WINDOW AUTOMATED NATURAL DAYLIGHT ASSISTANT (WANDA)

A Technical Report submitted to the Department of Electrical and Computer Engineering

Presented to the Faculty of the School of Engineering and Applied Science

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In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

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Fall, 2020

Technical Project Team Members

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Brandon Chan

Mesgana Dinare

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Signature ____ Date __________

Kwadwo Tenkorang

Approved ____ Date __________

Harry C. Powell, Department of Electrical and Computer Engineering

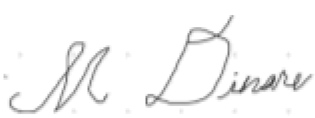
Vout of Here/WANDA

Brandon Chan, Edward Agyeman, Kwadwo Tenkorang, and Mesgana Dinare

December 12, 2020

Capstone Design ECE 4440 / ECE4991

Signatures



Statement of work

Brandon Chan

I was primarily responsible for selecting the appropriate motor and respective motor driver for the project by determining the lower bound pull-in torque required for tilting the blinds. I also assisted in deciding the encoder by discovering that absolute encoders could maintain their position data after powering off as well as choosing an absolute encoder over an incremental encoder. Furthermore, I not only picked the wall adapter and power barrel connector jack, but I also created the Ultiboard and Multisim components for them. I also created a finances sheet to manage our budget and included potential additional funding from the team.

I helped to design the user interface for the mobile application by brainstorming and creating the calibration section in Figma. Additionally, I developed the mobile application in Android Studio using Flutter and Dart as well as prepared the Cloud Firestore Database with Kwadwo so that any changes within the app are updated instantly online for extraction from the microcontroller. The application's calibration page is displayed in Figure 1.

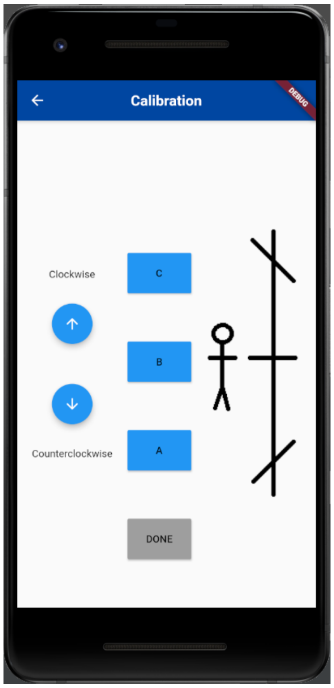


Figure 1: Mobile Application Development

Edward Agyeman

I was tasked with creating the multisim and ultiboard versions of our finalized components. To do so, I utilized the components' datasheets and the given footprints to create and label each unit. Another one of my given tasks was to figure out the communication subsystem for mobile development and WiFi connection. A wifi MCU, CC3200 SimpleLink™ Wi-Fi, was our choice for the main communication system. In addition, I found the upper limit for the torque needed for opening and closing the slats of the blinds. I was able to find several design documents from blind manufacturers that listed the same figure of 1 foot-pound for twisting the slats open or close. We used this figure for the upper limit in finding the right motor.

$$\text{Upper limit: } \frac{1\,(ft/lbs)}{0.73756} = 1.356\ N - m$$

I helped Kwadwo and Mesgana with testing and troubleshooting the major subsystems of the device. I was also a main communication base for reaching out to WWW electronics and other services when a problem occurred or their assistants were needed.

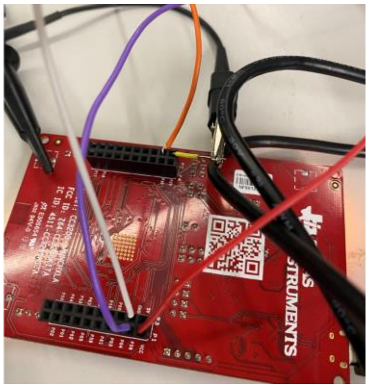


Figure 2: Testing CC3200 Signals

Kwadwo Tenkorang

My primary roles for this project involved prototyping and testing the major subsystems of the device. This consisted of setting up the ambient light sensor and the encoder. For both of these sensing components, I replicated our schematics on a breadboard to confirm that they were accurate and produced the correct outputs. An example of this can be seen in Figure 3, where I set up the ambient light sensor and a simple testing code on the CC3200 to be able to process the voltage readings off the sensor. I also did something similar with the encoder but worked with a simple microcontroller to isolate the hardware setup and write simple testing code to both write and read from the encoder.

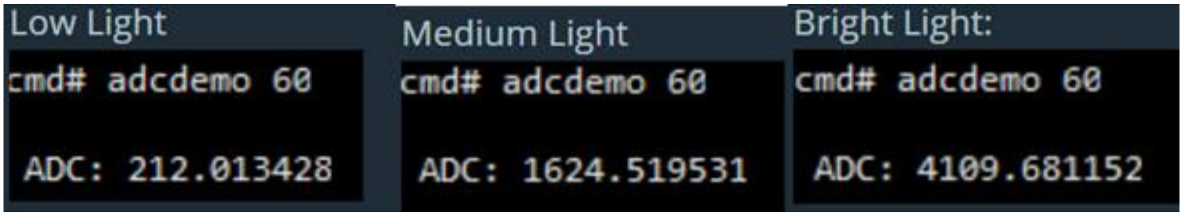


Figure 3:Testing Ambient Light Sensor

In addition to testing and prototyping some of the sensors, I also helped write the firmware to connect the CC3200 to the internet and process GET requests from our database and parse the JSON so that the rest of our firmware could use that data. I also helped Brandon set up the database for the project and helped him to write the cloud functions that were used to read from and write to the database.

Mesgana Dinare

I was primarily responsible for the hardware of this project, soldering each component onto the PCB, making sure they worked correctly beforehand. I also dealt with any hardware errors that occurred on the board. I started with researching ambient light sensors to get the correct one for our project. Next I created some of the new components into multisim and ultiboard helping out Kwadwo and Eddie with the schematics. After soldering most of the components and sockets onto the PCB I helped Kwadwo and Eddie with some of the testing for the components. Mainly I converted (we found some arduino code online for the motor and encoder) and tested the coding with the CC3200 for both the motor and the encoder. Then I created a 3D model of the mount that we are using for the motion and light sensor shown in the figure to the right. Finally I debugged most of the software or hardware of each component testing the final product making sure that all the components worked together without any faults or errors.

Table of Contents

Table of Figures

Abstract

The Window Automated Natural Daylight Assistant (WANDA) is a smart window wand. It can be attached to any household window blind to automatically vary the amount of light entering into a space. WANDA will be built with several privacy features and smart features to help the user better control the lighting and comfort of their home. This device hopes to aid many different groups of people from individuals with disabilities to those who would like an easy way to regulate natural sunlight in their homes. This product is in the growing market of smart home devices.

Background

Emerging “smart home” products ease the life of many homeowners and have affected many different aspects of the living experience. Though it might not seem as important as some of the other products, window blinds can also be improved. It is hassling to some people (sick or elderly) to constantly open the blinds during the day and close them during the night. However, these people need the sunlight to improve their mood throughout the day, which leads to the invention of a universal automatic window blind. Additionally, with the recent pandemic everyone around the world started working from home and a study was conducted on natural elements and sunlight on employee mental health [1]. This study showed that exposure to natural elements reduced levels of anxiety, depression, reduced mental fatigue and reduced the impact of stress [1]. Accidentally leaving window blinds open increases risk of theft and to combat this a privacy function is introduced. This privacy function closes the blinds whenever there is a person or movement within a certain distance of the home as to make sure no one can peek at the home's valuables.

In academia, there exist copious papers that introduce a method to either upgrading or replacing blinds. One joint study conducted by the California Polytechnic State University and University of Brawijaya created a hardware prototype of window blinds that adjusted the wand based on photoresistors measuring the light intensity [2]. The Federation University Australia suggested the approach of adding and automating an exterior awning, exterior blinds, and interior curtain to conserve energy optimally during each season [3]. Conversely, Najran University proposes to remove blinds and change the glass of the window to Polymer Dispersed Liquid Crystal (PDLC) glass which can vary between transparent and opaque due to the amount of sunlight [4]. The aforementioned systems present various methods toward reducing energy consumption, but improvements could be made for the overall design, installation process, and additional functionality.

Businesses have produced similar products to automate window blinds. The company Tilt manufactured MySmartBlinds which are Bluetooth connected built-in blinds hardware [5]. The company SOMA Smart Home produced SOMA Tilt which contains a wire that is connected to the tilt mechanism of the window blinds [6]. While both of these products can be controlled remotely, they don’t offer automated privacy.

Our proposed system is a unique design that primarily focuses on user privacy while still providing the additional benefit of optimal lighting through automation to conserve energy. The implementation of the outward-looking motion detector will identify suspicious movement to prevent trespassers visibility of the house's interior. Specifically, when the motion sensor catches movement, the stepper motor will be activated to quickly close the blinds in order to indicate that unknown interlopers are unwelcome visitors. Unlike most prior designs, the proposed prototype will be a simple replacement of the wand and arrangement of the motion sensor for simple installation.

The previous coursework that this project will call into play include: embedded systems, software development, signal processing, hardware design, and computer networks. All of the group members have experience in all these fields from previous classwork and research/internships. These classes include the FUN trilogy (ECE 2630, 2660, 3750), computer networks CS 4457, embedded systems ECE 3430, and program and data representation CS 2150. All group members have experience in hardware design from the fun series as well as embedded C and parsing documents for the necessary information. All of us have also been introduced to networks and have some level of comprehension with the subject and know the general idea of the inner workings. Brandon, Kwadwo, and Edward have a developed understanding of software developing through summer internships. They also have experience working towards a defined goal with team cooperation through these internships. Mesgana has some experience with research and software development through his summer research internship. These experiences and skills show promise in developing the project this semester, the automatic window blind.

Constraints

Design Constraints

The main constraints of the project required that a microcontroller unit or National Instruments myRIO [7] was used as the central processing unit (CPU) and an original printed circuit board (PCB) was designed by the team.

CPU Limitations

The Texas Instruments CC3200-LAUNCHXL [8] stated that there were 27 programmable general-purpose input/output (GPIO) pins, but the team was unable to use most of the aforementioned GPIO pins because of the conflicts with some of the modes included with the CC3200. As the number of available pins were quite low this project almost ran out of GPIO pins to use, however the team made sure to consolidate the pins with the same functionality.

Software Availability

Multisim [9] and Ultiboard [10] are software applications from National Instruments that UVA provides licenses for students. These tools were required to design and test the PCB as well as the included components. Additionally, Code Composer Studio [11] was used for embedded programming because of its compatibility with the selected microcontroller, the available software development kit, and the software was free to use.

Manufacturing Limitations

There are manufacturing limitations by the PCB Manufacturer. The PCB Manufacturer for this project was Advanced Circuits and they list specified requirements for different boards. The team is using a two-layer board for the project which Advanced Circuits note that the maximum board size for two-layer boards is 60 square inches [12].

