ECE 445 Senior Design Lab Design Document: Automatic Bookshelf Item Retrieval

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1 Introduction

1.1 Problem

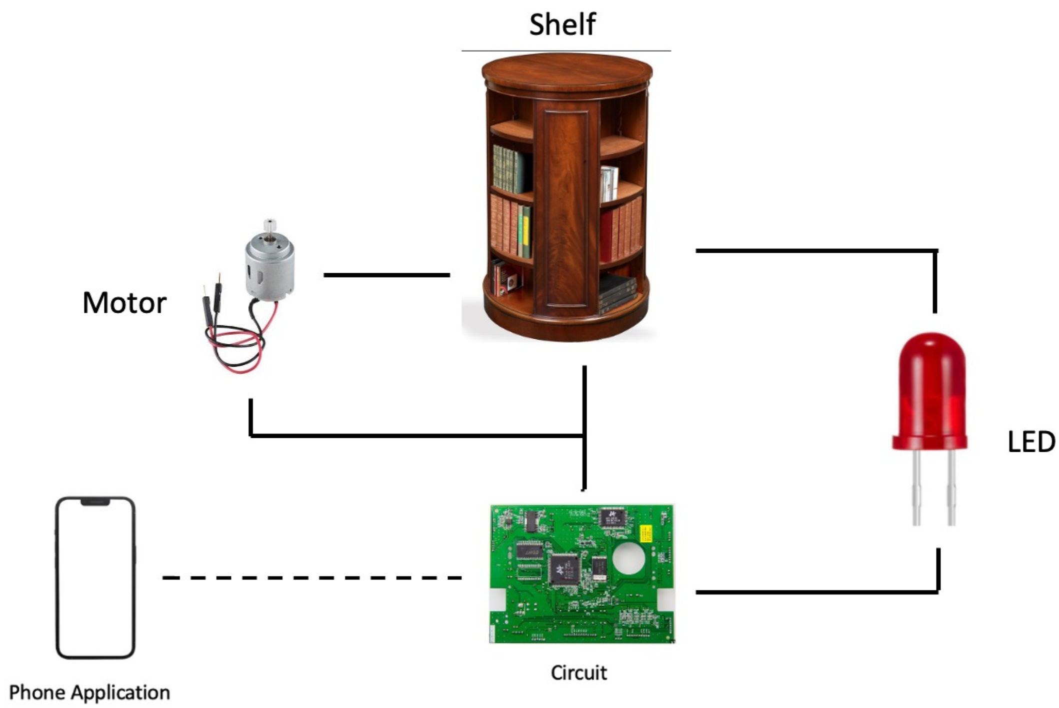
Oftentimes, when one has a lot of small electrical components, it can be very hard to keep track of everything. Components such as resistors and capacitors can be difficult to keep track of, especially when one has to keep track of many different components that look very similar. Things can get lost and disorganized very quickly. Something like a miniature bookshelf is what some use to organize their items, but they often can get very messy and it can be very tedious to find a specific item that one is looking for. It can also take a lot of time to find an item, and in general this is a bad user experience.

1.2 Solution

Our solution features a circular miniature bookshelf with 4 shelves. Each shelf contains one section to place items, and the entire bookshelf rotates using a motor at the base of the bookshelf. This bookshelf will aid the user in finding their items easier by keeping track of where an item is inserted. When inserting an item, the user will enter the shelf ID into the app in order to mark that shelf with the current item. They will also enter a description of the item they are inserting. On retrieval, the user will be able to look up the item on the app, which will result in the bookshelf rotating to the correct side and lighting up the shelf and specific location where that item is located. The app will then mark that item as having been removed from the bookshelf.

The setup will be as follows. There will be shelf IDs placed on each side of the bookshelf labeled with a unique number. When the user looks to retrieve an item, the app will first figure out which section the item is located. Then a stepper motor will rotate the bookshelf so the correct side face faces the user. Then, the LED will turn on to illuminate the object being retrieved through a hole in the base of the shelf. Insertion is much easier as all the user has to do is type in the shelf ID of the section they put the item in and give a name to the item. This information will be stored in the app's database.

