a score of 50 is added, otherwise, the score and message will not change.

The full code is attached in the appendix.

### **4.3. Challenges During Programming**

During programming, I met many problems and solved most of them. Here are some of the significant difficulties I encountered.

#### **4.3.1. Songs**

In the game mode where notes fall from the top in order, it's a question of how to make the right notes fall at the right time and at the right location to form a song. The key was to find the sheet music and then transform it note by note to compose the song. The notes and intervals between notes are all written in the sheet music, hence by calculating the intervals, the notes could be placed correctly. In the future, songs may be transformed and used by the laser harp automatically after the player has the sheet music. In this project, the duration of one note is defined as 2000, so half a note is 1000, a

quarter note is 500 and an eighth note is 250. Additionally, the falling speed on personal computers and Raspberry Pi is very different because of different processors. So it's tricky to adjust the right speed for users and the duration of the note has to be modified as well.

```
Twinkle_Twinkle_Little_Star = \
[[do, 0], [do, -250], [so, -500], [so, -750], [la, -1000], [la, -1250], [so, -1500], [fa, -2000], [fa, -2250],
[me, -2500], [me, -2750], [re, -3000], [re, -3250], [do, -3500], [so, -4000], [so, -4250], [fa, -4500],
[fa, -4750], [me, -5000], [me, -5250], [re, -5500], [re, -5500], [so, -6000], [so, -6250], [fa, -6500], [fa, -6750],
[me, -7000], [me, -7250], [re, -7500], [do, -8000], [do, -8250], [so, -8500], [so, -8750], [la, -9000],
[la, -9250], [so, -9500], [fa, -10000], [fa, -10250], [me, -10500], [me, -10750], [re, -11000], [re, -11250],
[do, -11500]]
```

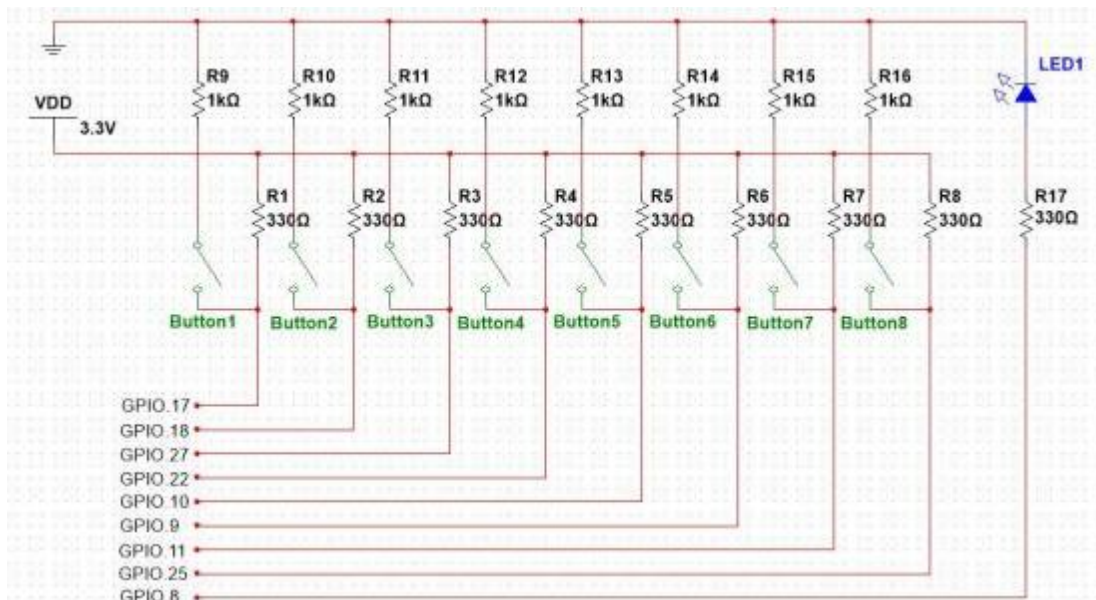
**Figure 15.** Example of a song Twinkle Twinkle Little Star

### 4.3.2. Pause

Pausing is an important function in the laser harp project. A game should have the ability to be paused and bring up the menu to adjust parameters like the difficulty or to change songs. The player can pause whenever they like to have a rest or to change parameters. During the pause, the game should stop where it was, and it should listen to the keys to control the menu without playing notes anymore. After pausing, the game should continue and the change that has been made should be active right away. Adding a pause feature to the programme meant rearranging the current programme structure and writing a completely different game loop. The game can transfer to each loop with no delay and the keys and settings should stay constant and compatible with each other.

