The Autonomous Smart Window

Group 7

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Project Overview

Project Motivation

Abdullah Husain

- Many intriguing window options and accessories exist, but very few multifunctional options are available
- Consumers are forced to pick and choose between which features they want
- Futuristic window features are easy to implement but are not yet mainstream
- Most, if not all, available window features can be incorporated into a single window unit design
- It is extremely difficult to find autonomous window accessories despite modern technological advances

Project Goals and Objectives

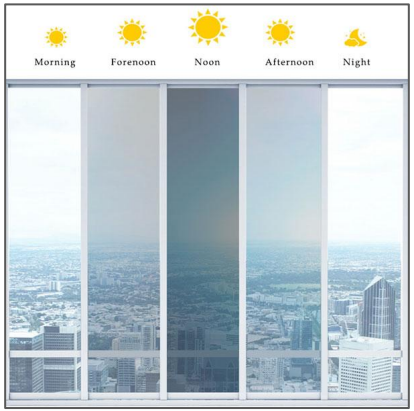
Abdullah Husain

Our goal is to design a window unit that incorporates the following features:

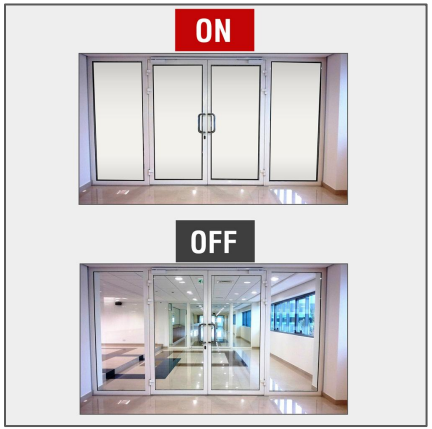
- Variable tint
- Dimmable privacy screen
- Colorful LED lighting
- UV and infrared protection (heat prevention)
- All features controlled via mobile device
- A network of sensors allows for autonomous operation
- Supports various autonomous modes:
  - Security mode
  - Economic mode
  - User-defined schedule
- Maintain a compact and aesthetically pleasing appearance at all times

Stretch Goals:

1. Install an LCD display on window to provide system feedback/info to user
2. Fully develop an Android application to control every aspect of window
3. Allow user to define schedule for window
4. Alexa (or other smart home device) compatibility
5. Incorporating window art/monogram via additional polarizer



Reference 1



Reference 2

Specifications

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The following table summarizes 6 specifications for the Smart Window, with the demonstrable specifications highlighted.

Spec #	Detailed Specification
1	Variable Tint: Window's light transmissivity can be varied between 5% and 45%
2	Privacy Screen: Window's transparency can be varied between 10% and 75%
3	LED Lighting: Window can emit 10 different colors of light uniformly across window (when privacy screen is engaged)
4	Security Monitoring: Window can scan for outside motion within 7m, and engage privacy screen when motion is detected
5	Light/Heat Management: Window can monitor incident sunlight and vary tint percentage if too much light is detected (threshold defined by user)
6	User Control via Mobile Device: Each of the above features can be controlled or toggled via computer or mobile device that is connected to the same WiFi network as the Smart Window.

Block Diagram

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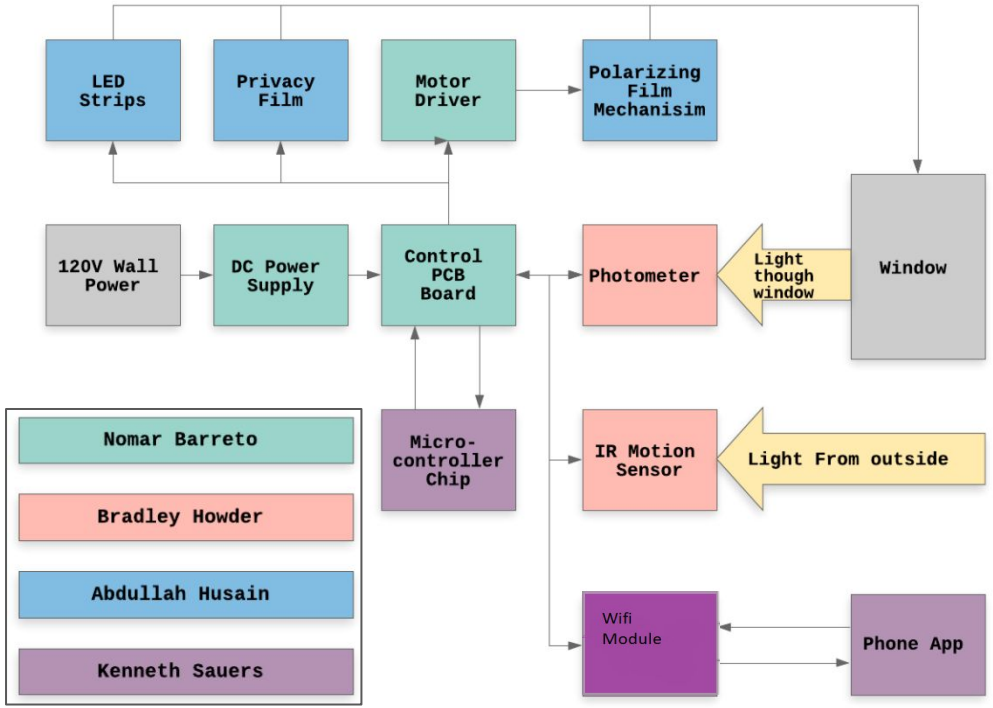

Autonomous Operation:

- Photometer and IR motion sensor send input signals to PCB
- PCB and microcontroller process inputs, send output signals to privacy screen and motor driver
  - Motor driver varies tint level

User Operation:

- Mobile app sends signals via WiFi
- WiFi communicates with PCB via ESP32, allowing user to control all features

Window Unit Design and Optical Features

Window Unit Design

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We designed and built a custom window unit:

- Encasement is 19.5”x19.5”x3.75”
  - Made with Birch wood
  - Sealed with oil-based polyurethane
  - Provides ample space to house all electrical/mechanical components
- Window is double-pane plexiglass
  - Plexiglass is lightweight and less delicate than traditional glass
  - Over 3.5” between panes to place films, LEDs, and rotating mechanism in-between
  - Window is circular (11.5” diameter) to compliment rotating features (to be discussed)
  - Exterior pane faces outside, interior pane faces towards the room
- Swings open via hinges for easy access

PDLC Privacy Screen

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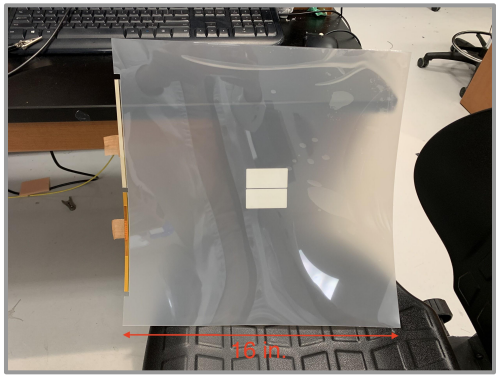
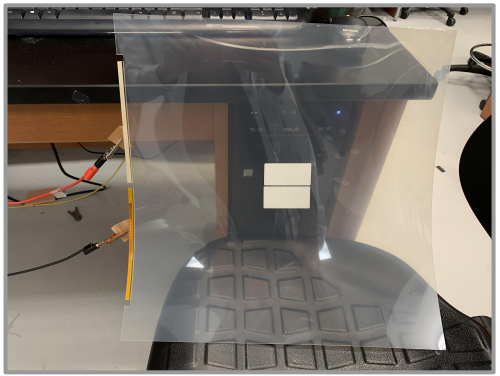
- With no voltage applied, screen stays in “privacy mode”, scatters incident light
- Applying DC current aligns liquid-crystal molecules, makes screen more transparent and scatters less light
  - Between the range of 0V and 30V, screen can be dimmed to the desired haze level
  - With 30V, screen becomes completely transparent
  - Switches on/off within 400 milliseconds
- Screen placed between panes, attached to the interior pane via adhesive
- Blocks out 99% of UV and 99% of IR when in “privacy” mode

Why use Invisishade PDLC screen?

