Computer Assisted Gomoku Board

ECE 445 Design Document

Fall 2018

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Table of Content

1. Introduction

1.1 Objective

Gomoku is a strategy board game and it requires a lot of moves. Our goal is to build a computer assisted Gomoku board which is able to simulate the on-board play automatically and simultaneously, and to project the simulation onto a screen. Often during practicing, players have to record the whole game move by move manually on paper so that they can later analyze their games. However, this way of recording not only distracts players during their games, but also is considered inefficient and tedious. Other than the negative influences on players, current technology of broadcasting Gomoku games is still outdated. The current method which medias adopt to stream Gomoku games is manually putting Go pieces on the Go board to simulate the actual game. In this way, for both players and audiences, replay of the game is inconvenient and not efficient enough. Gomoku has world championships every two years and is developing into a more popular and world-wide abstract strategy board game [1]. The current technology is not sufficient to support the growing need for efficient broadcasting and game replay.

We will use an array of pressure sensors in the design to achieve the automation of the board. The standard Go board uses 15×15 of the 19×19 grid intersections [2]. In order to simplify and increase the fluency of the design, we will make a board with 9×9 grid intersections instead. We will adopt an appropriate microprocessor to collect data from pressure sensors, analyze data and send signals to projected screen through a bluetooth device.

1.2 Background

Computer usage has been associated with Gomoku for decades. Artificial intelligence specialized in playing Gomoku games has been created. In Gomoku World Championship (GWC) 2017, Yixin, a program created to play Gomoku, had a 2-game match with Rudolf Dupszki, the champion of GWC 2015 [3]. However, there has not been a similar product designed for easier broadcasts of Gomoku games. We expect our project to be a possible solution for better gaming and broadcasting experiences. With similar working theory, we also expect the design to be applied to other board games, especially Go, which shares basically the same board as Gomoku.

1.3 High-level Requirements List

- Our board should be able to detect a piece being put onto the board, and accurately report which cell the piece is put in with a successful rate of over 99.8%.

- The microprocessor should be able to send the coordinate of the last placed piece to user interface via bluetooth, and the user interface should draw it correctly. The whole process is expected to be in real-time -- less than 1s latency.
- The board should be very sensitive for a force of from 30g to 50g, and insensitive for a force less than 30g, since a typical pressure applied by a player placing a piece is 30g to 50g.

2. Design

2.1 Block Diagram

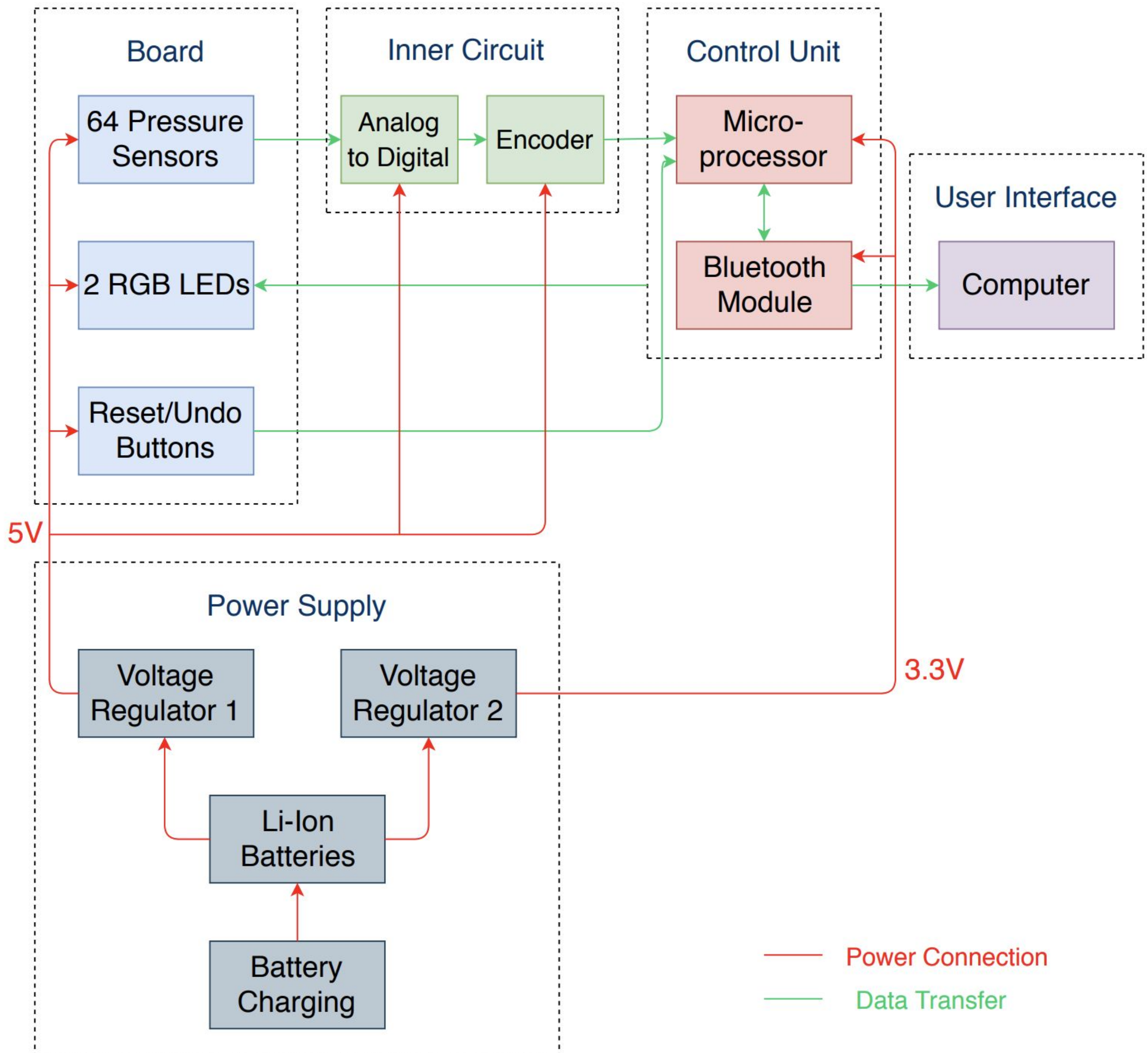

Figure 1. Block Diagram

The Board Block consists of 64 force-sensitive resistors, two LEDs, and two buttons (reset/undo). The data collected by the sensors will be sent to the Control Block after being processed by a analog to digital circuit and cascading by two layers of encoders. If the microprocessor detects a change of the game state, it will send the data to the PC Program(User Interface Block), via Bluetooth Module. The Power Supply Block supplies power to Board Block, Inner Circuit Block and Control Unit Block.

