Automatic Ball Borrowing System

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Abstract

This paper will cover the design, testing, development, and integration of components to build an automatic ball borrowing system. This system can store multiple balls inside the machine. If a valid ID is shown, the system will be able to lend exactly one ball out. In addition, it also allows the balls to be returned back to the machine. Two IR sensors are used in the project to check whether the item returned has the same size as a ball. The system also includes an alarm, which will be turned on if invalid ID is shown or something other than balls are put into the machine.

Contents

1 Introduction

1.1 Objective

At the Activity and Recreation Center(ARC) of our university, sometimes one have to wait for a long line to borrow balls, for example, basketballs, from the staff, which is fairly time consuming. The university also need to spend money hiring people to handle the borrowing and returning of those balls. In addition, if one forget to bring their credentials, in this case, i-card, one is not able to borrow the balls. Finally, if one want to return the ball, sometimes there is long line to get to the staff.

Thus we decide to build an automatic ball borrowing system to help both the students and the university. For demonstration purposes, we will build our system around borrowing and returning golf balls, which can be considered as the miniature version of larger balls, such as basketballs, volleyballs or soccer. Our system will be used to dispense golf balls and collect balls from a person. It will display the prompts and feedbacks on an LCD screen. We provide a keypad for a human being to choose whether he/she wants to return or borrow a ball. If he/she wants to borrow the ball, he/she can scan his/her RFID tag to borrow the golf balls, assuming the RFID tag information is in the system. Also, he/she can use the keypad to type in his/her UIN to get the balls if he/she forgets to bring RFID tag. When a user wish to return a ball that he/she previously borrowed, he/she must provide his/her RFID tag or type in his/her UIN. Then the machine will check the size of the ball after it is put into the machine to determine whether it is a golf ball and not something else. If the size does not match a golf ball, the alarms will be turned on.

1.2 High-Level Requirement

The system can use LCD display to print prompts and feedbacks. Then the user can follow the instructions to borrow or return the ball.

The machine can get users' information through keypad or RFID reader. Then the system can check if the users' ID is valid or not. If the ID is invalid, the alarm will be turned on.

After using valid RFID tag or ID number, the user can get one ball from the container, if there is any balls left. If there is not enough balls in the container, the system should print an error message on the LCD.

The user can also use valid RFID tag or ID number to return the ball. If wrong item is returned, the alarm will be turned on, and the system will be locked until the staff use their RFID ID to unlock the machine.

1.3 Block Diagram

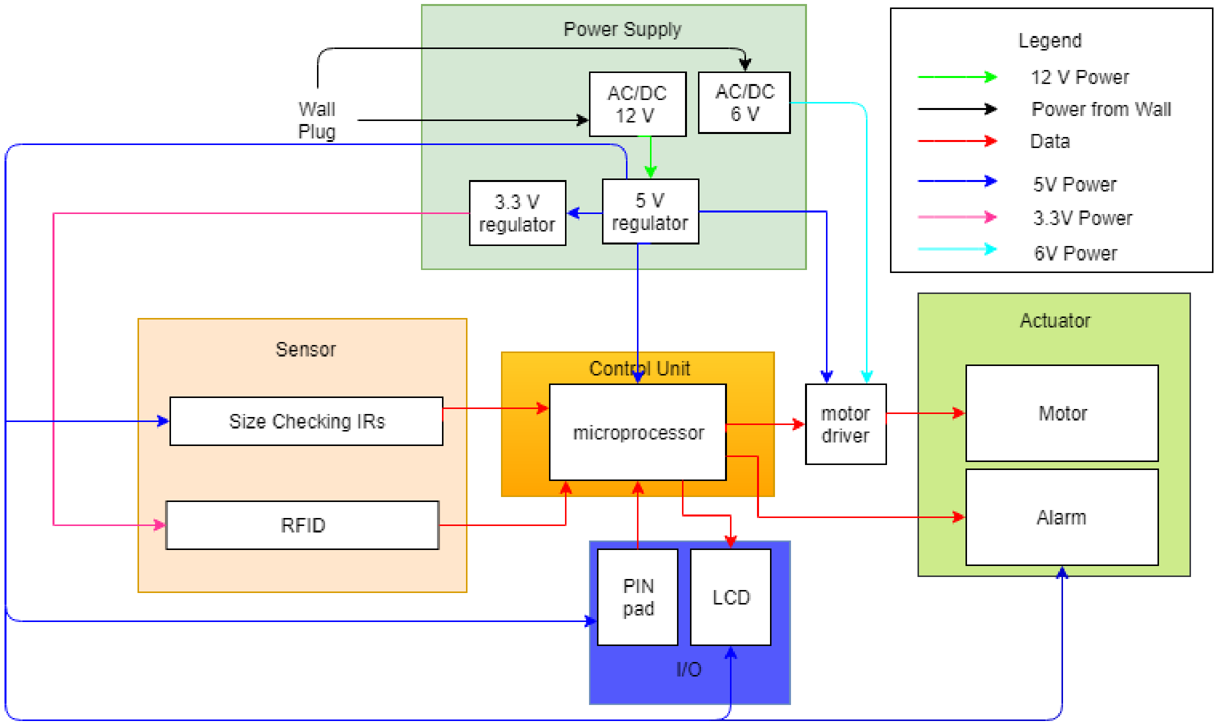

Figure 1: Block Diagram

The power supply module will supply the power for the system. Then sensor module will be used to detect information to help the microprocessor control the system. The I/O module will be used to interact with the users. The control unit module will collect the data from other module, and control the actuator to meet the high requirements.