Economic and Cost Constraints

The budget for the entire project was $500, but about $375 was used. This leaves a leftover of around $125, but any component failures that require immediate attention would lead to increased costs for overnight or two-day shipping.

External Standards

There are several external standards that the project had to abide by:

1. NEMA Ratings for Enclosures - Since the device is designed for household use, it must abide by the National Electrical Manufacturers Association (NEMA) Type I enclosure which states [13]:
    a. Indoor use to provide a degree of protection to personnel against access to hazardous parts.
    b. To provide a degree of protection of the equipment inside the enclosure against ingress of solid foreign objects (falling dirt).
2. IPC PCB Standards - The custom printed circuit board for the device needs to abide by the IPC-A-610—Acceptability of Electronic Assemblies standards, class 2 [14].
    a. IPC J-STD-001G sets the requirements for soldered electrical and electronic assemblies, details how to manufacture a PCB to meet the acceptability requirements of IPC-A-610 [15].
3. FCC Regulations - The system intends to incorporate Wi-Fi communication and a motor and as a result must abide by the Federal Communication Commission (FCC) regulations' section 15.
    a. The motor falls under section 15, part A §15.303 as an intentional radiator because it is an electrical device that is not designed to intentionally use, intentionally generate or intentionally emit radio frequency energy over 9 kHz. [16] And is not required to obtain an equipment authorization but needs to be designed to minimize interference.
    b. The Wi-Fi chip falls under section 15, part C §15.303 as a device that intentionally generates and emits radio frequency energy by radiation or induction

since the chip operates with the 802.11 standard with frequencies in the following bands: 900 MHz, 2.4 GHz, 3.6 GHz, 4.9 GHz, 5 GHz, 5.9 GHz and 60 GHz [16]. Using the CC3200 with a built-in chip, designed by TI helped meet these standards.

4. UART (Universal Asynchronous Receiver-Transmitter) - The device employs UART communication between the encoder and MCU. The UART peripheral is based on the industry standard TL16C550 asynchronous communications element [17].
5. JTAG Standard - JTAG is used by the CCS Debugger tool in order to flash and debug code to the device and must abide by the IEEE 1149.1 standard for JTAG [18].

Tools Employed

The software tools used for this project are design, simulation, and programming tools.

Software

Since the plan is to use the CC3200 series/family, Code Composer Studio [11] will most likely be used to implement the software relating the sensors to the motor. Additionally, we will be using some type of mobile app development software (Android Studio [19]) to create a mobile app to go in tandem with the blinds. Figma was also used in the design phase of the app to prototype the UI [20]. Github [21] will also be used to share the code of both Code Composer and the mobile app with the other team members while working on it concurrently.

Hardware

Multisim [9] and Ultiboard [10] is used for the design of the circuit structure and how the components physically interact as well as the simulation of the circuit. Autodesk Fusion [22] will be used for 3D printing and modeling of the product's initial and final implementation.

Ethical, Social, and Economic Concerns

Environmental Impact

Without proper disposal of the AC Wall Adapter through electronic recycling (e-cycling), the heavy metals within these devices could pollute groundwater if placed in landfills [23]. These heavy metals can cause contamination within the soil which could be absorbed by plant life as well as reduce crop yields. These contaminants could then negatively affect humans as heavy metals have been found to cause kidney damage and brain damage [24].

Sustainability

The device is designed to be highly sustainable, however instead of the original plan to use a battery, we will be using the power provided by a wall adapter. The energy consumption through both methods is low. Blinds are a convenient way of helping to retain heating inside of a home, especially those with less-than-optimal window insulation. Automatic blinds are even more efficient as they can be set to open and close depending on when the sun is out, helping to trap heat in when the sun sets and outside temperatures begin to drop. Instead of the use of artificial lighting, automatic blinds could help in using natural lighting by helping owners maximize window exposure. The option to cool your home and decrease light intensity could be set up by changing the settings of the blinds. These options could help curve the energy consumption of a home by reducing wasted energy by utilizing the available outdoor light.

Health and Safety

The current wiring of the project would not be safe around children, but if more time was available it would be devoted to wire management and casing so there are no exposed wires or metal. Moreover, there are blind standards that indicate the dangers of hanging objects from the window that could result in strangulation which the project avoids by being wall mounted [25].

Manufacturability

Many of the components in the system are relatively inexpensive and can be scaled with the exception of the encoder, motor and CC3200 launchpad. The encoder chosen for the project is the most expensive component because it is an AMT21 absolute encoder that can maintain its state between power loss [26]. Based on the team's research this was the most accurate way to determine rotation and position of the window wand, but more research and prototyping can be done to determine a cheaper encoder to be used. The next expensive component in the design was the unipolar motor [27]. In bulk the unipolar motor price is slightly reduced but additional cheaper motors will need to be tested to ensure they can supply sufficient torque to turn the blinds. Currently the project uses a CC3200 LaunchPad [8] which is an evaluation board. In order to take the device to manufacturing, the CC3200 chip will need to be put on a custom PCB to reduce the footprint of the device and integrate into the larger design.

The most difficult part of the PCB is loading the surface mount regulators. This can be done with some advanced soldering techniques and can even be automated with a machine.

Ethical Issues

There are a few ethical considerations with the system that is being developed. The system being developed is a smart home device that embeds itself in the living environment of its users. Inside of a home is a very personal space and thus the device needs to be designed to respect that space. Since the device attaches to a window blind, it must be designed to ensure it cannot accidentally break the blinds or move the blinds in a way that may expose the user without warning. The device is being built with an additional privacy component that allows the user to prevent others from looking into their homes. If this feature fails, the user can be exposed when they do not want to be, violating their privacy.

Additionally, the system works over Wi-Fi which opens the user's information to being potentially hacked. Since the application for the mobile device is being built using a 3rd party platform, it is up to the team to set up the correct access control in the database as well as the app to limit access to the information passed over the internet.

Intellectual Property Issues

[28] proposes a patent for “a method for setting a darkening or closing device that can be moved between the first and the second end position by means of an electric drive.” The first step of this process is described as “detecting the current position of the darkening or closing device by means of an image capturing means.” This step is further supported by the claim that “Sending a stop signal when the image capturing means detects the reaching of the first and / or second end position of the darkening or closing device.” The system then proceeds to send a signal to move from the first position to the second position until the image captured position is in the second position. The method presented in this patent relies on images of the window to determine the start and end positions. Based on these claims the capstone device is still patentable as the device presented uses an absolute encoder in conjunction with calibration from the user in order to determine the position of the window blinds.

Next, [29] presents a patent for an invention that “relates to a control unit for controlling the motor drive for a sun blind. The invention also relates to a sun blind provided with such a control unit and to the use of the control unit.” The device seeks to address the issue of window blind manufacturers having to navigate the complex logistics of automating their window blinds. Their design consists of a motor, microcontroller and an interface with at least one input and output. The capstone presented by Vout of Here can still be patentable because the claims of this patent differ from this capstone in several crucial aspects. First, according to their 7th claim, “receiver is an infrared receiver for wirelessly receiving infrared signals and converting them into an electrical control signal.” The primary communication method for this patent is an infrared signal sent which differs from this capstone since Wi-Fi is the primary means. Additionally, according to their 11th claim, “Control unit according to one of the preceding claims, wherein the electrical supply is formed by one or more batteries or by a battery.” The capstone uses an AC wall adapter to provide power whereas the patent uses batteries.

Lastly, [30] presents a patent for “an electronically-controlled roll-up window shade that can easily be installed by a homeowner or general handyman is disclosed.” This is a standalone system that is used to control roll up blinds by creating a motorized shade composed of “an internal power source, a motor, and a communication system to allow for remote control of the motorized shade.” This device also has the potential to be used in connection with a zoned or non-zoned HVAC system to reduce energy usage.” The claims of this patent do not exclude the capstone device to also be patented. Primarily, the patent is for roll up shades as mentioned in claim 1: “a tubular motor provided to said controller, said tubular motor configured to raise and lower a shade material, said tubular motor disposed in a tube member wherein said shade material rolls onto said tube member when said shade material is raised.” The device presented by this capstone controls venetian blind by turning the wand. Additionally, the patent describes a standalone product that replaces household blinds while Vout of Here’s device is an add-on to a homeowner’s blinds that adds automation to them.

Detailed Technical Description of Project

The smart window blind is a universal attachment that mounts to most household window blinds. It mounts to where the window's wand would originally be located and senses as well as regulates the amount of light entering a room by turning the wand accordingly. The device is designed with privacy in mind by incorporating a motion sensor to detect if there is someone outside of the window and close the blinds to improve privacy.

The system has four primary subsystems: sensing, actuation, communication and power, Figure 5. These systems work together in order to properly calibrate, sense, actuate and control the system as a whole. All of these systems will be coordinated using an CC3200 as the microcontroller.

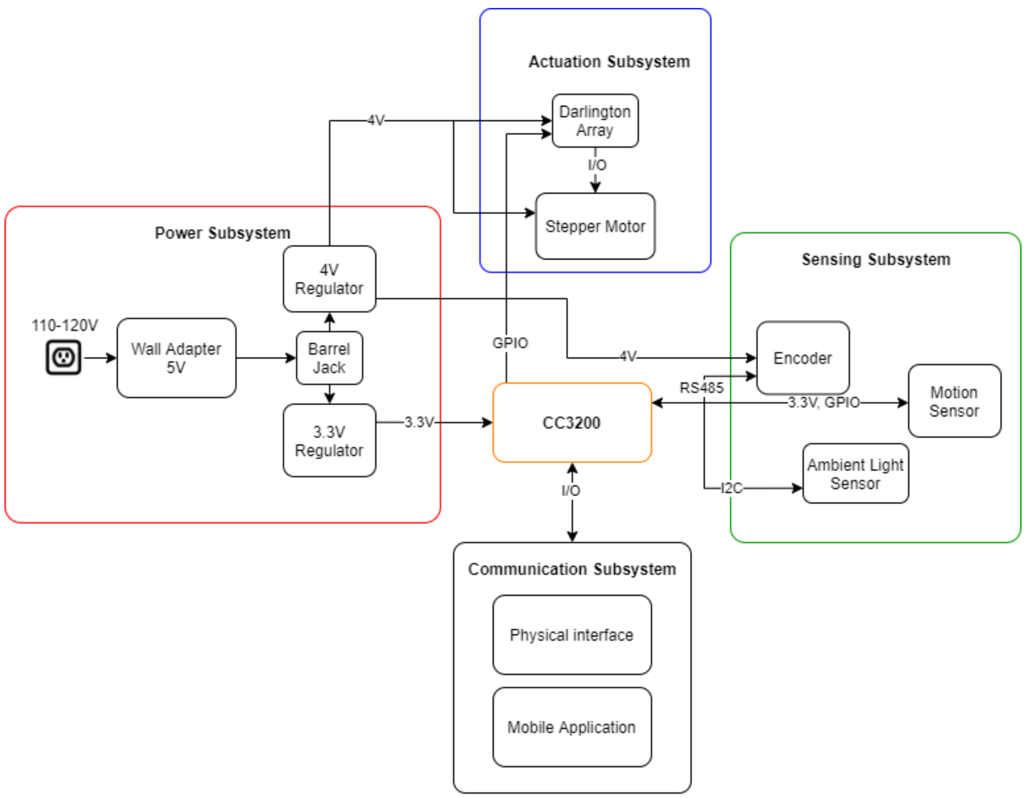


Figure 5: Subsystem Design

Hardware

The hardware consists of the CC3200 MCU linked with our power, actuation, and sensing subsystems. The actuation subsystem includes our motor and Darlington array. Sensing subsystem can be broken down to the encoder, motion sensor, ambient light sensor. The Main Wanda schematic is shown in Figure 6. This provides a high-level overview of how the hardware components are connected.