2.2 Physical Design

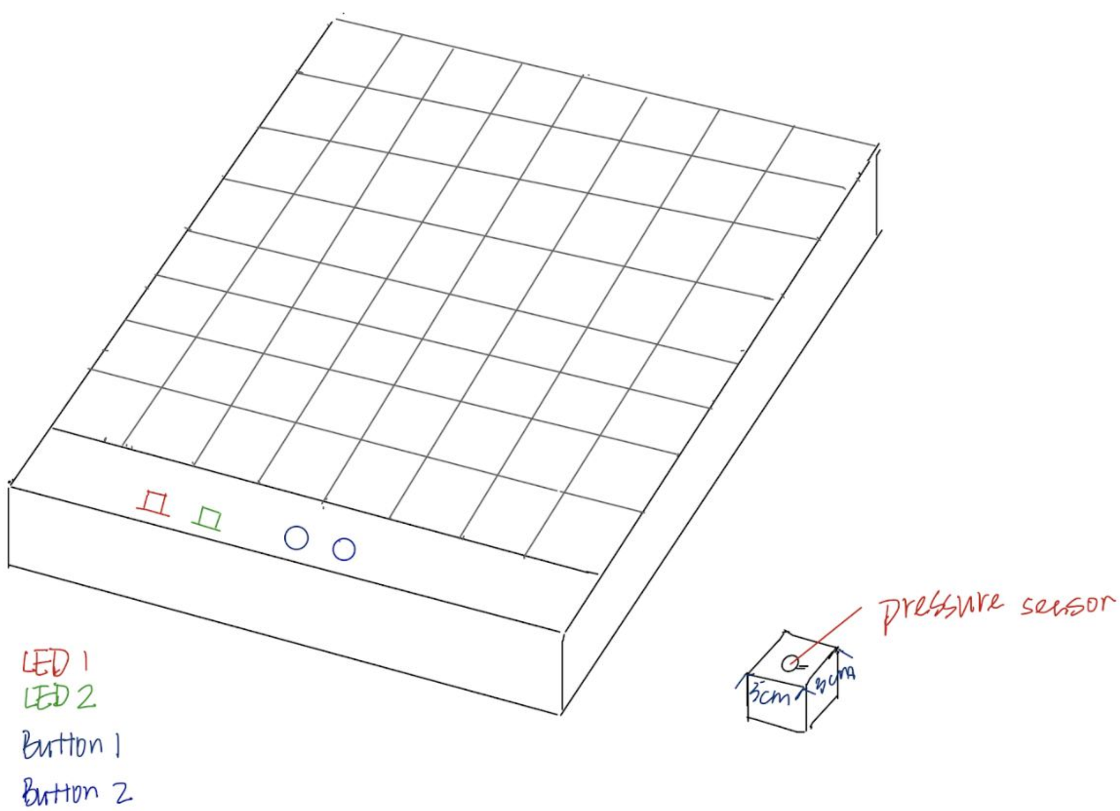

Figure 2. Physical Design

Ideally, the depth of the board should be around 4 centimeters, but because we expect to accommodate all PCB boards, power supplies under the board to make it look better, the depth may change. We also expect each cell to be 2 centimeters by 2 centimeter s dimension.

2.3 Block Design

2.3.1 Power Supply

Power Supply Block will be consists of three parts: Battery Charging Module, Li-Ion Battery, and a Voltage Regulator. This module will supply power to the pressure sensors and LEDs on the board, and will power the control unit including the microprocessor and bluetooth module.

- Lithium-ion battery
  To pick a proper model of lithium-ion battery, we need to calculate the maximum possible current draw of the system as below:

Part	**Current Consumption**
Pressure Sensor (At most 1 at a time)	1mA
LED (At most 2 at a time)	12mA * 2 = 24mA
Voltage regulator (2 at a time)	6mA * 2 = 12mA
Analog to digital converter (9 at a time)	2.5mA * 9 = 22.5mA
Microcontroller	150mA
Bluetooth Module	40mA
Total	**249.5mA**

Table 1. Current Consumption Calculation

With the calculated data and consideration of reasonable cost, we choose the Lithium-Ion Battery - 18650 cell (2600mAh) as our power supply. We plan for the batteries to support the system for 12 hours, which requires a minimum of 3Ah capacity of batteries. We choose this model because it is rechargeable with available recharging unit on sale and is low-cost.

Requirements	Verifications
1) Charge capacity larger than 3AH.	a) Connect the fully charged batteries to a known load which consumes 300mA. b) Use a LED as indicator. c) Ensure the battery system can last for longer than 10 hours.
2) Maintain a minimum voltage output at 5V for proper functioning of voltage	a) During the discharging process, check randomly and especially at the

regulators.	end of the 10 hour using voltmeter, the battery voltage should maintain above 5V.

- Battery Charger
  The 4-Bay T4s Intelligent Universal Charger from Tenergy is an automatic smart charger which is capable of charging 4 batteries simultaneously [4]. This charger can automatically detect battery status and select the appropriate voltage and charging mode. It also has three LED indicators that display the charging process for each charging bay and has a reverse polarity protection, which increases the safety of using lithium-ion batteries.

Requirements	Verifications
1) Fully charge four Li-ion batteries within 5 hours.	a) Put all four batteries into the charger. b) Use LEDs to monitor the charging process. c) Ensure the time required to fully charge the 4 batteries is less than 5 hours.
2) Charging process must maintain a temperature lower than 45°C.	a) During the charging process, monitor the temperature of both the charger and batteries using IR thermometer, and make sure it is under 45°C (suggested charging temperature of the battery).

- Voltage Regulator
  Due to different needs of different blocks in the system, we adopt two different voltage regulators to ensure the proper functions. One regulator is expected to output at 3.3V and the other should output at 5V.

Requirements	Verifications
1)Regulate voltage 3.3V +/- 5% or 5V +/- 5% from the source.	a) Connect the regulators to the batteries. b) Use voltmeter to measure voltages provided by the two regulators, should supply voltages within specified

	ranges.
2) Maintain thermal stability below 45°C.	a) Connect the regulator to a load which draws current at 300mA (the estimated largest current draw). b) Use IR thermometer to measure the regulator temperature, should stay below 45°C.

2.3.2 Board Block

Board Block will be consists of 81 Force-sensitive Resistors (FSR402), two LEDs, and two Reset Buttons. Our board has 9 x 9 intersections, and we need one FSR for each intersection. The 81 FSRs will be connected to Inner Circuit Block for further processings.