The power supply will get power from a wall plug. Then it will use two AC/DC adapters to get the 12 V DC and 6 V DC power. Then the 12 V DC power will be sent to two regulators, which will produce two different voltages for different parts of the system. The 5 V will be used to supply power for microcontroller, IR sensors, keypad, LCD screen, alarm, and motor driver. The 3.3 V will be used to supply power RFID reader. The 6V will be used to supply power for motor. The sensors, RFID reader, and keypad will collect data, and send them to microprocessor. Finally, the microprocessor will use them to control the motor, LCD, and alarm.

2 Design

The whole design is divided into hardware and software. The hardware portion includes power supply module, the microcontroller, two input device, namely the keypad and the RFID reader, one output device, namely the LCD, an actuator with its driver, the IR sensors and the printed circuit board (PCB).

2.1 Power Supply

Based on the hardware components chosen, there are three different voltages in use. The microcontroller, the LCD and the IR sensors work under 5V. The RFID reader requires 3.3V. The motor and the motor driver use 6V. Since the power consumption within 5V and 3.3V is reasonably low, a 12V wall adapter is chosen as the source for 5V and 3.3V. The motor consumes much more power than the rest of the circuit, thus a 6V 2A wall adapter is selected just to power the motor.

The 12V 1A wall adapter convert 110V AC from the wall outlet to 12V DC. A common 5V linear voltage regulator, L7805, is used for the delivery of a regulated 5V voltage source given the 12V DC from the output of the wall adapter. There are two capacitors at the input and the output of the regulator to stabilize the input and output voltage. The 5V and 3.3V regulator circuits are shown in figur 2 and figure 3, respectively. These circuits are designed according to their data sheet[1][2].

The 6V 2A wall adapter directly feed the 6V into the motor driver module because there is already a powerful voltage regulator circuit on the motor driver module that can handle the current usage of the motor.

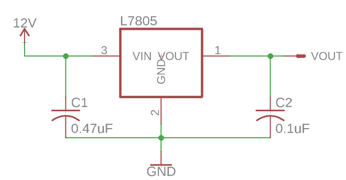

Figure 2: 5V Regulator circuit schematic

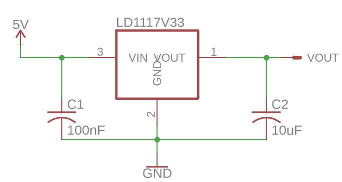

Figure 3: 3.3V Regulator circuit schematic

2.2 Microcontroller

Based on the hardware components chosen, five eight-pin general purpose input/output (GPIO) ports are required to connect all the desired components to the microcontroller to satisfy all the functionality of the whole design. The keypad requires a seven-pin connection within the same port to the microcontroller, the RFID requires a five-pin within the same port connection, the LCD requires a seven-pin connection within the same port, the motor driver requires a three-pin connection and each IR sensor requires one pin. Then the smallest simple microcontroller that have more than five eight-pin GPIO port is a 64-pin ATmega128.[3]

If the component requires less GPIO pins, for example, the keypad could only use up to four pin, then a microcontroller with less GPIO port is also a valid candidate.

2.3 I/O

To satisfy the human/machine interaction for the design, two input device and one output device is used. First, human input must be recorded, so a keypad can fulfill this purpose. Second, for the design, there should be two different ID checking methods, so a RFID reader is chosen. Third, the machine needs to provide prompts and feedback based on inputs, a simple LCD is used for this goal.

2.3.1 LCD

To display prompts and feedback, any display that can show multiple characters is valid. A 16x2 LCD is used for this design. As an alternative, a larger display that can show more characters at the same time can serve the display purpose better. The LCD sub circuit is shown in figure 3, per datasheet [6].

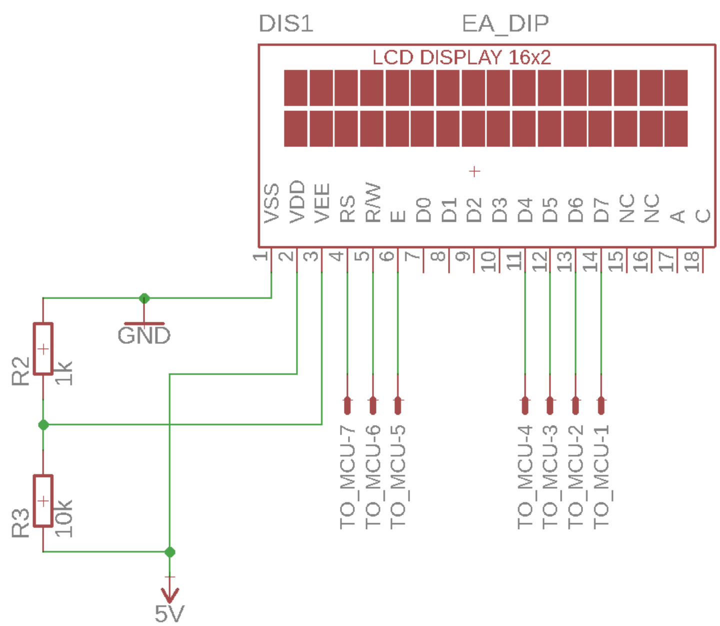

Figure 4: LCD display circuit

2.3.2 Keypad

The keypad can record the human input, such as what action to perform and what ID checking method to use, as well as checking ID based on the number a human provides.

A basic 12-key keypad is picked for simplicity. The keys are 0 to 9 with * and #.