### 4.3.3. Circuit design

As shown in the schematic of the structure, buttons are used to work as input and simulate the lasers at the beginning of the project. Eight buttons are used to simulate eight keys in one octave, and more buttons can be added in the future. A 1kΩ resistor works as a pull-up resistor, 330Ω is for protection of the circuit. The voltage is set to 3.3V for the Raspberry Pi circuits, one LED is placed to tell whether the circuit is working and the Raspberry Pi can send signals to control the circuits. Each button is connected to one GPIO pin on the Pi. Here's the diagram showing the design of the circuit.

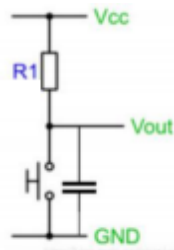


**Figure 16.** Design of the laser harp button circuit

After testing and modification to the programme, five more buttons were added to the circuit for menu navigation and 1 LED was added to give instructions to the player that they are currently navigating the menu and pausing the game.

#### 4.3.4. Key debounce

The key on the keyboard and buttons on the breadboard looks perfect while typing in Word, but the computer is automatically avoiding the noise signal for us. In practice, even if one presses the key really quick, the key is actually pressed for dozens of milliseconds and the programme will be told that the key is pressed many times. Changing the machine into debounce mode with milliseconds delay can reduce bounce [26]. So key debounce could be modified by proper programming or by circuits.



**Figure 17.** Connect a capacitor in parallel

The first option is to connect a capacitor in parallel so that the capacitor will work to filter the signal. The second option is to work on software.

```
if event.key == pygame.K
a: keys[0] = True
    play(C4, sustain=1)
    screen.blit(keyspressedimg, (interval * 0
```

**Figure 18.** Button pressing detail

As the code here shows, the programme will sleep for 0.01 seconds (this varies between different processors) to skip the unstable time duration. Then the programme will continue running after the sleep time, as 0.01 seconds is short enough for the human to feel almost nothing.

#### 4.3.5. Sound system

This was a very tough problem in the project. The laser harp project aims to provide high-quality sound effects to attract young engineers. The first sound system the programme used is the Pygame mixer.

However, the mixer can only load one music file at a time and the file can only store one instrument's sound. It can't be modified to have different musical effects or changed to have different instruments. Additionally, it is not able to play several files at the same time.

Another attempt was done using the operating system to play sounds. The Raspberry Pi has its own media player, this code uses that to generate sound. However, this is even worse than the Pygame mixer, it has poor sound quality and it can only play files but not generate its own sound. Also, it takes longer to open the media player.

At last, Sonic Pi, a perfect software package for coding music and synthesized sounds was discovered. Sonic Pi was designed to allow even school children to experience programming through making music [27, 28]. Collaborative relationships between computer scientists and teachers, as well as creative teaching methods, are necessary to give children a suitable opportunity to participate in live-coding learning experiences [28]. The Sonic Pi is capable of doing live coding and synthesizing many kinds of sounds. However, the problem is it has a different language, and it runs on completely different software, so it needs to be connected and send signals to the Python script. Psonic package is used for this situation, although the message and signal can be sent through the right port and OSC, it takes longer than using Psonic directly in python. After importing this package, the programme is able to play several different live threads at the same time.

```

use_synth(PIANO)
def loop foo():
    play (E4 release :: 0.5)
    sleep (0.5)
def loop_bar():
    sample (DRUM_SNARE_SOFT)
    sleep (1)
live_thread_1 = Thread(name='producer', target=live_loop_1, args=(condition, stop_event))

```

**Figure 19.** Playing multiple musical effects at the same time

The figure above demonstrates the code allowing multiple musical effects to play at the same time, in this case, one piano key 'E4' and one drum snare sample are playing in two threads. The sound effect is better and can be changed in the menu, additionally, release, attack, and sustain can be adjusted as well. Overall, the Sonic Pi is perfect for the laser harp project as it provides promising sound effects and different instruments, and musical effects can be selected.

#### 4.3.6. Audio latency

Audio latency is one of the main points of congestion in trying to achieve a better performance in these types of applications, particularly for live or open-air environments. To solve the issue of audio latency, the first step involved measuring and analysing the latency [29].

