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Title: “MaveCon” Customizable Universal Arcade Controller

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論文題目: “MaveCon”客制化泛用型街機控制器

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Abstract

The golden age of arcade video games has already ended but there still are a couple of players spend their times and money in game centers to enjoy the fun which consoles can't give them. However, because of the high price of arcade cabinet and low level of population of this kind of games not every game center will buy the latest or the most high-quality arcade games. Therefore, not everyone in the world have the chance to play the game they want. Besides, even somebody is lucky enough. They will still suffer from long travel distance, expensive gaming cost, long time for waiting in line and terrible maintenance of arcade cabinet.

In order to solve these problems and help more people be able to enjoy this fascinating but hard-core game category, we present MAVECON, a customizable universal arcade controller which can let people play any arcade games in their home. Because almost every arcade game has their own unique input devices especially for Japanese rhythm games, the controller divide input sensors set and main board into two parts. These two parts can use JST PH2.0 connectors to connect each other. Therefore, users can easily change their sensors to fit various arcade games and maintain the controller to keep its good performance.

At present, we have completed two games's sensors set. They are Chunithm [2] and Taiko set. These two games both are well-known rhythm arcade games in Japan and have a large player base in the world. Chunithm sensors set includes a PMMA controller shell, 6 pairs Active Infrared Sensors, 32 capacitive touch sensors and 96 TM1812 RGB programable LEDs. Taiko sensors set includes a dedicated wooden shell and four shock sensors. What's more, with long time testing, we can be sure to say that our controller can give almost the same game experience just like real arcade cabinet.

Keywords: home controller; arcade games; universal; customizable

摘要

雖然街機遊戲的黃金時代已經結束了，但是如今依然有一部分玩家每天在遊戲廳內遊玩街機遊戲來獲得主機遊戲所給予不了的快樂。然而因為街機框體的高價和玩家人數的稀少，並不是所有遊戲廳都會購入最新或者品質最好的街機遊戲。因此並不是所有人都能有機會玩到自己想玩的遊戲。即便遊戲廳有對應的街機，玩家依然要面臨大量的通勤時間，高昂的遊玩價格，極長的排隊等待時間以及街機框體糟糕的維護等嚴重影響遊戲體驗的問題。

為了解決這些問題，我們提出了 MAVECON 一款客制化泛用型街機控制器，它可以讓玩家在家中玩到任何想玩的街機遊戲。我們將控制器分為輸入感測器和主控板兩個部分，來應對幾乎每一款街機遊戲都有他們自己獨特的輸入裝置和對應的輸入方式的問題。他們之間可以使用 JST PH2.0 標準插頭連接。玩家可以輕鬆的更換感測器套組來適應不同遊戲的需求並維護設備保持較好的性能。

目前我們完成 Chunithm 以及太鼓達人的感測器套組。他們都是在日本十分有名的街機音遊，即便是在如今的環境下在全球範圍內都依然擁有龐大的玩家基數。Chunithm 套組中包含了一個控制器框體，6 對紅外對射感測器，32 個電容觸摸按鍵， 96 顆 TM1812 RGB 可程式設計 LED。太鼓套組包含一套對應框體以及 4 顆震動感測器。經過長時間的測試，我們已經確定該控制器可以給予玩家與真實街機框體幾乎一致的遊戲體驗。

關鍵詞：遊戲控制器 ； 街機遊戲 ；泛用型；客制化

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Chapter 1 Introduction

1.1 Background and motivation

Arcade games [1] are one of the oldest and most special game categories across the history of video games. They are known by their dedicated and highly immersion game control approaches, superior difficulty and unbelievable complex game mechanisms which means arcade games cannot be passed without several years practice. These features made arcade games become the most popular game category between the late 1970s and the mid-1980s and this period is defined the golden age of arcade video games.[1] However, with time going by, these features also become the biggest blocks for attracting new players to this game category. Because of the superior difficulty and complex game mechanism, people usually need to play it a couple of years to be a good player which can be costly for both time and money. What’s more, arcade game devices are extremely expensive and difficult to transport. Therefore, there are few game centers have the latest and most high-quality arcade games. Unfortunately, game centers are the only place for more than 99% people to play arcade games. Hence, the number of arcade game players are going down year by year.

However, in the Japanese gaming industry, arcades have remained popular through to the present day.[1] There are still many game companies developing new arcade machines and games. They are still trying to bring some creative features to improve gameplay. As of 2009, out of Japan's US$20 billion gaming market, US$6 billion of that amount is generated from arcades, which represent the largest sector of the Japanese video game market, followed by home console games and mobile games at US$3.5 billion and US$2 billion, respectively.[4] Hence, there are still a couple of arcade players and people who want to be arcade player in the world. To better help these people enjoy arcade games, we need to know what make this kind of game is so hard for players to play.

Generally, problems for people to play arcade games can be divided into two types. One kind of problems are about cost of playing arcade games including the time spending on traveling and waiting, the money spending in starting each round. Another kind of problems are about the rarity of arcade cabinets which means people are hard to find the arcade game which they want to play. For example, there are total 420 game centers and 1293 arcade rhythm game machines in China.[5] Most of them are in first-tier cities. Hence, only few people in China have the chance to play the latest arcade rhythm games.

In order to solve these two kinds of problems and encourage people to play arcade games, we developed a fully customizable arcade game home controller which we called MaveCon. It can be connected to PC, PS4, Nintendo Switch and any other platforms. It can be used to simulate any arcade games including fighting games, rhythm games, shooting games and even simulation games in arcade platform. To achieve these goals, we divide the controller into two parts. One is sensor set which including all the sensors which you need to simulate the input of arcade cabinet and a strong shell to fix all the sensors to ensure all the sensors can work properly when users are playing. Another one is the main control board which are used to control all the sensors and convert input signals from sensors to output signals which can be recognized by target platform. At present, there are some different types of arcade game home controllers in the market. However, because of the unique input approach of each arcade game. Most controllers can only be used to play one game. What's more, these controllers usually are very expensive and cannot be customized. Therefore, those controllers cannot fulfill everyone's needs.

All in all, the main goal of us is developing a controller which can give everybody a chance to play those interesting but rare arcade games without cost lots of money. In other words, we want to design and implement a controller with low price, high performance and high productivity. The original design of the controller is for arcade rhythm games. There is no doubt that the controller can be used in any arcade games. However, currently we have only finished Chunithm and Taiko sensors set and we spend most of our effort on Chunithm sensors set. Therefore, we will use Chunithm set as the sensors set example in this thesis.

1.2 Contributions

We present a functional action detecting system including a budget but powerful self-capacitance touch pad and several high accuracy hands' position tracking sensors.

We present a cross platform sensor data converting system including a main board with modular and customizable input interfaces, a high-performance sensors signals processing approach, HID device simulation function and cross platform feature.

1.3 Thesis organization

Chapter 2, we introduce the architecture of MAVECON.

Chapter 3, the details of hardware development in this chapter.

Chapter 4, we describe the implementation of our controller’s software.

Chapter 5, testing and evaluation will be discussed in this chapter.

Chapter 6 concludes the thesis.

Chapter 2 Architecture

In this chapter, we will illustrate the architecture of MAVECON, which can give a better understanding of the controller.

2.1 Overview

MAVECON consists of three parts. They are sensors set, main board and the code burned inside the chip. The detailed structure of each part as shown in figure 2-1. Each part has its unique and irreplaceable functions which will be illustrated in next sections.

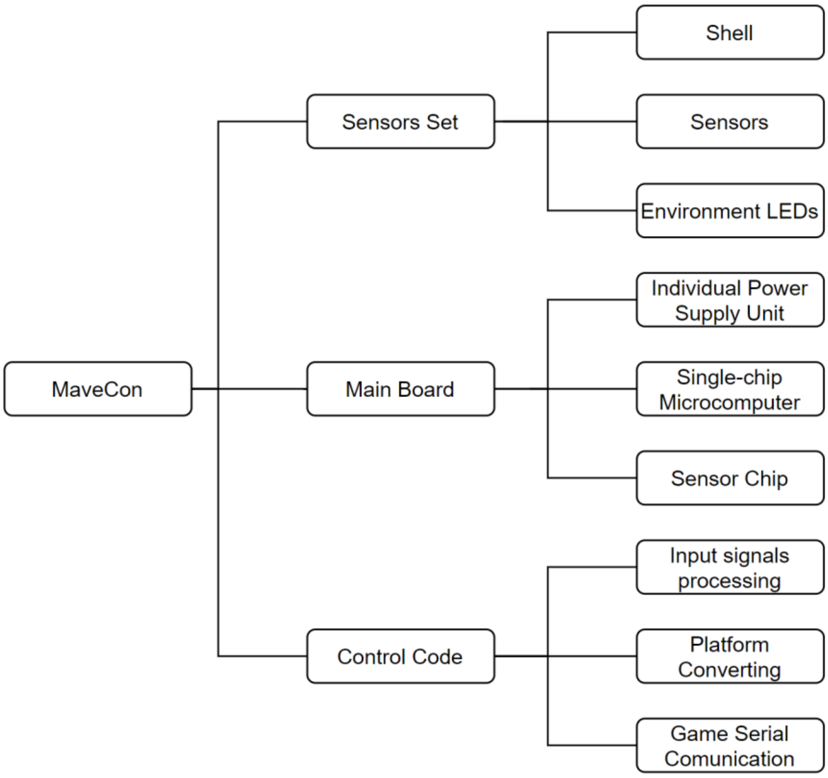

Figure 2.1 Controller Overview

2.2 Sensors Set

Sensors set has three parts including outer shell, sensors and environment LEDs which is the most significant part for controller to be able to simulate various completely different arcade games. Users can play different games by changing their sensors set. All the sets will be budget and easy for users to use. Currently, we have designed and implemented Chunithm sensors set. We can produce more sets and improve their performance in the future.

