Electric Blind

Department of Electrical and Computer Engineering

Final Report

Senior Design 2

Dr. Lei Wei

Group 13

Group Members:

Ryan Meinke (Computer Engineering)

Joshua Forrest (Electrical Engineering)

Tien Tran (Electrical Engineering)

Adedoyin Adepegba (Computer and Electrical Engineering)

Table of Contents

List of Figures

List of Figures

1.0 Executive Summary

Windows are something that everyone in America uses, in one form or another. Walk into any residence, or place of business, and you will see windows. You will see them in buildings from UCF's Student Union to a cabin in the middle of the woods. Now there is one thing that you will see attached to a massive amount of these windows, which is some variation of blinds. The purpose of windows is to allow light to pass through. These blinds (or variations of) are designed to be able to stop the transfer of light through the window, by placing opaque material in front of the window. This way the end user has control over if you can see through the window or not. Now due to the astronomical amount of use both windows and blinds see, any improvement to either has incredible potential to reach a large base of end users.

A lot like how there is an astronomical number of windows seen in use, there is a seemingly equal amount of different window types, purposes, and uses. Some windows are used to display a beautiful view. Some windows are used as a source of light. Some windows are used to assist with controlling the amount of thermal energy present in a particular area. Some purposes for windows are to simply increase the value of a property. The list of potential use cases continues on. The potential benefits and usage of a window that can realistically meet a large amount of these common use cases is incredible.

In one form or another, windows have been around for an unimaginable amount of time. Do you know what hasn't been around for nearly the same length of time? Technologies such as smartphones, Amazon Alexa, a computer in your lap that can perform infinitely more calculations than you could ever hope to accomplish in 10 lifetimes. In many homes today, you will see evidence of this technology. Instead of busting out a map to the airport to plan a route, you will simply push a button and verbally request directions to the airport. In place of having to juggle CDs that you are inserting into your stereo system, you will simply say "Alexa play Volbeat". You will find Air Conditioning control systems which will be increasingly more configurable to reach your desired usage. You are increasingly seeing technology implemented into buildings, with the hope of delivering a better end use.

What we did with this project was effectively implement modern technology into windows, in order to develop a better end user experience. Particularly we worked with frosted glass, then can switch between being translucent and opaque. We delivered this better end user experience via implementing functionalities that are not found in a standard window, but end users will find useful. Some of these functionalities that we implemented include the following. Having physical proximity be a trigger for switching the window between frosted and transparent. Being able to control the window with voice commands, or from a separate computer. We couldhave the capability for it to be integrated with Air Conditioning control systems, to assist with controlling the thermal energy. We automatically open and close the window to match with sunrise and sunset. We also added the capability where you can control the state of hundreds or thousands of windows from a single computer. As you can see, the potential capabilities we added to this window are seemingly infinite. This is excellent, since due to the wide range of window use cases, we developed corresponding capabilities to effectively meet those use cases. Now obviously with this project, due to the various constraints we had, wewere not able to develop a lot of these capabilities. However, after we effectivelydeveloped the first few capabilities, developing subsequent will become dramatically easier and more obtainable.

2.0 Project Description

This section gave a brief overview of this project which included project background, motivation for this project, goals, and objectives, and finally the requirement and marketing requirements.

2.1 Project Background

Every day, the march of progress moves forward. Technology improves each day, and humanity reaps the rewards. As this progress moves forward, technology is integrated into our lives at an increasing rate. One day we start carrying flip phones in our pockets, the next we are asking Alexa to order us some toilet paper before it runs out. This project aimed at moving that march forward a step. We accomplished this feat via integrating technology in a meaningful way into people's life that they can derive use from. Virtually everyone in America spends some of their times in buildings. Those buildings have a large array of objects that are in almost all of them. Such arrays include doors, floors, furniture, and windows. Specifically, windows have mechanisms to restrict the light flow through them. Such mechanism (or object) could be a cloth drape, wooden panel, blinds, or any opaque object that prevents light from getting through into a room or building. These objects usually have (unless they are broken) an operation which will change the position of the object to either allow light to enter the room, or to blockit out. This operation requires, to some extent, physical interaction by an end user. This interaction entails several things. First interaction involves the end user having to touch the object or mechanism. Proceeding that, the end user must inject physical energy into the system since that is the expected source of energy for thegiven mechanism for a window.

Now our project was to automate this process or interaction. This will remove the need for physical interaction from the perspective of the end user. This way, the end user could have a seemingly infinite number of ways to perform this operation without physically interacting with the system. They could, for instance flip a switch, ask Alexa to do it, or even trigger some sort of proximity sensor. This was accomplished using an embedded computer handling the operation of making light pass through the window, or block light from passing through the window into a room or building. The creation of this project did not lead to the creation of some incredible new technology. However, there was one extremely important detail to this idea. It is that virtually everyone in America could be an end user of this project. Even though this was a fairly simple idea, the latent ability for the reach of this project is endless because of the previous stated fact.

Another benefit of this idea, and why it has such great reach, was its customizability. By having a short five-minute discussion with a window manufacturer, the idea of a single type of window being used in a ton of applications is far-fetched due to several factors. The first reason is that there isn't a standard window size. This leads to a ton of different windows in use with a wide variety of form factors. In addition to that, you also must consider that there is a wide variety of specific use cases and conditions that different end users will want. Certain end users will place high value on aesthetic appeal (just take one look at Apple). Other end users will value the cost effectiveness of the unit. Other end users will place the highest value on the number of useful functionalities.

2.2. Motivation

The motivation for this project emerged from the team members goal for senior design which is to create a cost-efficient and energy saving project. After research, it was found that while there are automated blinds on the market, there are no electric blinds that allows multiple activation methods which also gives high energy efficiency. Therefore, this project aimed to create a low-cost, energy efficient electric blind that can be activated using multiple means. Finally, one of the motivations for this project was the need to work in a group and get the experience before graduating and proceeding into the workplace where teamwork is essential and avaluable tool.

2.3 Goals and Objectives

Our project idea was a simple idea of automating the process of interacting with a window. However, despite that, it has incredible potential to reach an astronomically large pool of end users. If we employ effective planning and design techniques to reach this goal, the applications of this project are seemingly infinite. Also, we were looking to completely remove conventional blinds from the system. Finally, another goal for this project was to develop great teamwork and produce a successful project that meets the requirement and marketing specifications of this project.

2.4 Requirement Specifications

Table 1: Requirement Specifications Summary

Description	Value	Unit
Activation method	3	ways
Opaqueness	≥ 90	%
***Cost**	≤ 600	$
Power consumption	≤ 10	W
Activation range	≤ 50	cm
Transparency	≤ 10	%
***Time to activate**	≤ 10	seconds
Efficiency	≥ 90	%
***Changing opaqueness**	≥ 10 and ≤ 90	%

*3 specifications to be demonstrated

2.4.1 Cost

The goal of the group was to implement a cheap but productive device that can satisfyall the engineering requirements with less than 600 U.S. dollars. The target budget was set out low because of the modern technology, there were many electronics equipment from different companies/suppliers that helped drive the cost for the project down.

2.4.2 Time to activate

The time to activate the device was set to be 10 seconds for now although the status of the PDLC film changes quickly where it only takes half a second. However, ourgroup hope we can improve the actual time to activate the device to be less than 3 seconds where the sensor senses the analog signal. The analog signal then can be converted to digital signal and sent to the MCU for data processing.

2.4.3 Changing opaqueness

The transparency of the PDLC film is less than 10% which is clear, and more than 90% which is opaque. Our group hope we can manipulate the voltage usage for the PDLC film to change the percentage of transparency for variety applications.

2.4.4 Efficiency

Due to many applications of the project such as blocking sun lights, view sightings when needed, etc. the efficiency can be set at 90% where 10% error is acceptable.

2.4.5 Power consumption

The PDLC film uses AC voltage with low voltage from 35-65 VAC or it can be used with a 12 VDC power source with a current of 0.08 A/m^2 which the maximum power usage for the film alone to be around 5W/m^2. The power for the film combines with other components of the project would not exceed 20W.

2.4.6 Activation methods

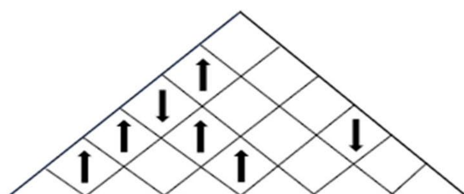
Our group discussed different activation methods and we came up with 3 ways:

1. Switch: this was the simplest form of how to activate the device. A flip from a switch turned the film on or off.
2. Use of different sensors: for this method, the electric blind was turned on and off through different sensors like PIR sensor that detected human presence, temperature sensor that detected change in temperature around the electric blind and light sensor that turned the electric blind on and off based on light or darkness.
3. Digital application interface: almost everything is accessible through our phones now, therefore, a handy app in a phone to control the PDLC film was necessary for this project. In addition to a phone app, a computer application and website were created to be used for the electric blind.