Two LEDs are needed in our Board Block. LED1 is Bluetooth Connection Indicator. If the Bluetooth is connected to the PC Program, LED1 will be on with green light. LED2 is a move indicator. If the Control Unit successfully detects a piece is put onto the board or a move is undone (controlled by the Undo Button), LED2 would blink Green.

Two buttons, Reset and Undo are also included in our Board Block. If Reset is pushed, the game state will be cleared and reset to initial state. If Undo is pushed, the previous move would be canceled.

- Pressure Sensor

  The FSR402 pressure sensors will operate under 5V voltage supply. They should manage to detect the contact of a piece with a specific intersection on the board.

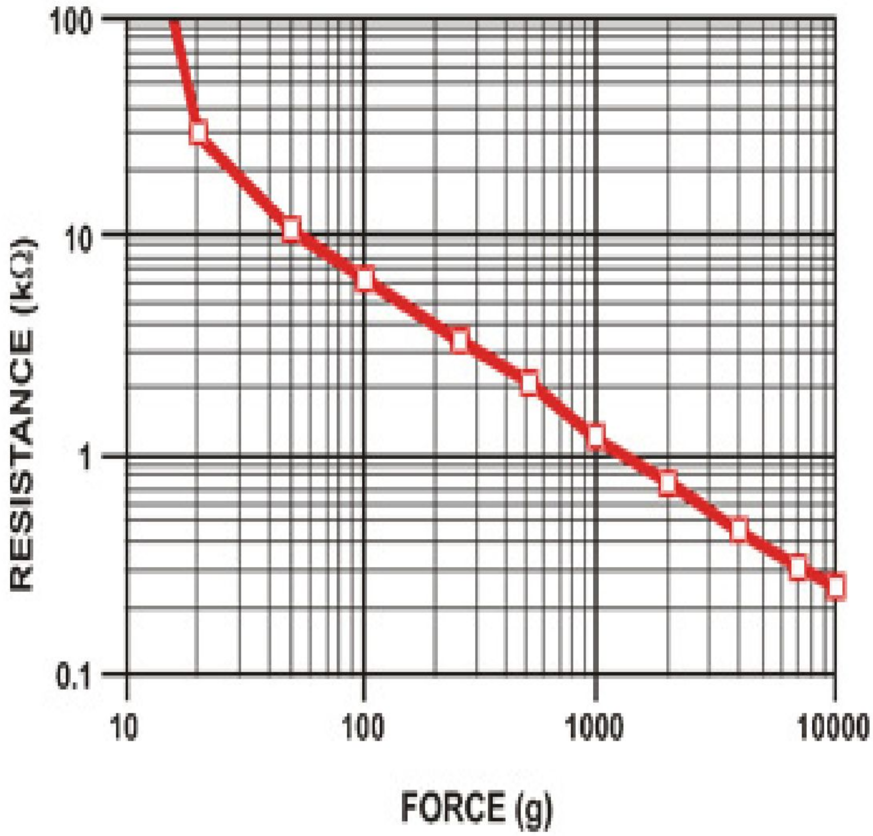

Figure 3. Force Curve for Pressure Sensor [5]

As characterized above, the turn-on threshold of the sensor requires a force of about 20g. Immediately after the turn-on, the resistance of the sensor drops rapidly [6]. We will make sure that the weight of a piece is well below the turn-on threshold of the pressure sensors, so the sensor will only detect the moment that a player places a piece and applys extra pressure on the block. The accuracy of such detection is significant to the success of this design.

Requirements	Verifications
1) Detection accuracy higher than 99.8%.	a) Connect voltage divider circuit of the pressure sensor into power supply and set it under a grid intersection of the board. b) Put a piece on the intersection and measure the Vout indicated in Figure 3 using a multimeter. c) Repeat the process for 1000 times

	and only 2 failure is allowed. d) If the accuracy cannot reach 99.8%, we should re-design the sensor block.

- LEDs

  The two LEDs should operate under 5V.

Requirements	Verifications
1) The LEDs must function for 4.5V < V_in < 5.5V.	a) Connect A LED with 300 Ohm resistor in series, and use a DC power supply to supply power. b) Change the DC power supply's output voltage from 4.5V to 5.5V gradually. c) Ensure that the LED works for the voltage in this range.

- Piece Set

  According to our tolerance analysis below 14, each of our piece set should weigh below the activation threshold of the pressure sensor.

Requirements	Verifications
1) All pieces must weigh less than 10g.	a) Weight each piece on a scale. b) Ensure each piece weighs within the required range.

2.3.3 Inner Circuit Block

The inner circuit block is the key component for us to determine the location of the piece that is put onto the board. The inner circuit block is composed of analog to digital circuits and two layers of encoders. With these cascading mechanism, we expect to solve the challenge of processing 81 sensor signals with limited I/O pins on the microprocessor we adopt.

- Priority encoder

  The priority encoder model we want to use is CD40147B type provided by Texas Instrument, which encodes the highest priority input into a 4-bit binary code. In order to cope with the fact that our microprocessor only have 23 I/O pins, we need to cascade two layers of priority encoders with first layer of 9 encoders and second layer of 4 encoders. With this design, we manage to cut the output signals from total 36 bits to 16 bits.

TRUTH TABLE (Negative Logic)

INPUTS										OUTPUTS			
0	1	2	3	4	5	6	7	8	9	D	C	B	A
0	0	0	0	0	0	0	0	0	0	1	1	1	1
1	0	0	0	0	0	0	0	0	0	0	0	0	0
X	1	0	0	0	0	0	0	0	0	0	0	0	1
X	X	1	0	0	0	0	0	0	0	0	0	1	0
X	X	X	1	0	0	0	0	0	0	0	0	1	1
X	X	X	X	1	0	0	0	0	0	0	1	0	0
X	X	X	X	X	1	0	0	0	0	0	1	0	1
X	X	X	X	X	X	1	0	0	0	0	1	1	0
X	X	X	X	X	X	X	1	0	0	0	1	1	1
X	X	X	X	X	X	X	X	1	0	1	0	0	0
X	X	X	X	X	X	X	X	X	1	1	0	0	1

0 = High Level 1 = Low Level X = Don't Care

Table 2 . Priority Encoder Truth Table[7]

According to the truth table, each first layer encoder provides a unique 4-bit binary code for a pressure sensor in a specific row. With 9 encoders each matching one row of sensors on board, we would get 9 4-bit binary codes. In the next level, we connect the 4-bit output separately to 4 encoders. Because CD40147B is a 10-line to 4-line BCD priority encoder, one input pin of each of the first-layer encoders would be left unconnected, as we only have 9 pressure sensors in each row.