2.2.1 Shell

Shell is used to fix all the sensors and ensure they can work properly when user is playing. Arcade games are not like those games in consoles or PC. Players are using individual input devices like controller, keyboard and mouse to give commands and signals to play the game. Arcade games combine the input devices, screen and any other devices together in a shell which is called cabinet. What's more, because of the playing place of arcade games and hard game difficulty, the cabinet usually cannot get high-quality maintenance and will be hit hard by players to release their angry and regret. Hence, almost all the arcade cabinet will be protected very will using industry level impact resistance materials. The situation is similar for home arcade controller. Because of the arcade game mechanism especially for rhythm games, players have to hit sensors very hard to keep their sense of rhythm the same as the game to get a high score. Therefore, the controller should use strong shell to fix all the sensors and protect them.

Generally, we will use PMMA[1] and 304 stainless steel which both are good material for making the shell. PMMA is a kind of material with good impact strength and the most important thing is its low price. For our Chunithm sensors set, we use PMMA to make the entire shell base and other individual shell parts.

2.2.2 Sensors

Sensors is the most important part of sensors set. They are used to simulate the same kind of input signals as the arcade games. For example, the main input devices of Chunithm are one touch screen with 32 touch areas and 6 pairs of air sensors. Hence, in order to simulate these two kinds of input signals, we use 32 capacitive touch sensors to input touch, hold and slide signals and 6 pairs Active Infrared Sensors to give air signals. In order to make all the sensors work in a terrible environment and meet our

[1] PMMA: Poly (methyl methacrylate), https://en.wikipedia.org/wiki/Poly(methyl_methacrylate).

original intention of developing such a controller, sensors should be highly reliable and budget. Hence, we will only choose the most common sensors to make our sensors set.

2.2.3 Environment LEDs

Almost all the arcade video games have complex lighting system which can be used to show the feedback of user input signals or help games improve the gameplay. For the controller, environment LEDs have the same function just like arcade games. To achieve this goal, we choose RGB LEDs with IC chip which can be controlled by address like WS2812B and TM1812[2]. Hence, these LEDs can show complex light effect or even do the same like real arcade games. Most arcade games use serial communication to control LEDs. What's more, we have already programed a simple serial communication port to using arcade games original light system control logical. Therefore, with correct led settings the controller can have the same light effect just like real arcade games' cabinet.

2.3 Main Board

The main board of our controller is consisted by single-chip microcomputer, sensor chip and individual power supply unit. The major function of it is handling input signals from sensors and output these signals to the arcade games working on different platforms and provide strong power to support various devices in the controller. To make the controller easy for users to use, we use JST PH2.0 [16] standard connectors to connect main board and sensors.

2.3.1 Single-chip Microcomputer

Single-chip microcomputer is the major part in the main board. All the logical control codes are burned in it including input signals handling, platform converting and LEDs serial communication. To develop such a hardware-based controller, using single-chip microcomputer is the best option. Because with the help of suitable single-chip microcomputer, developers can use high level program languages and take benefit from

[2] WS2812B and TM1812 both are an Intelligent control LED integrated light source which can be controlled by IC chip and output RGB lights. WS2812B's light direction is vertical to PCB board and TM1812's light direction is parallel to the PCB board.

the community. At present, there are countless suitable single-chip microcomputer in the market. Different microchips have different pros and cons. In this thesis, we use Arduino pro micro to be our single-chip microcomputer. Because Arduino pro micro has the best performance and smallest volume among all the supported Arduino compatible boards of keyboard HID library. Sparkfun pro micro uses ATmega32U4[3] chip which has powerful performance for making a home gaming controller. What's more, pro micro is the smallest Arduino boards among all the products of Arduino. Hence, the main control board can be small but powerful to reduce the need of setting space and keep users' great game experience. Besides, Atmega32U4 is one of the most common chips in embedded development. Therefore, we can use countless useful third-party libraries to reduce the cost of our development and improve the performance of our controller.

2.3.2 Sensor Chip

Sensor chips are necessary part for handling complex sensors like capacitive touch sensors. Because these sensors do not produce simple digital signals, developers have to use a complex algorithm to calculate the output value from the sensors and convert them into simple digital signals. To reduce the effort of making such a complicated algorithm and its hardware circuit, we use dedicated sensor chips to complete the job. We use MPR121 to be our sensor chip which are design for capacitive touch sensors, but it also can handle those sensors which can produce digital signals by themselves like microswitches. What's more, multiple MPR121 chips can be called by their addresses. Hence, we can use multiple sensor chips to manage different groups of sensors. Because of that, we can greatly increase the range of arcade games which can be simulated by our controller and reduce the difficulty of maintenance. Besides, MPR121 has a complex but fully customizable debounce algorithm, a simple static

[3] ATmega32U4 is a low-power Microchip 8-bit AVR RISC-based microcontroller featuring 32KB self-programming flash program memory, 2.5KB SRAM, 1KB EEPROM, USB 2.0 full-speed/low speed device, 12-channel 10-bit A/D-converter, and JTAG interface for on-chip-debug. The device achieves up to 16 MIPS throughput at 16 MHz, 2.7 - 5.5 Volt operation.

threshold setting and a dynamic baseline system which can improve the performance of capacitive touch sensors and make our controller be more customizable.

2.3.3 Individual Power Supply Unit

The function of individual power supply unit is providing enough power to support all the devices in the controller. The original USB port can only provide 800ma power which is enough for the microcomputer and sensor chips, but it’s not enough for LEDs and other high cost devices. Without enough power the reliability of each part in controller will be greatly reduced. Some sensors and chips may shut down and microcomputer will also have some running problems. Hence, we use an individual power supply unit to support the costliest devices in the system. The whole Chunithm sensors set has 96 LEDs. Each of them needs 60ma power. Hence, if all the LEDs working full loaded the total power input should be more than 5.76A. Fortunately, full loaded situation is very rare. Therefore, we use a 5A/24V DC power unit which can output a little bit less power than the full loaded situation to support the controller. It can fulfill our needs and make main board power supply traces be smaller to remain more spaces for logical traces.

2.4 Control Code

Control code is burned in the main single-chip microcomputer. The main function for control code is receiving input signals from sensors and output specific signals to communicate with different platform using serial or USB communication protocol.

2.4.1 Input signals processing

Most sensors will provide simple digital signals, some other sensors need algorithms to convert their output value into digital code. All of these signals will be handled by input signals handler. Handler will use signals to do communication with arcade games and users can use controller to play the game with the same gameplay as real arcade cabinet. To improve the performance of sensors, we implemented an effective debounce algorithm. The technical details will be presented in software chapter.

2.4.2 Platform Converting

There are a couple of arcade games released console or PC versions. That means some players may not only want to play arcade games running in PC simulators, but also want to play those console versions. Hence, we implemented a platform converting feature. Currently, it can support PS4 and Nintendo Switch. By changing the HID document, Atmega32U4 can simulate different kinds of input devices like keyboard, mouse and gaming controller. Currently, only PC and Nintendo Switch can be simulated by Arduino HID library. For PS4 and other platforms' simulation, we use GIMX [6], a well-known free software that allows to use a computer as a hub for gaming devices. By using our Taiko sensors set, we can play

2.4.3 Game Serial Communication

Most of the arcade games use serial port and serial communication to control sensors and other I/O devices. If we can use the original serial port to transfer I/O signals, the input latency will be greatly reduced. Hence, for some games which have been decrypted and known their serial communication structure, we will use their serial port to transfer signals especially environment LEDs.

Chapter 3 Development of Hardware

In this chapter, we will illustrate the technical details of hardware implementation of our controller and Chunithm sensors set. To improve the performance and reduce the difficulty of future maintenance, we use modularized structure and development method. The basic running routine for hardware as shown in Figure 3-1.

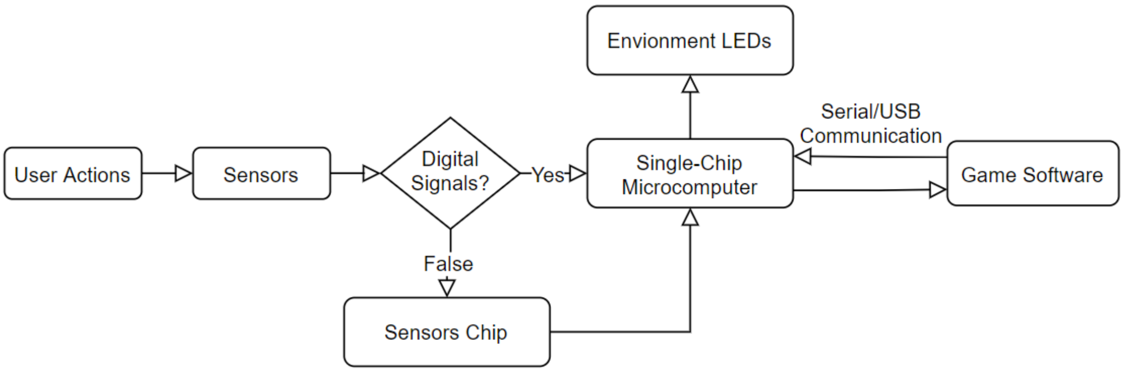

Figure 3.1 Data Flow of the System

3.1 User actions detecting by Sensors

To provider users the same gameplay as the real arcade games, designing a suitable approach for users to input commands by doing the same actions as real arcade machine is essential. For Chunithm sensors set, we designed an approach to track users' input commands just like Chunithm arcade machine.

3.1.1 Game Mechanism

In order to give better understanding for why we designed such an approach, it is necessary to know the game basic mechanisms.

Chunithm is a modern drop-style rhythm game in arcade platform. This kind of games use a scrolling "note highway" to display what notes are to be played, along with a score and a performance meter. Generally, players need to input click, hold to play the game. If players can keep inputting right commands at right timing, they can get score. Otherwise, they cannot get score and will lose their HP. The game will fail when the HP is 0. There are totally four kinds of actions in Chunithm. They are touch, hold, slide and air. Players need to touch and release the touch screen immediately to generate touch signal. Keeping touching the screen will give hold signals. If players keep touching the screen and slide their hands from one area to another area, it will provide slide signals. Finally, air signals will be generated when players hover in the air and between air sensors.