2.4.7 Activation range
For view sightings, a user needs to be close to the windows where the view can be captured completely by the eyesight. Therefore, we set the range to activate the PDLC film to be round less than 50 cm. Nevertheless, what if the user wants to activate the device with a further range? The answer is from the other 2 methods where the switch and the phone app were applicable.

2.5 Marketing Requirements
The device from this project will be marketed as a low-cost, energy efficient electric blind. Some other marketing requirements for this project (as shown in figure 1) are low-cost, high safety, reliability, ease of use, low power consumption and high and efficient performance.

2.5.1 House of Quality
Figure 1 shows the marketing and engineering requirements for the project herein including levels of polarity (positive and negative impact on project). Similarly, figure 1 shows the correlation between the requirements.



	Engineering Requirements	Power Consumption	Accuracy	Time Response	Cost	Idle Time	Board Dimension
Marketing Requirements	Polarities	-	+	-	-	-	-
1. Safety	+				↓↓		
2. Cost	-	↓					↓
3. Reliability	+		↑↑				
4. Ease of use	+				↓		
5. Performance	+		↑↑	↑↑		↑	
6. Power Consumption	-	↓				↑↑	
Targets for Engineering Requirements		< 20 Watts	≤ 150 cm	≤ 5 seconds	< $1000	≤ 5 minutes	≤ 4" x4 "

Figure 1: House of Quality

Polarity	
Positive	+
Negative	-

Correlations	
Strongly Positive	↑↑
Positive	↑
Neutral	
Negative	↓
Strongly Negative	↓↓

Figure 2: House of Quality (polarity and correlations)

2.6 Initial Block Diagram

This section shows the initial breakdown of work about the team members for this project. However, this breakdown could be changed as the project progresses.

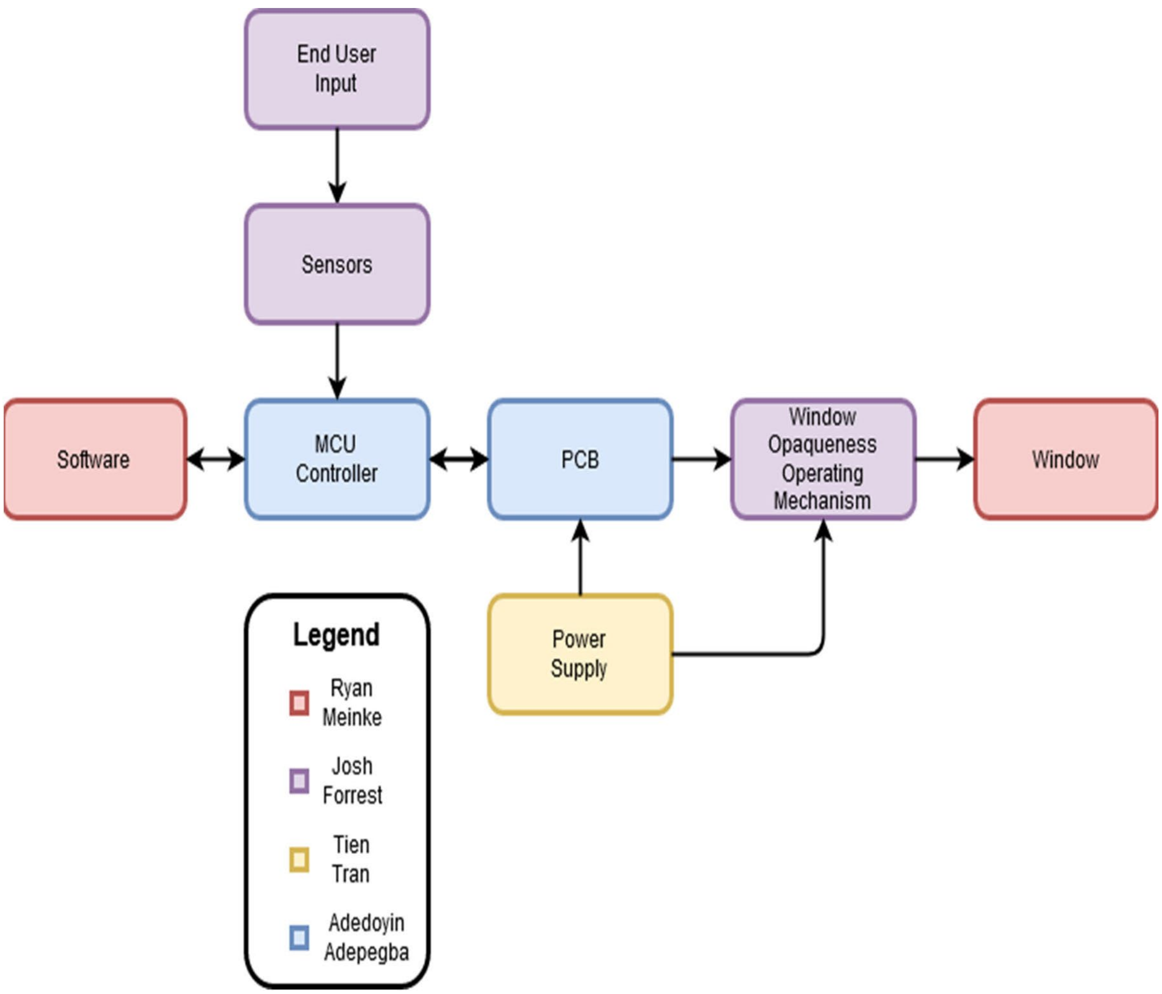


Figure 3: Hardware and Software Block Diagram for Electric Blind project

3.0 Research

This section explains the research done for this project. The research focused on existing projects related to the project herein, available products already on the market, and relevant technologies that would make this project possible (such as window frames, safety concerns, microcontroller units, proximity sensors, and power management).

3.1 Existing Projects and Products

Seeing how blinds I have been around for almost 300 years there have been many different iterations of blinds. However, it is recently that there has been the ability to take blinds into the Modern Age as you will see we combine smart film technology with the efficiency of modern-day sensors and a user interface to maximize the usefulness of blinds while also minimizing the area usage and energy benefit previously seen.

3.1.1 Serena Smart Shades

One of the existing smart blinds on the market are the Serena smart roller shades. These are unconventional blinds however they have added and a new take on things. They have motorized the blinds and added an interface to an app that allows you to connect with Alexa, Google assistant, or Siri. However, this product is an improvement on unconventional blinds; it still fails at the shortcoming of the traditional technology. There is also the need of the bulky installment of the blind housing.

Figure 4: Serena Smart Shade

3.1.2 Dream Glass: Smart Blinds

Another option on the market are smart blinds by The Dream glass group. This option uses the pdlc film technology however it blocks the technical sophistication as seen with the Serena blinds and our product. Essentially this product is pdlc film that is sectioned with each section being controllable. There is little to no mention of application interface with this device, which is one of the driving features of our products. Another concerning question that arises from this product is that there is no readily available price which indicates that each project will be custom made leading to a very large price. Hence this requires each project be quoted.

Figure 5: Dream Blind

3.1.3 Senior Design Project: Sunshade

A completed project that demonstrates and achieves some of the features of our project came from Group 13 in the summer of 2019 aptly named sunshade. This group also used the conventional technology of blinds however they motorized it and added an interface with an app. With this interface they even added the ability to control the tilt of the blinds so that you can control the brightness entering the room which in turn will improve your energy usage by reducing the cooling in the building or room. We were also interested and making this as easy as possible and forward-thinking with the internet of things in mind. Another admirable goal was the implementation of solar power to sell powdered systems and not create any additional energy usage. The main difference between our projects is that we are looking to completely remove conventional blinds from the system.

Figure 6: Sun Shade

3.1.4 Senior Design Group: Skylight Glass

Another group at UCF that shared a similar goal to ours was also Group 13 aptly named Skylight glass. This group focused mainly on the amount of light coming in and how to balance it seamlessly as said light was reduced throughout the day. They also relied on Smart film technology to achieve this. Where our projects differ heavily is that the Skylight glass group was mainly concerned with replacing the Lost Light from the smart film with LED lights so that it did not negatively affect do users inside said room. Our goal is to make a product that is extremely user-friendly energy efficient and effective.

Figure 7: Skylight Glass

3.2 Relevant Technologies

There were numerous relevant technologies required for the completion of this project. They included windows, blinds, Microcontrollers (MCU), Interface techniques, and Proximity sensors. Each technology enabled a successful creation of a working electric blind.

3.2.1 Window

With windows, except for the glass, the other major component of a window is the frame. This refers to the object which mounts the glass to the wall. These frames come in a variety of different forms, with various advantages and disadvantages. This section will investigate the various types of Window Frames.