2.3.3 RFID Reader

The RFID reader is used as a method for ID checking. It can read a unique binary string of a RFID tag or a RFID card. As alternatives, either an NFC reader or a magnetic card reader can accomplish the same functionality as the RFID reader. RFID method is chosen because of its relative small size. The connection for RDIF-RC522 module is shown in figure 4, per tutorial [8].

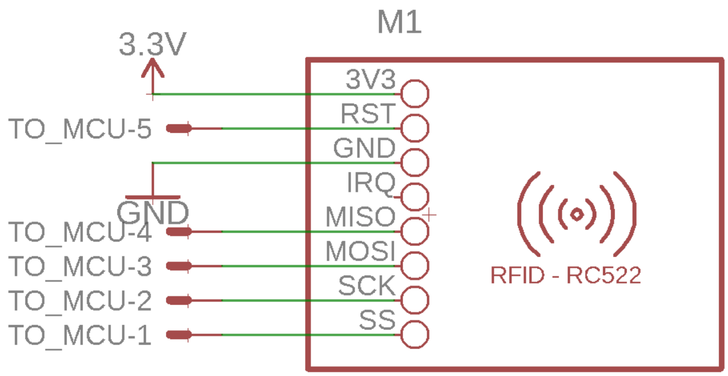

Figure 5: RFID Reader

2.4 Actuator

2.4.1 Motor

To turn the cylinder so that the balls inside the storage tube can be moved out, a motor needs to provide enough stall torque. The angular speed of the cylinder should not be too much. Also, to precisely control the motor, a motor encoder can monitor the rotation of the motor shaft. Therefore, an 18.75:1 gearmotor with encoder is chosen under the recommendation from the machine shop. With the 6V 2A wall adapter, it can provide a maximum of 33.6 oz-in stall torque.[10]

2.4.2 Motor Driver

To control the motor, a motor driver module based on VNH5019 suits the needs of the design perfectly. For the control side, it can work with 5V systems. For the power side, it can handle 12A continuous output current and 30A maximum, meaning that it is more than capable of handling the turning of cylinder. [11] It takes in a PWM control signal and output a corresponding PWM signal to control the motor speed.

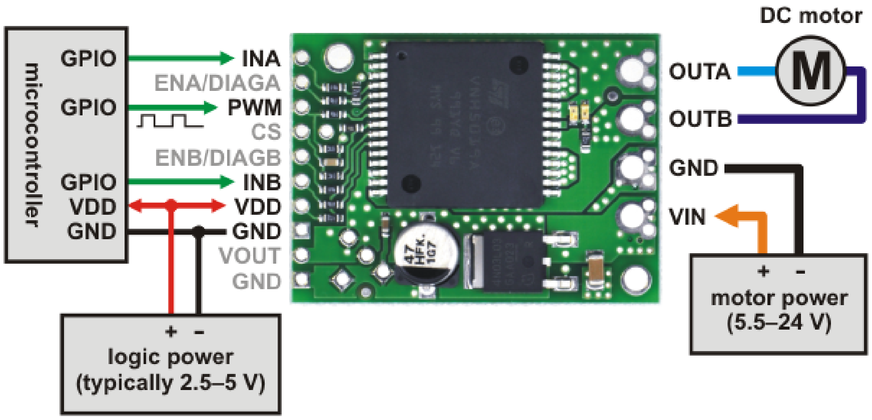

Figure 6: Minimal wiring diagram for connecting a microcontroller to a VNH5019 motor driver carrier [11]

2.5 IR Sensor

For verifying the returned object, two IR sensor is used for checking the size of the returned object. The QRE1113 IR sensor is able to detect a distance from 2mm to 20mm [9].

2.6 Circuit Board

The integration of all the hardware components is done within the printed circuit board (PCB) designed by the team. It contains all the power supply sub circuits, the crystal circuit needed for the microcontroller, and all the pin connection to the offboard hardware components.