- Cheaper than competitors
- Switchable and dimmable
- Looks nice when in privacy mode
- Light scattering effect is required for LED lighting
- Only other privacy alternative was one-way mirror film, but it does not satisfy the above requirements





LED Lighting Effect

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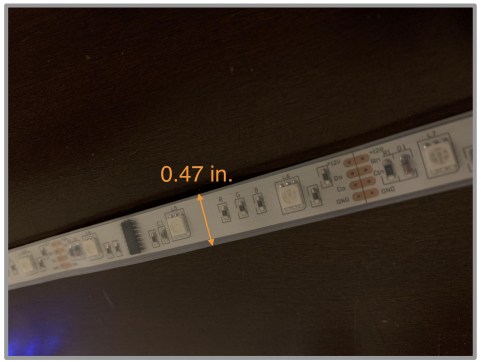
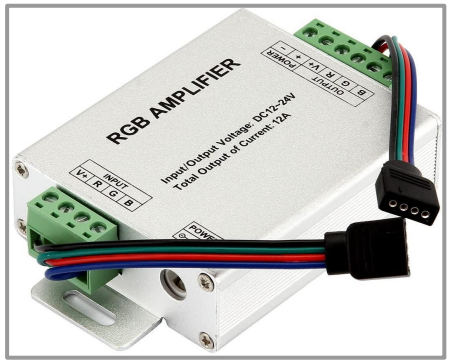
Color-varying LED strips:

- Mounted between window panes, directly facing privacy screen
- When privacy screen is in “privacy mode”, LEDs can be turned on
- Privacy screen will scatter LED light, illuminate entire window
- Scattered light is bright enough to act as a decorative light source in a dark room
- Color can be selected via mobile app
- Circuit requires LED amplifier, shown below





Why use SMD5050 LED strips?

- High lumens output
- Flexible and small, easy to mount around the inside of the window
- Large color gamut
- Multiple group members already had LED strips on hand
- Relatively inexpensive
- LED strips contain many periodic light sources instead of a few high-power sources, providing more uniform lighting across window

Variable Tinting: Polarizing Films

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Variable tint is accomplished via two linear polarizing films:

- Both films placed between window panes
  - First film mounted against exterior pane, determines the optical axis
  - Second film mounted on a rotating bearing, placed between the first polarizing film and the interior pane
- Whe oriented along same optical axis, 45% of visible light is transmitted
- Bearing rotates via pulley system, rotating the second polarizing film
- Rotating second polarizer off of optical axis results in tinting effect
- Angle can be selected to achieve 45%-0% light transmission through window

Why use linear polarizers to achieve variable tint?

- Photochromic films do not allow user to control tint levels
- Other alternatives are low quality, have an unwanted color filtering effect
- No other affordable, high-quality alternatives
- Linear polarizers obey Malus' Law, allow for precise control over tint level

Variable Tinting: Rotating Mechanism

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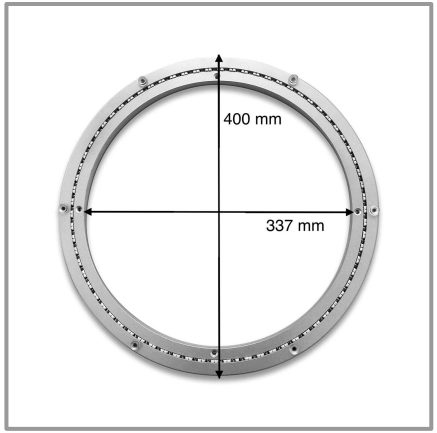
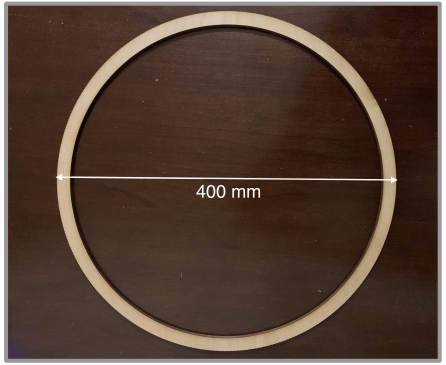
The gear/pulley system is responsible for precisely altering the window's transmissivity:

- 400mm diameter gear attached to rotating bearing
  - Gear was laser cut from birch wood
  - 1,256 teeth
- 13mm diameter gear attached to stepper motor
  - Made of aluminium
  - 20 teeth
- Round toothed rubber timing belt responsible for torque transfer
- Step size of stepper motor can rotate polarizer in increments of .0286 degrees
  - Extremely precise control over tint levels





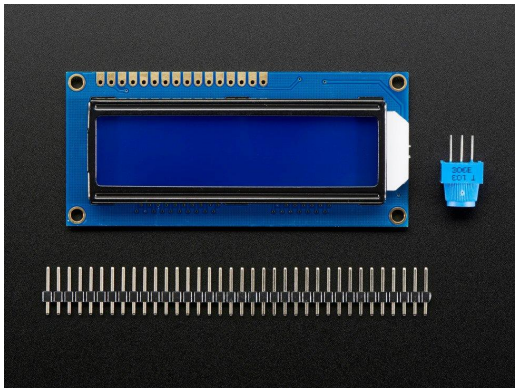
LCD Display

Abdullah Husain

- LCD unit mounted on window, facing inside the home
- Displays information related to window operation
- 3D printed encasement covers wiring

Why the Adafruit Standard 16x2?

- Very inexpensive and space-efficient
- Easy to integrate
- Contains a backlight
- Adjustable contrast
- All other displays (ie. LED) were more expensive and offered functions that were unnecessary and excessive for a stretch goal



Reference 5

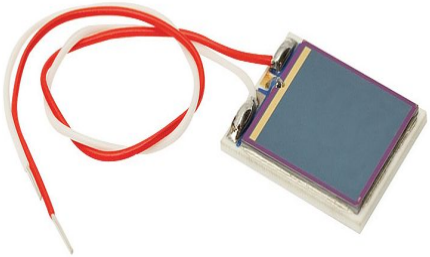
Detecting Lumen Output

Goal:
To create a natural light illumination/delumination device built inside of the window allowing for the user to control how much light passes through the window at any given time using the rotating polarizers.