Requirements	Verifications
1) First layer encoders should be able to read all 81 inputs from ADCs.	a) Connect the first layer encoders to microprocessor directly. b) The connected encoder should output a 4-bit binary code while the pressure sensor is pressed. c) Check all the encoders by pressing all 81 sensors row by row.
2) Second layer encoders should encode signals from first layer 9	a) After finishing testing the first layer encoders, connect the second layer

unique 4-bit binary signals.	encoders with the microprocessor. b) Press pressure sensors one by one and check the reading from the microprocessor. c) Ensure all the outputs from the encoders match our design of the sensor block.

2.3.4 Control Unit

Control Unit Block will be consists of a microprocessor and a Bluetooth Module. The microprocessor needs to take inputs from the circuit block (second layer encoders) and determine whether and where a piece is put onto the board. It also has to detect whether one of the Reset Button or the Undo Button is pushed. The microprocessor needs to keep track of the current game state, and send new game state to Bluetooth Module, if the game state is changed. It also has to control LED2. A Bluetooth Module is needed to take the current game state as input from the microprocessor, and send the game state to User Interface Block, a PC Program. The Bluetooth Module is also connected to LED1.

- Microcontroller
  We plan to use ATMEGA328p microcontroller. It has 32K FLASH, 2K SRAM, and 23 programmable I/O Ports.

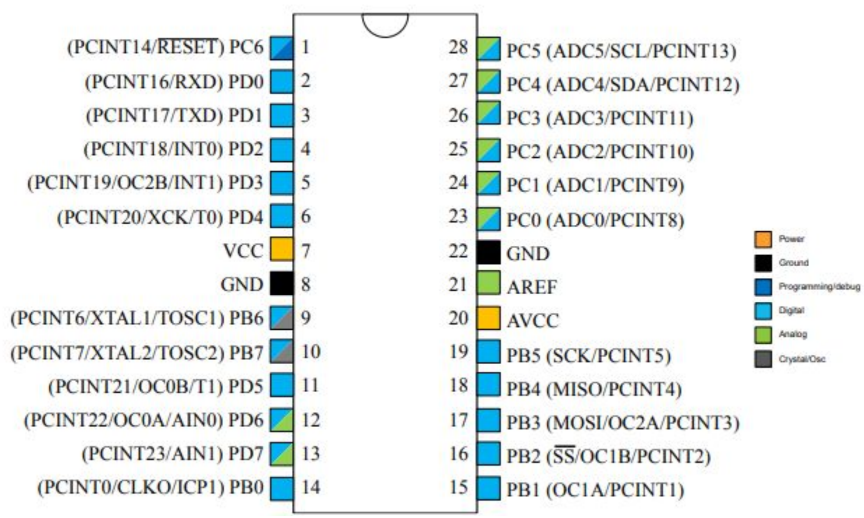

Figure 4. Microcontroller Pin Assignment

Requirements	Verifications
1) The microcontroller must process the inputs from encoders and send the coordinates to Bluetooth Module in less than 0.4 seconds.	a) Connect the an encoder and Bluetooth Module to Arduino A000066. b) Use the microcontroller's internal RTC to measure the time. c) Make sure the time is less than 0.4 seconds.
2) The microcontroller must output digital HIGH with a voltage > 2V.	a) Using arduino to program the microcontroller such that it outputs a digital HIGH from port PC5. b) Use a multimeter to measure the output voltage of PC5. c) Ensure the output voltage is greater than 2V.
3) The microcontroller must output digital LOW with a voltage < 0.4V.	a) Using arduino to program the microcontroller such that it outputs a digital LOW from port PC5. b) Use a multimeter to measure the output voltage of PC5. c) Ensure the output voltage is smaller than 0.4V.

- Software
  Figure 5 is the flowchart of the program we plan to load in the microprocessor in order to detect and update the changes of game state.
  The flowchart follows the process that when the board is powered up, the program should reset the game -- clear all the memory of previous game and set LEDs to the correct state. When the input of the second-layer encoders changes, which means there is a piece being placed on the board, the microcontroller should be able to calculate the piece's coordinate and update the game state. Then, it should determine whether a player has won the game, or a draw has occurred. If any of this situation has happened, it will send the end game signal to the UI and reset the game. The reset and undo buttons are treated as interrupts. When reset button is pressed, whatever the current state is, the program should reset the game; when undo is pressed, the program should undo the previous move immediately and wait for the next move.

Requirements	Verifications
1) The program must correctly determine the player's move, and the accuracy should be higher than 99.8%.	a) Play for 1000 moves, and record all the inaccurate moves. b) Ensure there are no more than 2 inaccurate moves.
2) The program must correctly determine the game result, and the accuracy should be higher than 99.8%.	b) Play for 500 games, record all the wrong results. c) Ensure that there is at most 1 wrong result.