1.3 Visual Aid



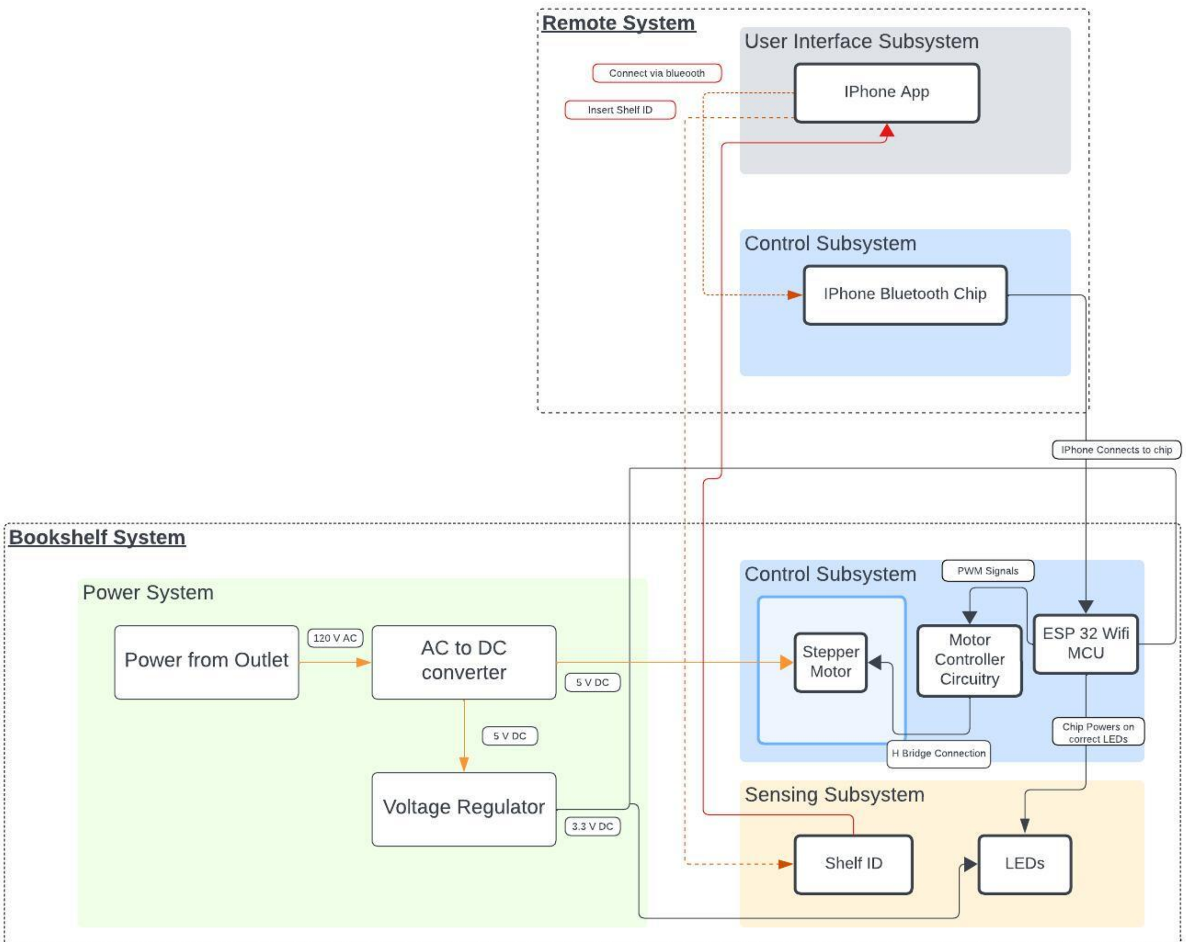
1.4 High Level Requirements

- Once prompted with the app, the bookshelf will turn to either angle 0, 90, 180, or 270 to face the user with the item that they requested to retrieve
- In the app, the user must be able to see 100% of the items they placed on the bookshelf (at least 8 items).
- Once the bookshelf has spun to the respective location based on what device the user is looking for, the LED will turn on within 15 seconds to illuminate that shelf.