Approach:

- Real-time measurement of the incident light coming through the window.
- Small enough to maintain Aesthetic appearance

Light Dependent Resistor Pros	Photodiode Pros
Low cost	Fast response time
Durable	Accurate and precise measurements
Low operation cost	Low noise and high light sensitivity



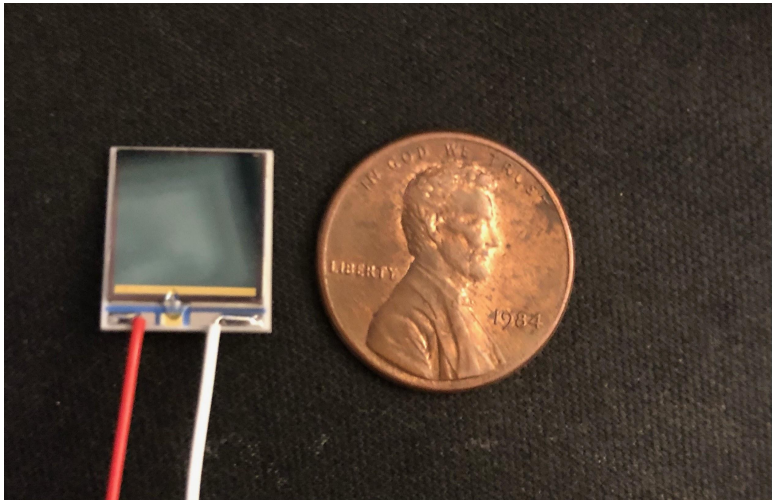
Thorlabs FDS1010 Photodiode

ORP12 light dependent resistor

Photometer Design

Function: Photodiode will receive light and convert incident light power to lumens. Polarizers will rotate until the desired lumen level in the room has been achieved.

Photodiode - FDS1010	
Wavelength chosen for Lumen measurement	555 nm
Responsivity at 555 nm (R_λ)	0.25 A/W
Max dark current (5V)	600 nA
Capacitance (5V)	375 pF
Rise time	65 ns

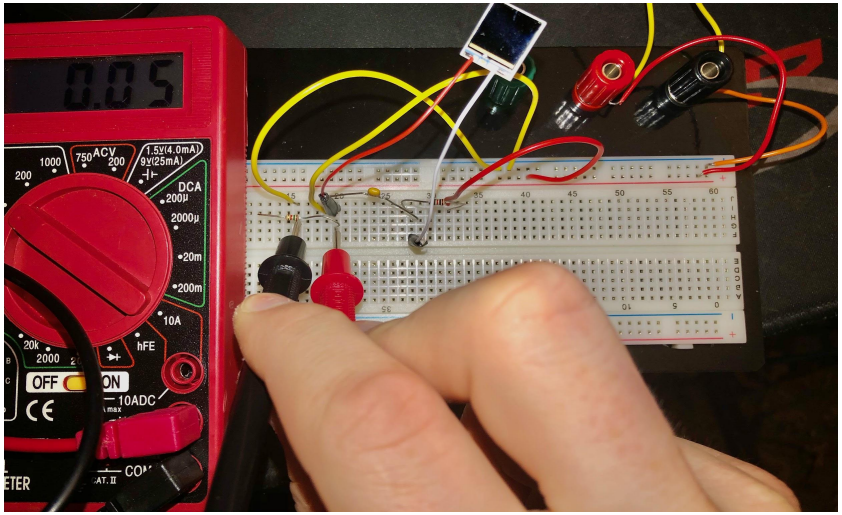


Photodiode- Thorlabs Fds1010

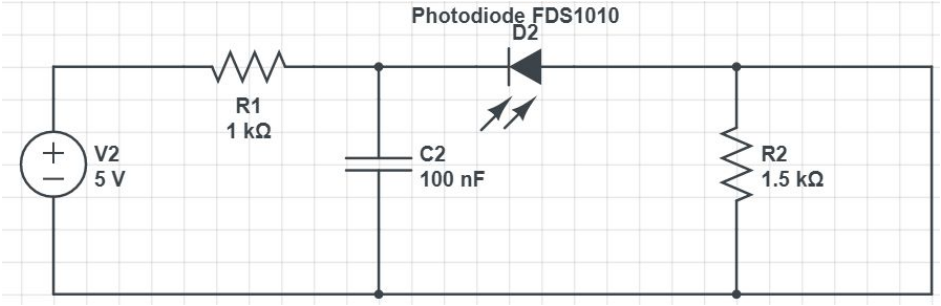
- Price: $55.73
- Wavelength Range 350 nm - 1100 nm
- Size: 1 cm x 1 cm

Photodiode Circuit Design

- Resistor R1 and capacitor C2 will be used as the noise filter.
- The voltage source is the reverse biased voltage, allowing for faster rise and fall times.
- Resistor R2 will be the load resistor where the photocurrent generated will be converted to voltage.



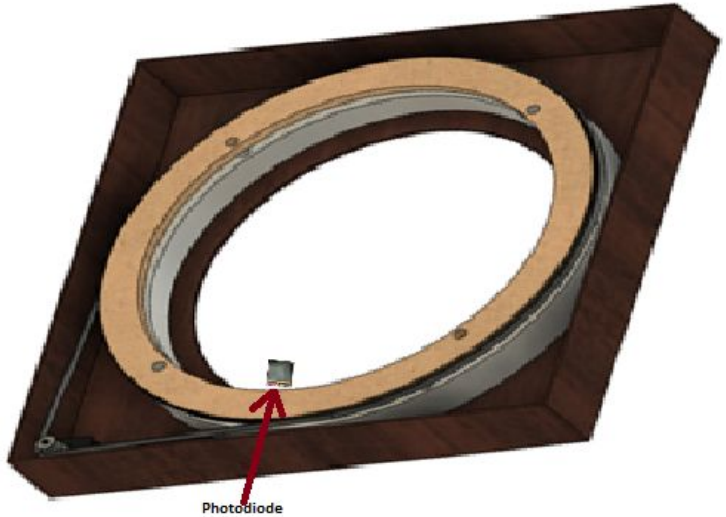
Photodiode Circuit test in low light.



Photodiode Circuit Schematic

Photometer Implementation

- $P_{(Watts/cm^2)} = I_{(photocurrent)} / R_{\lambda(responsivity)}$
  → Relationship of photocurrent to power
- $P_{(Watts/(cm^2))} = (V_{(out)})/(V_{(Bias)} * R_{\lambda(responsivity)} * R_{L(Load\ resistor)})$ → Relationship of photo voltage to power
- $P_{(Watts)} = (P_{(Watts/cm^2)} \times A_{(window\ area)})$
  → Relationship between photodiode area and window area
- Lumens = $P_{(Watts)} \times 683 \times y(\lambda)_{(photopic\ standard)}$
  → Relationship between generated watts and perceived brightness of window
- Difficulties:
  - Trouble implementing photodiode where incident sunlight can fully strike the surface without compromising aesthetic appeal.



- Window frame model with rotating polarizers
- Photodiode attached to inside window pane

Motion Detection

Goal:
To create a privacy/security system that will give the owner peace of mind. When somebody walks by the window or attempts to peer through the window up close the privacy screen will turn on.