3.2.1.1 Window Frame Types

Figure 8: Fixed Window Frame, Casement Window Frame, Awning Window Frame and Sliding Window Frame

3.2.1.1.1 Sliding Window Frame

The first type of window frame discussed was a Sliding Window Frame. The primary characteristic is that it allows for you to slide the window, to open and close it. This is done via having the glass mounted on a panel, which is attached to the frame via rails. Usually there will be multiple pieces of glass that can overlap. To open the window, you will slide one (or more) of the pieces of glass to overlap, which will allow for an opening. With this type of design, it can be hard to create a tight seal, which will hurt insulation.

3.2.1.1.2 Casement Window Frames

Casement Window Frames are windows which swing open. Each of the pieces of glass is mounting onto a panel, which is attached to the frame on a hinge. These windows are easier to seal than Sliding Window Frames, so they can allow for better insulation. In addition to that, they typically allow for more open space than a Sliding Window Frame, so they can allow for better ventilation. On the flipside, they require physical space outside of the window space to operate. This can be disadvantageous for instance having these windows open out onto a porch, which you are currently sitting in. In addition to that, they typically are more expensive than Sliding Window Frames.

3.2.1.1.3 Awning Window Frames

Awning Window Frame has a hinge on the top of the window. This allows the window to swing open, with the axis of rotation being the top side of the window. They will swing outside. One of the benefits of this frame is that it can be mounted higher up on a wall than other frames and still used with relative ease. In addition to that, since this window frame will have the window swing outside, they can be open during certain rainstorms without allowing rain to enter the household. A lot of the time, this window frame is used as a source of light. However, a downside to this type of window is similar to that of other windows that open outwards. They protrude from the structure and occupy space outside of the house, so you must ensure that you do not mind forfeiting that space.

3.2.1.1.4 Hopper Window Frame

Hopper Window Frame is a type of window frame that swings open and close. However, the axis of rotation is horizontal, in the middle of the window. When the window swings open, it will both protrude into the house, and out of the house. This style of window frame can work well when you are dealing with compact space situations, since to open it only requires a small amount of space directly in front of and behind the window. However, with this type of window, due to the position it occupies when it rotates, and the location of the rotational access, it is often difficult to have fixtures such as blinds or drapes attached to the window.

So, looking at all these types of windows, the main difference between them is how they open. Since windows rely on glass, which typically will not change the shape and its size, to open the window, you will have to change the position of the window. The different window frames will change where the position of the glass is when it is open, and the motion it takes to move it to that position.

In addition to different types of frame, you can also have a selection of different materials that you can have the frame constructed from. This section will analyze the various types of frame materials, and the corresponding benefits and consequences associated with usage of the material for window frames.

3.2.1.2 Frame Materials

3.2.1.2.1 Wood

The first window frame material we looked at was wood. This window frame is often considered one of the more aesthetically appealing. One of the primary drivers of real estate price is derived from the aesthetics, so this could be of benefit. In addition to that wood has certain insulating qualities which can be of benefit. However, there are a few drawbacks to wood. Compared to other types of material, wood is more costly. In addition to that wood requires more maintenance and upkeep than other types of Window Frame Material. Also, with wood, you might see frame warping at a much higher rate than frames made from other materials. The reason for this being is that wood can absorb moisture. Uneven absorption of moisture over time can cause the wood to warp.

3.2.1.2.2 Aluminum

The second type of window frame material we analyzed was aluminum. This material has several advantages. It generally requires less maintenance than other window frame materials. In addition to that, the material is strong for its application, and lightweight, and consumes less volume for the application to allow more space for the glass (and thus a bigger view from the window). In addition to that it is a cost-effective choice. There are several drawbacks for this. Since metal is a good thermal conductor, the insulation qualities it provides are less than that of other frame types. In addition to that, they are susceptible to corrosion from air with higher salt concentrations (so might not be the best choice for a beach front property).

3.2.1.2.3 Fiberglass

The third window frame material we analyzed was Fiberglass. Fiberglass frames are typically a bit more durable than other frames. In addition to that, theyhave good insulating properties. In addition, they require less maintenance than other window frame materials. However, on the flipside, they are on the pricier sideof window frames.

3.2.1.2.4 Vinyl

The fourth Window frame material we analyzed was Vinyl. This material is themost cost-effective material that we have seen so far. In addition to that, it is typically seen in higher availability than other types of window frames. However, some of the drawbacks for this material include that it is hard to customize, both interms of shape and in color.

3.2.1.2.5 Comparison for Window Frame Material

Table 2: Comparison of Window Frame Material types

Window Frame Material Type	Durability	Cost (relative To other Window Frame Material Types)	Has Great Insulation Properties	Risk of fracturing when drilling into	Maintenance Required
Wood	Moderately Durable	Higher Priced	Has Insulation properties	There is little risk of fracturing, when drilling	Requires Maintenance to Prevent Window Frame Warping
Aluminum	Extremely Durable	Cost Effective	Practically no Insulation properties	There is little risk of fracturing, when drilling	Low Maintenance
Fiberglass	Moderately Durable	Higher Priced	Has Great Insulation Properties	There is great risk of fracturing when drilling	Low Maintenance
Vinyl	Moderately Durable	Cost Effective	Has Great Insulation Properties	There is great risk of fracturing when drilling	Low Maintenance

3.2.1.2.6 Summary of Window Frame Material

So, looking over the various window material types, we saw how the various properties compared. In terms of ease of crafting a window frame from it, wood was first, followed by aluminum, and then fiberglass and vinyl. In terms of durability, aluminum was in first place, and the differences between the rest were roughly negligible. In terms of cost of the material, Aluminum and Vinyl were more cost effective than Wood and Fiberglass.

3.2.1.3 Window Safety Concerns

Windows are an essential part of most buildings. They are a source of free light and provide a good view. However, in many cases, they can provide hazards. These hazards can stem from the elements to malicious actors, to simple human error. With a large amount of these hazards, it revolves around situations where the window physically breaks. Here we will explore what these hazards are, and the consequences should these hazards manifest. The reason for this is because with any invention that is used, it must meet safety standards that would lead to reasonable use without really any chance of injury (assuming correct usage). With windows, they have such a large use of applications, that the potential safety hazards for windows is huge. As a result, taking into account the potential safety concerns into our design is critical for a good design.

Every day, burglaries happen. Every year in the US, there are more than 2.2 million burglaries that happen in the US. A large portion of that is accounted for by house burglaries. For around a quarter of home break ins (exact figure varies by a few points depending on the source) the point of entry is a window. The point being a lot of burglaries have the point of entry being a window. Now this is for several reasons. A lot of windows are not locked, so they can be opened from the outside. In addition to that, they can be easily broken, which will then provide an entrance.

Now the potential consequences of a home break-in from a window range widely. At the very least, you can expect to lose several hundred dollars' worth of objects. At the extreme end, you can have a loss of life. There are a lot of consequences in between, such as psychological (for example, anxiety derived from losing the feeling of safety in your house). Now obviously the window itself is not the main antagonist for this situation, the burglar is. However, you can design the window in such a way to deter burglars, by mitigating the reasons for it being a desired point of entry for a burglar.

3.2.1.3.1 Safety concern for Windows: Extreme Weather

Extreme weather can pose safety concerns with windows. These typically come in the form of extreme weather providing physical forces on the window, which will cause it to break. For instance, there is a hurricane in Florida that can have strong winds that propel an object with a sizable amount of mass, which will break a window. In addition to that you can have hailstorms that propel a piece of ice at a fast-enough velocity which will break a window. Now this weather will cause a variety of safety concerns. The first and immediate hazard that it creates, is that it exposes the interior of our house to the weather outside that causes the window to be destroyed. For example, if a hurricane sent a piece of a palm tree through one of your windows, expect the area in your house around the window to be soaked with rain, and battered by winds. Then you have the hazard that there is now shattered glass on the inside of your house, which can cut the people living inside of it.

3.2.1.3.2 Safety concern for Windows: Extreme Heat

Another safety concern that can present itself is extreme heat. This is caused by the fact that when glass gains significant amounts of thermal energy, the glass expands to occupy more volume. Now what often happens is the expansion of the glass is not uniform with the frame holding it, or even other sections of the glass. This uneven expansion will cause pressure build up in certain sections of the glass. If this pressure becomes too great, the window will shatter as a result. This is a common problem with house fires, which generate a lot of heat. For a house fire, this is especially dangerous since it will improve the ventilation the fire has, which will significantly increase the rate at which the fire grows. In addition to that, you will also have the hazard of broken glass.

3.2.1.3.3 Safety concern for Windows: Falling

Another common safety concern for windows is falling. This occurs when a person goes through an open window, exiting the person. This can be a window that was open either on purpose or was open by breaking. The danger that presents itself is from the fall that occurs. There is an array of variables that will affect the chance of serious injury and death because of this. The first of these is the height of the window. A window on the first floor will not pose nearly the same threat in this regard as a second or third floor window. The second variable would be what’s below the window. This is because when you fall through a window, you will land on this object, which will greatly affect the injuries you sustain. Landing on soft grass will yield a lower chance of injury versus concrete. Another major variable is how you fall out since that will change what parts of your body impact which objects.