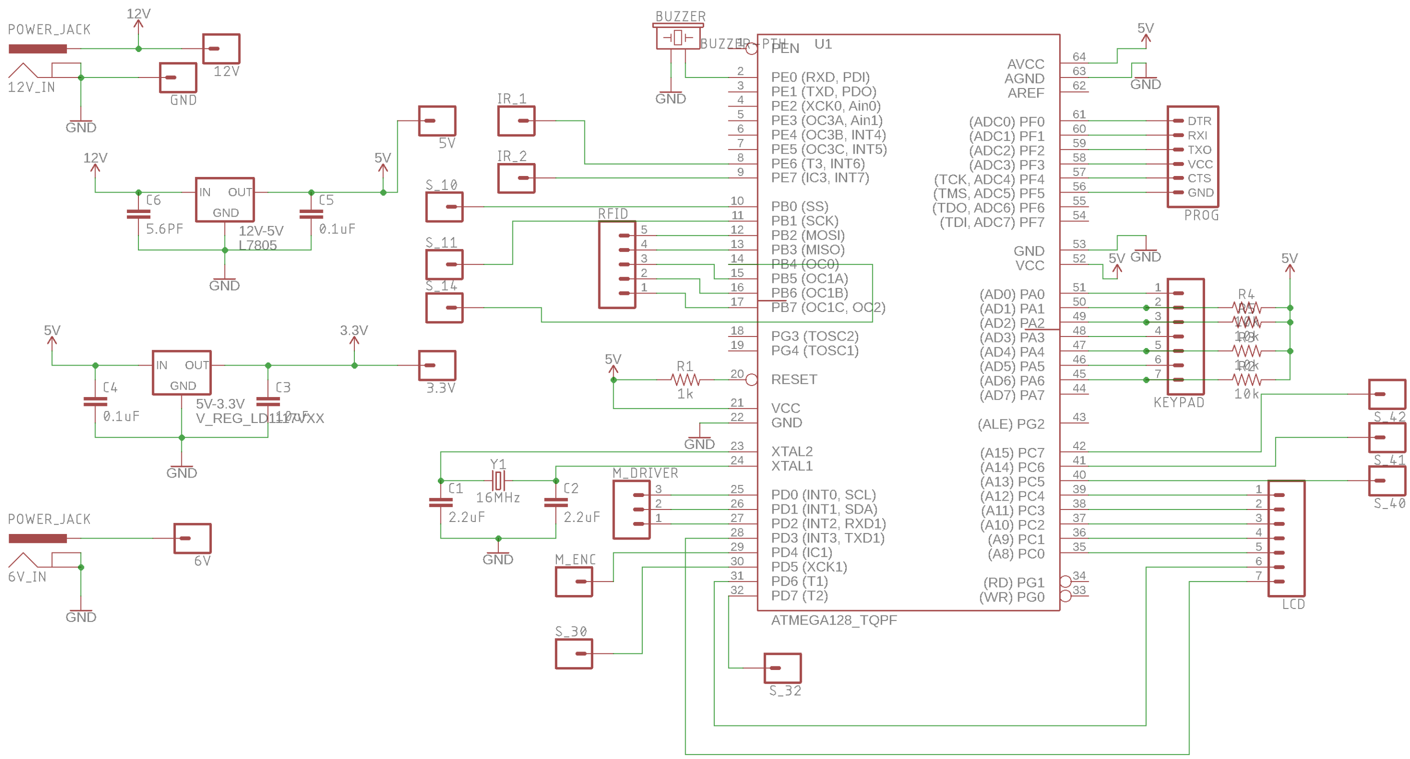

Figure 7: Circuit Board

2.7 Software

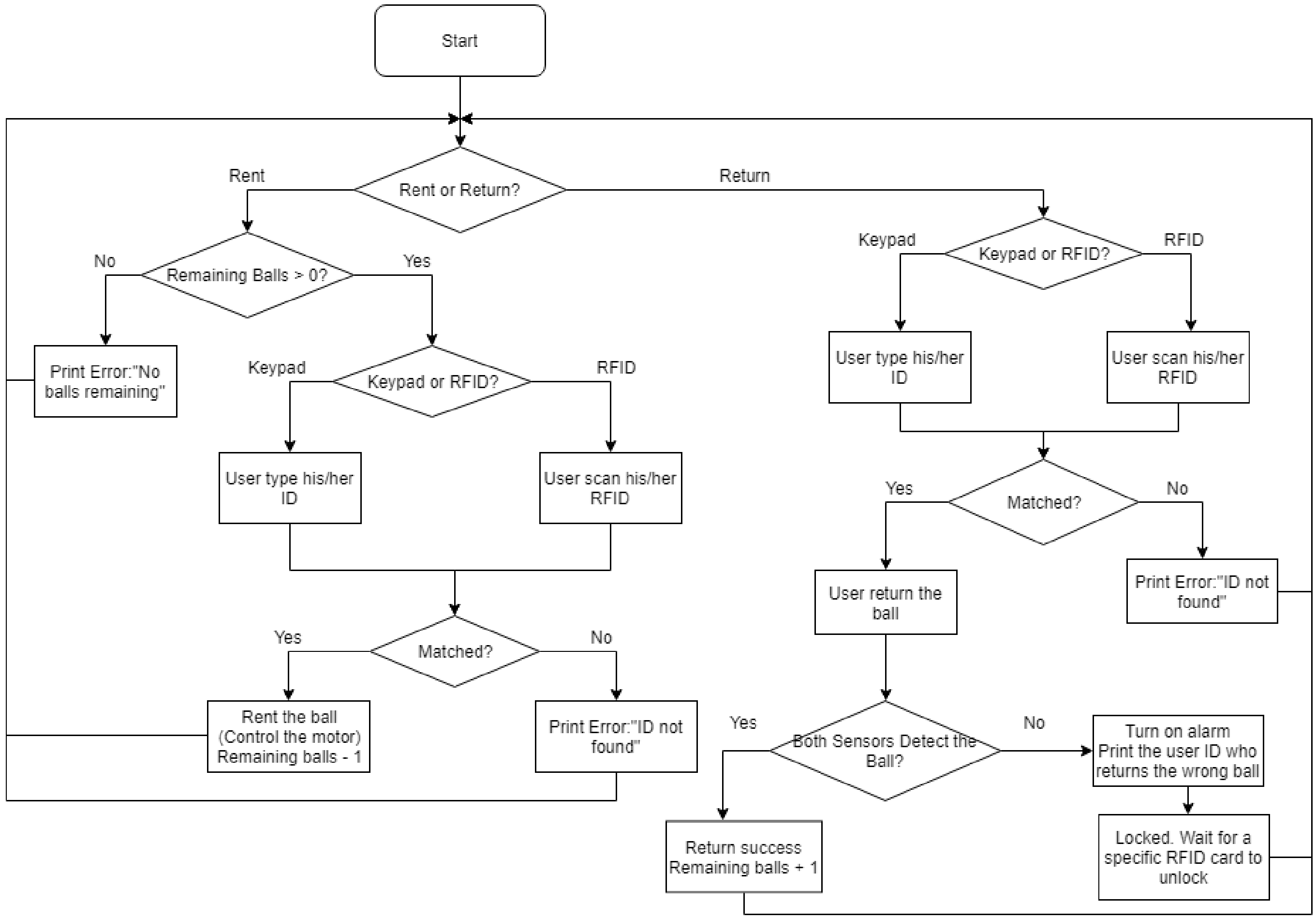

Figure 8: Software Flowchart

After starting the machine, the system will ask whether to return or to borrow a ball. If the user decides to borrow a ball, the system will check if there is any ball remaining inside the machine. If not, the system will stops renting. Otherwise, the system will ask the user to choose the method (RFID or type ID using keypad) to borrow the ball. After choosing the method, the system will read the ID and check if the ID is valid. If the ID is valid, the ball will be rented. If the user decides to return the ball, they will also choose the method to return the ball. Then the system will check if the ID is valid. If the ID is valid, it will allow the user to return the ball. After the ball is returned, the system will check the size of the ball. If the size does not match, the alarm will be turned on and the system will be locked until staff use their special RFID card to unlock the system.

3 Design Verification

3.1 Power Supply

To verify the LD1117V33, 3.3V voltage regulator, a voltage sweep from 3V to 7V is performed. Similarly, to verify the L7805, 5V voltage regulator, a voltage sweep from 5V to 13V is performed.

Table 1: Regulator Test Results

Input Voltage(V)	LD1117V33	L7805
3	2.172	
4	3.146	
5	3.297	4.176
6	3.298	5.0207
7	3.298	5.0244
8		5.0245
9		5.0245
10		5.0245
11		5.0245
12		5.0246
13		5.0246

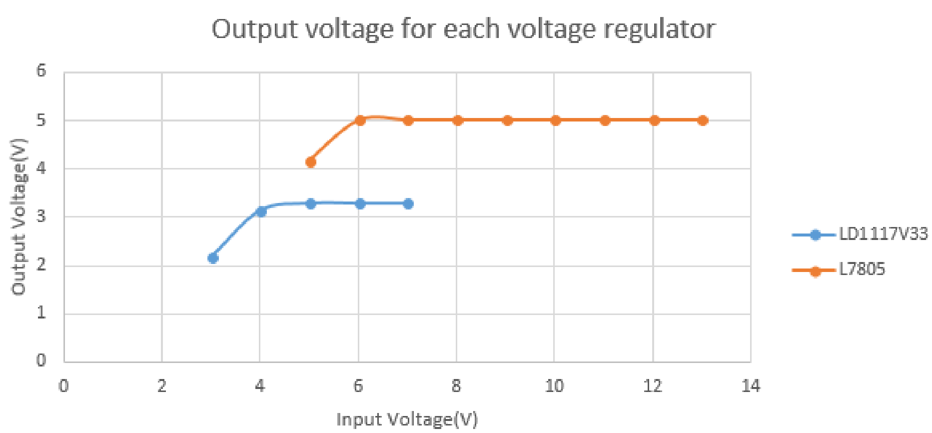

Figure 9: Regulator Input VS. Output plot

3.2 I/O

3.2.1 LCD

To test the desired functionality of the LCD, the following code is used to show a string of Hello World. The library used for LCD is from tutorial[7].

```
//LCD
LCD_Init(4,2,16);
LCD_printf("Hello World");
```

Figure 10: Test code for LCD

3.2.2 Keypad

To test the correct reading from the keypad, the following code can display the keypress to the LCD. If nothing is pressed, val should be 20. The code used for Keypad is written according to the keypad data sheet [4] and tutorial [5].