3.1.2 Selection of Sensors

To generate touch, hold and slide signals and try to simulate the gameplay as better as possible. We decide to use touch screen to complete the job. Arcade machine uses acoustic wave type touch screen which is an extremely rare and expensive approach. To keep our controller budget for everyone can get, we decide to use other more common approaches to implement touch screen. There are two common touch screen implementation methods in the world. First is capacitive touch screen, second is resistive touch screen. The former one has the advantages of lower prices and more simple structure which can be made even without professional industry machines. Besides, it is more suitable to make such a big touch screen without precise position detecting. Hence, we decide to use capacitive touch screen to be our main input sensors.

To output air signals, we need to detect the position of users' hands. Only output air signals, when users' hands hovering at a specific height. There are two effective approaches. First, we can use a camera and a motion detecting algorithm to track the position of hands. Second, using sensors to directly detect whether there are hands going through. First approach needs much bigger space than the second one. Because we need enough distance to make camera work properly. Besides, if we use first approach, the whole system will be much more unreliable. The devices settings will be insignificantly difficult to calibrate. Hence, we decide to use Active Infrared Sensors to finish the job. Those sensors have excellent performance for tracking objects' position. They can output digital signals with an extraordinary low latency which can be a major benefit for a rhythm gaming controller.

3.1.3 Implementation of Sensors

3.1.3.1 Capacitive Touch Screen

Capacitive touch screen uses capacitive sensing technology, based on capacitive coupling, that can detect and measure anything that is conductive or has a dielectric different from air. Its technical principles as shown in Figure 3-2

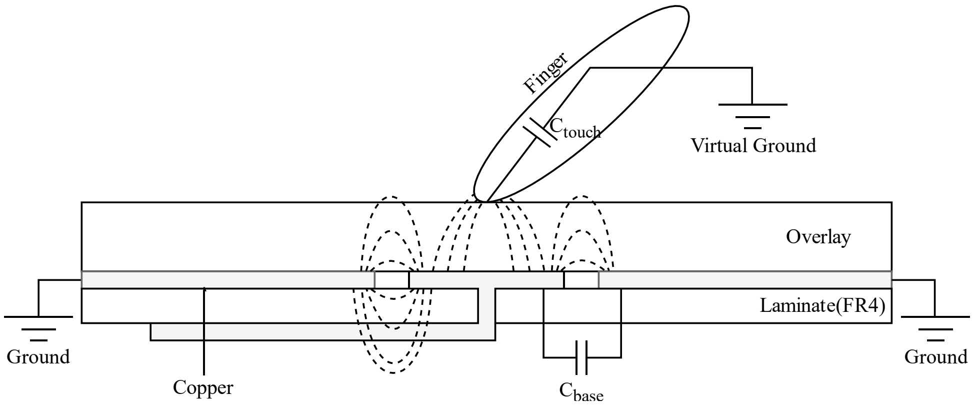

Figure 3.2 Capacitive Sensor Overview

A capacitor is a device that stores electrical energy in an electric field. It is a passive electronic component with two terminals. For capacitive touch screen, copper and finger are the two terminals and overlay are dielectric medium. Hence, we can get a capacitor and detecting the touch action by tracking the change of electrical energy in this capacitor.

According to the basic theory of parallel-plate capacitor, we can get the formula.

$$V = \int_0^d E(z)\,\mathrm{d}z = Ed = \frac{\sigma}{\varepsilon}d = \frac{Qd}{\varepsilon A}$$

The capacitance is defined as C = Q/V. Hence, here is the final formula for capacitive sensors.

$$C = \frac{E_0 \times E_r \times A}{T}$$

Therefore, in a capacitor the highest capacitance is achieved with a high dielectric constant material, large plate area, and small separation between the plates. What’s more, the highest capacitance means the sensitive of the sensor. Higher sensitive can give clearer and stronger signals. Therefore, in order to get as higher sensitive as we can, we increased the size of copper terminal, thinner and higher permittivity dielectric overlay. There are a couple of approaches to implement a functional capacitive touch sensor. We can use ITO, metal, PCB board and many other materials to complete it. In order to reduce the difficulty of manufacture and assembly. We decide to use PCB to make our capacitive touch sensor. Besides, environment LEDs will also be soldered on the touch sensor board. To find the best sensor PCB, we designed and tested three versions of PCB design. The first version PCB design[4] of capacitive touch sensor as shown in Figure 3-3.

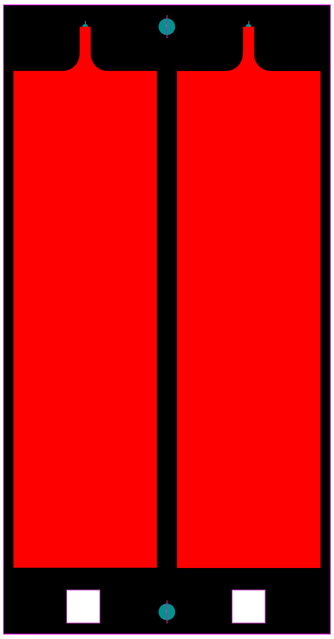

Figure 3.3 Capacitive Sensor Board V1.0

[4] We use Altium Designer 2020 and AutoCAD 2020 to draw all the parts. All the color and meaning of line and icons will follow their default settings. All the PCB board in this thesis follow the standard:

- 1.6mm.FR2
- Solder mask over bare copper
- 1oz copper
- Solder mask on both layers
- Supplied as singles

We will use 8 sensor boards to form touch screen. It has totally 16 touch areas and 16 WS2812B environment LEDs. The overlay uses PMMA material with frosted surface which have high permittivity dielectric and can help lights have a better effect.

However, the V1.0 design has three problems.

- The sensors cannot detect touching if users touch the area between two copper areas.
- Because of the uneven surface of frosted PMMA material, there is air between copper and overlay. Hence, the sensitivity of sensors is influenced. It will be a little bit lower than normal PMMA surface.
- The game software needs 32 touch areas, but by using V1.0 design we can only support 16 touch areas. Therefore, we designed another version to fix these problems.

Hence, we designed another version of our sensor board and overlay. The second version of capacitive touch sensor as shown in Figure 3-4.

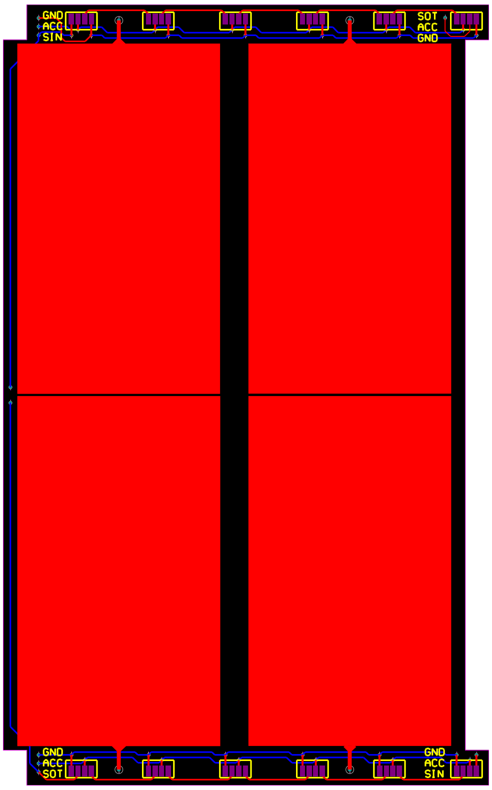

Figure 3.4 Capacitive Sensor Board V2.0

In the sensor board V2.0, we divide one touch area into two areas to support 32 touch areas like arcade machine. Besides, we added environment LEDs' soldering area to combine the LEDs and sensors board together to improve the performance of lighting system and simplify assemble process. The material of overlay is also changed. We select laser dotted light guide plate (LGP) which are made by PMMA material with smooth surface. Hence, there is less air between copper and overlay than frosted surface PMMA which can improve the sensitivity of sensors. The technical details about laser dotted LGP will be illustrated in next sub section.

After testing the second version sensor board, we conclude all the benefits from each version design and present our final version sensor board as shown in Figure 3-5.

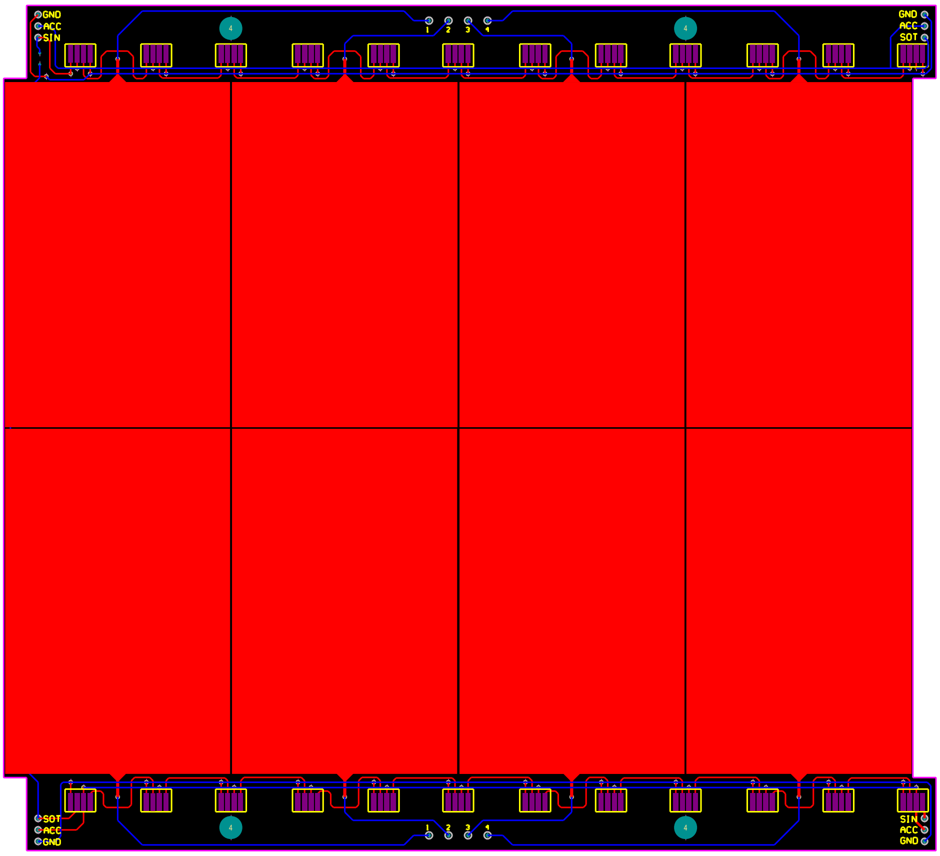

Figure 3.5 Capacitive Sensor Board Final Version

3.1.3.2 Active Infrared Sensors

Active infrared sensors usually consist of a pair of electronic sensors that measures infrared (IR) light. One is the transmitting end and another is the receiving end. Transmitting end will continuously beam IR light. If the IR light is blocked by some objects, the receiving end cannot receive the IR light. Then, it will generate digital signals and send them through the signal port. Because of the physical features of IR light and the special structure of the devices, IR light can travel long distance with high strength.