The mechanism which operates a window is susceptible to malfunction. Take for instance a sliding glass window, in which the rails get jammed. The end user applies a lot of force in order to operate the window and ends up breaking the window. With any mechanical device that has moving parts, after enough time and usage, it can expect to have some malfunction.

3.2.1.4 Window Cleaning Concerns

Windows are an everyday item. One of the things that will happen to windows is they are cleaned. We will need to take this into account with the design. The reason for this being, is that if we don’t take into account certain common cleaning methods, it could cause damages. For instance, if a person were to apply water to the window, and water would enter some electrical components of the window device, that could cause problems. So, the first method involves using soap and water. This usually includes the application of soapy water to the window, along with scrubbing with things such as a rag. Then there is a copious amount of water applied to the window, with methods such as pouring a bucket of water on it, or even using a hose. This is usually done on the outside portion of the window, since doing it inside would cause a lot of water to flood the area surrounding the window. In addition to that, glass cleaner is commonly used to clean windows. This is a liquid that will be applied to windows. The potential issue with this is if some of the window cleaner gets on the electronics, much like water it can also cause damages to the electronics. What every method of window cleaning here involves, is some sort of applied pressure to the window. This is usually in the form of either scrubbing, or a hose. As such we will need to take into account that every part of the window device should expect a moderate level of force applied to it.

So, what all of this boils down to is this. When we are designing this window device, and components that could be damaged by either water, household chemical cleaners, or gentle scrubbing with a rag should be in a case. This casing should be in a way that if either of the three things is applied to the casing, the casing acts as a competent enough shielding to prevent damage to the electronics.

3.2.1.5 Common Window Feedback

Windows are a super common item. Basically, every person in first world countries uses this in some capacity. What this translates into, is this is an object that has had a mammoth amount of testing behind it. As such, since we are designing a system which will radically change the functionality of windows, paying attention to common feedback from the end users will provide valuable insight into design considerations that would actually lead to a design that end users will find beneficial. We will first start by analyzing common window complaints, and criticisms.

3.2.15.1 Window Criticism

The first common window criticism we will analyze is faulty mechanical parts. All Windows that open and close, do so using physical motion applied to the glass which creates a hole. This requires having mechanical parts that move. Windows usually last a long time or are expected to. During this time, the parts that handle this mechanical motion will degrade. This will lead to handling the operation of opening and closing the window to either be more difficult than it should be, or practically impossible.

The second criticism we will look at is air leakage. When a window is closed, it is supposed to prevent air flow from the interior to the exterior, and vice versa. This criticism is for when windows fail by allowing air flow either in, or out of the window. This issue has certain consequences, such as reduced insulation. In addition to that it will cause drafts in the house. This issue is typically caused, from a mixture of reasons. Over the course of different days or seasons, the window will be heated differently. This differential heating will cause various parts of the window to expand or contract. This expansion or contraction will cause various gaps to open, which allows for the air leakage. Another reason for this, is erosion of the elements from over the years.

The third criticism we will look at is when glass shatters. Glass is generally considered to be a relatively weak material that can be broken in day to day life. As such, glass will shatter. An issue with this in many cases, is when the glass shatters, it will shatter into various pieces that scatter, and can be hard to visually detect. In addition to that, almost all these pieces will be relatively sharp, and can pierce skin. So, in many cases when glass breaks, you end up with a lot of small pieces that are hard to see yet can bring harm to you. This will cause a big problem in a lot of scenarios.

The fourth criticism we will look at, is similar to air leakage. This criticism is water leakage. Now it isn't as common as air leakage, since it requires bigger gaps, however the issues that stem from it are generally worse, since it will include water damage (which can cause a lot of problems which take cash to fix). Typically, this happens when either physical damage occurs to the window which leaves a large gap, or over time the frame of the window warps.

One thing that causes a lot of these criticisms, is wear and tear over a long period of time. With this, it's important to note that windows are expected to last around 25 years. With that, we will now start looking at popular benefits of windows.

3.2.1.5.2 Benefits of Windows

One main benefit to specific types of windows, is increased property value. Of course, the windows must be in good condition for this. Oftentimes what you will find, is before people will sell their homes, they will either repair or replace the windows. It is often found that the money spent doing that is not only returned but has a good return on investment when you are selling the property. Property value is something that is very important for a lot of property owners, since it directly affects how much capitol they have.

Another major benefit of windows is energy savings. This is when the window acts as an insulator. The reason for the benefit is that it saves people money, with AC. While the exact savings can vary greatly depending on the type of windows, type of house, climate, and AC usage, with properly insulating windows you can expect hundreds of dollars of savings each year.

A third major benefit that windows provide is sound isolation. The reason for this is windows can block out sound. This will cause noises from outside to not be heard inside, or conversations from the inside to not be heard outside (or if they are heard, not nearly to the same intensity).

3.2.1.6 Window Energy Savings

Almost every adult in the United States today pays an electrical bill. The price of the bill usually scales with how much electrical energy the power company has. As a result, many people try to reduce the amount of energy they use, so they will end up saving money with their power bill. This almost always ends up in reduced usage of devices that draw electrical power such as ovens, lights, and the AC (Air Conditioner). Although it can vary depending on the exact climate of where the building is, in many of these cases the AC consumes a large percentage of the power used in the home. As such reducing the power consumed by the AC would go a long way.

So that brings up the question of how you could realistically accomplish that task. The purpose of the AC is to control the temperature of the building, either by heating or cooling the building. So, the first solution is you forfeit some degree of control of the temperature, so the AC has to provide less work, and consume less energy. The second is that you can have other objects assist with the temperature control while consuming less energy than the AC would, so the AC consumes less energy. Windows can assist in that area.

Insulation helps block the transfer of heat between the outside, and a building. On a hot day, this would help limit the transfer of heat from the outside of your house to the interior. On a cold day, this would do the opposite. One way that windows can accomplish this is by having double or triple pane windows. What this means is that there are multiple layers of glass, with air in between them. These gaps are sometimes filled with special types of gas such as argon gas, which has additional properties that would be desirable for this task. These gaps help act as insulating layers.

Tinting your windows is another form of energy savings. What tinting a window involves for a typical window, is attaching a film to a window. This film will make the window appear black, but still translucent. What this will do is block a percentage of the light travelling through the window. As it does this, it will also block the heat that transfers into the house, usually by a factor of around 40%. This will assist in helping to reduce power consumption used by an AC in areas where you are concerned about having to cool a building.

This next idea will take the previous idea of tinting a step further. When you increase the opacity of a window, the amount of thermal energy entering the room with a window decrease. What this means is if you simply close the blinds, you will reduce the amount of thermal heating a room experiences, which is induced by the sun. Now one important thing to keep in mind with this, is that if you have the window be permanently opaque, then that defeats the entire purpose of having a window.

3.2.1.7 Window Form Factors

With many pieces of hardware ranging from bolts to screwdrivers, there are standards that specify certain aspects of the physical shape. This is done for compatibility purposes. This way you can use the same screwdriver on a wide variety of different screws. Unfortunately, such standards aren't as common for windows. Windows sizes can rage in the exact sizes, so taking into account the size of the window can be crucial for things such as tinting a window or making a replacement window. If we were to design a solution that is to go over a wide variety of applications, we have either three choices. The first is that we pick a specific form factor for the window and implement that in the design. The second is that we design the idea so that it can apply to a variety of window form factors, so the size of the window really doesn't matter. The third choice is an in-between of the previous two choices, where we choose a set of window sizes that we can support.

3.2.1.8 Window Market Prices

With any product, we must place special consideration on the price tag of the idea. If it is too expensive, that will severely reduce the reach the product has. If the price is too low, then realistically implementing the product will prove impossible. One of the huge considerations for what the price should be is what the price is of your competitors. This section will look at the current market price for windows, which will give us guidance for when we are trying to decide how much this idea should cost to implement. This price has multiple components factored into it. These factors include the window itself, the frame of the window, and the labor to install it.

Like how the type of window you can have installed varies widely, so does the price. The average price of a window can range between $200-$700. In addition to that, for higher priced windows, that price can range into the thousands of dollars. With windows, there are a ton of different options that you can pick. These options will fluctuate the price. The national average cost for a window frame replacement is around $300-$500. The labor for the job is around $40 an hour. While the complexity of the job will influence this price, it usually comes out between $100-$200 per window.

3.2.1.9 Window Environmental Impact

With any product, there is an environmental impact. This could come from the manufacturing, transportation, and usage of a product. With the fact that environmental hazards and protections are at the forefront of society, it is important to quantify these effects. By quantifying the impact, it has on the environment, we can take steps into mitigating them.

So first off, you have the manufacturing process. This involves heating materials to a high enough temperature that it melts. Now normally, this is done in a furnace.