```
//Keypad
while (1){
        int val = GetKeyPressed();
        if (val != 20)
                LCD_printf("%d",val);

}
```

Figure 11: Test code for keypad

During the testing, *, 0 and # keys could not be read because one of the seven pins of the keypad loses electrical connectivity due to bad construction of the keypad PCB.

3.2.3 RFID Reader

To test the functionality of the RFID reader, the following code can display the RFID binary string in hexadecimal format to the LCD. The RFID tag is read as 07 5d 4d 79 6e aa 4c c4, and the RFID card is read as f9 77 5d 2b f8 aa 4c c4. The library used for RFID reader is from the RFID tutorial[8].

```
//RFID
uint8_t byte;
int i;
spi_init();
mfrc522_init();
byte = mfrc522_read(VersionReg);
byte = mfrc522_read(ComIEnReg);
mfrc522_write(ComIEnReg,byte|0x20);
byte = mfrc522_read(DivIEnReg);
mfrc522_write(DivIEnReg,byte|0x80);
while (1){
        byte = mfrc522_request(PICC_REQALL,str);
        if(byte == CARD_FOUND)
        {
                byte = mfrc522_get_card_serial(str);
                if(byte == CARD_FOUND)
                {
                        for (i = 0; i < byte; i++){
                        LCD_printf("%x",str[i]);
                        }
                }
        }

}
```

Figure 12: Test code for RFID Reader

3.3 Motor

To test the motor along with the motor driver, the circuit was connected per figure (motor driver circuit). A test to find the PWM duty cycle to provide enough stall torque to turn the cylinder with various balls inside the machine is performed. The result is shown below.

Table 2: Motor Test Results

Number of balls	Duty cycle
0	17%
1	17%
2	17%
3	18%

3.4 IR

For testing the IR sensor, an Arduino Uno was used to record the readings. A golf ball was placed in front of the IR sensor with a distance sweep from 2mm to 30mm. The resulting distance vs. reading chart is shown below.