There are two types of Active infrared sensors. Break beam sensors and reflectance sensors.

Break beam sensors have emitter and receiver placed face to face that the IR emitted by the emitter falls directly in to the receiver. During the operation, IR beam is emitted continuously towards the receiver. The flow of IR can be interrupted by placing an object between the emitter and receiver. If the IR is transmitted but altered then receiver generates output based on the change in radiation. Similarly, if the radiation is completely blocked the receiver can detect it and provide the desired output. For example: let’s consider a Break beam sensor and a conveyer belt as shown in figure 3-6. When an opaque object interrupts the IR flow the receiver doesn’t receive any signal thus the conveyer belt stops.[8]

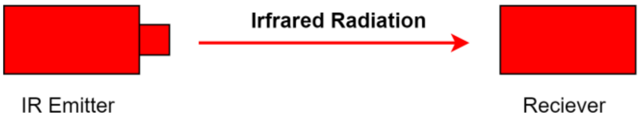

Figure 3.6 Break Beam Sensor

Reflectance sensors use reflective property of IR. The emitter emits an IR beam which is reflected by the object. The reflected IR is the detected by the receiver. The object causes change in the property of the reflected IR or the amount of IR received by the receiver varies. The degree of change is dependent on the reflectance of the object. Thus, detecting the change in amount of received IR helps in figuring out the properties of object such as surface geography and reflectance.[8]

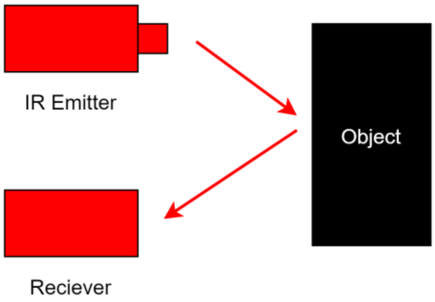

Figure 3.7 Reflectance Sensor

Because of the game mechanism, break beam sensor is more suitable for our controller. Besides, it can be easier to calibrate and generate clear digital signals. Hence, we use a shell structure to fix six pairs of break beam sensors to track users' action. Because game software only supports six signal inputs, so we only use six pairs of sensors.

In order to improve their performance in different working environment especially working with other light source which may interfere the function of receiving end, we select active IR sensors using modulated light signals. That means the emitter will emit light in a special frequency and the receiving end will only generate signals when it cannot receive the light in that frequency.

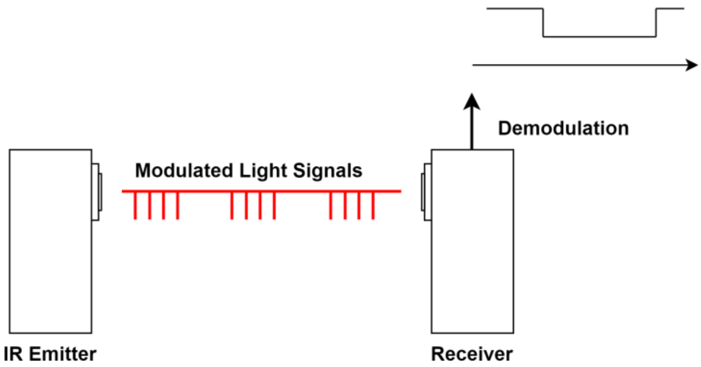

Figure 3.8 Modulated Active IR Sensors

However, when we use multiple active IR sensors together, there are another problem. The receiver may receiver light signals from other IR emitters, which means it will not generator signals even there is an object between it and its original IR emitter.

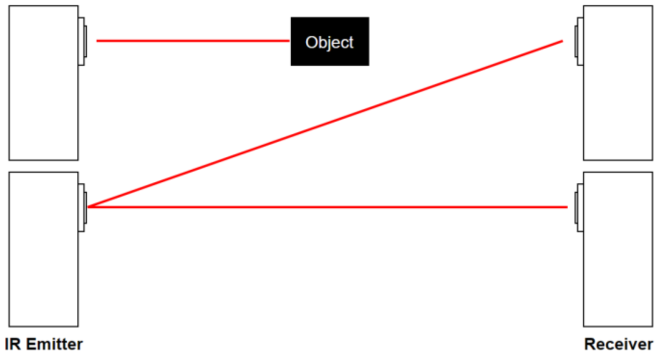

Figure 3.9 Receiving Light from Other Emitter

So, we designed a cover panel to block light signals from other IR emitters. This panel can also greatly improve the sensor performance in bright environment.

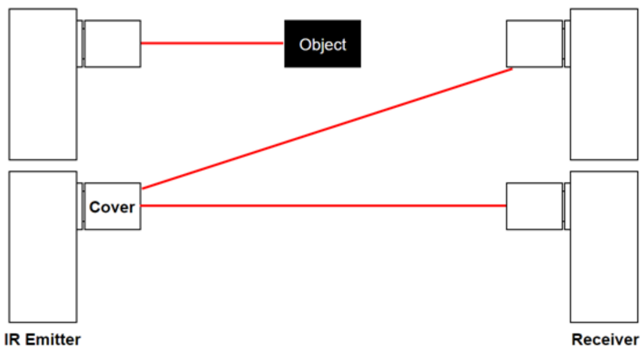

Figure 3.10 Extra Cover Panel

3.2 Design and Implementation of Shell and LEDs

3.2.1 Outer Shell

In order to fix all the sensors and give more customization possibility, we spend a lot of effort to design a suitable shell for our controller. Because of the demand of different sensors, outer shell has two parts to install different types of sensor which are shell base, top panel and air sensor holder.

3.2.1.1 Shell Base

Shell base is the most significant part for keeping the controller stable when users are playing. To increase its strength, we first tried 304 stainless steel, which is a common metal material in industry products. The design is shown in Figure 3-11.

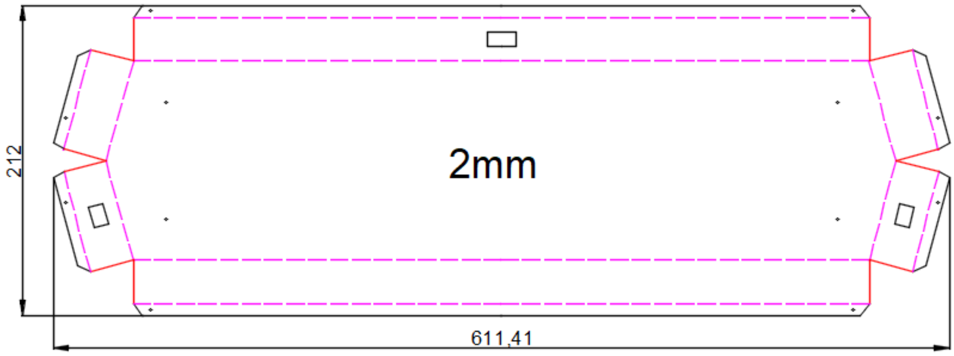

Figure 3.11 Steel Shell Base V1.0[5]

However, the error of steel material bending and welding process is too serious to pass our assembly test. Therefore, we decide to use PMMA material to build outer shell and try to design each part as simpler as possible to reduce process difficulty. The design is shown in Figure 3-12.

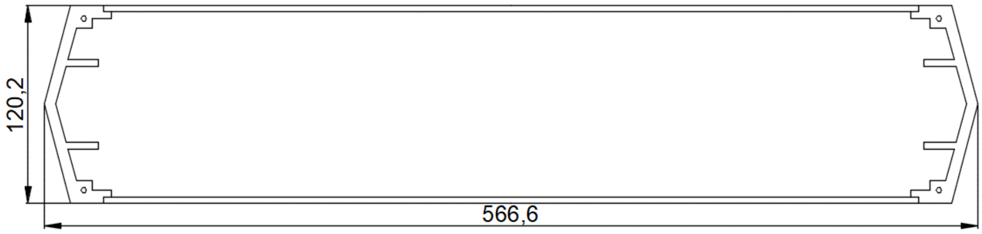

Figure 3.12 PMMA Shell Base V2.0

3.2.1.2 Top panel

Top panel are used to fix all the touch sensors and connect to air sensor holder. Besides, it should be removable. Because the controller should be easy for users to

[5] Followings are the meanings of all the icon and color in CAD Drawings:

Black Line: Cutting line

Red Line: Welding line

Pink Line: Bending line

The unit of all the number: mm

maintenance. Hence, each part in the controller having possibility to be broken should be replaceable without special tools. The design is shown om Figure 3-13.

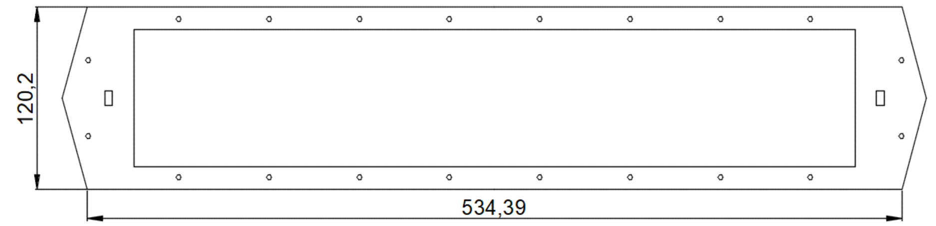

Figure 3.13 PMMA Top Panel

3.2.1.3 Air Sensor Holder

air sensor holder is the part have the most components. It is used to install active IR sensors. Because the detecting area of IR sensors are not big enough. Hence, we create customizable sensor base to make the controller can fit anyone's demand. Users can choose to stand and play the controller like playing arcade machines or sit on the chair and play games like playing console games. Because of the basic technical principle of active IR sensors, they need a dark environment to perform their function. Hence, we added extra cover panels which can be installed on the holder to keep sensors working in a dark environment. Whether to install these panels and install how many panels depend on users. Our design can support cover panels up to 4. All the components are shown in Figure 3-14.