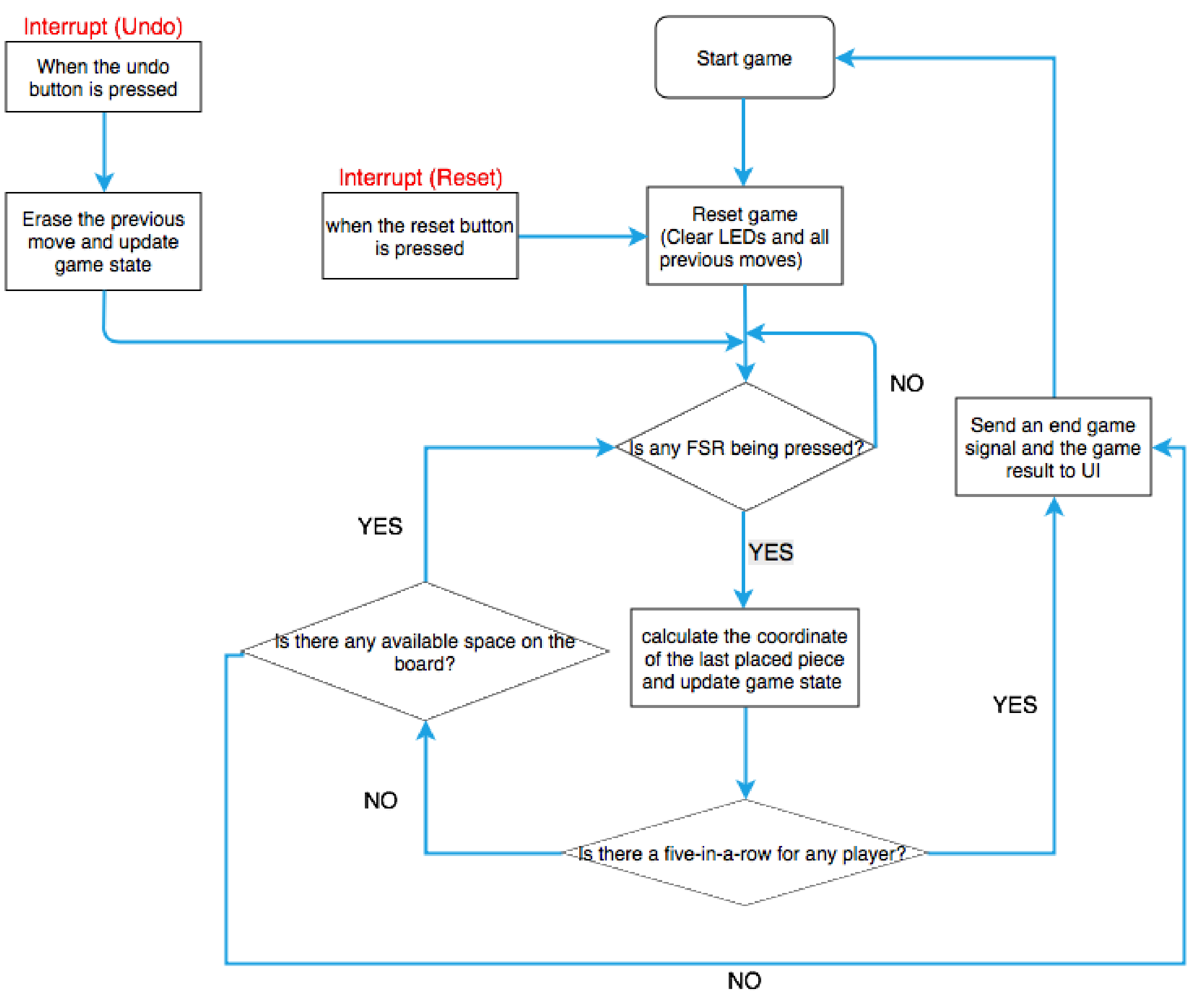

Figure 5. Flowchart of software

- Bluetooth

The bluetooth module is for communications between the microprocessor and the user interface, so that the game can be broadcasted through a screen. The bluetooth module we adopt is HC-06 which is widely used for wireless data transfer. It is low cost and can reach a range of up to 9 meters which is a sufficient transfer range for our design.

Requirements	Verifications
1)The signal integrity should remain perfect within 9 meters range.	a) To simplify the test procedure, we will use a mobile phone to test the connection range. b) Connect a mobile phone to the bluetooth device. c) Move around the bluetooth device with increasing range till 9 meters. d) The device should be properly connected and the mobile phone should receive all the data that is sent be the bluetooth device during the whole process.

2.3.5 Software and User Interface

User Interface Block will be consists of a PC Program. The program needs to receive data from the Bluetooth Module in the Control Unit Block. Whenever a piece is put on the board, the PC program should receive the data via Bluetooth and display the game board on the computer screen.
If the game is ended, the PC program should receive an end game signal via Bluetooth, and display the result (the winning player or it is a draw) on the screen.
If the game state is changed by the Reset Button or the Undo Button, the PC program should also receive corresponding signals reflect the change on the screen.

Requirements	Verifications
1) The UI must show the piece in its correct place on the screen in less than 0.2 seconds.	a) Use python’s timer to measure the time between the receiving of the signal from bluetooth and the end of drawing the piece on the screen. Also, the piece has to be in the right block.

2.4 Tolerance Analysis

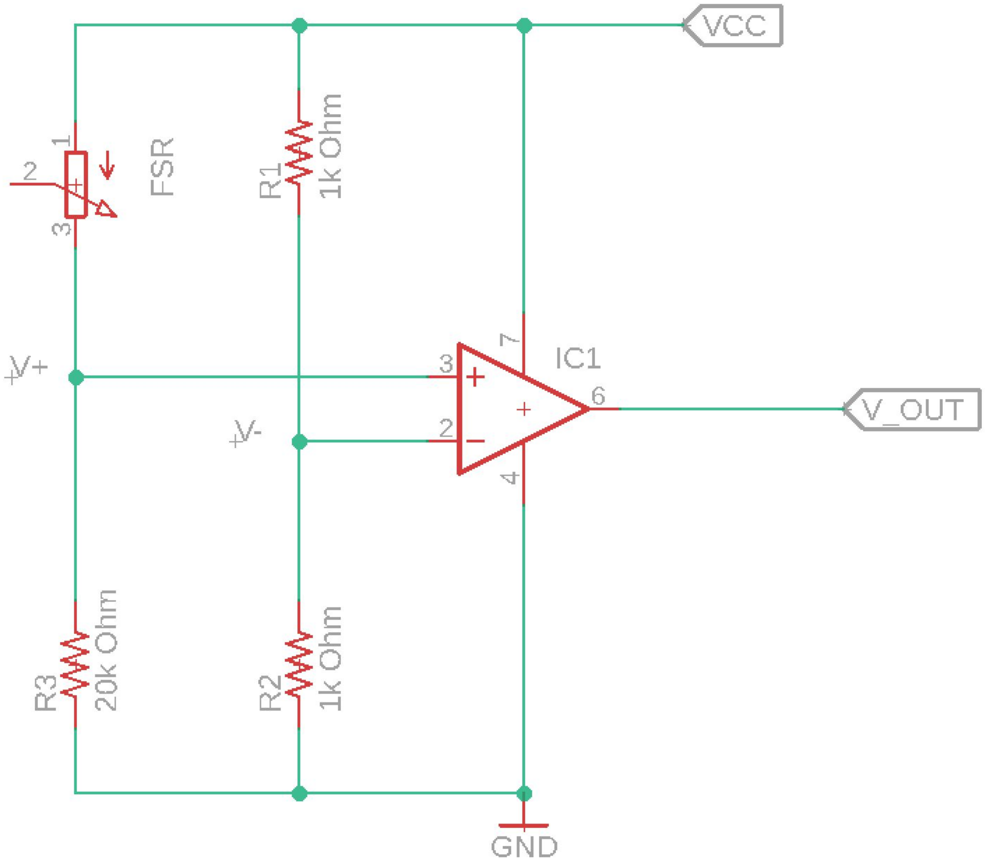

Figure 6. Pressure Sensor Module

The key component for our design to work is the sensor module. To ensure the success of our project, we need to make sure that the signal is only sent to microcontroller when a piece is put onto the board. A light touch on the board should not invoke a signal sent to the microcontroller. We adopt a non-inverting comparator circuit to achieve the function. We connect V_{cc} to a 5V output. As indicated in Figure 6, when V_+ is smaller than V_-, the V_{out} is expected to stay at 0. While V_+ is larger than V_-, V_{out} is expected to be 5V, and thus provides a digital "1" signal to the encoder.

$$V_+ = V_{cc} \times \frac{R_3}{R_{FSR}+R_3} \quad \text{Eq.1}$$

To simplify, we choose R_1 and R_2 to have equal resistance of 1k Ohm. In this case, V_- is 2.5V in all circumstances. When V_+ is larger than 2.5V, we can expect V_{out} = 5V. Refer to the force curve in figure 1, and our test on the average force of placing a piece on the board, we choose R_3 to be 20k Ohm. When the force of placing the piece is larger than 30g, V_{out} should be 5V.