2 Design

2.1 Block Diagram

- Remote System - Contains the User Interface Subsystem and Control Subsystem on the phone. The User Interface Subsystem is connected to the rest of the system through bluetooth.
- Bookshelf System - Contains the Control Subsystem, Sensing Subsystem, and Power Subsystem that will be present on the bookshelf itself.



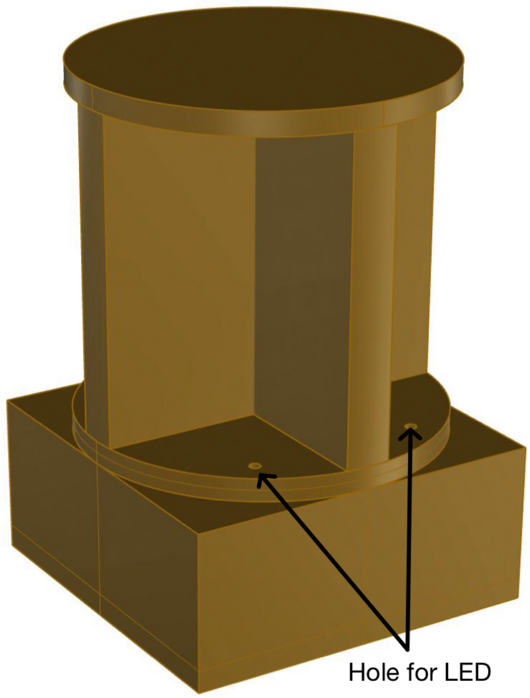


Figure 1: Front view of CAD representation of physical design.

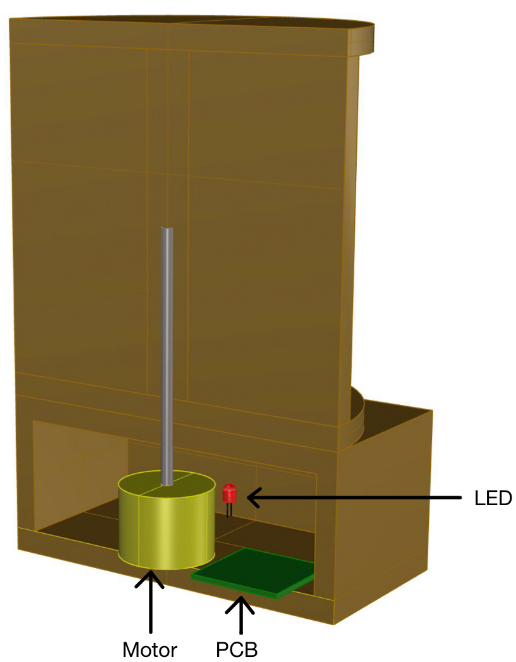


Figure 2: Section view of CAD representation of physical design

2.2 Subsystem Overview

User Interface Subsystem

- This subsystem is what allows the user to interact with our device. On a mobile app, the user will be able to add items to the bookshelf storage system, remove items from the system, and see what items are currently stored in the bookshelf.

Control Subsystem (on Remote System)

- This subsystem will allow the phone app to communicate with the PCB on the bookshelf system. It will use a bluetooth connection to send data between the Phone System and the Bookshelf System.

Control Subsystem (on Bookshelf System)

- This subsystem contains the microcontroller and motor. The microcontroller on the PCB will receive data from the remote system via a bluetooth connection. Based on this, the microcontroller will output the appropriate signals to the motor to turn it to the correct orientation.

Sensing Subsystem

- This subsystem contains the LED and shelf IDs, and in a way also acts as the main way the user interacts with the bookshelf system. The LED will alert the user to the exact shelf that their item is located, and the shelf ID allows them to input where they are placing the item to the system.