Combustion is used, which will cause the emissions of CO_2. In addition to that, the melting of the glass can emit particles that also contribute to emission pollution. On Top of that, you also need raw materials to feed into the furnace. This includes materials such as sand, and minerals. The extraction of these materials can pose its own series of environmental hazards. Following that, you have the transportation of the materials. This is almost always done with the use of vehicles, which burn fossil fuels, and thus emit C02 pollution.

Proceeding that, you have the usage of the windows which can pose certain environmental hazards. The first and foremost is the thermal heating problems, discussed earlier. Another factor is that of animal interactions with glass. The prominent threat this poses is with birds. There are a mammoth number of instances where birds will fly into glass. This is due to a variety of reasons, such as the window reflecting light as to make it look like the window is just open space. It can also be an instance where the glass looks completely transparent, so the bird doesn’t realize there is a physical object there. At the end of the day, it stems from two reasons for windows causing bird deaths. The glass causes light reflection in a way where the bird doesn’t realize there is a physical object there. The second is that the window itself is a hard-enough surface, that if a bird were to crash into it, it would cause fatal damage in many instances.

Estimates claim that windows on buildings (ranging from houses to skyscrapers) account for over 500 million bird deaths annually. Now there are several things that can be done in order to mitigate this effect. One such solution is to place a net in front of the glass. This will have the bird impact with a net versus a glass window, which will cause far less damage to the bird (in most instances the bird just bounces right off). Other solutions include making it apparent that the window is an object. This includes having patterns on the window that are easily visible. One other solution to this problem is to have shutters outside of the glass that will close when the window is not in use, so none of the glass is visible.

3.2.2 Blind

The choices for blinds were limited because this project focused on automation of the process of opening and closing of blinds. Therefore, the blinds herein would either be a film that goes onto the actual window or a motorized curtain or shade that gets connected to the window frame. If the motorized curtain or shade was to beused, some of the materials that would need to be added were cloth (to allow or disallow visibility), pulleys and gears (for moving the cloth up and down), brackets (to connect the cloth and pulleys or gears), belt, curtain or gear train for the pulleys and motors. However, if a film was to be used, all that would be needed was the film that goes onto the actual window, and adhesive for connection. The blinds we intended to use was wooden slat blinds due to these reasons. They are quite popular at the moment which will increase the chance of adoption, they're also more durable than plastic blinds, and we will be able to more easily conceal the components that we will use to operate this system. Though there are other blind options they mainly differ aesthetically if the same material is used. Ideally this design should be able to adapt depending on orientation of the blinds.

3.2.2.1 Motorized shade/curtain

If we decided to use the motorized option to automate these blinds, we would likely have to use motors. The choice lies between a Stepper motor and a Servo motor. These would be ideal options because of cost and ease of implementation. Along with this these motors very reliably perform repetitive motions of up, down, and tilting which you would all need when automating blinds.

3.2.2.1.1 Stepper motor (28STH32 NEMA-11)

This motor would be ideal for controlling the blind shaft by using one motor to control the height of the blinds and another motor to control the pitch. We would be able to connect these to our MCU and produce the desired transparency. An issue to tackle would be determining whether to use an encoder or transmission hardware to interface it with our other systems. With a torque of 14 kg-cm this motor should be able to support the weight of a full set of blinds even when in a standstill state. Given a typical window we would expect the blinds to be able to fully retract in 2 minutes which does not meet engineering requirements. However, these motors barring the additional needed hardware will be much cheaper than the smart film options.

3.2.2.1.2 Servo motor: DFRobot DF15RSMG

This motor is more compact than the stepper motor previously shown. This is an added benefit because we will be able to conceal it more easily and with this potentially dampen the sound from this motor. It also comes with the added benefit that it can support 20 kg-cm it should be able to lift most blinds. There are also multiple part configurations for the servo which gives us more flexibility in design. You control this Servo motor with a PWM controlling signal, there is also the added benefits that there is a lock function only activated by pulse detection which should reduce the amount of power consumption for this Servo motor. Since the servo does not require an encoder or additional transmission hardware there is an added benefit over the stepper motor, however this motor has a low humming sound when operating compared to the nearly silent stepper motor during operation.

3.2.2.1.3 Comparison of Motors

Table 3: Comparison of possible motor choices

	28STH32	**DF15RSMG**
Motor Type	Bipolar Stepper	Servo Motor
Rated Torque	14 kg*cm	15 kg*cm
Holding Torque	600g*cm	
Max Speed	50 RPM	N/A
Rated Voltage	24 V DC	7.2V DC
Rated Current	670 mA	2A

3.2.2.1.4 Conclusion for Motors

When comparing these motors, they do have the benefit of being lower cost than the electrochromic devices listed, as a downside though there are more maintenance costs in the long term, the need to maintain traditional blinds, and the slow transition state as seen with traditional blinds. By keeping blinds, we reduce the opportunity for this system to be installed in various places as once the control system is installed with the smart film configuration the transparency device can be placed and sized to almost any shape of an enclosure. There is also the fact that these motors do not meet some of our engineering requirements as they depend on the blinds themselves to be the transparency device and there will be less controllability as compared to one of the smart film options. As always with mechanical devices they are reliable and consistent in their function but there ends up being I need for maintenance and replacement due to wear in the system. So, we went with the Smart Film as the “blinds” though they cost more.

3.2.2.2 Smart Film

For our project, there was a general technology we were aiming to use that is known as smart glass/ film. It comes in two states, passive and active. Passive smart glass comes in two variations. The first is thermal chromatic which as the name suggests is affected when heat or direct sunlight, which initiates a chemical reaction in the film. The other version is photochromatic, this material changes based on the intensity of light being shined on it. Similar to transition eyeglasses that change when you go inside or outside. For active Smart Glass, there are three options: Electrochromic (EC), Suspended Particle Devices (SPD), and polymer dispersed Liquid Crystal (PDLC). All three of these Technologies are activated when a voltage whether it be AC or DC are applied to the electrodes and affect the state of said technology

3.2.2.2.1 Electrochromic

Electric automatic devices operate on the property of Electrochromism, this is a property that occurs due to the electrochemical redox reactions that take place in these materials. The composition of these materials are usually multi-layered substrates that are then charged with an electrode which allows ions to pass through one side to the other creating the effect desired. The effect seen in these devices offers low shading however there is the unique property that once a state is transitioned no further electricity is needed to maintain that state. Another downside to this technology is that the state transfer takes tens of seconds to minutes to complete fully and as use increases the transition time grows [Figure 9].

3.2.2.2.2 Suspended Particle Device (SPD)

Suspended particle devices are composed of nanoscale particles that are put in a liquid thin film that act as the agent that creates the darkening and lightening effect.

In the default state SPD's particles are in disarray which cause light to scatter giving you the opaque state.

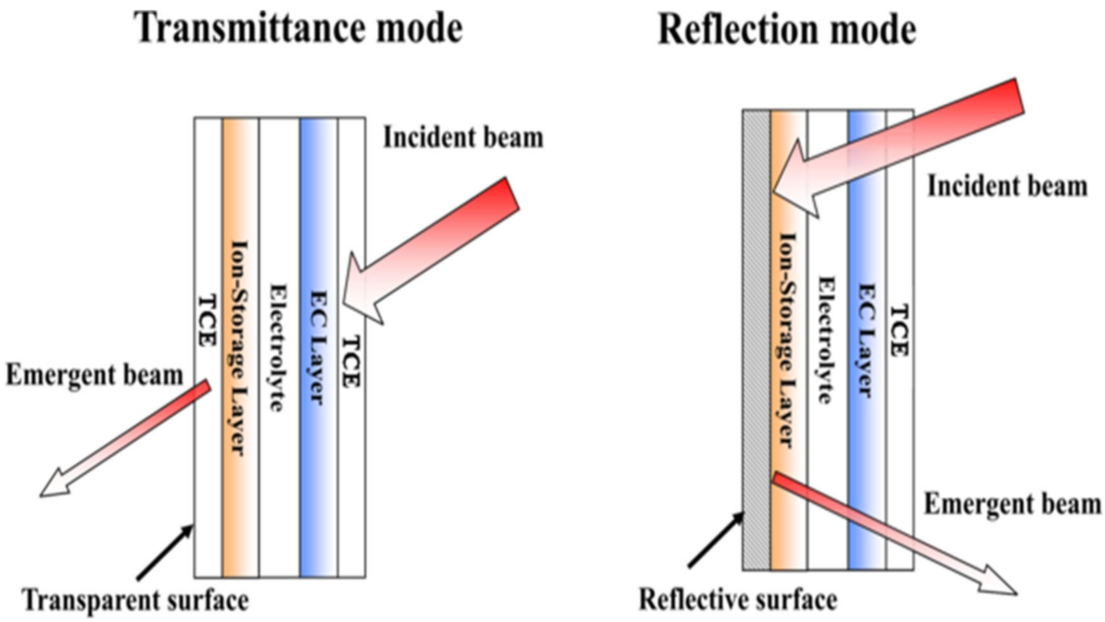


Figure 9: Electrochromic

When electricity is applied to the thin film the particles of align which allows for high transmittance resulting in the transparent state. This State transitions in a matter of seconds usually starting from the outer edges inward. Electricity must be constant to maintain the desired state or the effect becomes opaque. A major downside to this technology is that if the thin film is disturbed the effect to transition is greatly diminished and the solution is a complete replacement of the glass and thin film.