In real world situations, pressure sensors usually don't have the exact behavior as on the datasheet. Assume an FSR has 10% error on its resistance curve. A force needed to activate a 5V V_{out} has a range of 27g to 33g. According to our test, a player normally apply around 0.4N pressure on the intersection when naturally place a piece on the board. Thus, we believe the error of our sensors is tolerable.

All the above discussion is based on the theoretical analysis of the circuit. In actual design of the project, we will make more test on pressure sensors and the circuits to choose a proper R_3 in order to achieve the best gaming experience.

2.5 Schematics

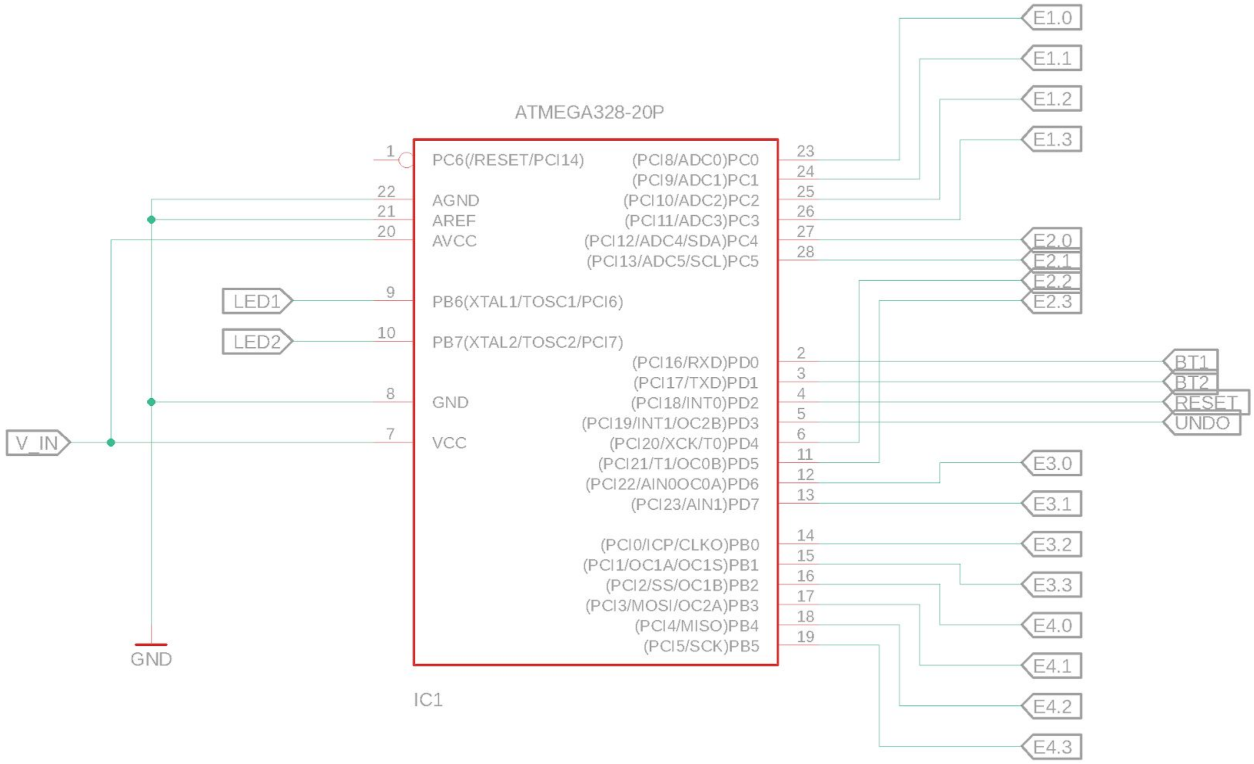

Figure 7. Microcontroller Schematic

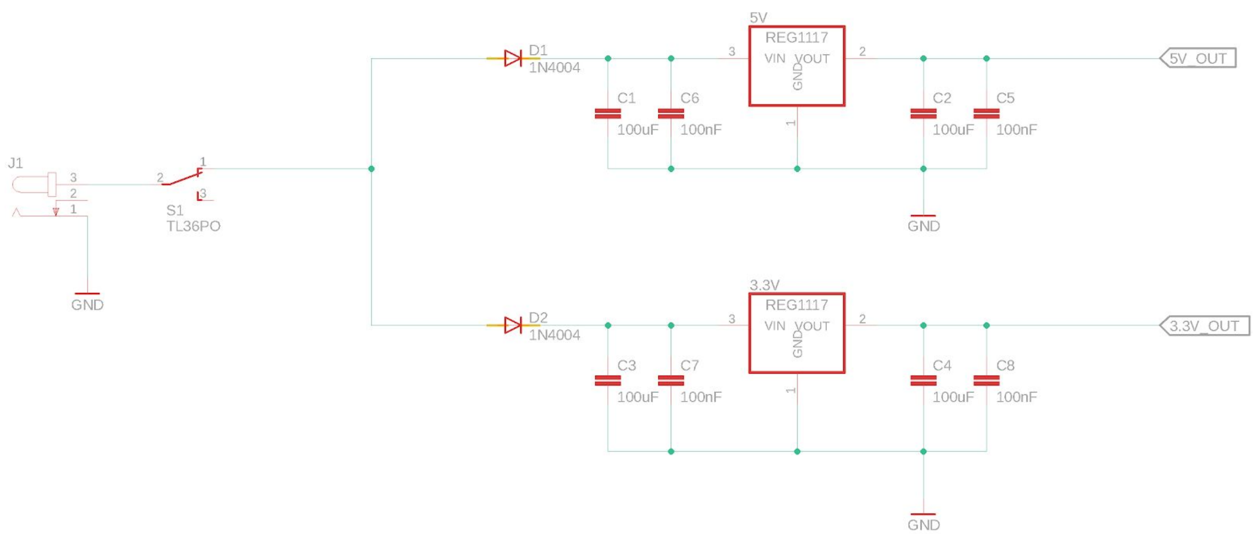

Figure 8. Power Supply Schematic

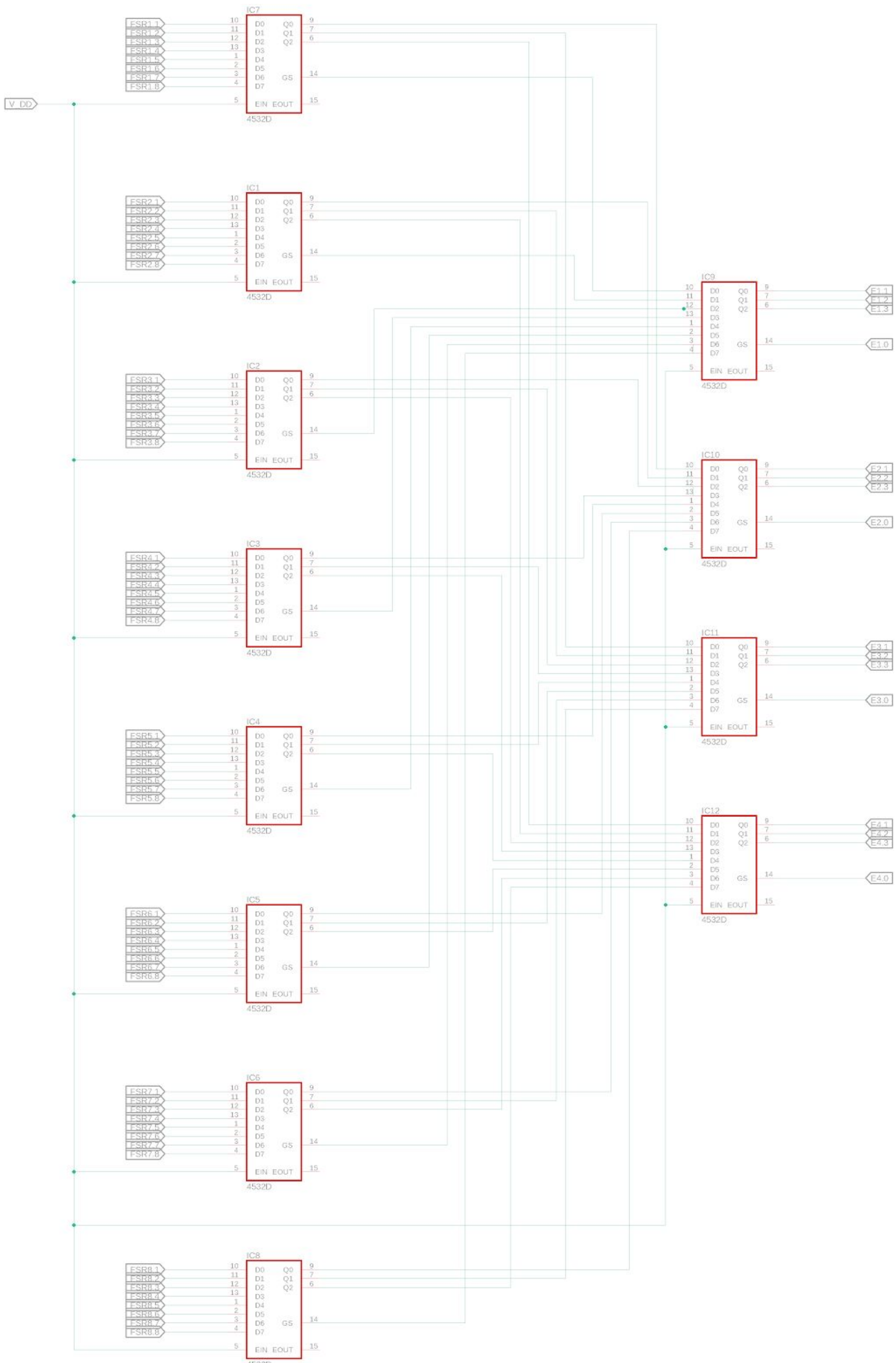

Figure 9. Signal Cascade Schematic

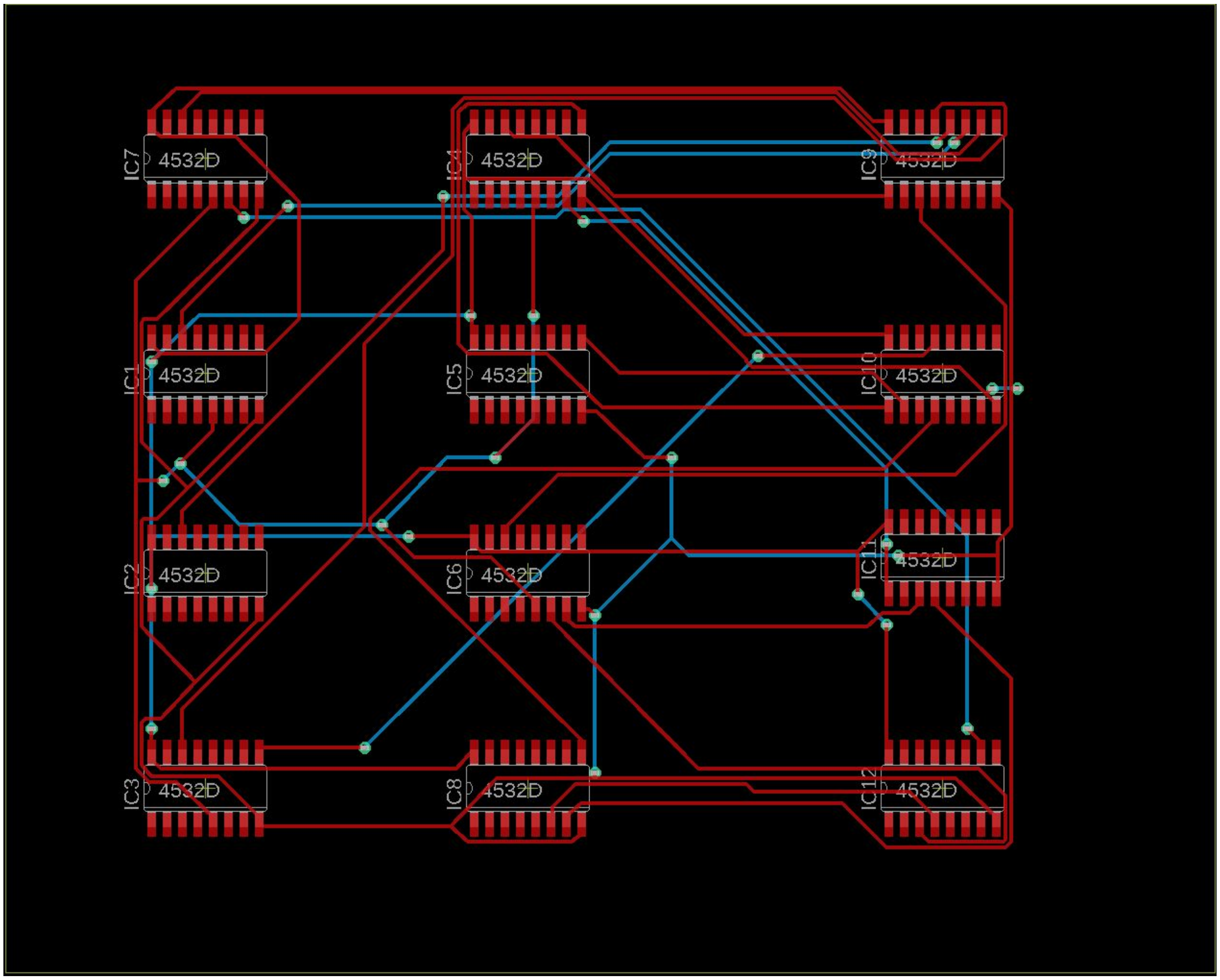

Figure 10. PCB Layout of Encoders

3. Cost and Schedule

3.1 Cost Analysis

According to the starting salary for students graduating with a bachelor's degree in electrical engineering (2016-17), our estimated labor cost is $35 per hour per person. The estimated working time per week is 20 hours per person. We started the design process two weeks prior to the schedule and the total design process is expected to be 12 weeks. Regardless of overtime working during weekends and Thanksgiving break, the estimated labor cost is calculated as:

$$3 * (\$35/hr) * (20\ hrs/week) * (12\ weeks) = \$25200$$

Our parts and manufacturing prototype costs are estimated as each:

Part	Quantity/model	Unit Price($)	Cost($)
Pressure sensor: FSR Model 402, 0.5'' circle	81	4.85	392.85
Battery: 18650 3.7V Lithium-Ion Battery Rechargeable (Secondary) 2.6Ah	4	6.50	26.00
Voltage regulator: AZ1117E 1.0A low dropout linear regulator	2	0.44	0.88
LED: 4302H-5V, 12V Series Integrated Resistor-5 Volt and 12 Volt Operation T-1 3/4 (5mm)	2	0.80	1.60
Button: ALPS Electric SKTQ Series Tactile Switches	2	0.56	1.12
Bluetooth Module: BLUETOOTH-SERIAL-HC-06	1	9.94	9.94
Microcontroller: ATMEGA328p	1	22.00	22.00
PCBs	3	3.10	9.30
Priority encoder: CD40147B	13	0.50	6.50
Battery Charger: 4-Bay T4s Intelligent Universal Charger	1	25.00	25.00

Table 3. Cost Estimation

All the prices listed in Table 3 is according to Mouser Electronics.