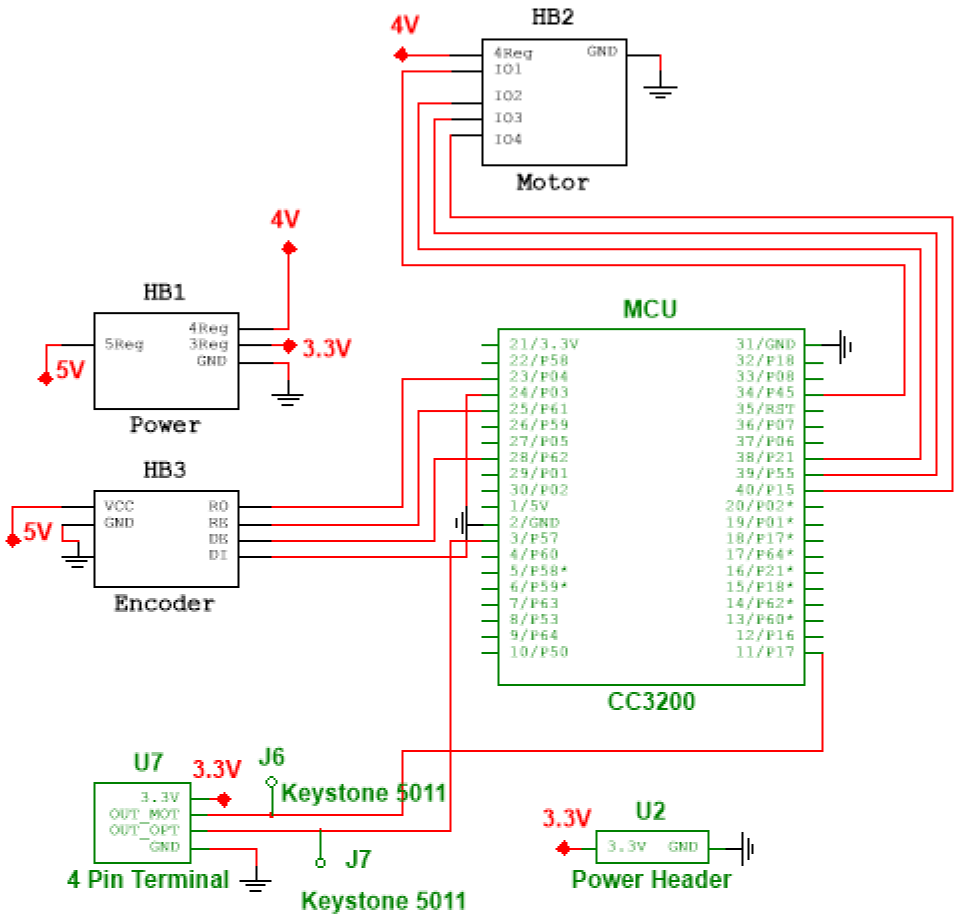


Figure 6: Main WANDA Schematic

Power

In order to deliver power to the various subsystems, a persistent power supply was needed to ensure that each component worked properly. To simplify the integration process, the team opted to receive power from outlets using a wall adapter instead of lithium-ion batteries [31]. This design tradeoff cost the system some flexibility because it limited where the system can be placed, since a power cord would be needed. To deduce the power component, all other components in the system had to already be confirmed as the greatest voltage as well as the sum of each component's current rating in the system were needed. Once the greatest voltage was revealed to be about 4V from the encoder and motor and the sum of the currents had a total of around 4 A, a 5V voltage output, 5A max current output wall adapter was selected. The wall adapter has prongs designed for North American outlets with a fixed blade input capable of taking in 110-120V which is standard in American households and has a suitable cord length. Additionally, the wall adapter requires a power barrel connector jack to send the power to the PCB, so a barrel jack with the same mating inner diameter (2.1mm) and outer diameter (5.5mm) as well as with greater rated voltage (48V) and rated current (6A) values was chosen [32].

The power subsystem schematic is shown in Figure 7. The 5 volts voltage supply from the barrel jack is taken as inputs into a 3.3 voltage regulator and is adjusted accordingly in order to provide the correct supply voltage for the MCU, motion sensor, and ambient light sensor. We intended to feed the 5 volts from the barrel jack into a separate 4 volts regulator to provide the proper voltage supply for the actuation system and encoder. However, we encountered a problem with the motor supply current, refer to the problems and design modifications section for details. 5 volts was instead provided to the actuation system and encoder. This also caused a separate issue of overheating, refer to the problems and design modifications section for details.

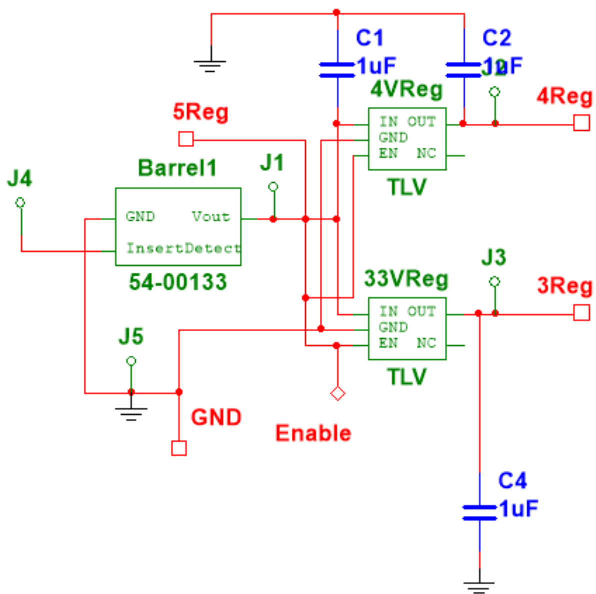


Figure 7: Power Subsystem Schematic

Encoder

The encoder is a crucial component in the final device because it helps accurately determine the amount of rotation that the motor needs to get the blinds in their correct position. Without the encoder the motor can overturn and potentially damage the blinds in use. The team decided upon the AMT21 [33], an absolute, multiturn encoder with a RS485 interface. An absolute encoder was chosen over an incremental one because it would allow the position of the blinds to be known in the event of a power outage and have a more accurate measurement of the position relative to a particular start point. A multiturn variant was chosen because from testing, the team realized that most blinds needed multiple complete revolutions of the wand in order to change the position of the blinds. A RS485 interface was chosen because it enabled simpler asynchronous communication with the CC3200 and used less ports on the device once we added the MAX485 transceiver component [34]. A schematic of both of the encoder and transceiver is shown in Figure 8.

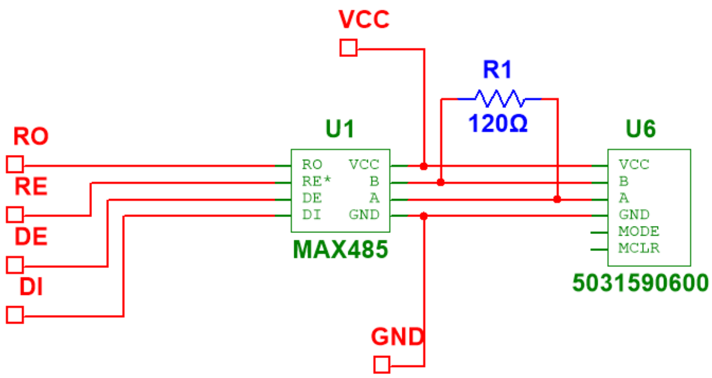


Figure 8: Encoder Schematic

Both of the devices from the encoder subsection. The AMT485 produces a differential voltage output over a half-duplex RS485 connection which the MAX485 transceiver processes and outputs to the CC3200. The MAX485 helps enable the half-duplex communication between the CC3200 and the encoder by using control lines for receiving and transmitting that are controlled by the CC3200.

Actuation

Actuation for the system will primarily be done using a stepper motor because of its high torque at lower speeds and the team's familiarity with programming it in an embedded course. More specifically we decided to use the 1200 Pololu a 6-lead unipolar motor [27] which requires a 5V input to run with adequate torque. We decided on a unipolar motor as opposed to a bipolar motor because unipolar motors don't require reverse current and thus are easier to drive. The driver that we used, the ULN2064B [35], constructs the communication between the motor and the microcontroller and the input voltage ranges 3-5V. The 6 pin Phoenix connector [36][37] is used to make the connection easier from the physical stepper motor to the PCB. The layout of the connections of the are shown in Figure 9, illustrating the power to the system and the communication between the driver and the 6 pin connector.

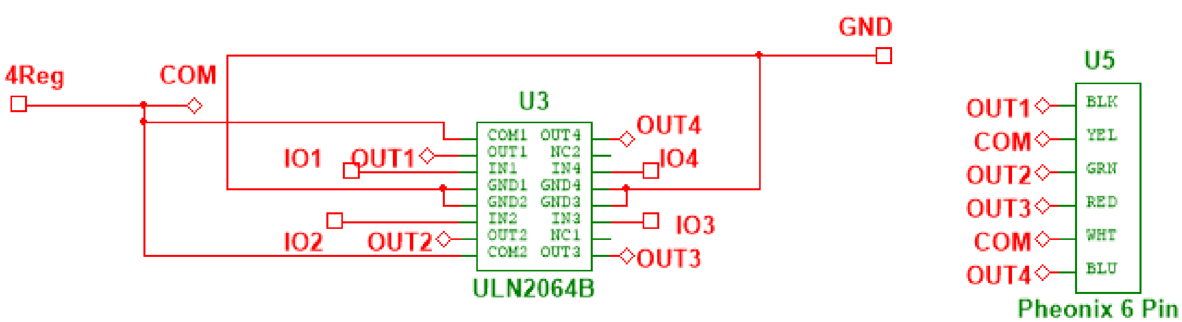


Figure 9: Actuation Subsystem Schematic

Ambient Light Sensor and Motion Sensor

The ambient light sensor and motion sensors are key components in enabling the device to sense the light levels and incorporate privacy. The ambient light sensor is an OPT101 which is a monolithic photodiode that produces a voltage output in response to the light level on the sensor [38]. It was chosen because it contained a transimpedance amplifier that reduced noisy signals and produced voltage output that increased linearly with light intensity. The simple voltage output could be sampled with the ADC to determine the light intensity.