Power Subsystem

- This subsystem will contain the circuitry to convert the power to appropriate voltage levels. It will distribute the power to the motor, and all the components on the PCB such as the microcontroller.

2.3 Subsystem Requirements

Sensing Subsystem:

This subsystem contains shelf IDs that will be read by the iPhone app of the user interface subsystem. There will be 4 unique shelf IDs. When the user is storing an item, the shelf ID allows them to select the location of the item being placed. This way, when an item is being retrieved, the control subsystem is aware of where the item is. For this component to be considered working, it should be able to be inputted into the app and the correct shelf should be interpreted from that. When an item is being retrieved, the control subsystem will signal the LED to light up. This will allow the user to easily see where their stored item is. The LED should light up within ~15 seconds of an item being selected for retrieval, otherwise this subsystem would not be working as intended.

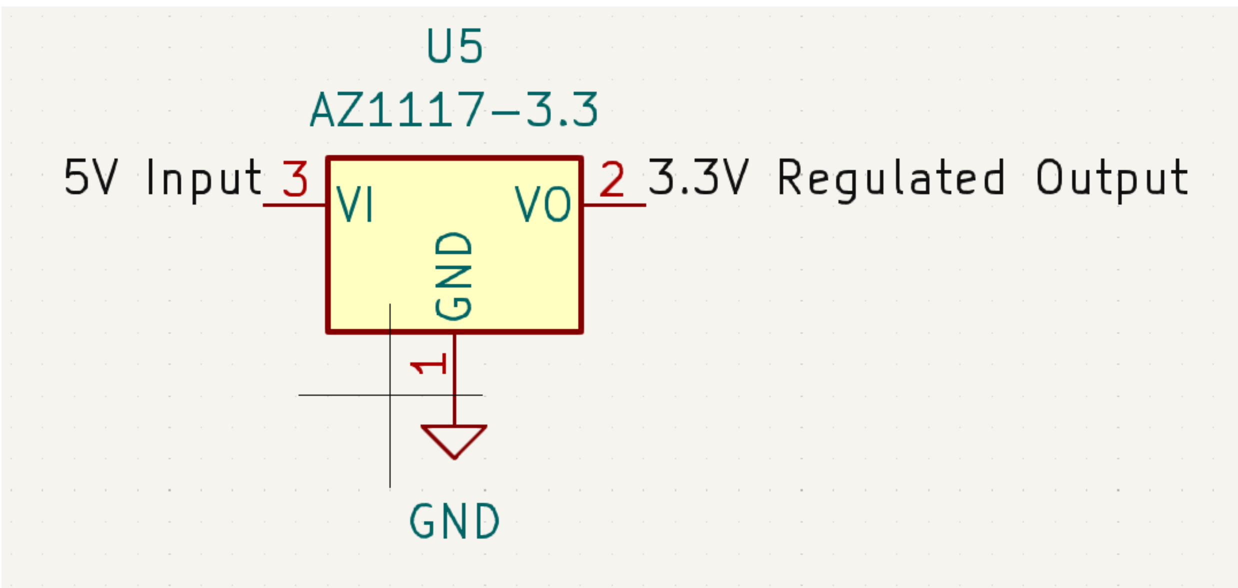
Requirements	Verification
● The shelf ID should be assigned to a specific storage space in the app	● Insert the shelf ID for 10 objects into the app ● Using the app, check the contents specific shelf ID ● Verify that only the items of that shelf are showing up under that shelf ID ● Repeat steps 2 and 3 for the other three shelves until all 10 objects have been verified in the correct location
● The LED should turn on only when the hole of the correct shelf is directly above it	● Insert the shelf ID for 10 objects into the app ● Using the app, retrieve one item in one of the shelves. ● After the motor rotates to the correct location, check the LED displacement from the hole that is above it ● If the LED is within +/- 1 cm when it turns on, the LED is in the proper location
● LED lights up within 15 seconds of retrieval	● Insert the shelf ID for 10 objects into the app ● Using the app, retrieve an item of choice. ● After the bookshelf rotates and comes to a stop, start a timer ● Stop the timer when the LED turns on ● Ensure that the timer reads less than 15 seconds ● Repeat steps 2-4 until the LED has been turned on within 15 seconds for each of the four shelves