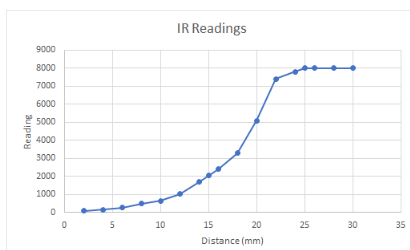

Figure 13: Plot of IR Test Results

3.5 Software

Since the software verification needs all the individual components integrated into the machine and the PCB, it also serves as the whole design verification.

Given different test vectors, the following functionality is achieved:
1.Not allow returning a ball if the storage is full.
2.Not allow borrowing a ball if the storage is empty.
3.The software can recognize different RFID signature
4.The software can recognize keypad input with debouncing.
5.The software can control the motor to turn the cylinder 90 degrees.
6.The software can correctly decide when to turn the cylinder 180 degrees.
7.The software can fully perform the flowchart specified in figure 8.

4 Cost and Schedule

4.1 Parts

Table 3: Parts Costs

Part	**Seller**	**Quantity**	**Total Price ($)**
RC522 RFID Reader	Amazon	1	7.98
COM-08653 ROHS Keypad	Sparkfun	1	3.95
LCD-00255 LCD Screen	Sparkfun	1	13.95
Alarm	ECE shop	1	1.95
ATMega 128 MCU	Microchip	1	11.50
37Dx68L Motor	Pololu	1	39.95
VNH5019 Motor Driver	Pololu	1	24.95
QRE1113 IR Sensors	Sparkfun	3	5.85
LD1117V33 Regulator	Sparkfun	1	1.95
L7805 Regulator	Sparkfun	1	0.95
12V DC Adapter	Sparkfun	1	5.95
16 MHz crystal	Sparkfun	1	0.95
SMD Resistors and Capacitors	DigiKey	1	8.95
6V DC Adapter	Sparkfun	1	4.95
Total			133.78

4.2 Labor

The design and implementation cost of each person in our three people group is estimated to be $30/hour, 10 hours/week. We have around 8 total weeks to finish this project. Thus the total development labor cost is:

$$3 \cdot \frac{\$30}{hour} \cdot \frac{10 \quad hours}{week} \cdot 8 \quad weeks = \$7,200 \tag{1}$$

4.3 Total Cost

The total cost will be sum of the labor cost and components cost:

$$\$7,200 + \$133.78 = \$7333.78 \tag{2}$$

4.4 Schedule

Table 4: Schedule

Week (Monday)	Jingyang Liu	Qihao Wang	Yang Xiao
2/26	Finalize physical design	Start writing software framework	Search for electrical components for project
3/05	Design the first version PCB	Writing a simulation program to test the software framework	Order electrical components
3/12	Finalize the first version PCB	Test voltage regulators, crystal, and UV sensors	Test the functionality of UV sensors
3/19 (Spring break)			
3/26	Finish the final version PCB	Test RFID reader, IR sensors, and keypad with Arduino	
4/02	Test the LCD screen, motor driver, motor, and motor encoder with Arduino	Test the LCD screen, motor driver, motor, and motor encoder with Arduino	
4/09	Soldering all the components	Write the final C code for the project	
4/16	Integrate all the components, and test the entire project	Integrate all the components, and test the entire project	
4/23	Summarize the hardware components of the project. Write the final report	Summarize the software components of the project. Write the final report	

5 Conclusion

5.1 Accomplishments

The LCD screen can print the prompts and feedbacks successfully. If a valid RFID is scanned, or a valid ID number is typed through keypad, the system can successfully dispense exactly one golf ball by controlling the motor. In addition, the system can handle various edge cases when the user want to borrow one ball. If there is nothing inside the machine, user cannot borrow any ball. The system also keeps track of the status of the wheels to determine the rotation degrees needed to dispense exactly one ball. The system will allow the user to return the ball if a valid RFID is scanned, or a valid ID number is typed through keypad. If the container is full, the user cannot return the ball. If invalid ID is shown, the alarm will be on for 1 seconds. If wrong item is returned, the alarm will also be turned on, and the system will be locked. A special RFID card is required to turn off the alarm and unlock the system.

Although our IR sensor can detect the ball, it fails to check the size of returned item. Since our program cannot run in parallel, it cannot read the values of both IR sensors at the same time. As a result, if the system detects the ball, and then try to read the value from the other IR sensor, the ball has already gone into the container. Low sampling rate leads to this issue.

5.2 Uncertainties

The LCD screen only has 2 rows, and each row can only display 16 characters. As a result, the system can only display a limited amount of information. Thus some additional features, like displaying the number of balls inside the container, are not possible.

Although the duty cycle (18%) used to run the motor is enough ideally, sometimes additional power is needed because the ball may be struck near the intersection between the container and the cylinder.

The IR sensors cannot be used to check the size of the ball because the system cannot read the values from both sensors at the same time. In order to solve the issue, the two sensors should be separated a distance of d. To calculate d, the sampling rate f should be found. Also, the velocity of the ball should be known as well. If the initial velocity is 0, then the acceleration should be

$$a = g * cos(52^o) = 6.0m/s^2 = 600cm/s^2 \tag{3}$$

If one of the sensor is placed 12 cm away from the entrance of the tube, and the sampling rate is 30 Hz, then the second sensor should be placed at d cm away from the first sensor, where

$$d = a\sqrt{\frac{12}{\frac{1}{2}a}}\frac{1}{f} + \frac{1}{2}\frac{a}{f^2} = \frac{120f + 300}{f^2} = \frac{39}{9} = 4.33cm \tag{4}$$

Since the initial velocity may not be zero, the distance should be higher.