The motion sensor that was chosen for the project was a Panasonic EKMB [39] passive infrared (PIR) sensor with a built in Fresnel lens for getting a more accurate signal reading. This sensor was chosen because PIR sensors are commonly used in motion detection systems. The interface for the PIR would be a digital output that could be read by the CC3200 to determine if motion was present.

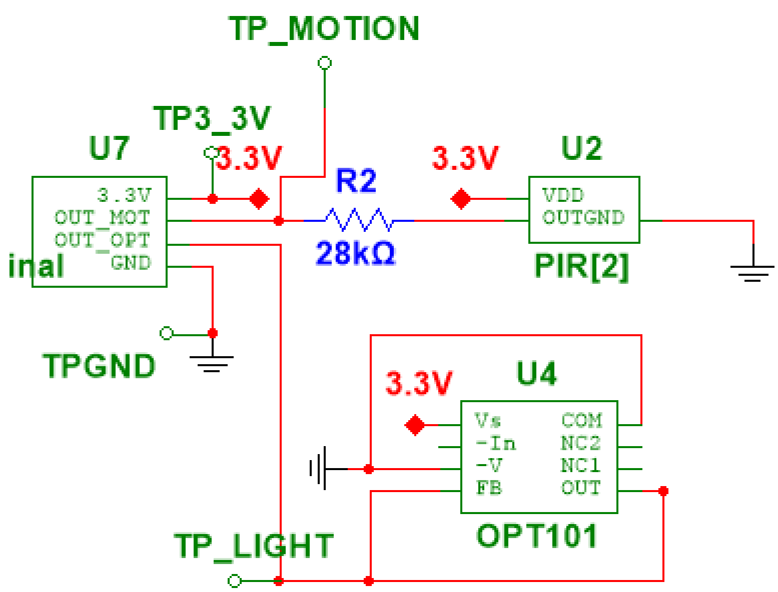


Figure 10: Motion & Light Schematic

Both of these sensors were placed on the same schematic shown in Figure 10 because they would both be placed on the window in order to detect the outdoor light levels as well if anyone was standing in front of the window for privacy purposes. Since they both used the same power supply and would end up on the same PCB shown in Figure 11, they were placed together.

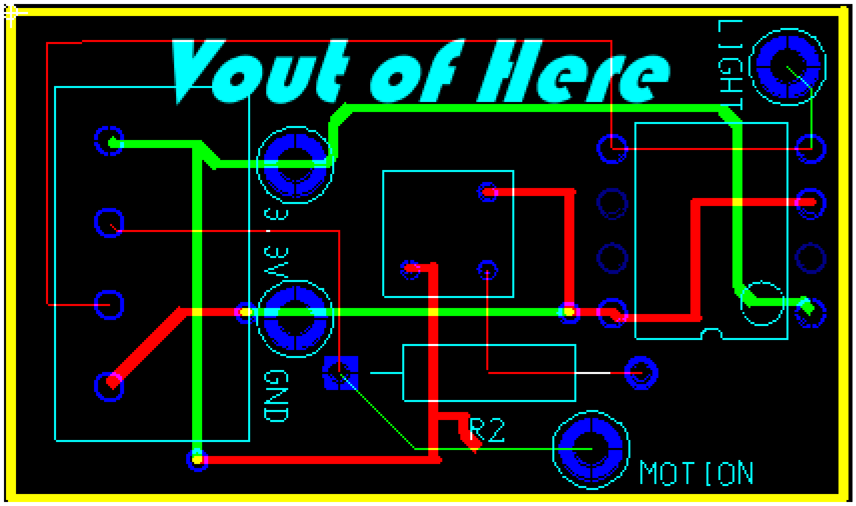


Figure 11: Window Sensor PCB

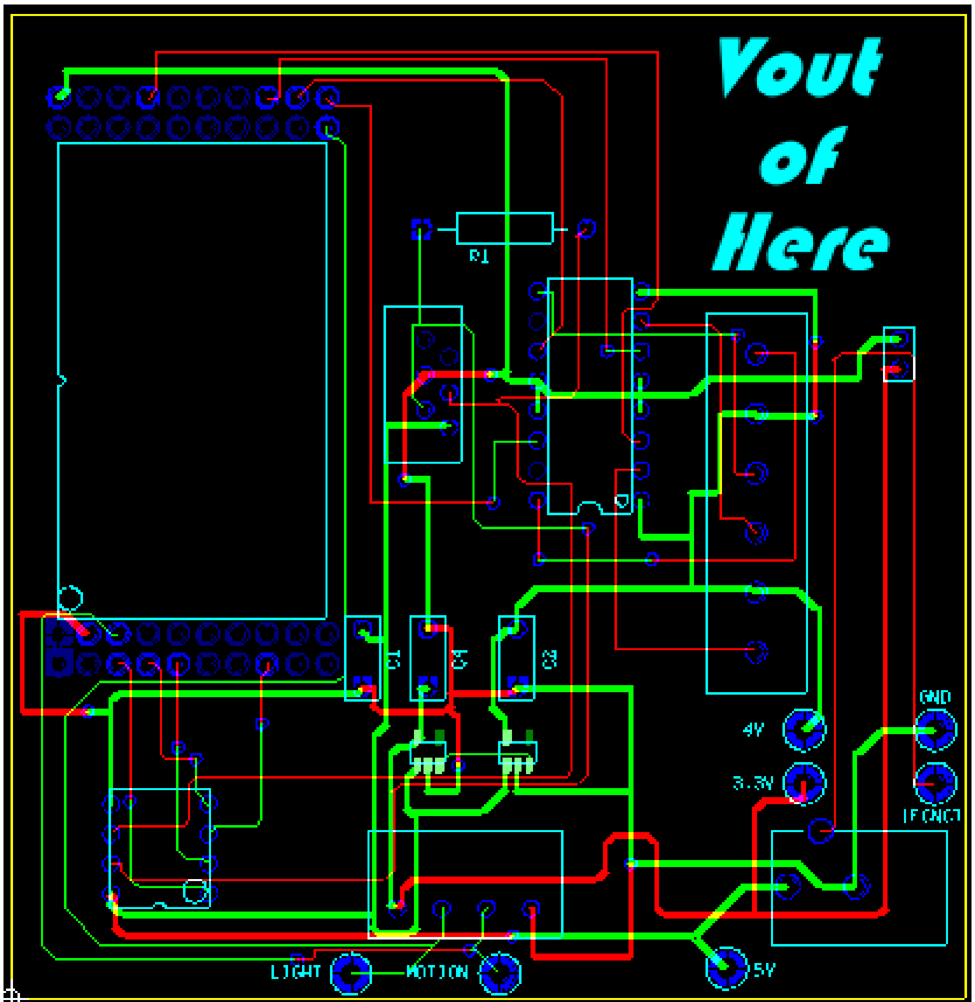


Figure 12: Main PCB

The main PCB for the device is shown in Figure 12. The layout was primarily done by each subsystem. The power subsection was kept close to the end of the board so that the power jack could be plugged in and the regulators and bypass capacitors were kept close to each other in order to minimize the noise from the AC wall adapter. Additionally, we used a FreeDFM tool [40] in order to calculate the trace width needed to carry enough current to the motor since that way the highest current component on the board and we wanted to be able to power it properly. The distance between the motor connector's phoenix connector and the motor driver was reduced to ensure there would not be much power loss to control the actual motor.

Firmware

General

The overall firmware for the embedded system is shown in Figure 13 as a higher system flow diagram. System calibration is initiated by the mobile application which sends commands over the cloud to the CC3200 in order to determine the correct position of the blinds. The calibration component is described in more detail under the mobile application section following the firmware section.

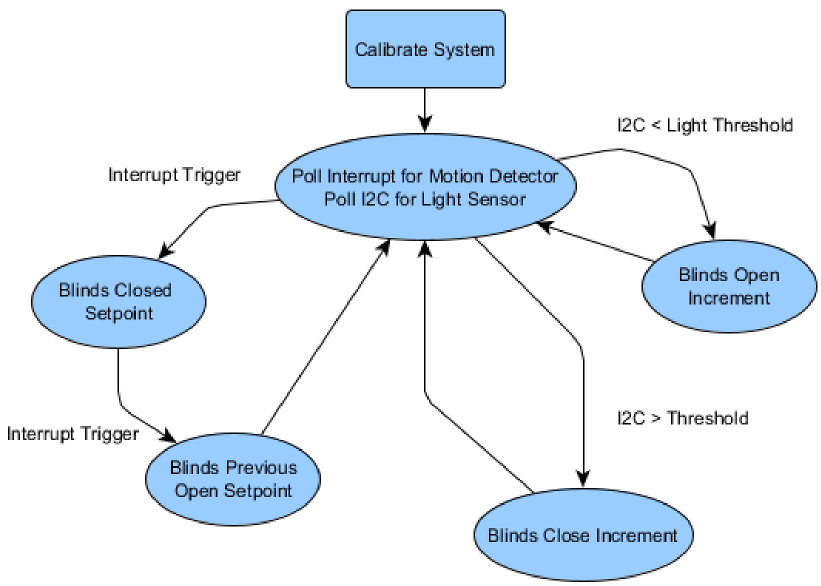


Figure 13: Overall Firmware Flow Chart

Following calibration, the system enters a state machine that is broken into two main sections: one for the privacy setting and the other for light levels. The left half of the system flow diagram describes the privacy setting which is enabled from the app and read by the CC3200. If this setting is enabled, the CC3200 will have an interrupt triggered when the motion sensor detects movement in front of the window. This interrupt will cause the system to enter a routine that will quickly close the blinds. Following this, the system will wait a short amount of time to check if there is still motion before setting the blinds to their original position before movement was detected. The right half of the system flow diagram represents the device automatically controlling the light levels. This flow is detailed in a state machine shown in Figure 14.