Power Subsystem:

This system will be responsible for distributing power throughout the entire Bookshelf System. It will have 120V AC power as an input, and will output 3.3V DC power to the microcontroller and 5V to the motor. To test this subsystem, a test load can be chosen that draws a large amount of power. This amount of power should be higher than the peak draw of the Bookshelf System. If the power subsystem can output this power continuously, then it can be verified to be working, otherwise this subsystem does not meet the necessary requirements. It will be shown later that the peak current draw will be approximately 370 mA for 3.3V and 400 mA for the 5V circuit. A circuit schematic of the linear regulator component of the Power Subsystem is shown below. It consists of a 5V unregulated input that comes from the AC-DC converter, and outputs a 3.3V regulated signal that will be used by the microcontroller as well as parts of the motor controller circuit.

Requirements	Verification
• The system should be protected against overvoltage, overcurrent, undervoltage, and undercurrent.	• Connect to power and ensure all systems are attached to the bookshelf. • Solder wires to the power rail and ground. • Using a multimeter, measure voltage, current, and resistance and connect the probes to the power and ground wires to check that all their values are within their allowed range.
• The Power Subsystem must be able to supply at least 400mA to the rest of the system continuously at 5V ±0.1V and at 350 mA 3.3V ±0.1V.	• Connect to power and ensure all systems are attached to the bookshelf. • Solder wires to the power rail and ground. • Connect the multimeter to the probes to measure the voltage of the device of a multimeter to ensure it is 5V ±0.1V and 3.3V ±0.1V after the step down. • Measure the current by connecting a

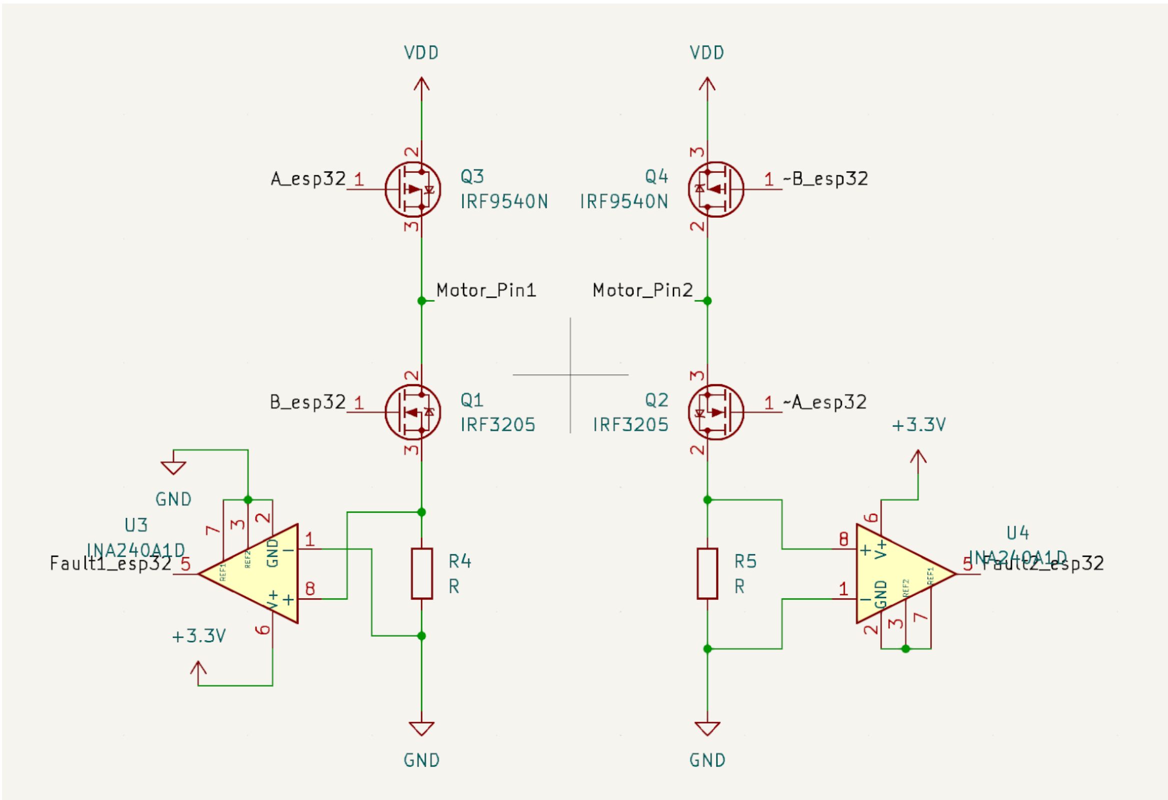
	resistor to the power supply and placing the probes of the multimeter on either side of the resistor ● Check to make sure that the current is greater than or equal to 400mA/350mA