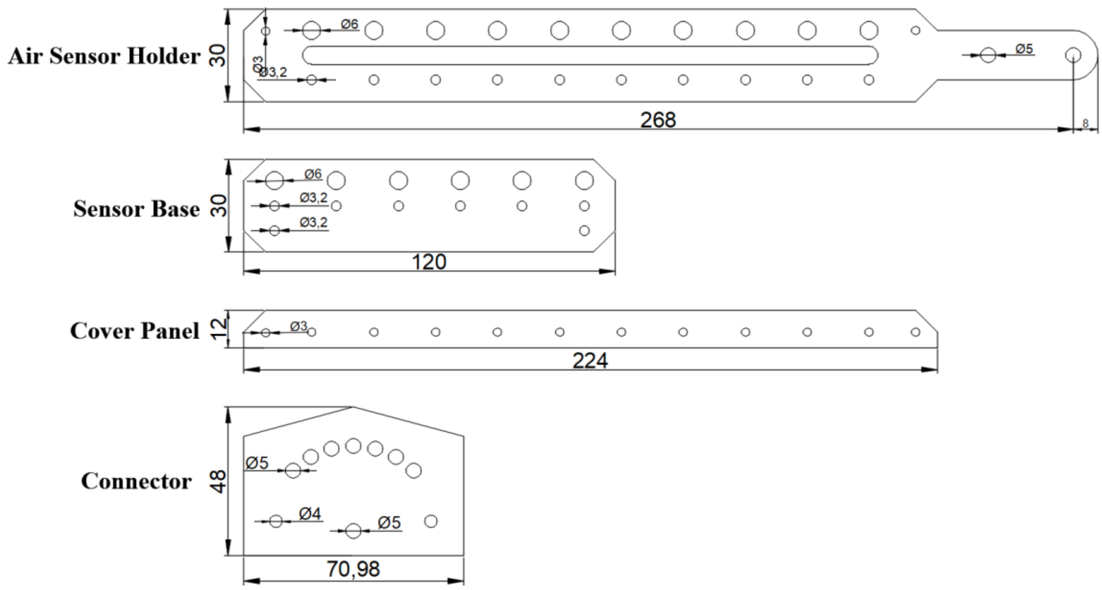

Figure 3.14 The CAD Drawing of Air Sensor Holder V1.0

3.2.2 Environment LED

Environment light system is made by two parts. The LED and LGP. The first version of LGP frame design as shown in Figure 3-15.

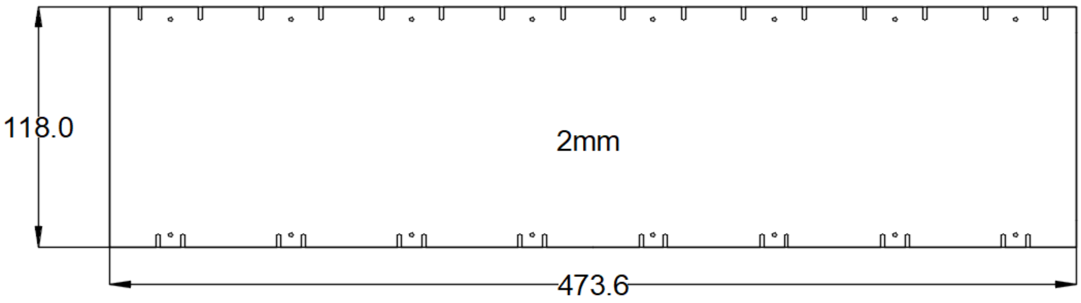

Figure 3.15 LGP Frame V1.0 CAD Drawing

We use this version of LGP frame with WS2812B LED [9] as shown in Figure 3-16.

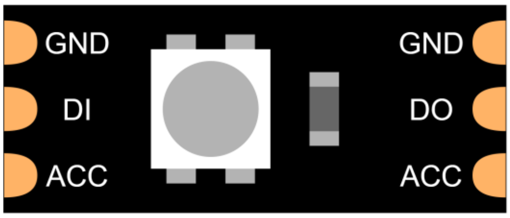

Figure 3.16 WS2812B

WS2812B is an intelligent control LED light source that the control circuit and RGB chip are integrated in a package of 5050 components.[9] It is a very popular and useful RGB LED in industry scale. Thousands of programable lighting systems are made by WS2812B. Hence, in the first version design, we also tried this kind of LED.

However, common WS2812B using the 5050 packages. Hence, they can only emit light to vertical direction. After physical test, the effect of this approach is not good. They can only light up a small area of LGP. Besides, the first version of LGP frame design also has problems about different LEDs' light may interfering each other which means the light effect are not clear enough for players to recognize their input commands by watching the light color. Therefore, in order to construct a high-quality lighting system. We redesigned back light unit structure. The new structure as shown in Figure 3-17.

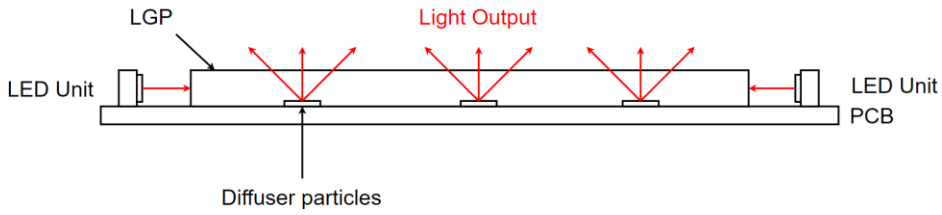

Figure 3.17 Back Light Unit (Backlit unit) Structure

This back light unit structure needs a LED can emit light in parallel direction and a suitable LGP frame design. Firstly, we select a TM1812 [10] RGB LED. It has similar appearance and functions to WS2812B, but it uses a different package to emit parallel light. Secondly, we designed the second version of LGP frame which can use reflective coating to prevent light interfering. The design is shown in Figure 3-18.

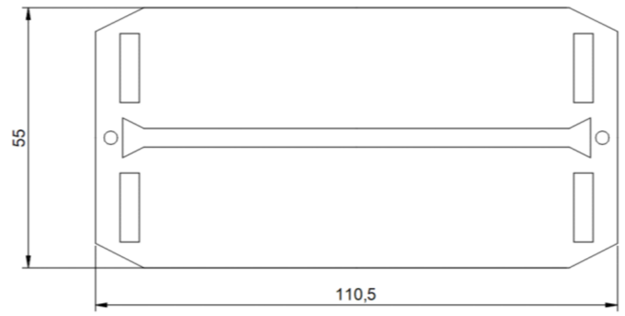

Figure 3.18 LGP Frame V2.0 CAD Drawing

Besides, we also need to select a suitable type of light guide plate (LGP) to be the LGP frame material. Generally, there are two types of LGP in industry scale. They are laser LGP and silk print LGP. The differences are shown in table 3-1.

Type of LGP	**Reflector Method**	**Dimensions**	**Reflecting Material**	**Anti-UV**	**Light Transmittance Rate**	**Error**	**Quality Guarantee**	**Application Environment**
Laser Dotted	Laser Concaved Point	3D	No Addition Material	Yes	93%	0.1mm	10 years	Indoor and outdoor
Sile Print	Raised Point	2D	Print Ink	No	70%	1mm	2 years	Indoor only

Table 3.1 Comparison between the Laser LGP and Silk print LGP

Hence, we can find that laser dotted LGP has much more advantages than silk print LGP. What's more, the material of laser dotted LGP is Mitsubishi optical acrylic (PMMA) which has many excellent features including high light transmittance, uniformity reach to 90%, no yellowing, long life span (at least 10 years), no addition chemical substance and high permittivity dielectric. Because of these advantages, we select it to be the material to make our LGP frame. [11]

3.3 Implementation of Main Board

In this section, we will illustrate the approach to implement main board. It is consisted by four sensor chips and one single-chip microcomputer. Main board is used to process all the input signals and output processed signals to game platform.

3.3.1 Sensor chips

Because not all the sensors can generate simple digital signals by themselves. Some sensors can only output analog signals or other types of value. Hence, we need use special algorithm to handle these output values and convert them into direct and effect value to track users' action. In order to reduce the cost of development and enhance the reliability of our system, we use Adafruit MPR121 12-channel capacitive touch sensor breakout board's compatible board to finish the job. MPR121 can handle up to 12 individual touch pads. The MPR121 has support for only I2C, which can be implemented with nearly any microcontroller. Developers can select one of 4 addresses with the ADDR pin, for a total of 48 capacitive touch pads on one I2C 2-wire bus. Using this chip is a lot easier than doing the capacitive sensing with analog inputs: it handles all the filtering for users and can be configured for more/less sensitivity. [12]

Because of these features, we can use MPR121 to implement a touch screen including at most 48 touch pads which can be fit most arcade games' demand. Besides, the board can process not only analog signals, but also digital signals. Hence, we can connect sensors which can generate digital signals like microswitches to the board. It can greatly enhance the generality of our controller. Users also can find some creative approaches to implement their own controller by using our main board. The MPR121 board is shown in Figure 3-19

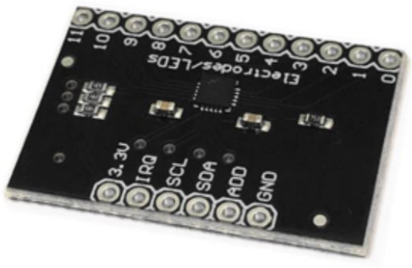

Figure 3.19 MPR121- Breakout Compatible Board

3.3.2 Single-chip Microcomputer

There are thousands of various single-chip microcomputers in the market. To give a better understanding about why we choose Sparkfun pro micro, we will present our reasons from multiple aspects.