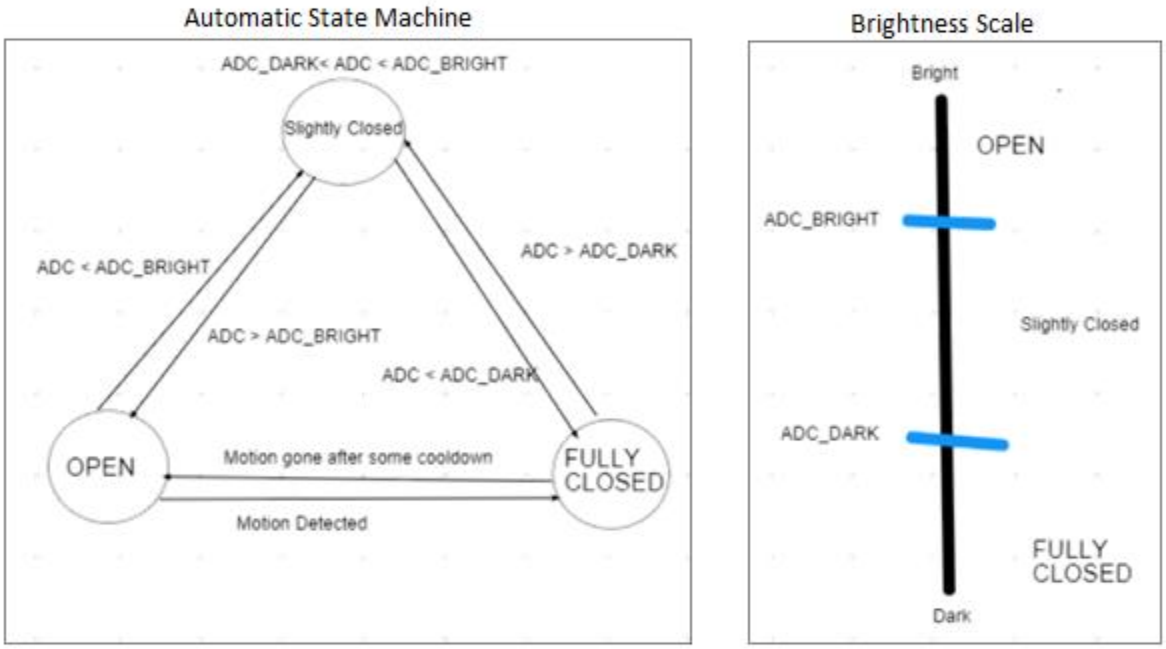


Figure 14: Automatic Control Flow Chart

This automatic control helps the blinds maintain a certain level of brightness for the room the window is in. On the right of Figure 14 is a scale with a completely dark room on the bottom and a fully lit room on the top, with 2 setpoints ADC_BRIGHT and ADC_DARK. Based on the readings from the light sensor, the position of the window blinds will transition between the 3 states defined by the state diagram in the left of Figure 14. The state machine will enable the device to control the light level without user input. If the user wants to change the position of the blinds manually, they can use the app as described in the next section to achieve that.

Motor

The 1200 Pololu 6-lead unipolar stepper motor has 4 pins designated as GPIO and the other 2 pins are used for voltage inputs. The 4 pins are connected to the microcontroller through the driver to accurately change between each phase. There were documentations of the correct coding principles for the stepper motor and which pins needed to be powered to turn the stepper motor correctly. The code uses a count system where a “step” is 1/200 of a full turn. The motor is also able to make the motor spin either forwards or backwards depending on a direction variable, this will allow the device to operate the blinds both ways for opening/closing the blinds. The speed of the motor can also vary depending on the delay between the “steps” this can be used for adjusting the blinds at a slow speed and closing the blinds for privacy reasons a lot quicker.

Encoder

The AMT21 absolute encoder we used for this project used a RS485 balanced digital multi-port interface as its primary communication protocol [33]. It used this protocol to both transmit and receive data over a twisted pair connection. As mentioned in the hardware section, the MAX485 [34] RS485 transceiver was used to interface with the encoder and this was the main interface to the CC3200.

The MAX485 has 4 primary connections to the CC3200, 2 GPIO pins to enable transmit or receive and 2 UART pins for receiving and transmitting. Since the baud rate of the AMT21 encoder is 2Mbps, the UART for the CC3200 had to be configured to run at that speed. In order to switch between transmitting and receiving commands and data to and from the encoder the following table in Table 1 from the transceiver data sheet [41].

INPUTS			OUTPUTS	
$\overline{RE}$	DE	DI	Z	Y
X	1	1	0	1
X	1	0	1	0
0	0	X	High-Z	High-Z
1	0	X	High-Z*	High-Z*

INPUTS			OUTPUT
$\overline{RE}$	DE	A-B	RO
0	0	$\geq$ +0.2V	1
0	0	$\leq$ -0.2V	0
0	0	Inputs open	1
1	0	X	High-Z*

Table 1: Left Transmit/Right Receive

In order to receive commands from the encoder, specific commands needed to be sent to it. The table in Table 2 details the 3 primary commands that were used to receive data from the encoder [42].

Byte(s)	Command
0x54	Read Position
0x55	Read Turns
0x56, 0x75	Reset encoder

Table 2: Encoder Commands

The data sent from the encoder back to the CC3200 is a packet shown in Figure 15, where the command, the low and high bits of the response are sent consecutively. Since the AMT21 has a 14 bit resolution and a 2 bit checksum, 2 bytes needed to be sent and parsed to determine the information sent from the encoder.

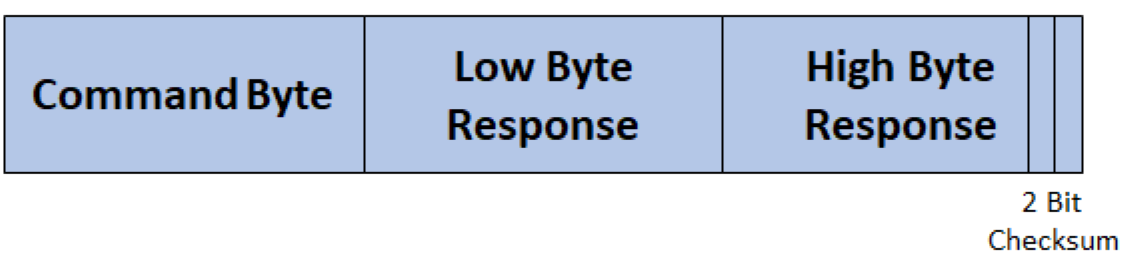


Figure 15: Encoder Packet

Ambient Light Sensor

The ambient light sensor, OPT101 produced an analog voltage signal to represent the light intensity that it measured. In order to read the voltage signal, the CC3200's ADC was used to sample the voltage signal. The ADC was configured to collect 4090 samples which was to match the sampling rate set based on trial and error to get a good signal reading. Originally the following equation was used to determine the voltage from the ADC value:

$$V = \frac{ADC * 1.4}{4090}$$

But the team determined that the raw ADC value would be more helpful in gauging light levels because it was an unsigned integer that could be more easily used in other parts of the firmware code.

Motion Sensor

The motion sensor, PaPIRs, is a passive thermal detector that detects changes in infrared heat around its environment, like a person moving. These detections are turned into a digital signal that was passed to the CC3200 MCU. The signal from the motion sensor is essentially a button, On/Off, where if the signal is above a certain threshold it is programmed to be read as On and if below it's Off as seen in Figure 16. To prevent any problems from debouncing, the program used a simple delay. Using this logic, if motion was detected by the sensor, On signals were passed to the MCU. We used this motion detection for our privacy feature.

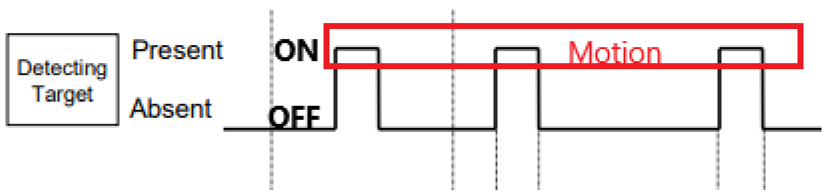


Figure 16: Motion Detector Logic

Wi-Fi

Setting up Wi-Fi was an integral part of WANDA's firmware because it enabled the device to receive updates that would be sent from the accompanying mobile application. The CC3200 has an integrated WiFi chip that enables wireless communication through an access point. The Ti SimpleLink Wi-Fi API [43] was utilized in order to connect the CC3200 to an access point and to make requests to the API that the team setup to receive requests for the mobile application. The core of the Wi-Fi integration was utilizing the Jasmine (JSMN) JSON Parser [44] because it is a lightweight JSON parser that does not require any additional memory. The parser was used to parse JSONs provided by the custom functions' setup in our cloud tooling. A sample of the JSON returned is shown in Figure 17.

```
{
        "A" : 20,
        "B" : 35,
        "C" : 50,
        "X" : 40,
        "P" : 1
}
```

Figure 17: Sample JSON Response

The letters A, B, C represent the setpoints determined in calibration, X is the position set from the app's slider for the new position of the blinds and P indicates whether the privacy setting is enabled on the app. The JSON was then parsed into a struct that mimicked the key value pairs in the response so that it could be used by other parts of the program.

Mobile Application and Database

The mobile application provides a simple interface to configure as well as control WANDA. The user interface for the application was brainstormed using Figma [45]. In order to ensure a convenient and straightforward design, the application consists of only two pages: the home page and the calibration page. The aforementioned pages were created to be minimalistic and are displayed below in Figure 18. The home page consists of a slider which would control the angle of tilt of the blinds, an eye icon button on the bottom left which can close the blinds, and a gear icon button on the bottom right to navigate to the calibration page. The calibration page contains two arrow buttons which either rotate the blinds clockwise or counterclockwise, three buttons which configure the positioning of three different tilt angles on the right, and one button which confirms the calibration as well as navigates back to the home page.

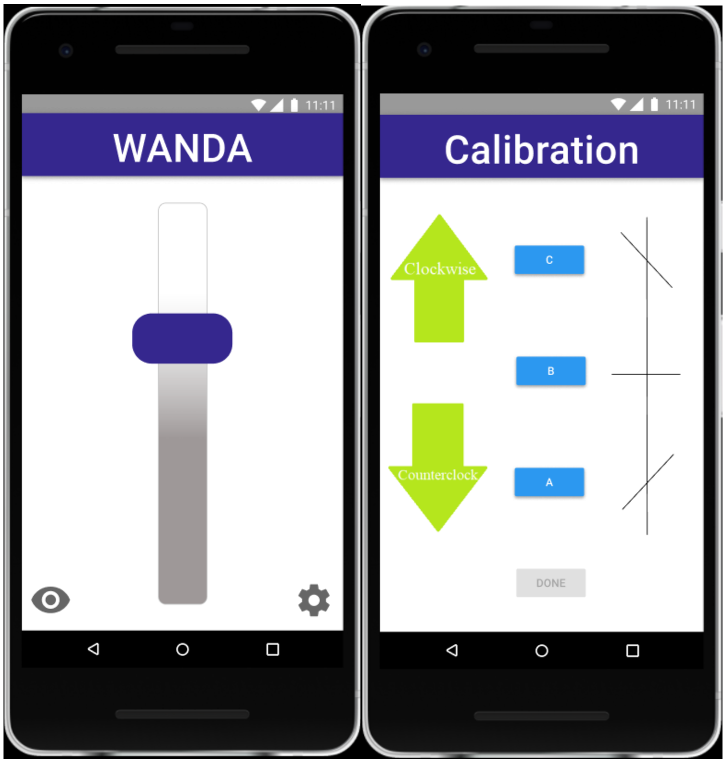


Figure 18: Figma Potential User Interface Designs

The mobile application was coded in Dart [46] using Flutter [47] on Android Studio [19] and an Android Virtual Device (AVD) was used to emulate the application on a phone. The final user interface design is shown in Figure 29. The slider has five different tilt states that the user can select and is connected to the eye icon button to match the visibility state of the slider. The position buttons on the calibration are disabled after being clicked and the "Done" button is enabled after the previous three buttons are pushed. On the calibration page, a picture of a person is displayed next to the different angle tilts for perspective.