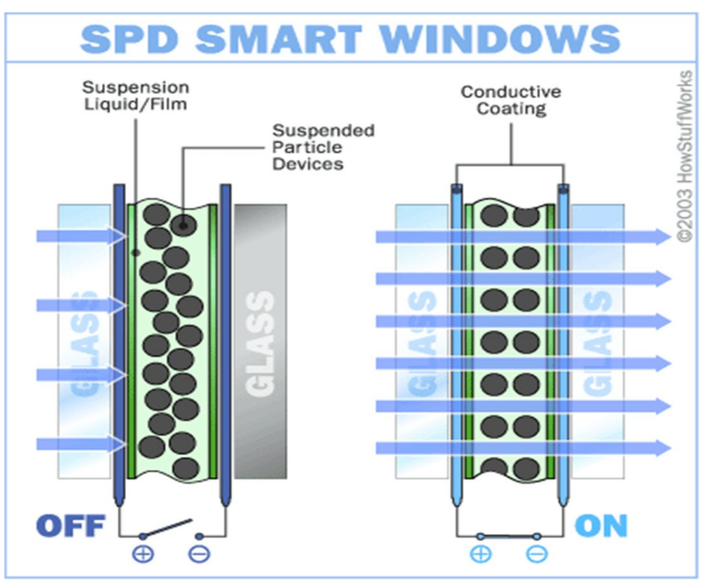


Figure 10: Suspended Particle Device

3.2.2.2.3 Polymer Dispersed Liquid Crystal

Polymer dispersed liquid crystals are created when liquid crystals are placed in liquid polymers and allowed to solidify forming the sheet. Depending on the quality of the curing process this will determine the quality of the transparent effect. Usually there are two options that this technology appears in. A thin film that is placed between two panes of glass or as a plastic like sheet that is composed of this pdlc. In the default state the crystals are randomly dispersed which causes light to scatter in the film producing the opaque effect. When electrodes are applied to the sheet similar to the SPD the crystals align allowing for light to pass through with high transmissivity be producing the transparent effect. The alignment of the crystals is determined by the quality of the produced PDLC and the amount of voltage applied to the sheet at the electrodes. As higher voltage is applied the crystals become more aligned which increases the transparency through the sheet. This effect takes place in milliseconds the fastest of all three described technologies. If the plastic sheet is used this also becomes the safest and easiest to replace medium of these three technologies as compared to the electrochromic glass and the SPD which if anything damage occur and the film is affected the entire replacement of the glass is required.

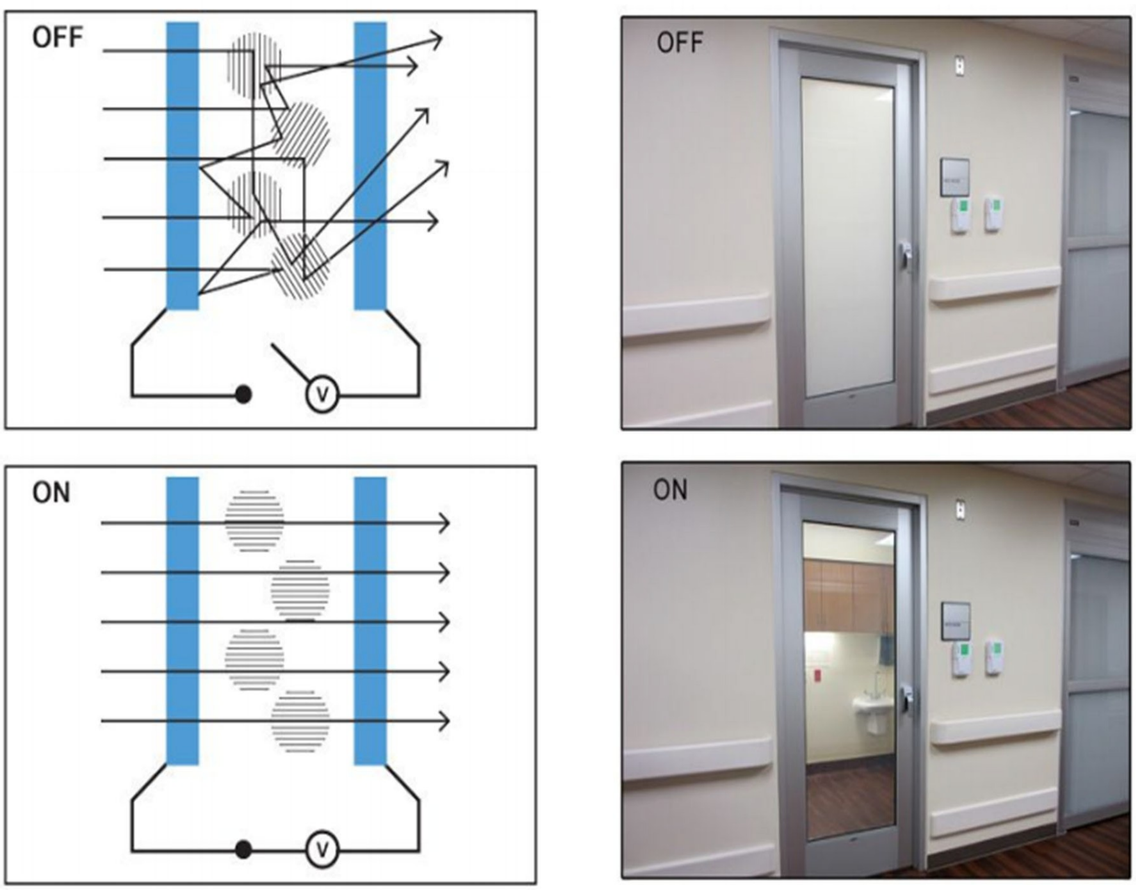


Figure 11: Picture description of Project goals

3.2.2.2.4 Conclusion for Smart Film

Seeing the benefits and cons of the above technologies, it was clear that smart glass passive devices have many downsides being a lack of control and producing an opposite effect of what our group desires are. This led us to the active smart glass, when it came between electrochromic glass, SPD, and PDLC it became quickly apparent that PDLC would be our best option going forward. It had the fastest transition time of all the materials which met one of our engineering requirements, it was easy to replace as any damaged sheet could be removed and reinserted simply by sizing and attaching the electrode, and it had the simplest installation and was most user-friendly as there was not a need to have specialized glass inserted.

Table 4: Summary of Smart Film choices

Technology	States	Power	Transition time
Electrochromic	on	burst	15+ seconds
	off(default)	burst	15+ seconds
S.P.D	on	continuous	3+ seconds
	off(default)	n/a	3+ seconds
PDLC	on	continuous	.1 seconds
	off(default)	n/a	.3 seconds

3.2.3 Microcontroller Unit (MCU)

A microcontroller is an integrated circuit that contains one or more processors with memory and programmable input and output units. Microcontrollers are designed for specific embedded system applications. MCUs (Microcontroller Units) usually contain one or more of the following components: processor, memory (Read Only Memory and Random-Access Memory), input and output ports, Timers and Counters, Interrupt Controls, analog-to-digital converter, digital-to-analog converter, and Serial ports for interfacing with other systems. The advantages of using an MCU for this project are: 1) lower cost because many elements of the processor will be contained within one chip, 2) low power consumption thereby minimizing overall power management of the entire project, and 3) integration of all components on one chip allows optimization of the processor. However, there are also some disadvantages of microcontroller units which include: 1) less flexibility since all components are integrated onto one small chip, 2) MCUs have limited performance considering that the size of memory for MCU is usually limited due to the size of the chip in question, and 3) MCUs are application specific which limits choices. Some of the downsizes to using MCUs also include slow processing speeds and use of little energy because MCUs are designed in applications that require less computational capabilities. Some of the criteria that would be considered when selecting an MCU for this project include: 1) availability of the MCU i.e. ease of procurement, 2) compatibility with the overall project i.e. ability to interface with other devices and components of this project, 3) cost (low cost which is a very essential aspect of this project due to the goal of delivering a low-cost project, 4) speed which will allow the quick activation and 5) power management (which takes into account the overall power management of this project since this project aims to deliver an ultra-low power device in addition to the other requirements stated earlier). For the scope of this project, the MCU will be used to interface the software design of this project with the sensors (proximity sensors) used for some of the activation methods. The subsections go through different possible MCU choices that could potentially meet the requirements needed herein.