The audio latency in the laser harp project was measured by a single shot measurement. A digital oscilloscope was used for the measurement. Channel 1 was connected to the button which worked as an input. Channel 2 was connected to the audio output on the Raspberry Pi. The single-mode was selected, and the digital oscilloscope waited for the signal to trigger a shot and it would stop when the shot was captured. The audio latency was then measured by using cursors.

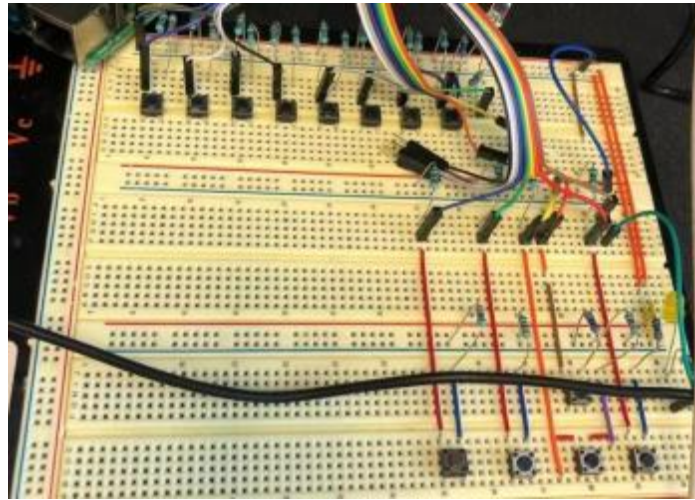


**Figure 20.** vertical cursors in orange shows the audio latency (signal on top shows when button has been pressed, signal on bottom shows when the audio signal comes out)

The audio latency was found to be around 700 ms for all the buttons. The latency is far less than 700 ms when using the Pygame mixer sound system, and it becomes 700 ms when using Sonic Pi as the sound system. Studies have shown that audio latency around 45 ms is acceptable while gaming, at this point the delay is unnoticeable and is deemed 'in sync' with the video [30]. This problem remains unsolved because of time constraints, but it needs to be solved in the future.

#### 4.4. Analysis

The circuit was designed to have eight buttons for keys and five buttons for menu navigation. Two LED lights were set up to tell the user whether they were using the menu or pausing the game. The left 4 keys at the top can also recognize certain gestures to control the menu.



**Figure 21.** Eight buttons at the top are 8 notes in 1 octave, 5 buttons at the bottom works for menu navigation



**Figure 22.** Showing the notes falling from top to bottom. 8 keys at the bottom shows when should the user press the corresponding buttons

The screen is large and contains two background images and eight keys at the bottom of the screen. Notes fall in the correct order according to the song selected from the music pack. The score is calculated and shown at the top of the screen, and a message showing the player if they pressed at the right time is shown in the middle.



**Figure 23.** When pressing keys at the right time, ‘Perfect’ shows and a score of 100 is added. The image shows that when the user presses the key at the right time, a score of 100 is added to the total, whilst a message simultaneously appears in the middle of the screen that says ‘Perfect’. The notes fall continuously until the end of the song, or until the game is paused.



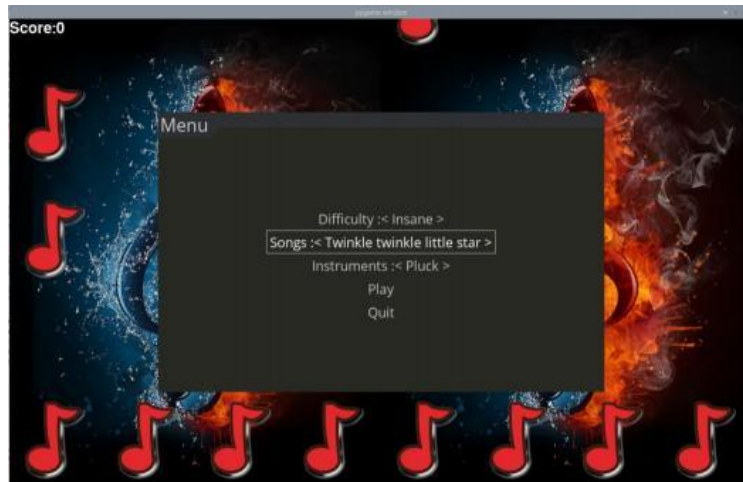
**Figure 24.** When pressing keys earlier or later, ‘Good’ shows and a score of 50 is added. After pressing 3 notes at the perfect time, the score will reach 300. If the player presses the note slightly outside the specified perfect time range, the message will show ‘Good’ and a score of 50 is added. If the player misses a note, the score and message will not change.