Control Subsystem (Bookshelf System):

The control subsystem contains most of the logic of the bookshelf system. It contains the ESP32 microcontroller, as well as the motor and motor controller circuit. The ESP32 will receive data from the phone system through the inbuilt bluetooth capabilities of the microcontroller. Based on this, the microcontroller will send signals to the motor controller to rotate the motor the correct amount and direction. Some ways of verifying this subsystem is working correctly include verifying that the bookshelf stops within +/- 10 degrees of the correct orientation. There are also end to end tests that can be conducted. This includes inputting a retrieval request on the app, and confirming that the bookshelf aligns itself correctly. While this test relies on another subsystem, it is the best way to test the overall capabilities of the control subsystem. The image shown below is a part of the motor controller circuitry that we will implement. It consists of an H-Bridge circuit with overcurrent detection. In the image, 1 H-Bridge is shown, but the control subsystem will have 2 of these H-Bridges in order to drive the motor. Each H-Bridge will connect to a phase of the motor. These H-Bridges will be controlled by PWM signals outputted by the ESP-32. An important consideration to be made in the design of this circuit is the concept of dead-time. Because of the switching time of transistors, it may be possible for 2 transistors on the same side of the H-Bridge to turn on. This would effectively short the power supply to ground and would result in a dangerous current which could be a fire hazard. To stop this from happening, the PWM signals will be outputted with dead time. This is a gap in between pairs of transistors turning on. This ensures that even if the transistors take time to switch off, the power supply is never shorted to ground. The ESP-32 MCPWM module is able to create PWM signals with deadtime included, and we will be utilizing this capability. The other feature we have to stop this overcurrent event is a current sensing IC that is placed near the ground legs of the H-Bridge. This current sensor will monitor the voltage across a known shunt resistance. During an overcurrent event, this voltage will spike, resulting in a larger voltage. This voltage signal will be sent to the microcontroller, which will be able to stop the motor.

Requirements	Verification
• The system should allow users to choose an item to retrieve, and have the bookshelf turn towards the user with the requested item	• Using the app, choose an item from the bookshelf you want to retrieve • Once chosen, the bookshelf should spin to “angle 0,” which faces the user • If the bookshelf stops within +/- 10 degrees of “angle 0,” it can be assumed that it works properly



VDD
VDD
A_esp32
Q3
IRF9540N
Q4
IRF9540N
~B_esp32
Motor_Pin1
Motor_Pin2
B_esp32
Q1
IRF3205
Q2
IRF3205
~A_esp32
+3.3V
GND
U3
INA240A1D
Fault1_esp32
R4
R
R5
R
U4
INA240A1D
Fault2_esp32
+3.3V
GND
GND

User Interface Subsystem:

This subsystem is how the user adds and retrieves items from the system. There will be a mobile app which allows the user to see all the current items in the system. They will also be able to insert the shelf ID of the item into the app in order to add an item. This is how the system will keep track of where each item is. When an item is being added, the user will be able to enter a name affiliated with each item. The app will also allow users to request items through the app. For this subsystem to work, it must be able to accurately keep track of each item and its location.