Estimated part cost: $495.19.
The total estimated cost of labor and manufacture is $25695.19.
This total cost excludes some expenses that are hard to quantify like electricity, and soldering, so the final cost will be higher but the difference will be very small.

3.2 Schedule

Week	Jiahe Shi	Qianwei Li	Hanfei Wang
10/01/2018	Read data sheet of the microprocessor and design the circuit for microprocessor.	Read data sheet of the bluetooth module and design the circuit for bluetooth.	Design the board block and inner circuit block.
10/08/2018	Finish and test version 1 software program used in the microprocessor.	Test and finalize Bluetooth Module functions.	Order parts; Finish and test version 1 sensor block design (schematics and layout).
10/15/2018	Refine, debug, and finalize the software program to improve performance and to lower cost.	Finish and test version 1 user interface.	Begin version 1 power supply design
10/22/2018	Test and finalize microcontroller functions.	Refine, debug, and finalize user interface to improve visual effect.	Test and finalize version 1 sensor block and power supply.
10/29/2018	Coordinate microcontroller with Bluetooth Module.	Coordinate microcontroller with Bluetooth Module.	Prototype version 2 sensor block and power supply.
11/05/2018	Integrate the MCU block with other blocks. Run unit and integrated test for all modules.	Integrate the MCU block with other blocks. Run unit and integrated test for all modules.	Test and finalize version 2 sensor block and power supply; Coordinate with MCU.

11/12/2018	Finalize all the coding and PCBs.	Finalize all the coding and PCBs.	Finalize all the coding and PCBs.
11/19/2018	Thanksgiving break.	Thanksgiving break.	Thanksgiving break.
11/26/2018	Finalize all testing of the project. Start preparation for presentation and final paper.	Finalize all testing of the project. Start preparation for presentation and final paper.	Finalize all testing of the project. Start preparation for presentation and final paper.
12/03/2018	Prepare demonstration and presentation; Keep working on final paper.	Prepare demonstration and presentation; Keep working on final paper.	Prepare demonstration and presentation; Keep working on final paper.
12/10/2018	Finish final paper.	Finish final paper.	Finish final paper.

Table 4. Schedule Plan

4. Discussion of Ethics and Safety

4.1 Ethics concerns