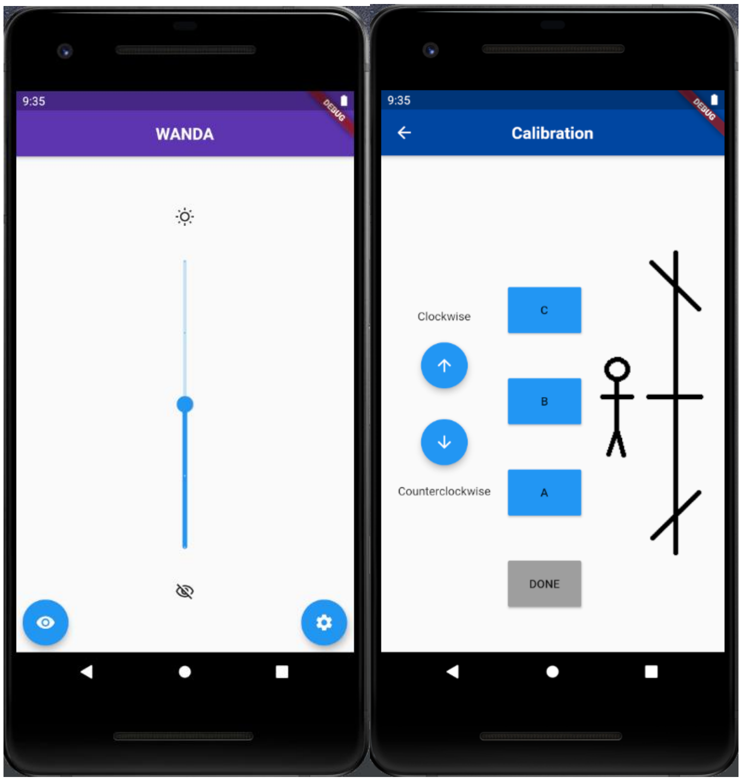


Figure 19: Android Studio Final User Interface Design

A Representational State Transfer (REST) application programming interface (API) was implemented to integrate serverless functions to read and write from the database. Data is written to the Cloud Firestore Database from the Android mobile application through an access point that connects the phone to the network and the application to the WANDA Firebase project [48][49]. Specifically, a completed calibration or any change to the window blinds tilt angle will send the relevant information to the database which will be read in JSON format from the CC3200 through the aforementioned custom-made cloud functions for Firestore. The previously stated database system is revealed in Figure 20 while the information stored in Cloud Firestore Database is shown in Figure 21 (some information is blocked for security purposes).

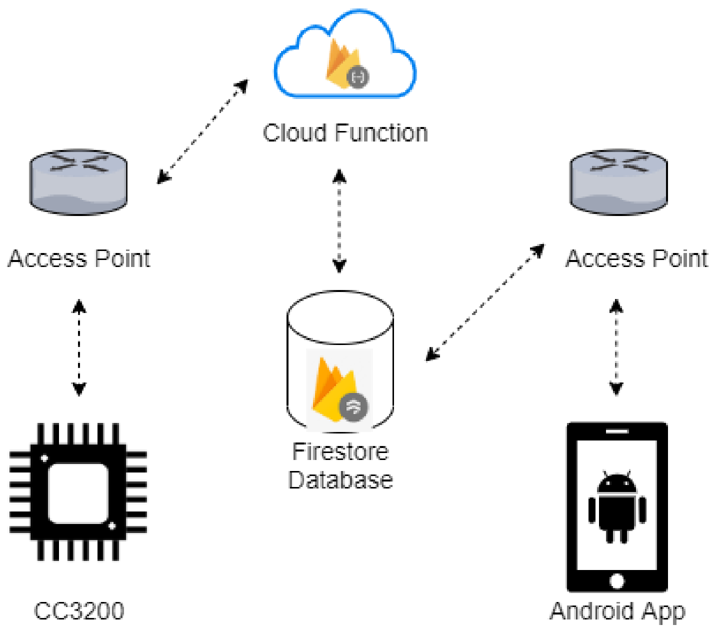


Figure 20: Cloud Firestore Database System

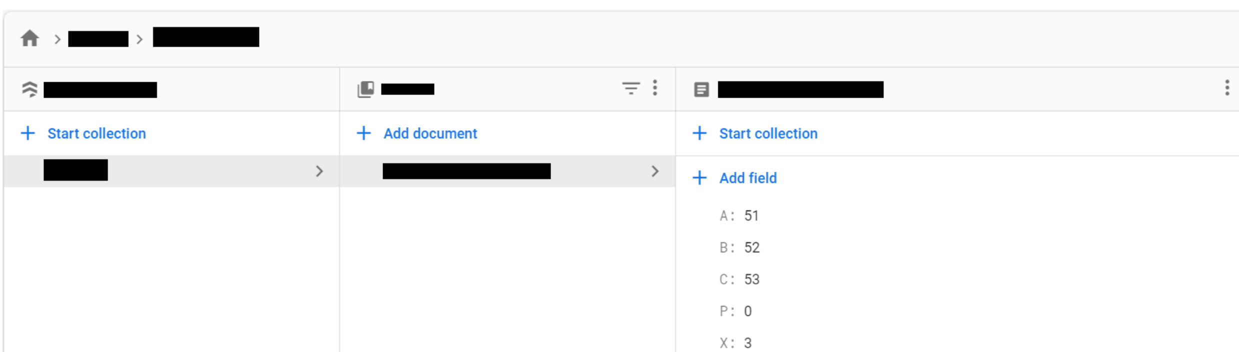


Figure 21: Cloud Firestore Database Information

Problems and Modifications

The team encountered three major issues and one critical issue throughout the project that resulted in modifications and some delays.

After testing the motor, we determined that the motor was not providing enough torque to rotate the blinds consistently, Powell suggested that we look at the current input for the motor and determined that not enough current was coming from the 4V regulator into the motor and driver. Since there was not enough time to request a new PCB, we decided to jump the 5V from the wall adapter into the driver and motor bypassing the output of the 4V regulator which has an input current of 5A. However, this new voltage and current input makes the driver overheat whenever all the connections are made on the PCB (wall adapter and microcontroller). Again, after discussing with Powell, he suggested that we should purchase a heat sink to make sure that the driver does not overheat.

CC3200 connections being reserved. One of the major problems that kept recurring throughout the development process had to do with particular ports on the CC3200 being reserved for other functionality. These ports were unfortunately found to be unusable after the final PCB had been sent out and the design was finalized. The team first encountered this issue with setting up the GPIO for the motor. Pin 55 was originally chosen as one of the GPIOs used to adjust the phase of the motor but according to the datasheet for the CC3200, pin 55 is connected to FTDI and needed a jumper (J7) to be moved in order to connect it to the GPIO port. But this would not be a final fix because after running into issues configuring our original pins for UART to work with the CC3200 library, we needed to switch to the default UART pin which was pin 55. Which meant we needed to move the GPIO for the motor to pin 61. This move to 61 was only possible after we realized that since the logic for the enables for receive and transmit on the RS485 were inverted, they could be controlled with the same GPIO. This freed pin 61 to be able to be used for the motor.

Another pin affected by switching the UART was that pin 57 could no longer be used for the ADC for the light sensor so that was moved to pin 58. Another motor GPIO pin that had additional functionality was pin 21 which was reserved for configuring the CC3200's sense of power (SOP) setting and needed an additional jumper to be set according to the CC3200 datasheet [50]. The next pin that had an issue was the GPIO for the motion sensor which was originally set to pin 17. When we were configuring this pin, the team realized through stepping through our code that every time that the pin was read from, the CC3200 would lose connection to the debugger. It was determined that pin 17 was actually reserved as a wake-up source and that accessing it would put the board to sleep, thus we had to move this functionality to pin 18. The final modification was done to the encoder's receive and transmit enable pins. Since their logic was inverted, they could be toggled using the same GPIO. All of these changes provided the team a lesson in digging deeper into the pin configuration for the chip before layout the connections.

The next major issue is when the team had to change from using Realtime Database to Cloud Firestore Database. This issue became apparent when the CC3200 was unable to retrieve the information from the current database and the implementation of custom cloud functions were incompatible with Realtime Database. Despite both databases being Firebase products, each database utilized different functions and had unique dependencies so the mobile application code required refactoring. After successfully modifying the database, the custom cloud functions had some initial problems with retrieving the data in JSON, but were eventually resolved.

The last major issue occurred late into the development of the project, only a few days before the project was due when the CC3200 stopped connecting over USB. This happened after the team attempted to fix the encoder's unstable connection which was a persistent issue. The terminal connections to the AMT21 needed to be inspected, but since the connection had not been undone in a while, the wires came loose. The team suspected that when this occurred, the encoder's 5V VCC may have come in contact with one of the GPIO inputs which have a maximum input voltage of about 3.3V according to the CC3200 datasheet and broken the

CC3200. Thus, the team had to order a new CC3200 quickly and was delayed for two days before the project deadline.

Project Timeline

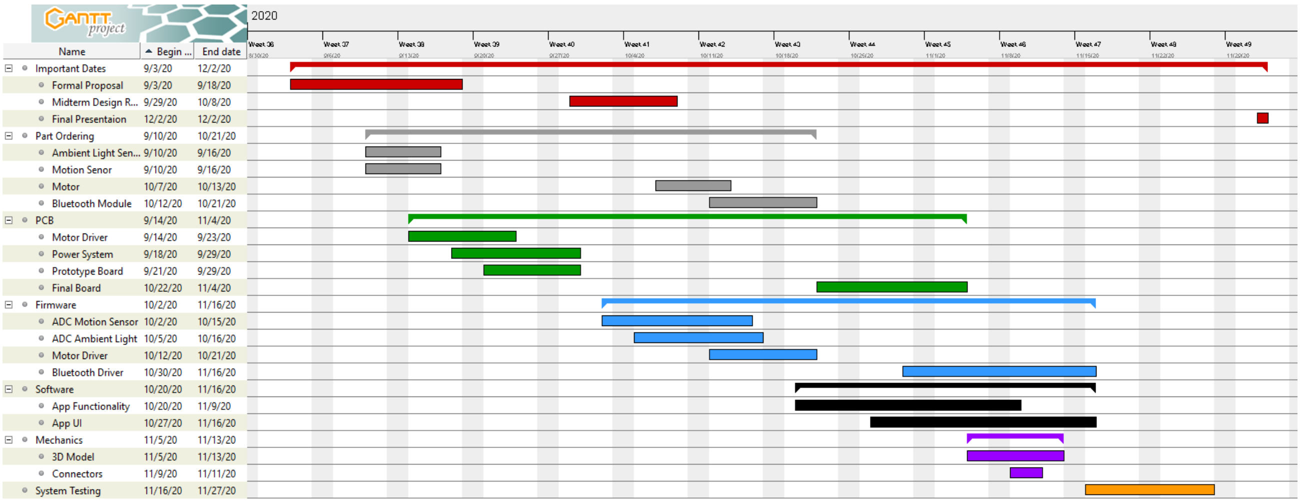


Figure 22: Project Timeline

Listed above is a Gantt chart that shows the timeline of the project with important dates and concepts. The important concepts are the firmware, PCB, mechanics, and software. The first thing that needs to be done is the ordering of parts to get a general idea of the layout for the prototype PCB to do development and testing. For the firmware, since the components either work in tandem or don't interact with each other, there is time for implementation in parallel. Once we have the components working and have the final layout of the design set, some 3D modeling (if needed) and connections are introduced and then system testing to determine if any mistakes exist or something needs improvement.