3.2.3.1 ESP32

ESP32 is the successor of the ESP8266 MCU that combines I/O, Bluetooth and Wi-Fi capabilities while being one of the cheapest solutions for Home Automation projects (which is the goal of this project). Similarly, ESP32 has dual core i.e., it has 2 processors. Some of the specifications of ESP32 MCU are:

- Number of cores: 2 (dual core) i.e. has 2 processors
- Wi-Fi: 2.4 GHz up to 150 Mbits/sec
- Bluetooth: Bluetooth Low Energy (BLE) and Legacy Bluetooth (classic Bluetooth)
- Architecture: 32 bits
- Clock Frequency: Up to 240 MHz
- Memory: Random Access Memory (RAM) of 512 kilobyte (KB), Read Only Memory (ROM) of 448 kilobytes
- Pins: 30 0r 36
- Security: Hardware accelerators for AES and SSL/TLS
- Peripherals: Capacitive touch, analog-to-digital converter, digital-to-analog converter, Inter-Integrated Circuit, Universal Synchronous Receiver/Transmitter, CAN 2.0 (Controller Area Network), Serial Peripheral Interface, built-in temperature sensor, Pulse Width Modulation
- Arduino Integrated Development Environment compatible

These microcontrollers have a robust design which allows functionality in industrial environments (with temperatures from $-40\ ^{\circ}C$ to $+125\ ^{\circ}C$). They also have ultra-low power consumption. This feature was advantageous to this project because minimizing power consumption of the overall project was important. Also, ESP32 have Bluetooth and Wi-Fi chips which allows interfacing with other systems. This feature came in handy because one of the requirement specifications for this project involved using wither Bluetooth or Wi-Fi connectivity for activation methods.

Figure 12: ESP32 Development Board with ESP-WROOM32

3.2.3.2 PIC

Peripheral Interface Controllers (PIC) are microcontrollers that can be programmed to do a large range of tasks using circuit-wizard software. The advantages of using PIC MCU are: 1) Fast performance due to RISC architecture usage, 2) Less power consumption, 3) easy programming, and 4) Easy interfacing with analog device without use of extra circuits. However, some disadvantages include: 1) High length of program due to using RISC architecture, and 2) Inaccessibility of program memory.

Some of the specifications of PIC Microcontrollers are:

- Number of cores: one 8-bit processor
- Architecture: RISC
- Memory: ROM of size 2 megabytes (MB), RAM between 256bytes and 4096bytes
- Peripherals: Timers, Analog-to-Digital Converters, USART PROTOCOL for other system communication, input/output ports between 16 to 72 pins, SPI PROTOCOL and I^2C PROTOCOL for memory communication
- Circuit-Wizard software compatible

While this MCU (Microcontroller Unit) met some of the criteria needed for this project, the disadvantages made it a less likely choice because this project team members would rather spend more time on the hardware assembly and creation than dedicated numerous amounts of time on creating long and lengthy program for this MCU.

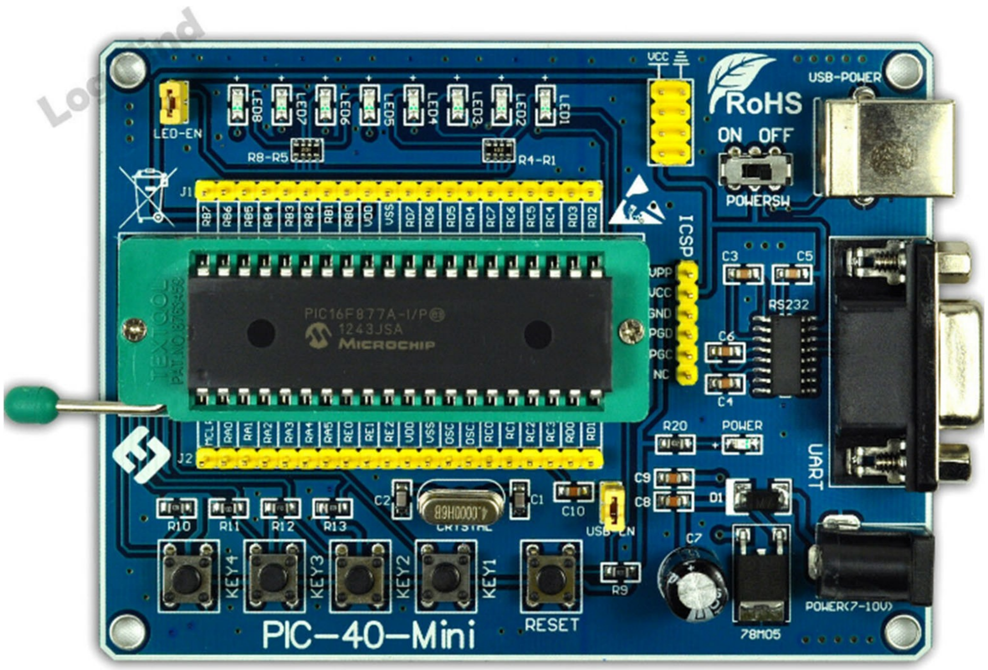


Figure 13: PIC Development Learning Board with PIC16F877 Microchip

3.2.3.3 MSP430

This microcontroller unit from Texas Instrument, is a 16-bit MCU platform that provides low power consumption and is the ultimate solution for low-cost embedded applications. An advantage of using MSP430 MCU is that it provides ultra-low power which is an important feature for this project.

Some of the features of MSP430 Microcontrollers are:

- Architecture: 16-bit RISC
- Clock Frequency: 12kHz (typical) but can range anywhere from 4kHz to 20kHz
- Ultra-low power
- High performance analog, optimized serial communications
- Peripherals: General purpose input/output ports, Analog-to-Digital Converter, Timers, Digital-to-Analog Converter, Power Management Unit, Inter-Integrated Circuit, Universal Synchronous Receiver/Transmitter, Serial Peripheral Interface, USB

MSP430, while it had the necessary specifications required for this project, was not the right choice of MCU for this project because it didn't provide built-in Wi-Fi and Bluetooth (as compared to the ESP32 MCUs) which were essential for the activation methods proposed for this project.

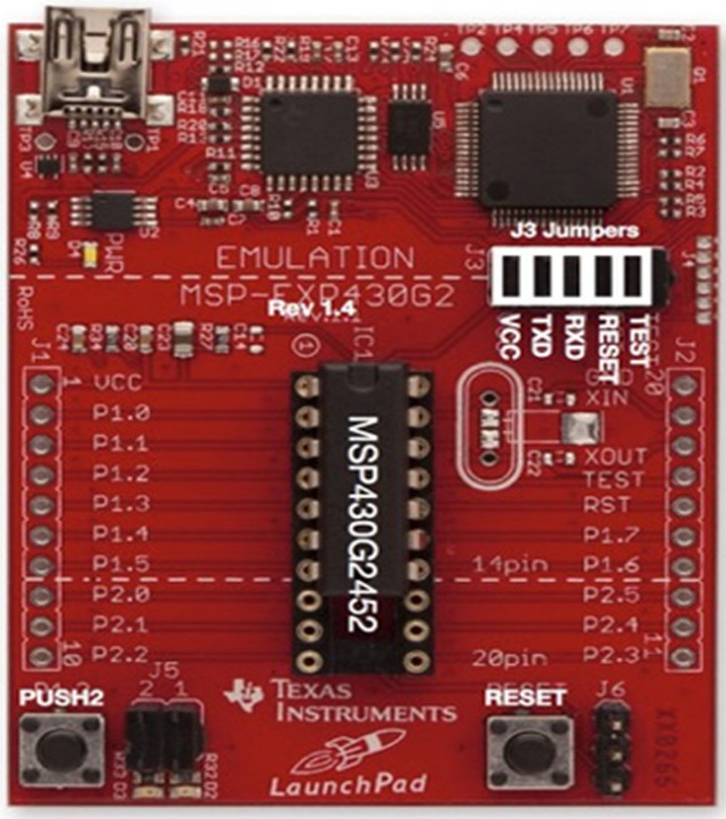


Figure 14: Texas Instrument Launchpad with MSP430G2452

3.2.3.4 Comparison of MCU choices

The table below shows the comparison between the possible choices for microcontrollers that can be used for this project. The comparison was done based on the requirements for the proposed electric blind herein.

Table 5: Comparison of Microcontroller Choices

	ESP32	**PIC Series**	**MSP430**
Architecture	32-bit	RISC	16-bit RISC
Number of cores	Dual core processor	1 processor	1 processor
Clock Frequency	Up to 240MHz		12kHz
Power Consumption	Ultra-low	Low	Ultra-low
Important Peripherals	SPI, UART, USB, built-in temperature sensor, ADC, I2C	SPI, UART, USB, ADC, I2C, Timers	SPI, UART, USB, ADC, I2C, Timer
Built-in Wi-Fi module	2.4GHz		
Bluetooth	Built-in BLE and classic Bluetooth		
Integrated Development Environment	Arduino	Circuit Wizard software	

3.2.4 Proximity Sensors

For the scope of this project, one of the specifications was providing a contactless activation method to change the status of the PDLC film from opaque to transparent and vice versa. An extensive research on the proximity fuse was necessary. There are multiple types of proximity fuse technologies that can be applied to a variant of operations from large scale for industrial purposes to small scale such as this project.