Considering ethical concerns, we will divide the discussion into three parts. As for the general ethical principles, we would abide strictly according to #1.2 and #1.3 of ACM Code of Ethics and Professional Conduct to avoid harm and stay honest and trustworthy during the design process. We would be clear on the qualifications and be honest with the limitation of our project [8]. Through the design process and presentation, we would address the advantages and disadvantages of our projects clearly. We would not try to hide mistakes or fabricate data in testing stages. Next, considering the professional responsibilities, we would attempt for highest quality on both the design process and final product of the project. We would be willing to seek and accept criticism, to understand, acknowledge and correct mistakes, and to credit properly to all contributors [9]. We would try for highest possible quality of our project and seek for criticism from TAs, instructors, team members and students in other groups. We would strive to fix all problems encountered during design process. Furthermore, professional leadership principles are also significant in our senior design project. As a group of three members, each of our group members would do the utmost to contribute to the progress of the project. We would look forward to and respect every member’s idea and strive to put thought into reality.

4.2 Safety Statement

Our project comes with some safety hazard which requires our attention. Lithium-ion cell becomes thermally unstable at 150°C, a condition that can lead to a thermal runaway in which flaming gases are vented [10]. The required charging temperature for our model is 0-45°C and the required discharging temperature is -20-60°C. For safety concern, we should ensure that with the designed circuit loaded onto the power system, batteries always operate inside safe temperature range.

As a circuit with 64 pressure sensors, the whole project can be malfunctioning with only one sensor out of order. And short pass of a single sensor may damage the circuit and cause safety hazard. We must ensure all sensors are connected properly with suitable voltages and current drawing. As we need to solder all sensors onto PCB by ourselves, we need to obey all safety requirements.

5. Reference

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