**Figure 25.** Menu during pause which shows the options available for users

If the menu gesture is recognized or the menu button is pressed, the game is paused and the menu will display in the middle of the screen. Here five options can be chosen. The first option is for changing the difficulty by adjusting the falling speed of the notes. Four speeds are provided for the user to choose from. The second option is for changing songs. Currently, two songs are stored in the music pack but more songs could be added to it later. The third option is for changing instruments. Five kinds of synthesizers are listed and users can choose their favourite instrument. The fourth and the fifth options allow players to continue the game or quit. Alternatively, users can close the menu

to continue the game. During a pause and whilst navigating the menu, the user can always control the menu by using certain gestures and eliminate the need for a keyboard.



**Figure 26.** Menu after changing options to insane difficulty and another song and Pluck instrument

As the figure above shows, the difficulty is changed to insane mode, the song is changed to the second song and pluck is now selected as the instrument instead of piano. Users can then close the menu and enjoy the new experience the game will provide.

Overall, the game is designed to have a nice background and keys. The messages and scores are displayed clearly and correctly to direct users on how to perform better. The Menu appears when the game is paused. Several settings can be adjusted in the menu module. Notes will keep falling with a different speed or order if users change difficulty or songs. Moreover, the musical effect will change if the user changes the instrument option and selects other synthesizers.

A short video of the project showing how the code works is available online at <https://youtu.be/jreBtPZos8E>.

## 4.5. Chapter Summary

This chapter provides the results of the programming. The notes will keep falling from the top of the screen to the bottom. The system can identify whether the user has pressed the keys at the right time and show the corresponding score and message. The menu is brought up during a pause, where several options can be changed.

## 5. CONCLUSION

This project aimed to provide a fun and interesting laser harp to attract young pupils to study engineering. Currently, the laser harp has a game mode that contains an interactive input, fancy displays and a high-quality audio output. A survey on what people think of this laser harp could be done in the future.

### 5.1. Summary of the Laser Harp Project

Achievements:

Agree on a system level design of the laser harp with Bohdan

Complete the main function of the laser harp, it will generate sound and display images when pressing buttons.

Successfully develop music games like laser harp hero game (Press key when notes reach bottom).

Add music effects including attack, sustain and use synthesizers to have more instruments

Add several settings to provide options for users to change

Add menu to provide a better user experience. Menu module contains pausing.

Provide gesture recognition to navigate the menu and control the harp This project has achieved most of the objectives.

First, the joint project successfully collaborated with another student and we both agreed on a system-level design of the laser harp.

While the user is playing the game mode, the sound could be generated when pressing buttons. The sound is generated by Sonic Pi which is capable of playing high-quality sounds and changing the musical effect. Buttons will be replaced by lasers and diodes, and maybe some ADC and DAC will be used to obtain the correct signal as input.

The game is designed to have two modes, training mode and playing mode. Training mode is easy to play with a keyboard. The notes continuously fall from the top and will return to the top when the corresponding key is pressed. This mode is designed for testing and training. The main interactive mode is the playing mode. Users can choose a song and its difficulty, and then the notes will fall in the song's order. There are currently only two songs for users to choose from, but this number could be increased later on.

Sonic Pi is the sound system in this laser harp. Music effects like attack, sustain, and release can be adjusted easily by changing some code in the script. It also contains live coding and multiple threads and samples. Multiple kinds of sound can be played at the same time without conflict and could be changed conveniently. Lots of samples can be added to make the game more exciting or a mode with background music playing could be added to it. More importantly, it has many synthesizers for users to choose from [23], so users can change instruments to the one they like and have a different listening experience. It is a very comprehensive and powerful piece of software, and more and more functions and music effects could be found if there was more time.

A menu with settings was designed with the help of the Pygame-menu package. The menu can pause the game and display to the user the game's current status. Then by adjusting the three options on the menu, users can change the game's difficulty, the current song and the instrument.

Currently, the gesture recognition function is sufficient but could be improved in the future. The system can recognize calling out the menu and menu navigation. Menu navigation uses four of the buttons at the top of the circuit, and the code is modified to suit the buttons. If the buttons are replaced with lasers in the future, the code will be slightly different. Firstly, it is easier to block more lasers than pressing only a few buttons. Users will be able to do the gesture more quickly than using buttons, and more difficult gestures can be recognized with more laser beams. Overall, gesture recognition is working and provides a better user experience. More gestures could be added when using lasers.