Passive Infrared Motion Sensor	Ultrasonic Motion Sensor (RADAR)
Line of sight detection	No visibility detection
Low cost	Medium cost
Blackbody radiation detection method	Frequency detection method

Approach:

- Real-time monitoring of human motion passing in front of window.
- Long range and low cost with low false detection rate

Panasonic AMN 34111

Price: $13.68

URM06 - Analog Ultrasonic Sensor

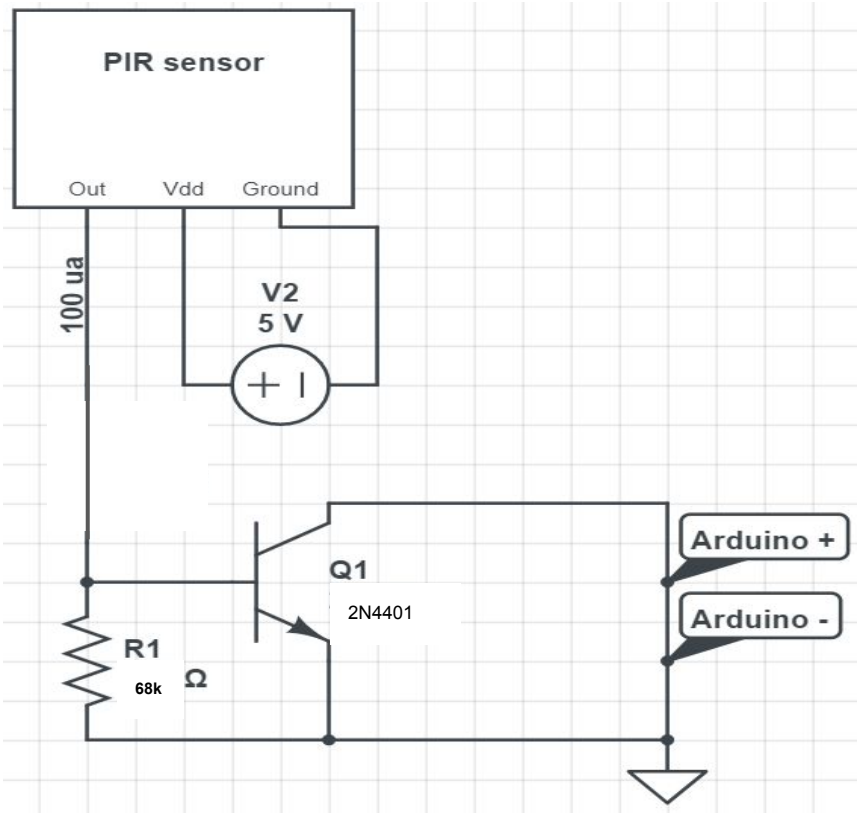
Price: $59.90

PIR Motion Sensor

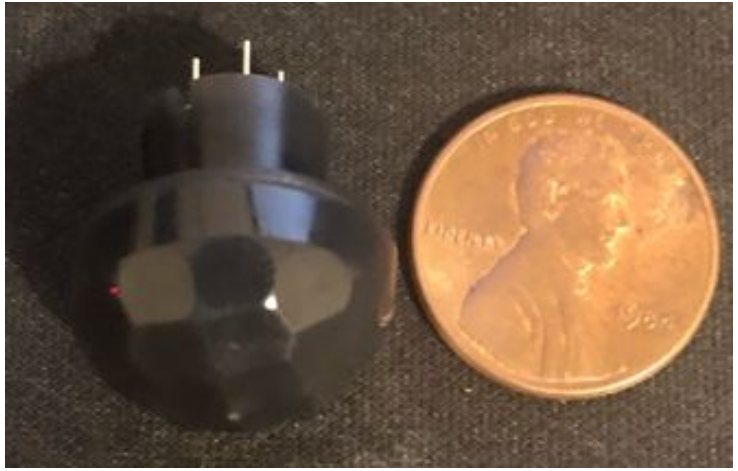
Panasonic AMN34111	Detection Characteristics
Detection range (max)	10 m
Detection angle horizontal (max)	110°
Detection angle vertical (max)	93°
Circuit stability time	7s (typical) 30s (max)

Panasonic AMN34111	Operating Characteristics
Vdd	3V DC (min) 6V DC (max)
Output current (detecting)	70 µa
Output voltage (detecting)	Vdd - VL(load)
Transistor type	NPN

PIR Motion Sensor Design



Motion sensor circuit design



Pansonic AMN 34111

Range: 10m

Size: 18.53 mm x 17.4 mm x 17.4 mm

Motion Sensor Implementation

- PIR motion sensor lens cap must protrude 5.6 mm outside of window to achieve maximum horizontal and vertical angle .
- Will communicate with mobile app to enable on/off functionality.
- Maximum detection range of 10 m due to ambient temperature range may vary from 7-10 m.
- Difficulties:
  - Protecting the motion sensor lens cap without sacrificing range and aesthetic appeal.

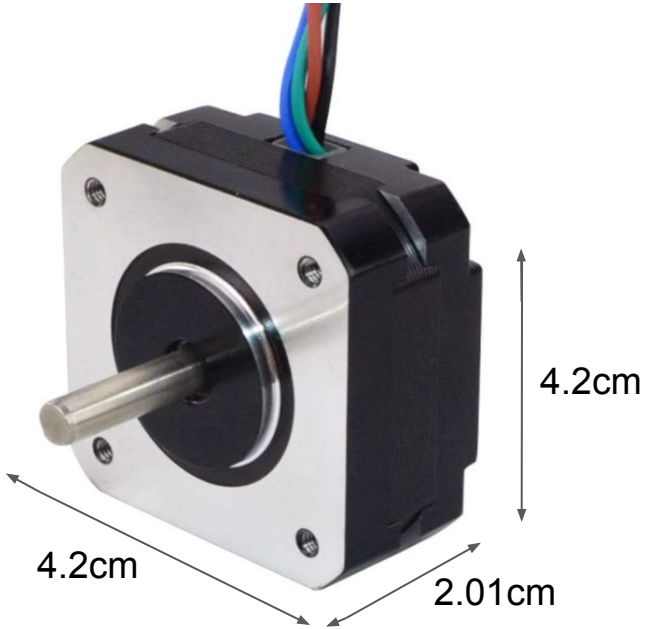
Smart window with PIR sensor placed outside

Electrical Components

Stepper Motor

Manufacturer	OSM Technology	Twotrees	SIMAX3D
Step Angle	1.8deg	1.8deg	1.8deg
Holding Torque	13Ncm	42Ncm	14Ncm
Rated Current/phase	1.0A	1.5A	1.5A
Phase Resistance	3.5Ω	1.5Ω	4.0Ω

OSM Technology NEMA 17 Stepper Motor (17HS08-1004S)



- Price: $10.99
- Type: Bipolar
- Voltage Rating: 3.7V

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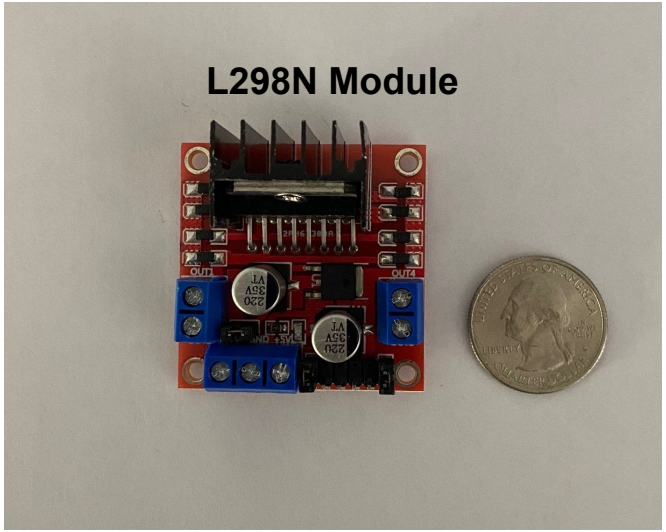
Motor Driver

Function:
Take a low-current signal and turn it into a high current signal to drive the stepper motor to rotate the polarizing film mechanism.