3.3.2.1 Requirements of Microcomputer

Before illustrate the reasons, we should know what kind of microcomputer is suitable for our project.

- High Performance and High Reliability
- Big and Active Community
- Easy for Software and Hardware Development
- Small Size and Low Price

Firstly, because it is responsible for most computation. If the microcomputer shutting down or crashed when users are playing, the controller will stop work. Hence, high performance and high reliability of the microcomputer are very important.

Secondly, because of differences between various microcomputers' bottom hardware structure, the implementation of software which have the same functions will be different. If the microcomputer can be supported well by the community, the development cost will be greatly decreased. For example, the HID simulation function is necessary for our project. Popular chips have countless useful and high-quality HID simulation libraries. By using them, our controller can have a much better performance and less development time than using most not popular chips. Therefore, we try to find a most common used microcomputer and have the biggest and most active community.

Thirdly, microcomputer is relative to both software and hardware development. More exactly, we should use different programing language to develop our software and design PCB with different complexity to integrate sensor chips and microcomputer depending on the microcomputer. Hence, we should find a microcomputer which can be easy for software and hardware development.

Finally, the size of microcomputer should be small with low price. Because our controller should be able for everyone to play at home. Hence, each component should be as small as possible except outer shell which should have the same size like arcade input devices with low price to reduce the cost.

3.3.2.2 Selection of Microcomputer

It was estimated in mid-2011 that over 300,000 official Arduinos had been commercially produced,[5] and in 2013 that 700,000 official boards were in users' hands. There is no doubt that Arduino products have one of the biggest and most active community in the world. Hence, we decide to find a suitable product from Arduino microcomputer product line. The usage of Arduino Board as shown in Figure 3-20.

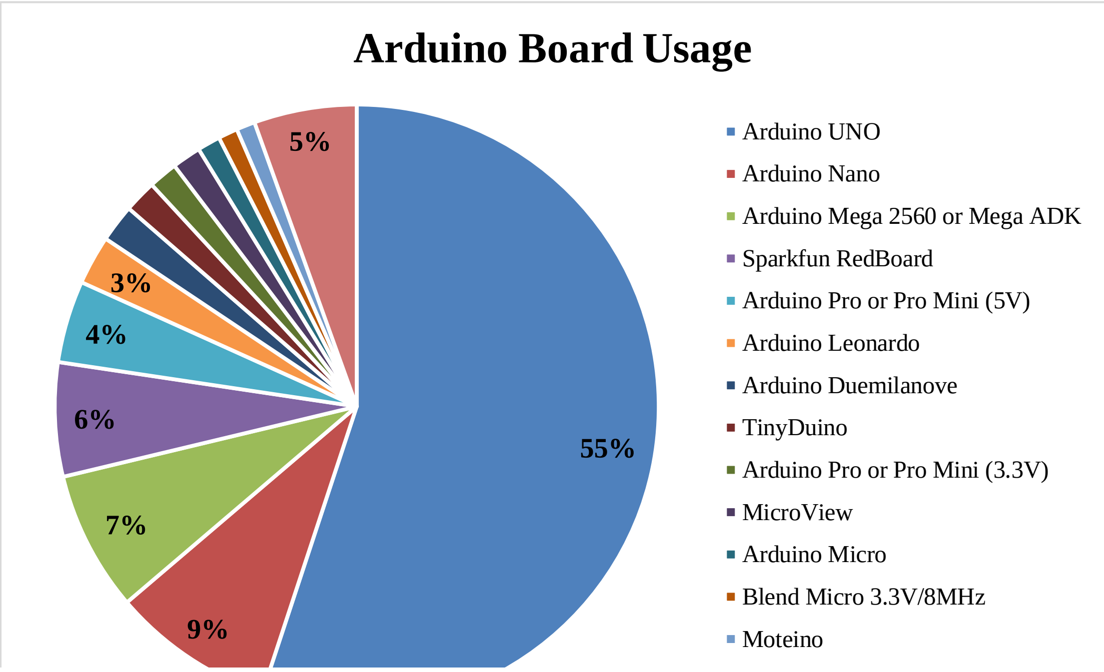

Figure 3.20 Arduino Board Usage

Arduino UNO definitely is the most common used Arduino Board, but it is too big for our project. Atmega328P is the most popular processor as shown in Figure 3-21. However, Atmega32U4 can use the same code running by Atmega328P and it has USB transceiver inside the chip which can do away with bulky external USB interface. Hence, we finally decide to use sparkfun pro micro which has a small size, low price and high performance for us to make a controller. The software development can be supported by Arduino IDE and many useful third-party libraries.

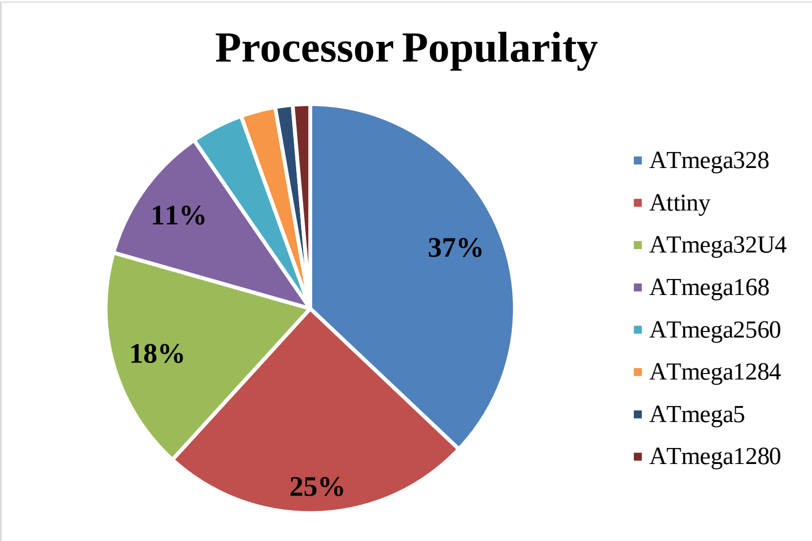

Figure 3.21 Processor Popularity

Sparkfun Pro Micro has 3.3V and 5V versions. One can run at 3.3V/8MHz. Another can run at 5V/16MHz. To get higher performance, we select 5V/16MHz version.

Pro micro can only output 500ma current which is not enough for all the environment LEDs. Hence, we added an individual power supply unit.

3.3.3 PCB of Main Board

Because of the requirement of our controller, every component in the project should be fixed well and can be replaced or installed without special tools. Hence, we designed a PCB to integrate sensor chips, microcomputer and power supply unit. We also use JST PH2.0 standard connector to reduce the difficulty of connecting sensors to main board. The design is shown in Figure 3-23.

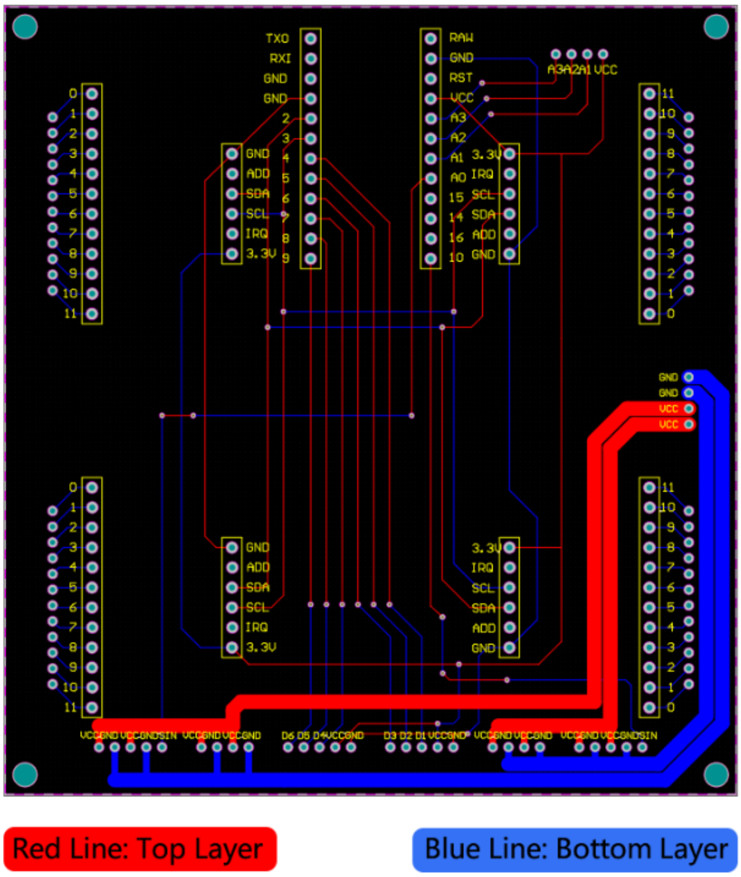

Figure 3.22 PCB design of Main Board

Environment LEDs need about 5A current. Because of the current heating effect, we need wider power traces to keep its temperature in the safe zone. The effect is shown in Figure 3-24. Generally, 5A current needs about 6mm wide trace. However, the space is not enough for 6mm power traces and ground traces. Therefore, we use 4mm traces and divide environment LEDs into two group to balance the load of power trace. We try to design the main board within 10cm * 10cm size is because most PCB producers will give the lowest price for boards within that size. If the board is larger than 10cm * 10cm, the price will be at least twice the original price. It will greatly increase the development cost and the difficulty of production.