Requirements	Verification
• The system should allow users to accurately input bookshelf items onto the app interface.	• Choose an item from the bookshelf to add to the app. • Input a description of the item, and the shelf ID of where the item has been placed. • Once added, verify that the item is shown on the app with the correct description and bookshelf location.
• The system should allow users to accurately choose an item from the bookshelf to retrieve.	• Choose an item from the app that you want to retrieve. • Once an item has been chosen, observe the bookshelf to see if it turns to the correct location and lights up within 15 seconds.

Control Subsystem (Remote System)

This subsystem is responsible for sending data to the other control subsystem on the bookshelf system. The communication will occur using the phone's inbuilt bluetooth capability. This subsystem must accurately transmit all item additions and requests to the microcontroller for it to meet its requirements.

Requirements	Verification
• The system should be able to accurately transmit data from the mobile app to the bookshelf	• Once app has been completely implemented, verify if all items on bookshelf are shown on the app interface • Once all items on bookshelf are verified, choose one item that you would like to retrieve • Once item has been selected, observe bookshelf to see if it turns to the correct location with the item you are looking for, and if the LED turns on • Repeat for different items on the app to confirm if app and bookshelf has synced properly

2.4 Tolerance Analysis

Part	Worst Case Current Draw at 3.3V (mA)	Comments
ESP32-S3	340	In active mode, the worst case current draw is quite high. In practice, it will likely be lower as the highest RF power will not be required.
Red LED	15	Red LED has a voltage drop of 1.8V and with a series resistor of 100 Ohms this results in a 15 mA draw
Current Sensor (4)	9.6	2.4 mA draw from each current sensor, of which there are 4

Variable	Value	Comment
Max Temperature	150°C	From LM317 datasheet
Iout	364.6 mA	Calculated above
Vin	5V	Output from AC DC converter
Vout	3.3V	Regulated voltage
Θ_{ja}	100 C/W	Junction to ambient thermal resistance
T_a	40°C	Ambient Temperature

$$T = i_{out} * (V_{in} - V_{out}) * (\Theta_{ja}) + T_a = 0.3646A * (5V - 3.3V) * 100\, C/W$$

$$= 61.982°C + 40°C = 101.982°C$$

This temperature is significantly below the maximum operating range for the AZ1117-3.3. Based on this preliminary result, the AZ1117-3.3 will be able to output the required power while not overheating.

3 Cost & Schedule

3.1 Cost Analysis

3.1.1 Labor Costs

We are assuming that the average ECE graduate from UIUC makes $50 per hour. We plan to work on this project for around 10 hours per week for the next 9 weeks. Therefore, we plan to work for 270 hours with all three of us combined at a rate of $50 per hour. As a result, our total labor costs are $13,500. We estimate that we require around 20 hours of labor from the machine shop over the course of the semester to finish our project.

3.1.2 Parts Cost

Part	Cost	Quantity
Wood	$20.00	1
ESP8266-12E WiFi Enabled MicroController	$1.98	1
Stepper Motor	$5.00	1
LED	$2.00	1
AZ1117-3.3	$1.10	1
INA240	$3.50	4
1 Ohm Resistor	$0.25	4
1k Ohm Resistor	$0.40	8
IRF3205 - NMOS Transistor	$0.89	4
IRF9540N - PMOS Transistor	$0.89	4
4-pin connector	$0.19	1
2-pin connector	$0.13	2
RS-15-12	$10.86	1
AC-C7 NA	$2.78	1

3.1.3 Grand Total Costs

Our parts will total to $69.36 and our labor will total to $13,500. Therefore our grand total cost for this project is $13,558.50.