For the responsibilities of each member in the team, Brandon will be primarily tasked with software implementation such as development on the mobile application. Also, Brandon will have a secondary role as the financial manager to maintain the budget. Mesgana will be primarily responsible for hardware and firmware implementation such as integrating the sensors with the motor. Additionally, Mesgana will have a secondary role as the prototype manager to gather valuable references and necessary components. Kwadwo will be primarily tasked with ensuring appropriate testing is done at each stage of the project. Furthermore, Kwadwo will have a secondary role as the project manager to oversee the team's progress and evaluate sprints. Edward will be primarily responsible for designing the prototype and final PCB boards. Moreover, Edward will have a secondary role as the communications manager to organize meetings and interact with ECE staff on the team's behalf.

Test Plan

The major subsystems of the device were tested independently of each other to ensure they were working properly. Each subsystem was prototyped on a breadboard when their parts came in. The firmware for each subsystem was also tested independently of each other in order to isolate them for each other.

The main PCB that holds the majority of the components was designed to be easily able to test the data and power lines entering it. The first components that were tested when the full PCB came in after the regulators were soldered by 3W were the regulators. When the 3.3V regulator was originally tested, the team followed the test plan outlined in Figure 23 with a digital multimeter (DMM). The voltage shown on the DMM was not 3.3V but it also was not the 5V either.

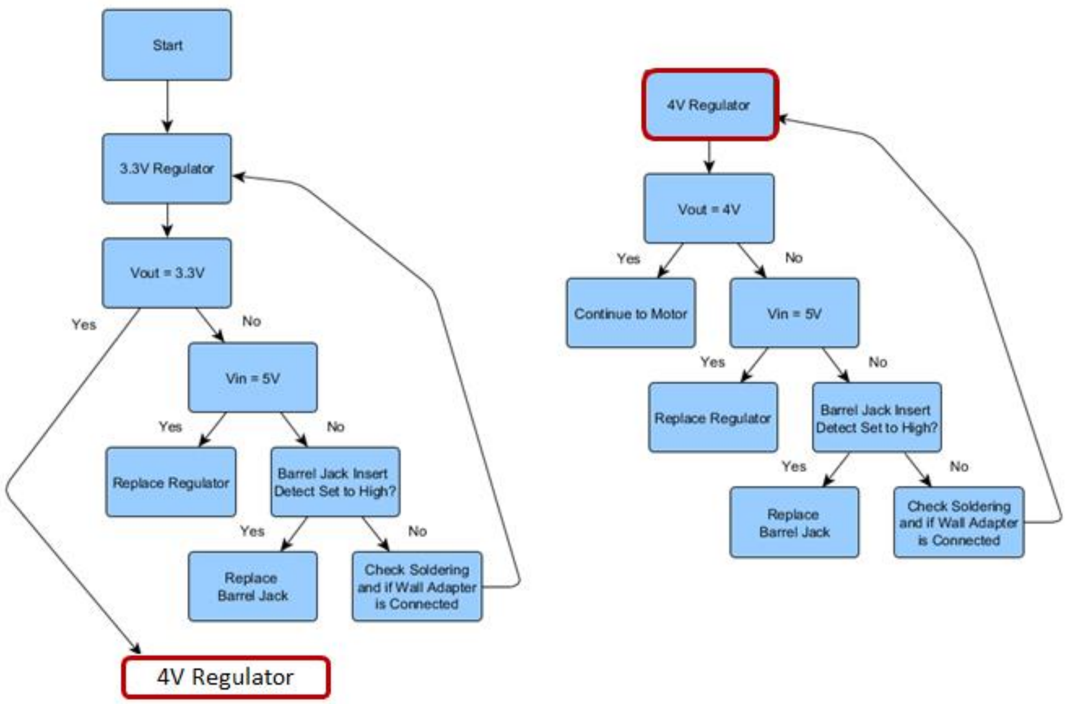


Figure 23: Regulator Test Plan

After looking at the datasheet [52] for the regulator and rechecking the schematics, the team realized that it had failed to enable the regulator by driving one of its pins to high. This was remedied by connecting the 5V trace on the PCB to the enables on both the 3.3V and 4V regulators. This design choice meant that the regulators would always be enabled which was the original plan. Once this was working all of the power traces connected to various components on the PCB were also tested.

Once the power levels were confirmed, the motor was tested. Initially the motor was tested with the driver chip on a breadboard with the same connections as PCB and was able to make the motor move in a set direction at a set speed with power supplied from the virtual bench. Once the motor was successfully moving on the breadboard to confirm the firmware operated as expected, the setup was moved over to the PCB. After making all the connections the team followed the test plan shown in Figure 24 to ensure it was working properly. Once power was supplied to the PCB the motor began to vibrate but not turn.

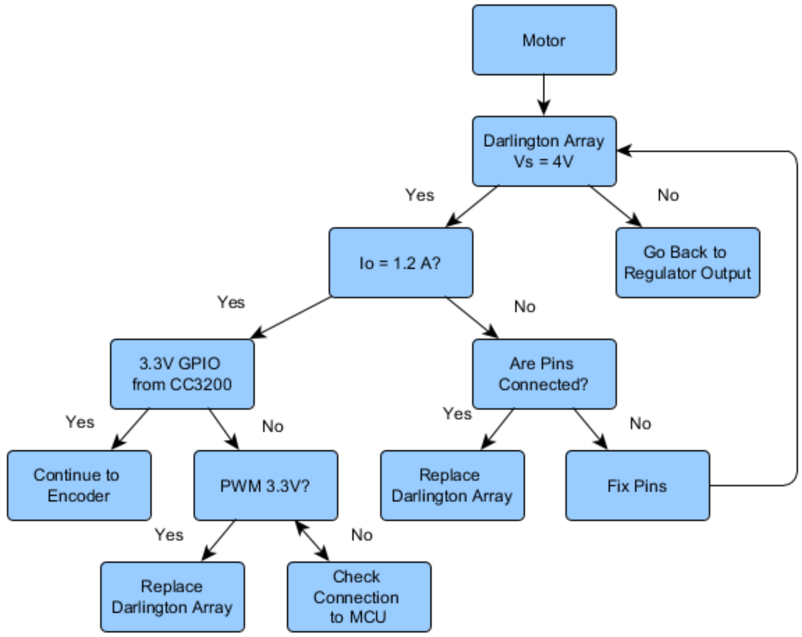


Figure 24:Motor Test Plan

Referring to the test plan, it was determined that the Darlington array was correctly receiving 4V from the regulator. The next step in the plan was to confirm that the Darlington array was receiving 1.2A, the rating on the motor for each phase to turn [27] with an ammeter. The ammeter showed that the current was far too low to turn the motor. The team soon realized that the 4V regulator being used could not output the necessary current because the max output current of the 4V regulator was 1A [52] but the motor needed 1.2A per phase to be driven. After consulting with the professor, the team decided to take the 5V output from the wall adapter and use that to power the motor. While powering a 4V motor with 5V did not pose a large problem, the increase in current resulted in drastic overheating from the Darlington array. To resolve this problem, the team added a heat sink to the Darlington array to try to dissipate the heat. While this helped some, the array was heated near its maximum capacity so we ran the motor as little as necessary.

In order to test the encoder, a simple setup was done on a breadboard with the transceiver and the encoder. Since the CC3200 was being used by another team member during this time, a simpler microcontroller was used to write and read the encoder. The test plan shown in figure 25 was used and Figure 26 shows the result of this testing.