At last, the distance sensor was designed to be placed at the side of the laser harp. Users can activate the sensor with one hand. It can be set to adjust the volume or add vibrato to the sound. Due to limitations caused by COVID and time constraints, this sensor will be added in the future.

The project achieved most of the objectives in my software part. As it is a joint project, the other objectives in the hardware part will be accomplished by my partner Bohdan in September.

## **5.2. Future Plans**

The time for the project is limited during the COVID situation, hence more fantastic functions and improvements can be applied in the future. Suggestions for these improvements are described below.

### 5.2.1. Graphics User Interface

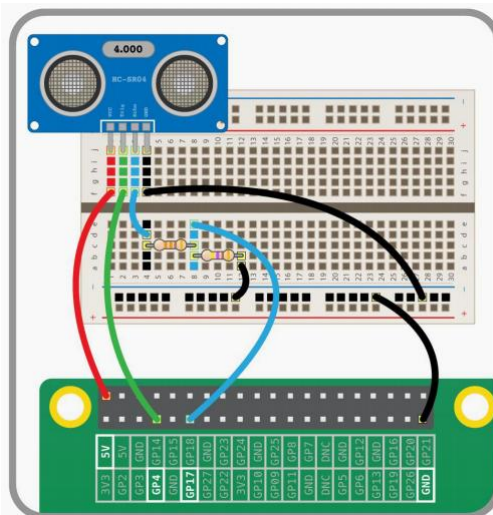
The GUI creates the first impression for users. To attract more pupils to study engineering, a better GUI with more graphics or more animations would be very helpful. The background images can be changed to a prettier one and the images of the keys and notes could be modified to have a better look. The messages showing the score and the performance of the user could also be changed to a fancier font with some special effects. With the help of Tkinter, widgets, and submenus, including tags and the menu bar could be added [31]. Alternatively, some simple themes and a fancier UI layout could be added through the Pygame GUI package [32].

### 5.2.2. Sound system

As discussed before, the Sonic Pi is a comprehensive and powerful software package for coding music. More and more functions can be discovered to give better sound effects. More threads can be used, more samples can be added as background music, and more tricks can be added as well. The most important problem with the sound system is the audio latency. It is around 700ms which is not acceptable when playing music games. Different ways of sending the signal to the Python script still cause the same latency, so it's the Sonic Pi that causes such an audio latency. In the future, maybe another sound system that has a better latency could be used, or steps could be taken to reduce latency in Sonic Pi. Additionally, a better computer with a processor better than the Raspberry Pi can solve this problem.

### 5.2.3. Distance sensor

The distance sensor could be added to the laser harp. It will add a different kind of input for controlling the volume or vibrato. The ultrasonic sensor is used to simulate an instrument named theremin. It has 4 pins. Ground, trigger, echo and power. As Figure 27 shows, the ground to the ground pin on the Raspberry Pi, Trigger to one GPIO pin, Power to the 5V pin. Echo to another GPIO pin through one 330Ω resistor, and that GPIO pin to the ground through one 470Ω resistor [33, 34].



**Figure 27.** Ultrasonic distance sensor circuit [33]

Python should then import the gpiozero package which contains DistanceSensor commands.

Then, `sensor.distance` was used to present the distance it measured. It's an analogue signal and by using software or additional circuits, it can be transformed into a digital signal for adding vibrato (1 for disable, 0 for enable). The precision of the distance sensor could be measured and analyzed in the future.

### 5.2.4. Games

More games could be played on the laser harp. For example, some street fighter-style games like King of Fighters may attract some pupils. The characters will be able to move and punch when blocking

lasers. Also, some economic management games like Monopoly could be added to attract more users. The laser beams could be used to throw the dice and purchase the properties. Many games will suit the laser harp well, it just requires imagination and creativity to make it happen [35, 36]. However, that's an entirely different large project. Maybe even more game modes in laser harps would work as well. For example, the notes could fall in groups of 4 which makes them like Tetris and the player uses lasers to rotate and move the pieces. Or players could start writing their own song by blocking lasers and then adding it to the music pack.

### 5.2.5. Lasers

Lastly but most importantly, improvements for a complete laser harp would be done by replacing the buttons with lasers. Laser generators will be placed on one side and the photodiodes will be placed on the other side. Beams will be separated with 2cm intervals between each other, users can block a single beam easily with one finger. With the help of the lasers, more gestures can be recognized, and more keys and octaves can be added. Therefore, more music can be composed in the right format and added to the music pack.

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