3.2 Schedule

Week of 10/2	• Design Review with Instructor and TAs • Review order with TA and submit order request • Visit machine shop to submit final design for shelf • Begin designing PCB
Week of 10/9	• Determine what parts need to be ordered • Begin designing mobile application • Check-in with machine shop on status for shelf
Week of 10/16	• Continue building mobile application • Parts should be delivered by EOW • Add motor to shelf and test if it is able to turn smoothly
Week of 10/23	• Complete PCB design • Connect mobile app to bookshelf via bluetooth • Start adding LED functionality to shelf
Week of 10/30	• Complete LED functionality • Integrate PCB, motor, and LED together with shelf and app
Week of 11/6	• Run thorough tests to ensure motor, app, and shelf are working properly • Run through practice demos for next week
Week of 11/13	• Mock demo with TA
Week of 11/20	• Fall break
Week of 11/27	• Final demo with TA
Week of 12/4	• Final presentation

4 Ethics & Safety

There are some ethical and safety concerns that we must consider when building our automatic item retrieving bookshelf. Additionally, as discussed in the IEEE code of ethics section III, we will treat all people involved fairly and respectfully, regardless of race, gender, disability, age, origin, sexual orientation, gender identity, or gender expression. We will be open to any and all criticism, and will be sure to fix any mistakes made along the way while prioritizing the safety, health, and welfare of everyone involved.

4.1 Ethical Concerns

- **Privacy:** Privacy is a very prevalent ethical concern that many devices face. It is imperative that we consider the privacy of bookshelf users to ensure that we aren't collecting and storing any personal information that could be used negatively. When designing the app, we will adhere to the guidelines of the IEEE code of ethics section 1, and ensure that privacy is considered throughout the design process. Our team will be transparent with the users involving what data is being collected and how it is being used.
- **Data Security:** For data that we are collecting, it's important to protect the data effectively to ensure that no sensitive information is being stored in insecure locations. We must also not collect any more data than is necessary for our design to work. We will also adhere to IEEE Code of Ethics section 10, and make sure that the entire team upholds these ethics. We will ensure that our fellow team members follow the rules, and will uphold each other to the highest standards.

4.2 Safety Concerns

- **Physical Safety:** When thinking about physical safety with the design of our bookshelf, it's important to consider that the mechanical and electrical components of the device are up to industry standards. With the mechanical components, we have to make sure that the motor is strategically placed in locations that won't be able to physically harm users of the bookshelf. With electrical components, it's important to ensure all wires are properly grounded and aren't exposed. Since this design contains 120V AC power, we must be sure to design a safe power distribution system that follows industry standards. We must also ensure that there are no pinch points in the mechanical design that could harm the user. We will follow IEEE Code of Ethics section 1 and keep the safety of our users paramount throughout the design process. Our primary goal throughout the design process will be to create a system that prioritizes safety.
- **Fire Safety:** As we are using electrical components and various power sources, it's important to ensure that we don't input too much power at a given time to reduce overheating and potential fire hazards. We must also size all conductors correctly to reduce the risk of overheating, and will have to use appropriate overcurrent protection methods. This is an especially important point to consider because our design contains a motor which will have a high inrush current. We will be sure to keep these considerations in mind when developing our system.

References

1. *ESP32 Technical Reference Manual*, www.espressif.com/sites/default/files/documentation/esp32_technical_reference_manual_en.pdf. Accessed 28 Sept. 2023.
2. *AZ1117 Datasheet*, www.mouser.com/datasheet/2/115/AZ1117-1596017.pdf. Accessed 28 Sept. 2023.
3. "INA240 4-V to 80-V, Bidirectional, Ultra-Precise Current Sense ..." *INA240 Datasheet*, www.ti.com/lit/ds/symlink/ina240.pdf. Accessed 28 Sept. 2023.
4. "H-Bridge DC Motor Control Using Complementary PWM, Shoot-through, and Dead-Time - Technical Articles." *All About Circuits*, www.allaboutcircuits.com/technical-articles/h-bridge-dc-motor-control-complementary-pulse-width-modulation-pwm-shoot-through-dead-time-pwm/. Accessed 28 Sept. 2023.
5. "IEEE Code of Ethics", https://www.ieee.org/about/corporate/governance/p7-8.html