5.3 Ethical considerations

Since our machine is an automated system, the main safety concern when using the machine are the moving parts. Peoples hands or clothing could get stuck in the machine if people try to access the inside of the machine. In our design, we keep the moving parts of the project to the minimum, only one motor should be used and we will build in safety protocols based on the sensors in the machine to uphold the IEEE Code of Ethics, # 1: to hold paramount the safety, health, and welfare of the public.[12]

When working with power supply units, and other electronics, components could carry an excessive amount of current which may lead to harmful situation. When working inside the lab, it is critical to follow the safety guideline and remember the lab safety training.

According to IEEE Code of Ethics # 8, our product will target on all users and treat fairly all persons and to not engage in acts of discrimination based on race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression [12].

During the process of making the project, we may collect wrong data or some unexpected results. We will not make up data or results on our reports. We will follow IEEE ethics that we will treat wrong data and results honestly [12]. We will honestly report the actual data and analyse which part we do wrong. Then, we will correct errors.

Since our project has many electric parts, it is possible to have some risks of exploding if we did some steps wrong. So, when we do electrical parts, we will make sure no other people around to ensure we dont injure other people. We also follow the safety guidelines, for example, never let current to excess safety current limits [13], when dealing with any electrical component to prevent risks. If we need to handle the high voltage, we will report our action and complete additional training.

We will treat our project professionally and strive to make higher quality of our product. This is to not only improve the quality of our project, but also make sure we are safe when making the project. We promise that we will not do the project individually in the lab. We will always make sure at least two people deal with the project at lab.

5.4 Future work

The system can store how many balls each user has already borrowed. Also, the users can borrow multiple balls at the same time by entering the amount of balls they want to borrow through keypad.

A larger LCD screen can also be used to provide more information for the users. Multiple LCD screens can also be an alternative.

Since the system cannot read the two IR sensors at the same, the two sensors can be placed at two different locations, or sensors with higher sampling rate can be used. Also, using two separate microprocessors can only be a possible solution. With two microprocessors, the two sensors can be sampled at the same time.

Finally, the system can be used for other balls, like basketball, if the size of the container, cylinder, and the placement of IR sensors are adjusted properly.

References

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Appendix A Requirement and Verification Table

Table 5: System Requirements and Verifications

Requirement	Verification	Point	Verification status (Y or N)
1. AC/DC Adapter (a) It should convert 110V AC to $12V \pm 1V$ DC	1. **Equipment:** 110 V Wall Adapter, Oscilloscope, wire-to-BNC cable **Procedure:** (a) Connect the adapter to the wall outlet. (b) Connect to barrel plug to the power jack. (c) Connect the wire end of the wire-to-BNC cable to the two pins on the power jack (d) Connect the BNC end of the wire-to-BNC cable to the bench oscilloscope (e) Read the oscilloscope to determine the average voltage and amplitude of the ripple **Expected Results:** The average voltage should be around 12V and the amplitude of the ripple should be less than $\pm 1V$	6	Y
2. 3.3 V Voltage Regulator (a) It should take 5 - 7 V as input voltage and 3.3V as output to the circuit. The range is 3.2 V to 3.4V.	2. **Equipment:** Oscilloscope, wire-to-BNC cable, DC Power Supply **Procedure:** (a) Connect the 3.3 V regulator to the circuit. (b) Connect the DC Power Supply to the input of regulator. (c) Connect the output of regulator to Oscilloscope using wire-to-BNC cable. (d) Sweep the input voltage from 5 to 7 V. (e) Check whether the output voltage is between 3.2 V and 3.4 V. **Expected Results:** The voltage is around 3.3V and the deviance is $\pm 0.1V$	5	Y

Continued on next page

Table 5 – continued from previous page

Requirement	Verification	Point	Verification status (Y or N)
3. 5 V Voltage Regulator (a) It should take 7 - 12 V as input voltage and 5 V as output to the circuit. The range is 4.5 V to 5.5 V.	3. **Equipment:** Oscilloscope, wire-to-BNC cable, DC Power Supply **Procedure:** (a) Connect the 5 V regulator to the circuit. (b) Connect the DC Power Supply to the input of regulator. (c) Connect the output of regulator to Oscilloscope using wire-to-BNC cable. (d) Sweep the input voltage from 7 to 12 V. (e) Check whether the output voltage is between 4.5 V and 5.5 V. **Expected Results:** The voltage is around 5 V and the deviance is $\pm 0.5V$	5	Y
4. ATMega 128 (a) The microcontroller has at least 31 I/O pins that can be controlled by program. (b) The microcontroller can successfully distinguish high digital value from low digital value. If the input voltage is between 0 0.2 V, the microcontroller should consider input as low. If the input voltage is above 3 V, the microcontroller	4. **Equipment:** AVR Pocket Programmer, breadboard, wire, LED, bench power supply **Procedure:** (a) Connect all the required I/O pins to LED. (b) Write a simple program to make the LED blink. (c) Use bench power supply to supply power to the circuit. (d) Upload the program to the microcontroller using AVR Pocket Programmer. (e) Observe the LED to see if it blinks. **Expected Results:** The number of I/O pins are larger than 31 and the LED blinks. 5. **Equipment:** AVR Pocket Programmer, breadboard, wire, LED, bench power supply **Procedure:** (a) Use bench power supply to supply power to the circuit. (b) Connect one LED to one of the I/O pins. (c) Connect the bench power supply to one of the I/O pins as input. (d) Write a program that will turn on the LED if the input value is high. (e) Upload the program to the microcontroller using AVR Pocket Programmer. (f) Observe the LED as we change the input voltage from 0V to 5V. **Expected Results:** The LED should be off at first. Then the LED should be on when the voltage is higher than 3V.	11	Y