Motor Driver Model	L289N	L293D	BTS7960
Manufacturer	SongHe	NOYITO	Aideepen
Operating Supply Voltage (Max)	46V	25V	27V
Max Continuous Output Current per Channel	2A	600mA	43A
Motor Types Compatible	DC & Stepper	DC & Stepper	DC



- Power Consumption: 25W
- Dimensions: 43x43x27mm
- Price: $8.71 (3 modules included)
- Input Voltage: 12V

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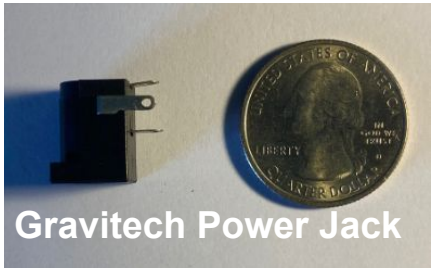
AC Power Adapter & Connector

Function:
Take 120V AC voltage from wall and provide DC voltage to PCB and all other components.

Manufacturer	TMEZON	Maxson
AC Input Voltage	100-240V	100-240V
DC Output Voltage	12V	15V
Current Rating	2A	2A
Max Wattage	24W	30W
Power Plug Dimensions	2.1mm x 5.5mm	2.1mm x 5.5mm, 2.5mm x 5.5mm
Cord Length	8ft	6ft

TMEZON Power Adapter

- Price: $7.99
- Configuration: Center Positive
- Frequency Range: 50-60Hz


Gravitech Power Jack

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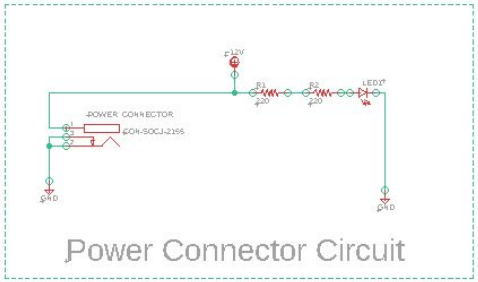
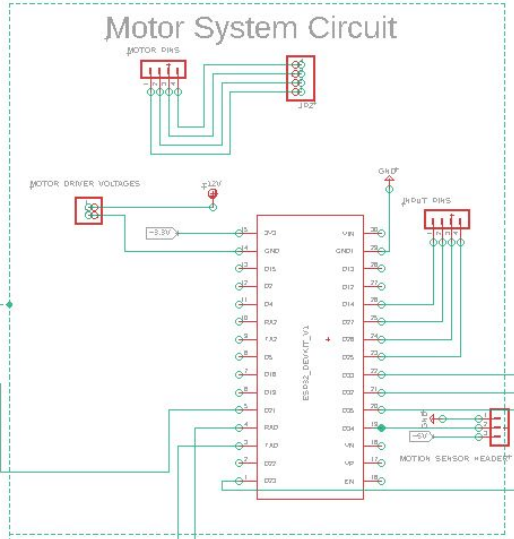
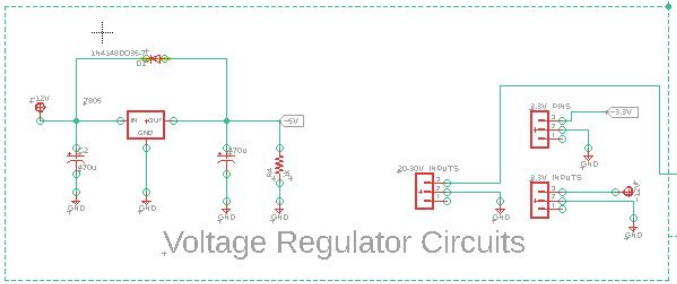
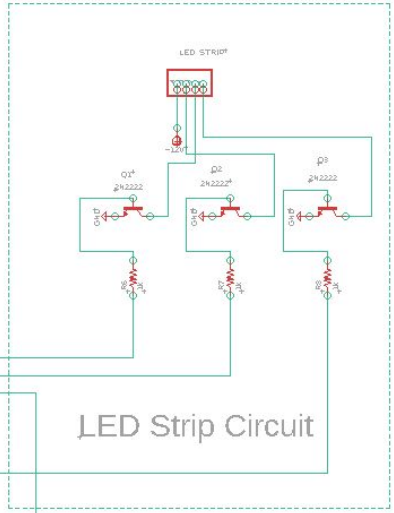
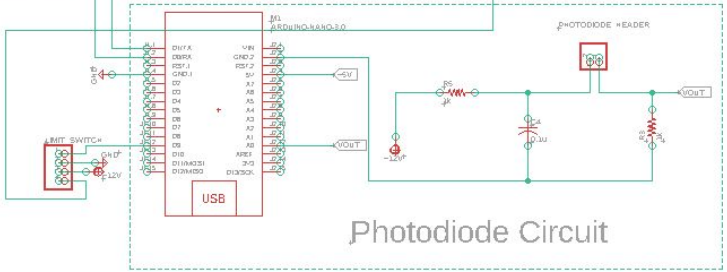
PCB Schematic 1











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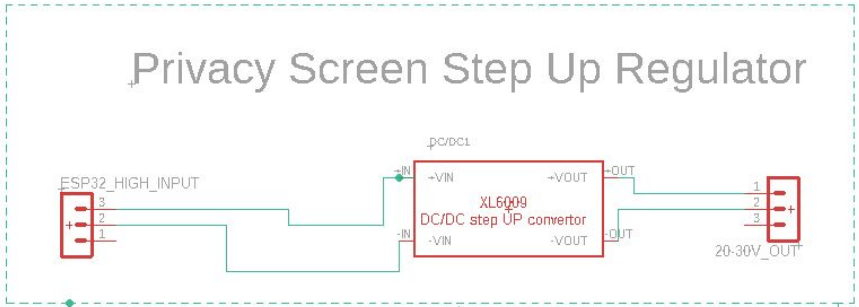
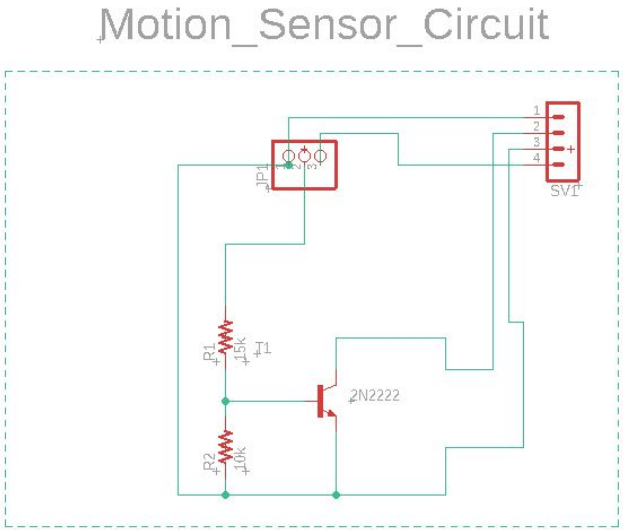
PCB Schematic 2