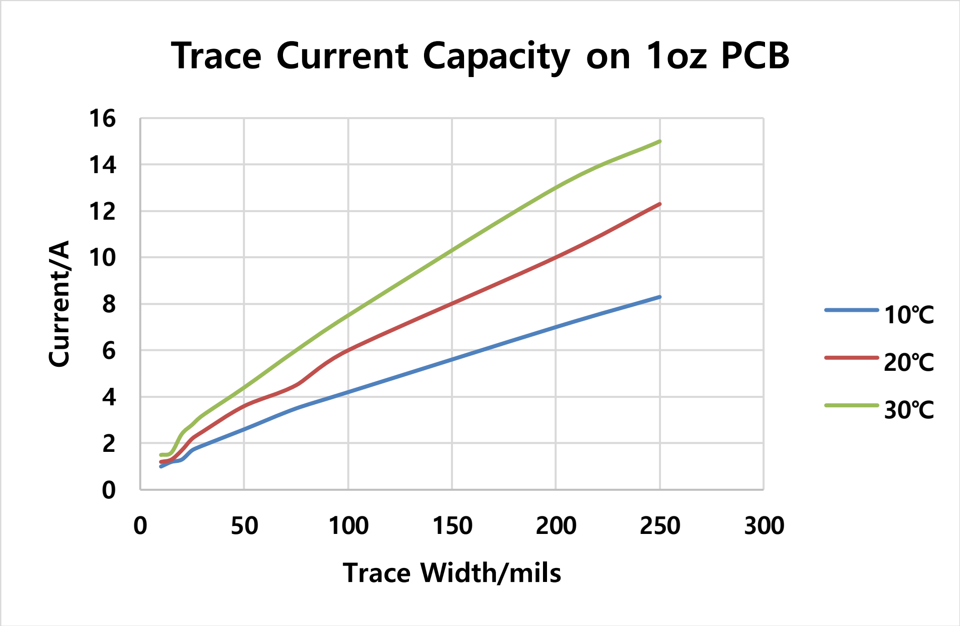

Figure 3.23 Trace current capacity on 1oz PCB

Besides, we added an extra encoder connector for further development. It can be used to change current supported game of the controller so that users need not to recompile or reburn the code to fit different games.

3.3.4 Individual Power Supply Unit

There are various individual power supply units (PSU)in the market. Generally, A power supply unit is used to convert mains AC to low-voltage regulated DC power for the internal components of a computer. The function is a little bit different for our controller. It has an individual AC-DC converter which is used to convert 220V AC power to 24V DC power. Then, it uses DC power to support LEDs and other components in the board. The technical details about our PSU is shown in Table

Operating Voltage	DC 9V-36V
Output Voltage	5.2V/5A/25W
Output Ability	9~24V input: 5.2V/6A/30W output
	24~32V input: 5.2V/5A/25W output
	32~36V input: 5.2V/3.5A/18W output

Table 3.2 Technical Parameters of Controller's PSU

Chapter 4 Development of Software

In this chapter, we will discuss the implementation of our code. To give a better understanding about how the controller work from software aspect. The code structure is shown in Figure 4-1.

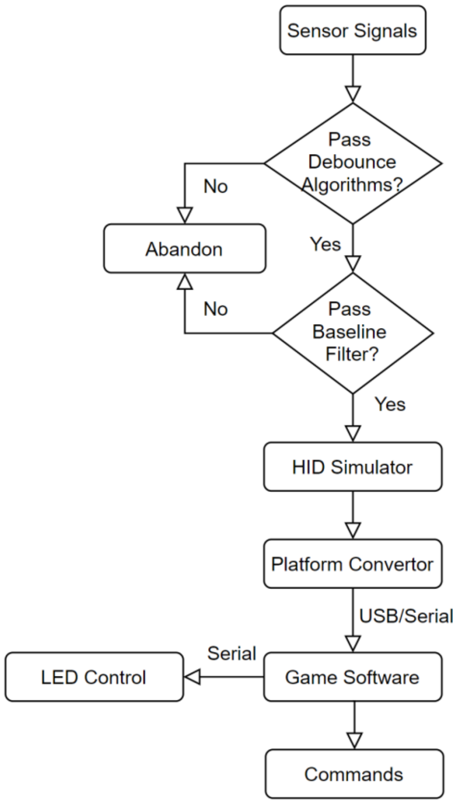

Figure 4.1 Data Flow Diagram

4.1 Debounce Algorithm and Baseline System

In this section, we will illustrate the implementation of debounce algorithm and MPR121 Baseline system.

4.1.1 Debounce Algorithm

Contact bounce (also called chatter) is a common problem with mechanical switches and relays, which arises as the result of electrical contact resistance (ECR) phenomena at interfaces. Switch and relay contacts are usually made of springy metals.

When the contacts strike together, their momentum and elasticity act together to cause them to bounce apart one or more times before making steady contact. The result is a rapidly pulsed electric current instead of a clean transition from zero to full current. The effect is usually unimportant in power circuits, but causes problems in some analogue and logic circuits that respond fast enough to misinterpret the on-off pulses as a data stream.[17] In the design of micro-contacts controlling surface structure (surface roughness) and minimizing the formation of passivated layers on metallic surfaces are instrumental in inhibiting chatter.

The effects of contact bounce can be eliminated by use of mercury-wetted contacts, but these are now infrequently used because of the hazards of mercury. Alternatively, contact circuit voltages can be low-pass filtered to reduce or eliminate multiple pulses from appearing. In digital systems, multiple samples of the contact state can be taken at a low rate and examined for a steady sequence, so that contacts can settle before the contact level is considered reliable and acted upon. Bounce in SPDT switch contacts signals can be filtered out using a SR flip-flop (latch) or Schmitt trigger. All of these methods are referred to as 'debouncing'. [18]

The bounce problem will also happen in analog signal sensors like capacitive sensors, shock sensors which are using in our sensors set. Because of lacking in test circuit design and development budget, we choose software to do debounce. The implementation of original debounce algorithm in MPR121 chip is obtaining multiple samples and testing them with the baseline value. If any of these samples fail to pass the test, these signals will be abandoned. However, this algorithm can cause serious input latency. Hence, we implemented a debounce algorithm with rate-limiting and throttling the frequency of sensor signals’ receiving. The effect of algorithm is shown in Figure 4-2.

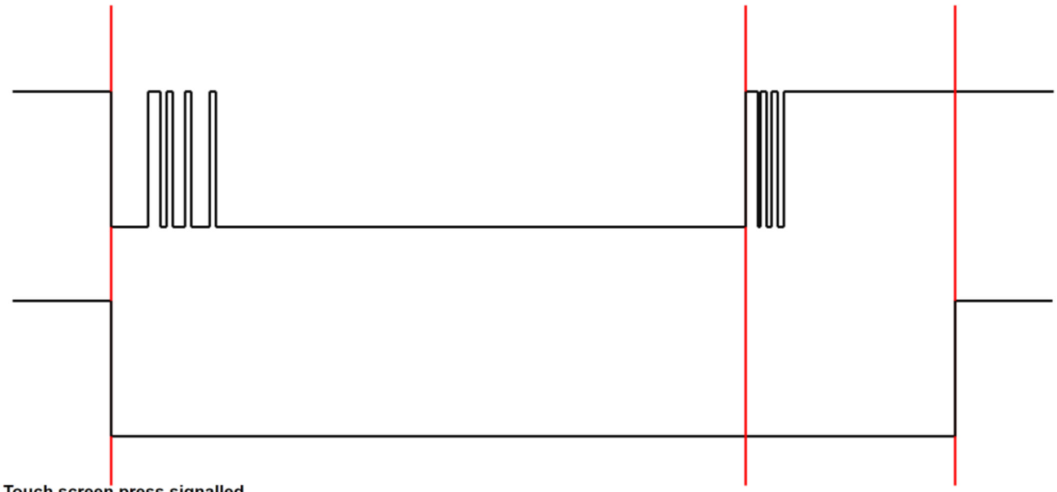

Figure 4.2 The Effect of Debounce Algorithm

From the figure we can find that the current level will be unstable when user press and release the switch. Therefore, we limited the input frequency and set a fixed press duration. Currently, the world record for most mouse clicks in 1 second is 16CPS[6]. [19] Hence, we limited the input frequency to 20CPS. In other words, the controller will not generate 2 signals in 50ms. The limitation even is a little bit higher than the record. Therefore, it will not cause problems with missing input data for most users. By using these measures, the bounces when user press and release the switch will be ignored. Users can generate clear input signals and the game will have stable and correct actions.

4.1.2 Baseline System

Besides having bounce problem, touch sensors also have noise problem. In signal processing, noise is a general term for unwanted (and, in general, unknown) modifications that a signal may suffer during capture, storage, transmission, processing, or conversion. [20] Hence, we also need an algorithm to filter them. The purpose of the baseline filter is to “filter out touches” resulting in a system that is similar to a long-term average but also takes into account that one specific signature. A touch must have different properties than noise and environmental change with respect to the filter response. This is accomplished through four register types that operate under different

[6] CPS: Click per second

conditions. These are Max Half Delta (MHD), Noise Half Delta (NHD), Noise Count Limit (NCL) and Filter Delay Limit (FDL). [21] We can change the value of these registers to customize the baseline filter and get clear touch signals. The data flow is shown in Figure 4-3.

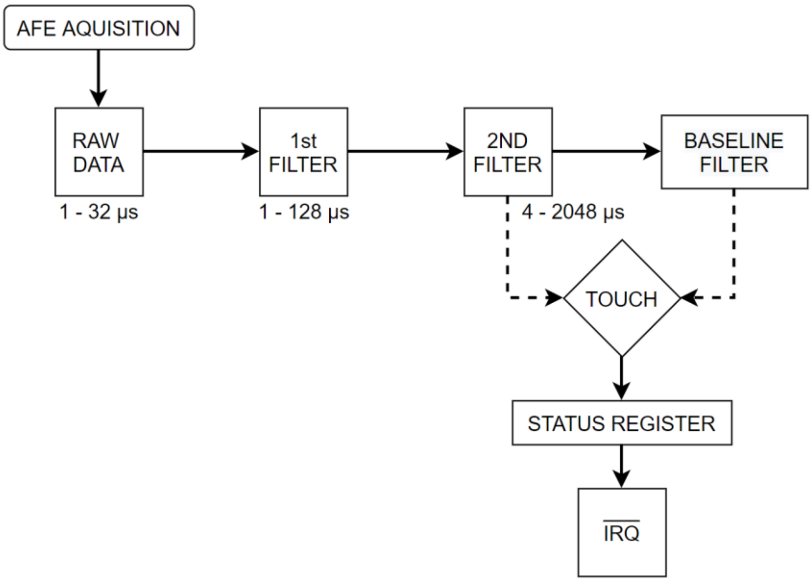

Figure 4.3 Data Flow in the MPR121

4.2 HID Device Simulation

4.2.1 Purpose of HID Device Simulation

In order to output signals which can be accepted by the game software, we need to convert our controller into specific devices with correct driver which can be identified by the target platform. For example, Windows 10 identify devices by their HID drivers. We can use keyboard with keyboard drivers to input commands, but we cannot use it with mouse drivers. Because the actions of some switches are not defined in the driver. Hence, the system may cannot identify it or cannot receive right input commands.