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Requirement	Verification	Point	Verification status (Y or N)
5. Crystal (a) The crystal can generate 16 MHz clock signal for the microcontroller. The range of the frequency is 15.6 MHz to 16.4 MHz.	5. **Equipment:** breadboard, capacitor, wire, oscilloscope, wire-to-BNC cable, bench power supply. **Procedure:** (a) Connect the crystal to the breadboard. (b) Use bench power supply to power the circuit. (c) Use capacitor to connect the crystal to the ground. (d) Connect the two ends of the crystal to an oscilloscope. (e) Check the frequency of the signal from the oscilloscope. **Expected Results:** The output signal should be a square wave with a frequency between 15.6 MHz and 16.4 MHz. $\pm 0.1V$	5	Y
6. Keypad (a) All 12 input keys can generate different outputs. Since exactly two output pins of the keypad will be low if any button is pressed, then the pairs of output pins that are low should be different for different buttons.	6. **Equipment:** Multimeter, breadboard, wire, bench power supply. **Procedure:** (a) Connect the keypad to breadboard. (b) Use bench power supply to supply power to the circuit. (c) Connect all the output pins to the breadboard. (d) Connect the multimeter to each output pin. (e) Press each button and record the output of each pin. (f) Check whether all 12 presses lead to 12 different outputs. **Expected Results:** All 12 keys lead to different records.	10	Y
7. LCD Display (a) Can display all 26 letters and number from 0 to 9.	7. **Equipment:** Microcontroller. **Procedure:** (a) Connect LCD per circuit diagram of the MCU. (b) Write a program that includes LCD library and initializes LCD. (c) Use LcdPrintf() function to print all 26 letters and number from 0 to 9. (d) Verify if the LCD can display those char/string correctly. **Expected Results:** The LCD can display those char/string correctly.	7	Y

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Table 5 – continued from previous page

Requirement	Verification	Point	Verification status (Y or N)
7. IR Sensor (a) The IR sensor can detect the item placed in 5 mm from the IR sensor.	7. **Equipment:** Arduino, wire, golf ball. **Procedure:** (a) Connect IR sensors to Arduino. (b) Write a program that initialize the IR sensor. (c) Print the value read by IR sensor on monitor. (d) Record the value read by IR sensor when nothing is placed in front of the sensor. (e) Place the golf ball in 5 mm from the IR sensor, and record the value read by IR sensor. (f) Compare the recorded value. **Expected Results:** The value read when there is a golf ball should not exceed half of the value read when there is nothing placed in front of the sensor.	10	Y
8. Motor (a) The motor can provide enough torque to rotate the turning wheel.	8. **Equipment:** Breadboard, wire, motor driver, bench power supply, motor, all the mechanical part of the machine **Procedure:** (a) Assemble the motor driver circuit on the breadboard. (b) Connect the outputs of the motor driver to the motor that is in the machine. (c) Use bench power supply to power the circuit. (d) Check that whether the motor can rotate the shaft along with the turning wheel with a ball inside. **Expected Results:** The turning wheel that contains one ball can be turned by 90 degrees in 5-10 seconds.	10	Y
9. Alarm (a) The alarm can make the sound loud enough for people away from 5 meters to hear.	9. **Equipment:** Breadboard, wire, bench power **Procedure:** (a) Connect the alarm to the breadboard. (b) Use bench power supply to power the circuit. (c) Check that whether we can hear the sound clearly. **Expected Results:** We can hear the sound clearly even if we are 10m away from the alarm.	5	Y

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Table 5 – continued from previous page

Requirement	Verification	Point	Verification status (Y or N)
10. RFID Reader (a) Can read RFID tags. (b) Different RFID tags will generate different signals	10. **Equipment:** Breadboard, wire, bench power supply, LCD, microcontroller **Procedure:** (a) Connect RFID reader to breadboard. (b) Write a program to read the RFID tags, and print the ID on the LCD screen. (c) Use bench power supply to power the circuit. (d) Put the RFID tag 30mm in front of the RFID reader. (e) Check that whether LCD screen shows the ID number in the tag. **Expected Results:** When we put RFID tags 30mm in front of the reader, the LCD screen shows corresponding student ID numbers. 11. **Equipment:** Breadboard, wire, bench power supply, LCD, microcontroller **Procedure:** (a) Connect RFID reader to breadboard. (b) Write a program to read the RFID tags, and print the ID on the LCD screen. (c) Use bench power supply to power the circuit. (d) Put one RFID tag 30mm in front of the RFID reader. (e) Put different RFID tags and other tags 30mm in front of the RFID reader. (f) Check whether LCD screen shows different ID numbers and whether LCD shows the ID number when we use other tags. **Expected Results:** Different ID numbers appeared on the LCD screen when different RFID tags shown in front of the reader. When we put other tags in front of the reader, nothing shown on the LCD screen.	19	Y
12. Motor Driver (a) The motor driver can control the motor and provide output current 300mA.	12. **Equipment:** Breadboard, wire, bench power supply, microcontroller, ampere meter **Procedure:** (a) Connect the motor driver to the breadboard with the motor. (b) Use bench power supply to power the circuit. (c) Use ampere meter to measure the output current from the motor driver. **Expected Results:** The ampere meter should show the current is in the range from 290mA to 310mA.	7	Y