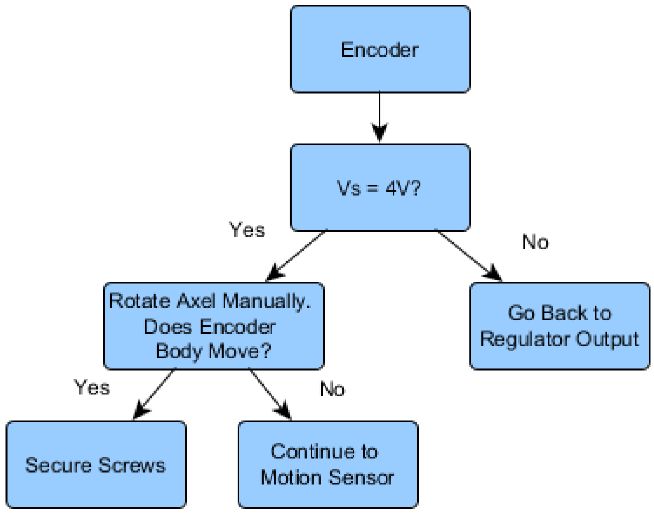


Figure 25: Encoder Test Plan

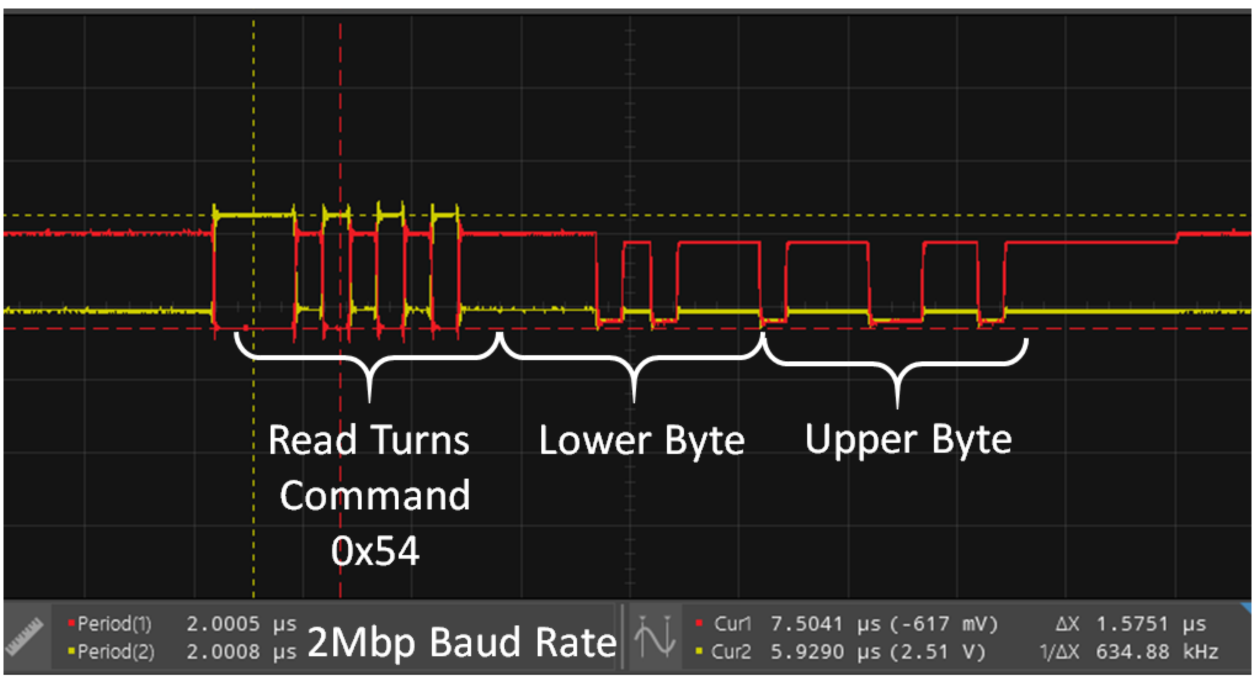


Figure 26: Encoder Signals Test

Final Results

The overall project worked quite well; WANDA was fully functional. The system contained most of the subsystems discussed throughout this report; accurate positioning with the motor, detected motion was conveyed to the motor, and the light sensor could open or close the blinds depending on the amount of sunlight. Table 3 provides the 5 criteria that we initially decided to determine the success of this project. Starting first with the light sensor, it could differentiate the varying levels of brightness decently staying in the blind positions we decided until it passed the thresholds we defined. The motor seamlessly turns the blinds at a consistent speed. It was possible to increase the speed of the motor, but we chose to keep it at a mid-level speed so as to not damage the blinds. The communication between the device and the app worked the best, within the calibration mode we could adjust the blinds in either direction. In the running mode we could close the blinds or set the blinds at one of the 5 preset values. Again, the motion detector conveyed its information to the sensor and closed the blinds, with the privacy mode enabled, depending on if motion has been detected. The blinds are set at the same mid-level speed when closing from motion to make sure the blinds do not get damaged. The power of the device was wired, but there were no LED indicators as we were focused mainly on the other components. Following this rubric metrics this device satisfies most of the criteria and looking at Table 4 it should be placed in the A grade range.

Expectations

Points	Light Sensing	Motor	Communication	Privacy	Power
3	Can differentiate varying levels of brightness	Motor smoothly opens and closes window quickly	Full control with app and physical input on device	Motion detection, blinds close quickly	Wired power with LED indicators
2	Senses couple levels of light brightness	Motor smoothly rotates but does not stop smoothly	Full control with physical input on device	Motion detection, blinds close	Wired power with no LED indicators
1	Only detects if light exists or not	Motor moves with jitters	Partial physical input on device	Motion detection works, blinds don't close	Wired power with most components powered
0	Cannot detect light	Motor incapable of moving wand	No physical input on device	No motion detection	Wired power but only a few elements get power

Table 3: Grade Rubric

Points	Grade
12-15	A
8-11	B
4-7	C

0-3	D

Table 4: Points to Letter Grade

For our final results, the last column referencing power in Table 3 changed from battery to wired due to various considerations such as how an additional container to hold the batteries would be required for the project as well as the environmental impact of batteries relative to AC wall adapters [53]. Additionally, we changed the communication column because we initially stated that the device should work with physical buttons, but we realized afterwards that this completely defeats the purpose of the convenience of WANDA.

The encoder was having connection issues at the two female connections to connect the wires from the encoder to the PCB and were unstable at some points. While trying to figure out this issue the RS485 got fried and we had to work with just the stepper for demoing. The stepper motor was fairly accurate in our testing which helped us out. However, the encoder is an included component of WANDA to make sure that the blinds do not get damaged when the system gets power cycled. While the connection was stable, we could accurately get information from the encoder depicting either the number of turns or the 2^{14} number associated position of the encoder's turn.

Disregarding the encoder, WANDA could show everything that we initially thought of and with more experience with this specific microcontroller we could have avoided some potholes. Better understanding the functionality of the pins on the microcontroller would have saved us a great time and energy.

One of the major takeaways from this project was test driven development in both firmware and hardware. By debugging smaller sections of the PCB or code as they were being built, the team was able to catch errors quicker and resolve them faster since there were fewer moving parts.

Costs

The total cost of producing one WANDA system for this project was calculated to be $374.87 and the breakdown is displayed in the Table 5 below. This table includes every purchase made for the project including backup components.

Expenses	Cost
MCU (CC3200-LAUNCHXL)	$35.99
Second MCU and Shipping	$71.96
PCB and Shipping	$33.00
Phoenix contact- Male (1781027)	$9.60
Phoenix contact- Female (1755778)	$1.92
Wire contacts (5025790000) 10x	$0.45
Motor Driver (ULN2064B)	$2.81
Light Sensor (OPT101P)	$8.80
Motion Sensor (EKMB1393111K)	$12.62
Encoder (AMT212D-V)	$56.07
RS485 Transceiver (MAX485EPA+)	$4.01
Encoder Connector Male (5025780600) 2x	$0.64
Encoder Connector Female (5031590600)	$0.57
Wall Adapter (KTPS36-050500WA-VI-P1)	$18.42
Barrel Jack (54-00133)	$0.97
4 V Regulator (TLV75740PDRVR)	$0.61
3.3 V Regulator (TLV73333PDBVR)	$0.32
MCU to PCB (ESQ-110-14-T-D) 2x	$5.80
4 Pin Connector Female (TJ0431530000G) 2x	$2.78
4 Pin Connector Male 180 (OSTOQ043250) 2x	$1.78
8 Pin Sockets 2x	$0.40
16 Pin Socket	$0.25
Test Points 12x	$4.80
Another Light Sensor (OPT101P)	$8.80
6 in Crimped Wires 10x	$6.78
4 V Regulator (TC1015-4.0VCT713) 2x	$0.72
Lowes+Heak Sink	$29.19
Eddie/Stepper Motor (1200)+Crimped Wires 12in M-M 4x+Crimped Wires 6in M-M 6x	$38.01
Shaft Couplers	$14.85
Male to Female Wire Jumpers	$1.95
Total Cost:	$374.87

Table 5: Finances

The total cost of one WANDA system if one unit was produced is 223.22 while the total cost of one WANDA system if 10,000 units were produced is revealed to be $161.56. Therefore, there is a $61.66 difference if the project was mass-produced. A detailed table is located at Appendix A. The costs for reading and writing to the database is not accounted for as that is dependent on not only the number of users on the mobile application, but also how active the users are. Additionally, Cloud Firestore database offers 50,000 free reads as well as 20,000 free writes and deletes.

Future Work

The team offers four areas that could be improved from the current WANDA project: sensing, PCB design, mobile application features, and source of power.

Although motion sensing could capture people moving nearby and send a signal to close the window blinds, trespassers could stand still in front of the window until the window blinds open up which may not be detected by the motion sensor. This problem could be resolved with the implementation of a proximity sensor. Specifically, if someone were to approach the window, the proximity sensor will determine if the detected object has passed the selected threshold and notify the microcontroller unit. Thus, even if the trespasser were to stand still, the proximity sensor will be able to notice their presence. A version of WANDA that uses both the motion sensor and proximity sensor could also be considered.

The main PCB design could be more compact and made into a smaller form factor. This would help with making mounting easier for consumers, in addition to helping with visual presentation. There was a lot of space between components that could be reduced and, in turn, reduce the overall size of the PCB. Smaller components can be found for most of the electrical components that were used for this project. Although this might increase the production costs, we predict that the costs would be minimal.

Four additions to the mobile application could improve user experience and overall automation of the WANDA system. The first feature is to incorporate a scheduling function that opens and closes the blinds based on calibrating sunrise and sunset illuminance levels. The second feature is to have notifications when the motion sensor detects a trespasser and the window blinds close. The third feature would include user accounts for security and customization which could be integrated with Firebase Authentication. The fourth feature would be compatible with a smart assistant such as Amazon Alexa, Google Assistant, and Apple Siri for voice control of WANDA.

Like in our original plan, the source of WANDA's power could be switched to a battery. The use of a lithium-ion battery would provide additional flexibility in placement and mounting. Solar power would provide the same benefits, but would be more environmentally friendly.

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Appendix

Appendix A

Component	Quantity for 1 WANDA	Cost per unit for 1 unit	Cost for 1 WANDA if 1 was produced	Cost per unit for 10000 units	Cost for 1 WANDA if 10,000 were produced
CC3200	1	$ 35.99000	$ 35.99	$ 35.99000	$ 35.99
PCB and Shipping	1	$ 33.00000	$ 33.00	$ 2.17000	$ 21.70
Phoenix Contact Male	1	$ 9.60000	$ 9.60	$ 5.83600	$ 5.84
Phoenix Contact Female	1	$ 1.92000	$ 1.92	$ 1.19100	$ 1.19
Motor Driver	1	$ 2.81000	$ 2.81	$ 0.95000	$ 0.95
Light Sensor	1	$ 8.80000	$ 8.80	$ 3.01200	$ 3.01
Motion Sensor	1	$ 12.62000	$ 12.62	$ 5.29700	$ 5.30
Encoder	1	$ 56.07000	$ 56.07	$ 44.09100	$ 44.09
RS485 Transceiver	1	$ 4.01000	$ 4.01	$ 1.87100	$ 1.87
Encoder Connector Male	2	$ 0.32000	$ 0.64	$ 0.09400	$ 0.19
Encoder Connector Female	1	$ 0.57000	$ 0.57	$ 0.23909	$ 0.24
AC Wall Adapter	1	$ 18.42000	$ 18.42	$ 10.05700	$ 10.06
Barrel Jack	1	$ 0.97000	$ 0.97	$ 0.41300	$ 0.41
3V Regulator	1	$ 0.32000	$ 0.32	$ 0.41975	$ 0.42
Elevated Socket	2	$ 2.90000	$ 5.80	$ 1.40100	$ 2.80
4 Pin Connector Female	2	$ 1.33000	$ 2.66	$ 0.33200	$ 0.66
4 Pin Connector Male	2	$ 0.89000	$ 1.78	$ 0.11800	$ 0.24
8 Pin Sockets	2	$ 0.20000	$ 0.40	$ 0.05700	$ 0.11
16 Pin Socket	1	$ 0.25000	$ 0.25	$ 0.07300	$ 0.07
4V Regulator	1	$ 0.36000	$ 0.36	$ 0.18200	$ 0.18
Stepper Motor	1	$ 21.28000	$ 21.28	$ 21.28000	$ 21.28
Shaft Coupler	1	$ 4.95000	$ 4.95	$ 4.95000	$ 4.95
Total Cost			$ 223.22		$ 161.56

Table 5: WANDA Unit and Total Costs