Mounting Holes



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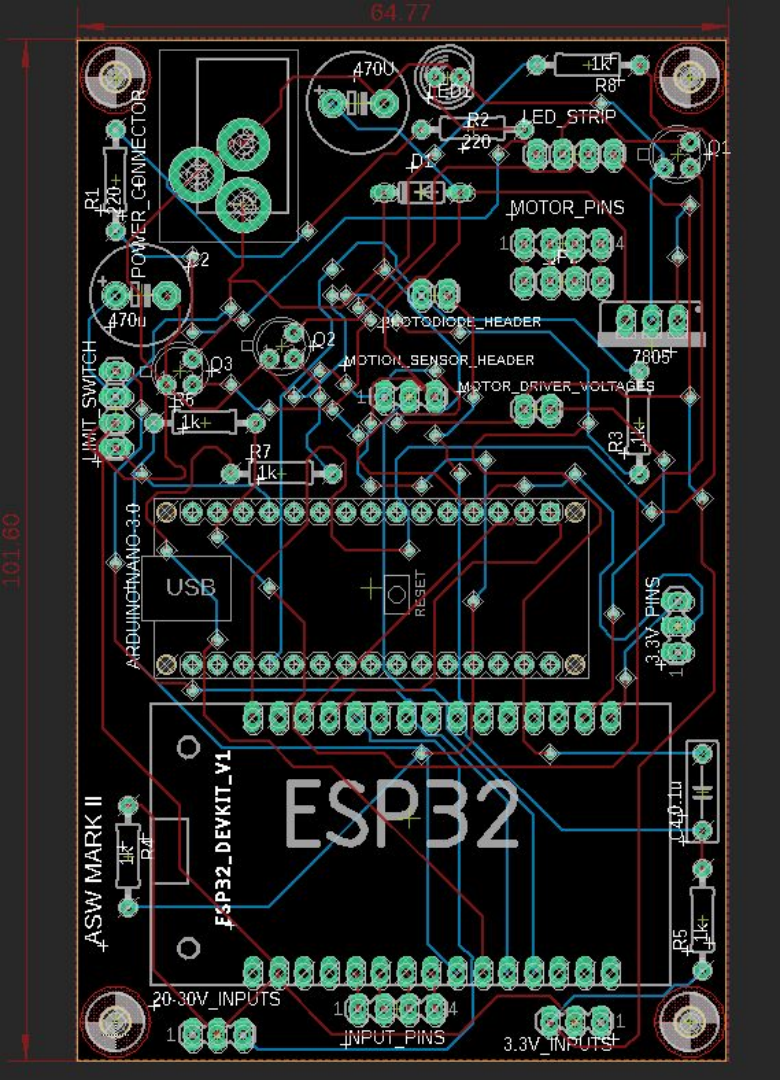

PCB Layout 1

Board Purpose:

Receive 12V DC voltage from AC adapter to power all subsystems. Includes headers for external connections.

- Layers: 2
- Current Dimensions: 64.77mm x 101.60mm
- Copper Pours: 2
- Manufacturer: JLCPCB
- # of Boards: 5

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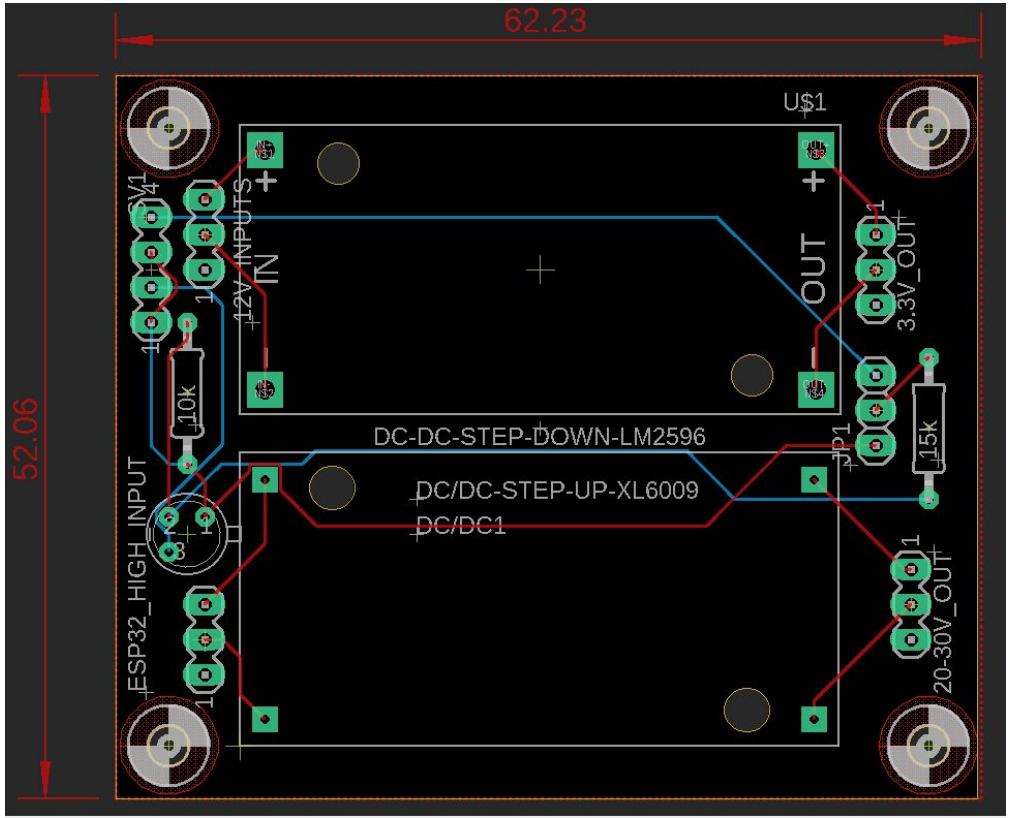
PCB Layout 2

Board Purpose:

Contains a buck converter and a boost converter to step down and step up the voltage. Also contains motion sensor components and headers.

- Layers: 2
- Current Dimensions: 62.23mm x 52.06mm
- Copper Pours: 1
- Mounting Holes: 4 (for 2.8mm diameter screws)



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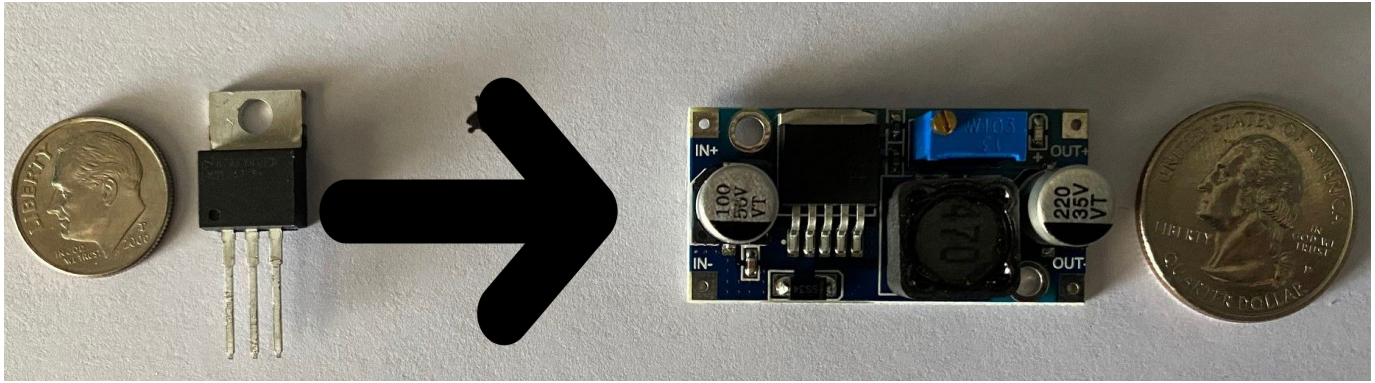
Circuit Design Successes and Difficulties

Difficulties

- 3.3V regulator overheating and overshooting voltage value
- Connecting motor driver, buck converter, and other components together resulted in system switching on and off