4.2.2 Selection of HID Device

There are various HID devices like gamepad, mouse, midi keyboard and other devices in the world. To provide an unlimited software environment for the controller, we consider the most suitable HID device is NKRO keyboard. NKRO keyboard has a significant feature that normal keyboards do not have. It has n-key rollover feature. This means that each key is scanned completely independently by the keyboard hardware, so that each keypress is correctly detected regardless of how many other keys are being pressed or held down at the time. The drivers for PC system are also different. With NKRO keyboard driver, the number of input commands which system can accept at the same time is unlimited. Normal keyboards only have 6-key rollover which means they can only input at most 6 keys once. It is not a big problem for daily used keyboard. However, if the device is a game device, there is no doubt that it will greatly influence the game experience especially for fighting game and rhythm game which are the most popular genres in arcade games. Our controller has 32 touch sensors and 6 active IR sensors. Hence, user can input at most 38 commands once which is much greater than normal keyboard input limitation.

4.2.3 Implementation of HID Device Simulation

Arduino company has implemented a simple keyboard library [22]. However, it is a normal keyboard library which means it can only input 6 keys once. Therefore, we need to find another way to complete this function. Then, we find a third-party library from GitHub. Its name is Arduino HID Project [23] which provide a simply approach for developers to implement a NKRO keyboard.

The HID library provides two approaches to implement NKRO Keyboard simulation. The first approach is similar with Arduino official keyboard library. We need to use press() and release() functions to output a key command. The second approach use add() and send() functions to output a series of added key commands. In order to give clear game commands and improve users' game experience, we use press() and release() to complete the basic logic of sending keyboard commands.

4.3 Platform Convertor

Most of arcade games can be played in PC platform by using various simulators and similar fan-fiction works. These games can be played directly by the controller's default settings. However, there are a couple of arcade games having official console games in PS4, XBOX and Nintendo Switch. In order to expand controller's function and reduce the cost for new players to enjoy arcade games, we implemented a platform convertor to make the controller still functional in console platforms.

Generally, we use third-party project GIMX [6] to implement our platform convertor. GIMX is a free software that allows to use a computer as a hub for gaming devices. It works on Windows and GNU/Linux platforms. It is compatible with PlayStation and Xbox gaming consoles. The structure of GIMX is shown in Figure 4-4.

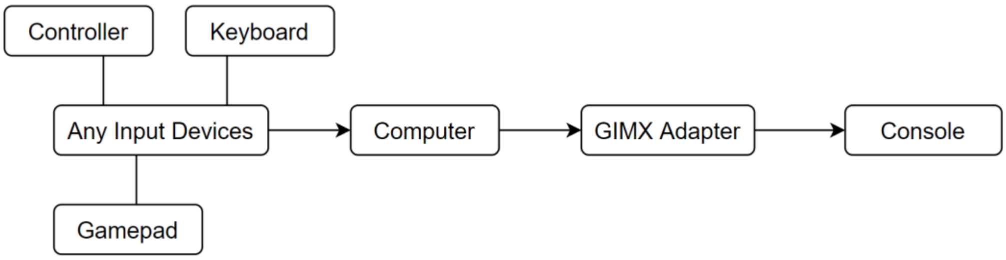

Figure 4.4 GIMX Structure

GIMX adapter is a USB adapter which can be made by AVR development board like Sparkfun pro micro which is used in our main board. At present, GIMX project can support PS4, PS3, Xbox One and Xbox 360. The controller will be converted to specific console controller with good performance.

For Nintendo Switch, we use HID simulation function. The reason why we do not use it to complete other platforms conversion is PlayStation and Xbox having an extra identification process to check whether the connected device is the controller with identification chip inside. However, for Nintendo Switch, it does not have such procedure. Hence, we can simply change the HID information and simulate our controller to be a Nintendo Switch official controller.

Unfortunately, because of the implementation approach of our controller, PC mode cannot coexist with NS mode. In other words, we need to recompile the code to change the mode of the controller to support different platform. It can be improved by adding extra switch. For PlayStation and Xbox, they can coexist with PC mode. Because GIMX is working in PC environment.

4.4 Serial Communication and LED Control

Serial communication is the process of sending data one bit at a time, sequentially, over a communication channel or computer bus. For most arcade machines, they use serial communication to finish most of their data transmissions. Hence, we implemented our LED control code by receiving values from the game software. Sensors signals also can be transmitted by serial communication, but because of the mechanism of serial communication, it has serious problem with data missing. Sensor signals are the most significant part in our project. It should be stable with low latency. Hence, if we want to use that we need to finish an extra structure for solving this problem, it will spend much more time with little improvement for our controller. Therefore, we decide to use USB communication for sensor signals and use Serial communication for LED control.

There are totally 96 LEDs in our controller. They can be divided into 32 groups. 16 groups with 64 LEDs are touch area LEDs. 15 groups with 30 LEDs are the area between two touch area. Finally, 1 group with 2 LEDs are redundant. By leaving an extra redundant group can reduce the difficulty of production. We have left a customizable value for users to change the data serial port. The controller will change LEDs' RGB value by receiving the data from that serial port.

Chapter 5 Testing

5.1 Main Board

In this section we will test the function of our main board. Generally, main board has two functions. They are receiving signals and transmit these signals to game platform. We tested the connection between four MPR121 chips and pro micro. MPR121 chip has a begin() function to check the connection status. The result is shown in Figure 5-1.

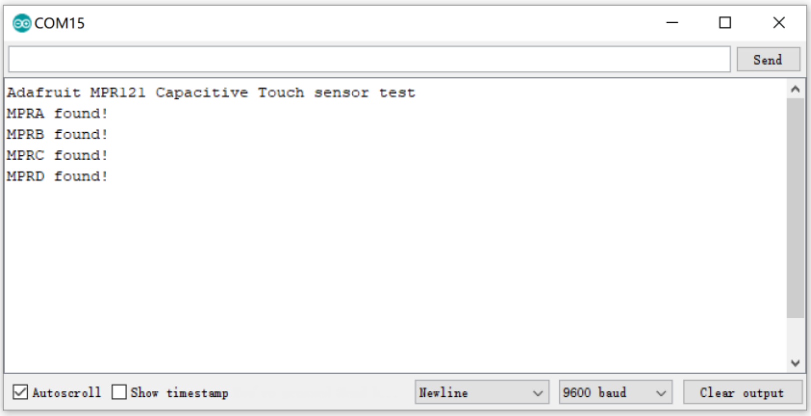

Figure 5.1 MPR121 Testing Result

Besides, power supply unit is functional, it can support all of our devices. The finished main board is shown in Figure 5-2.

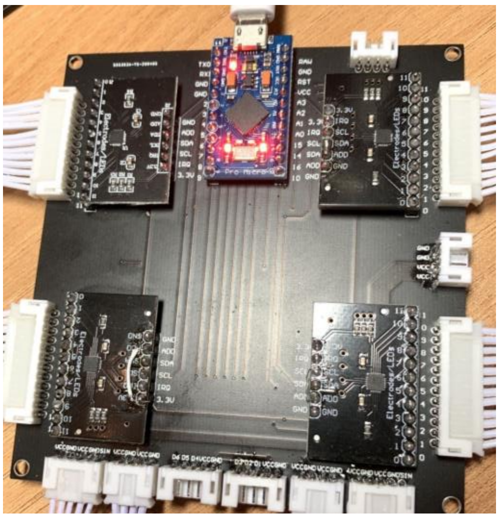

Figure 5.2 Complete Main Board

5.2 Sensors Set

In this section, we test the function of all the sensors in our sensors set. There are totally 8 actions divided by action types, speed and intensity. The result is shown in Table 5-1. According to the result, we can find that the touch screen can receive heavy click, hold, fast slide well and active IR sensors can always track users’ action clearly. However, because of the theory of self-capacitance sensors, light click and low speed slide have serious signal missing problems when we touch the sensor with LGP. Fortunately, the problem can be simply fixed by removing LGP.

Actions / Result	Click (Light)	Click (Heavy)	Hold	Slide (Fast)	Slide (Normal)	Slide (Slow)	Air (Flick)	Air (Hover)
Received	21	48	49	41	32	17	50	47
Missed	29	2	1	12	18	33	0	3
Input Number	50	50	50	50	50	50	50	50

Table 5.1 The Result of Sensor Testing with LGP

Actions / Result	Click (Light)	Click (Heavy)	Hold	Slide (Fast)	Slide (Normal)	Slide (Slow)	Air (Flick)	Air (Hover)
Received	49	48	49	47	48	43	50	48
Missed	1	2	1	3	2	7	0	2
Input Number	50	50	50	50	50	50	50	50

Table 5.2 The Result of Sensor Testing without LGP

Chapter 6 Conclusion

6.1 Conclusion

We have presented an approach to build a customizable universal arcade controller. The controller can support most of arcade games in the market and some of the console games which have similar input mechanism like arcade games. All the components in the controller are budget and easy for user to maintenance. We designed sensors set and main board two individual structures which can let users play completely different games by using the same controller. Besides, they are protected well by the shell structure. Hence, the controller can work properly in poor environment without regular maintenance. Therefore, it will be a good device for new players who want to play arcade games.

6.2 Future work

We use self-capacitance structure to make our touch screen, but its sensitivity is a little bit too low to track every small action made by users. Using mutual- capacitance structure may have better performance. Besides, a functional hardware debounce structure should be added to the PCB. The debounce algorithm cannot handle all the situation. Some noises still will cause unexpected input signals.

The PCB design of touch sensors should add extra JST connectors to further reduce the difficulty of production and maintenance. The main board should a little bit larger to give more space for power and ground traces.

Reference & Bibliography

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Resume

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