Successes

- Buck converter solved the 3.3V problem and turned on the ESP32
- Photodiode Circuit reads a voltage in sunlight presence
- Serial communication between ESP32 and Arduino Nano using code



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Mobile Application and Firmware

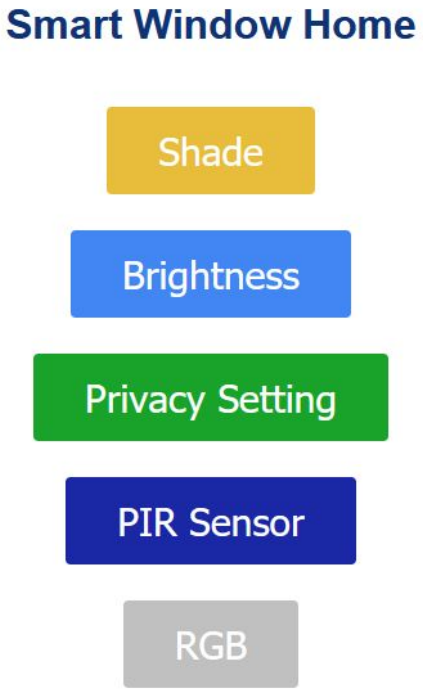
Kenneth Sauers

Web Application

We change the user interaction method from bluetooth to web based. This gave us many benefits such as allowing multiple devices to control the window unit.

It also allowed the user to control the device without having to download an application first.

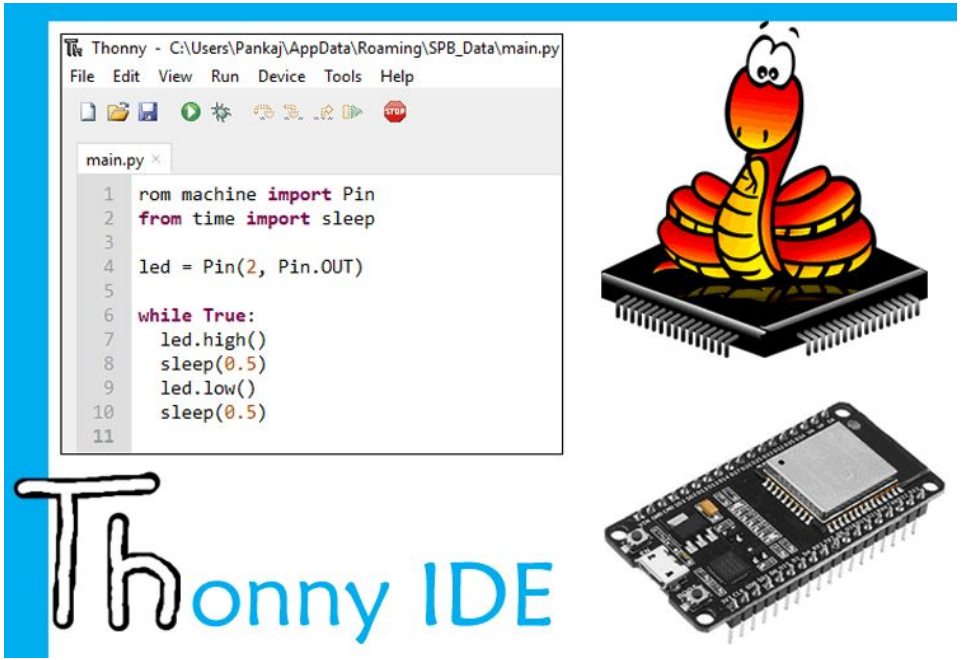
Kenneth Sauers



Processor And Firmware

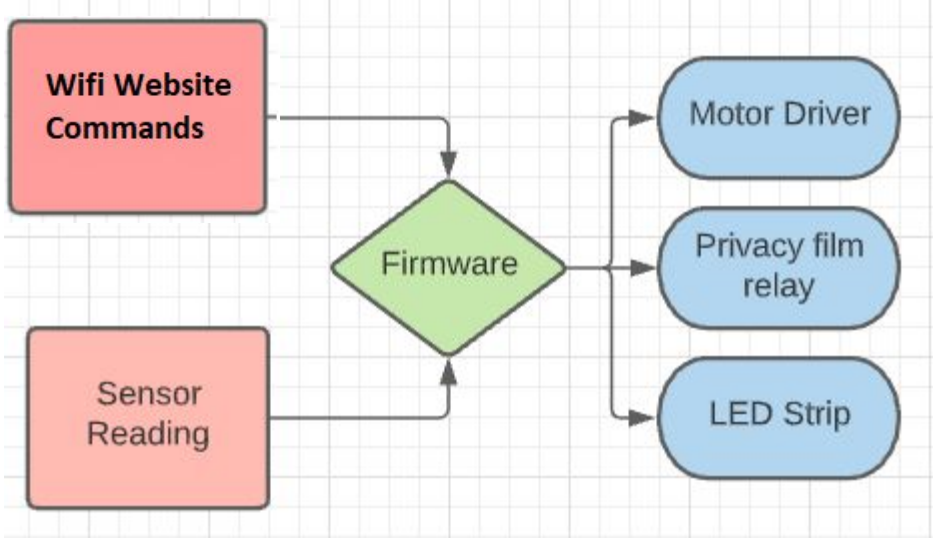
The esp32 breakout board contains a dual core processor with wifi and bluetooth communication capability at extremely low cost.

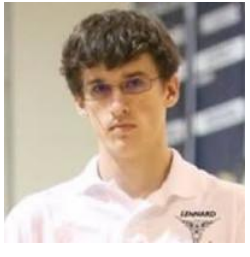
The Micropython library is used to flash a low level python operating system to the esp32. This allow the firmware to be developed in python



Firmware

- Receives commands via HTTP
- Commands Get or Set data values
- Commands call functions on processor
- Processor running constant updates which control automated functionality





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Firmware Functionality

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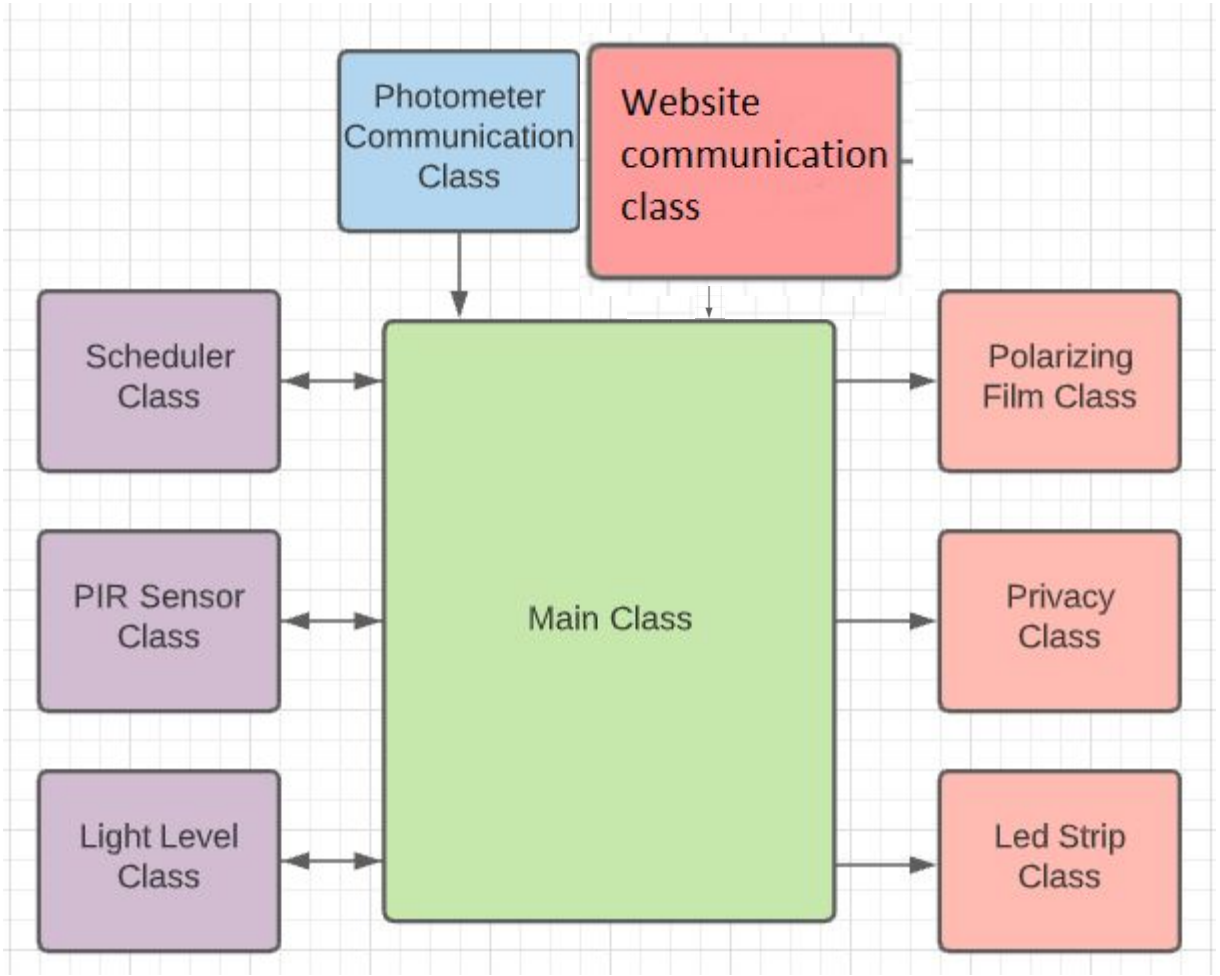

Photometer Communication Class

Brief: Communicates with photometer via serial communications

Startup: Starts serial communication with photometer

Runtime: Parces serial communication and sends light reading data to Main Class

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PIR Class

Brief: Handles PIR sensor

Startup: Sets up digital pins to receive data from PIR sensor

Runtime: Interpretes reading from digital pins. Runs calculations that turn PIR data to useable data

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Light Level Class

Brief: Handles the amount on light which passes through the window unit

Startup: Initialize polarizing film to home position

Runtime: listens for HTTP commands to dictate what the light level should be

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Scheduler Class

Brief: Handles time related aspects of the window system.

Startup: creates a empty time table.

Runtime: Reads current time are matches it to the time table. That element of the time dictates the light level and privacy setting.

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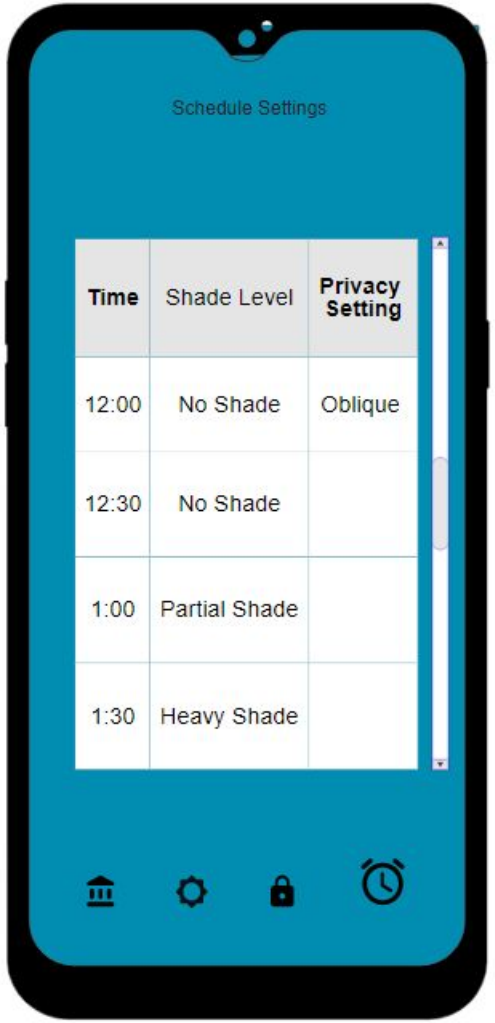

Privacy Class

Brief: handles privacy screen relay.

Startup: sets privacy screen to the clear setting.

Runtime: receives data from main class which dictates the state of the relay

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Polarizing Film Class

Brief: handles the polarizing film mechanism.

Startup: Move the motor to home position

Runtime: Receives all positioning data from main class. Then moves the motor to have the desired effect of light level

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LED Strip Class

Brief: Handles Led Strip relay

Startup: Turns the relay to the off position

Runtime: Listens for HTTP commands which change the values of the LED strip relay

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Administrative Content

Workload Distribution

Abdullah Husain

	Nomar Barreto	Bradley Howder	Abdullah Husain	Kenneth Sauers
Window Construction			Secondary	Primary
Tinting Mechanism		Secondary	Primary	Support
PIR Motion Sensor	Secondary	Primary	Support	
Photodiode & LCD	Support	Primary	Secondary	Support
PCB Design & Power	Primary			Secondary
LED Lighting	Support	Secondary	Primary	
Remote Operation	Secondary	Support		Primary
Microcontroller Code	Primary	Support		Secondary
Autonomous System	Secondary	Support		Primary
Privacy Screen	Support	Secondary	Primary	

Project Budget

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Component	Item Model	Price
Motor Driver	L298N	$8.71
Power Connector	CON-SOCJ-2155	$1.00
Power Adapter	TMEZON Adapter	$7.99
Arduino Nano V3.0	Nano Board CH340	$13.86
PCB Components		$80.27
PCB Board	Mark III	$15.80
Photodiode	FDS1010	$69.71
Processor	ESP32	$11.99
PIR Motion Sensor x2	AMN34111	$46.98
Arduino Nano	A000005	$20.25
Transistors x50	2N4401	$9.25
LED Amplifier		$9.98

Component	Item Model	Price
Timing Belt	5M GT2 Timing Belt	$15.99
Stepper Motor	Short Body Nema 17	$10.99
Frame Plywood	2ft*4ft	$32.65
Frame Siding	3in*1in*8ft	$6.00
Plexiglass	1ft*2ft	$19.96
Frame Mics	Hinge, finish, nails, glue	$7.98
Adafruit LCD Display 16x2		$13.87
2 Laminated Polarizers	PF030	$118.00
Privacy Screen	16"x16" Film	$199.00
Bearing	16 inch bearing	$35.00

Intended Budget	$500

Actual Budget	$746.52

Challenges & Constraints

Abdullah Husain

- Difficult for group to meet up due to COVID-19 living situations
- Photodiode and multiple microcontrollers frying
- PCB malfunction 1 week before final demonstration
- Late decision to swap from Bluetooth communication to WiFi
- Trying to achieve multiple stretch goals (LCD display, mobile app, scheduling feature, etc.)
- Restricted access to laboratory equipment and professor advisory (due to COVID-19)

References

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