3.2.4.1: Proximity Sensor Requirements

Before choosing out what requirements of the sensor for this project. A definition for a proximity sensor should be studied. Proximity sensor is a mean of a contactless sensor that can detects different types of objects in the range of sensor. The types of objects can be from different materials such as metallic object or non-metallic object. The different types of proximity sensor can be used based on the object's shape disregard of the colors. The state of the object such as liquid, solid, or gas can also be detected with a correct types of proximity sensors. Proximity sensor's range is an important parameter for the selection to implement with each of the project.

With the basic knowledge of the proximity sensor, some parameters for this project can be prioritized such as the material of the target should not be metallic because the sensor will detect human beings. The physical shape of a user as well as the different colors of the clothes won't affect the working scheme of the proximity sensor. Finally, the working range is of the sensor need to be considered. The range should not be far away, an ideal working range for the sensor should be from 10 cm – 50 cm since the user needs to get close to activate for sight seeing.

The proximity sensor will be placed at a position where it can sense an approaching human being. The 2 best applicable places to mount the proximity sensors are at the upper and lower frames of the windows. However, the benefit and requirements of the places are different. With the upper frame of the window, the proximity sensor must be pointed down to some angle depends on the height of the window. The higher the window, the steeper the angle the proximity sensor must be to sense. Moreover, some proximity sensors do not work well at close range (< 10 cm). A benefit of mounting the proximity in the lower frame of the window is the sensor can be mounted parallel with the ground where the sensing components cannot miss the target who is in its range.

With those requirements defined, a search for the best suited proximity sensor need to be conducted. There are different types of proximity sensor could be examined: inductive capacitive, magnetic, photoelectric, and ultrasonic proximity sensor.

3.2.4.1.1 Inductive Proximity Sensor

The device consists of an inductive coil made from numerous turns of conductive material such as copper and a capacitor to store electrical energy. The inductive coil and the capacitor create and maintain an oscillation sine wave supplied by a power source. The oscillation sine wave generates an electromagnetic field in front of the sensor. When a metallic target is close to the front of the sensor in a defined range, the electromagnetic field transfer its energy into the object as a form of eddy current. The internal resistant of the object resists the eddy current and creates heat where the heat is a loss of energy as the electromagnetic field. When the energy loss in the electromagnetic field is reduced to a certain level, it will trigger the sensor's output to indicate the metallic object is in front.

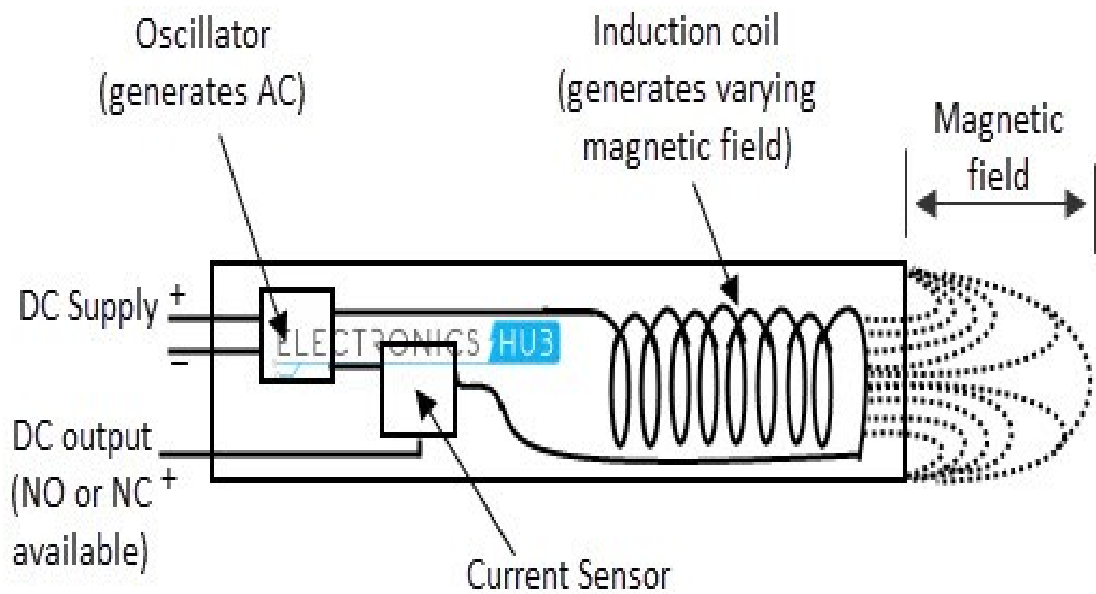


Figure 15: Inductive Proximity Sensor Schematics

The advantages of the inductive proximity sensor are cheap. It usually comes in a cylindrical shape so it's compact and can fit to the frame of the window. However, the inductive proximity sensor has a very short range, around 5-10 mm. Moreover, it can only sense metallic object where a human factor plays an important role in the scope of the project.

3.2.4.1.2 Capacitive Proximity Sensor

This device acts like a capacitor where it has its own metal plate connected to the oscillator circuit. The sensed target acts like another metal plate and the air in between the two plates is a dielectric. The device is powered by an electric source and creates an electrostatic field. When the target is in range, the amplitude of the electrostatic field increases which make the amplitude of the oscillation signal also increase. When the oscillation of the signal increases and reaches the threshold of the device, a sensor's output will be trigger as an indicator.

An advantage for this proximity sensor is it can sense non-conductive objects. This advantage could be a plus for the selection of this sensor. However, the range of the sensor depends on the object's material and size. The standard target's size for a conductive object must have a side length equals or three times larger than the diameter of the sensing plate. For non-conductive object, range can only be determined by many reduction factors. The capacitive proximity sensor is also affected by the temperature because the dielectric is air.

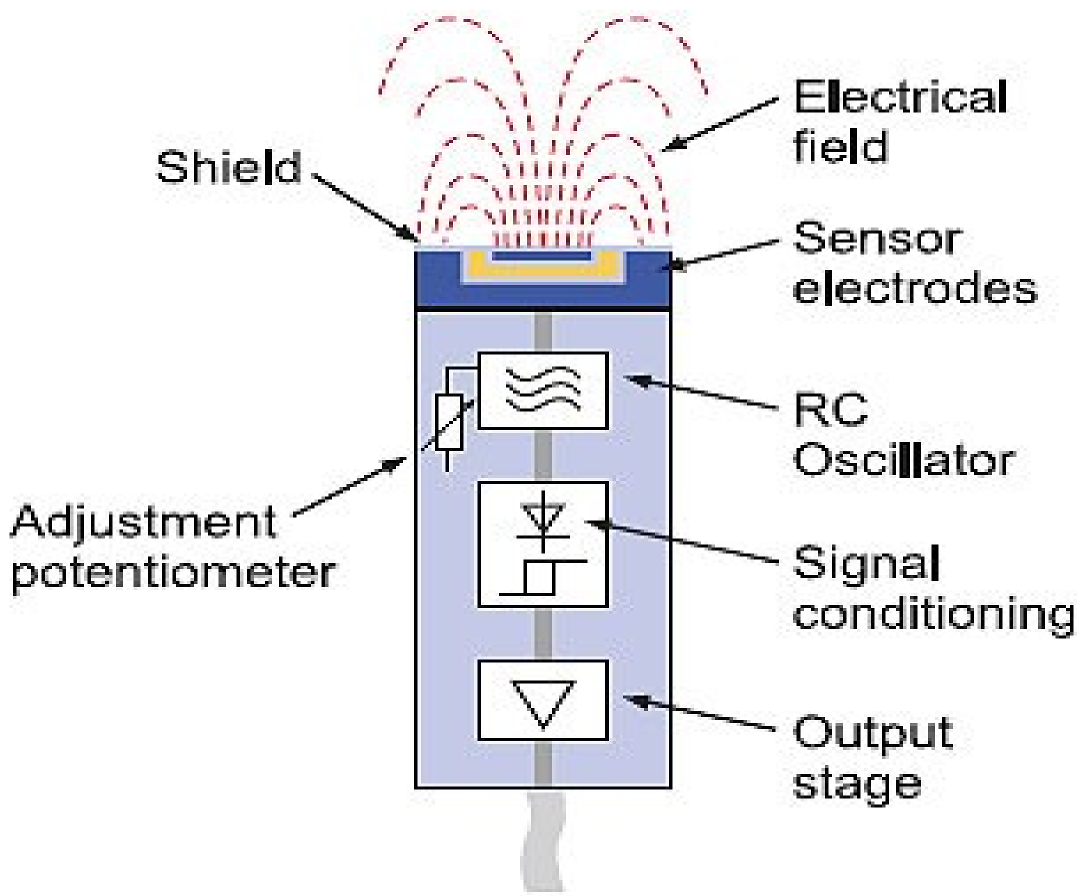


Figure 16: Capacitive Proximity Sensor Schematic

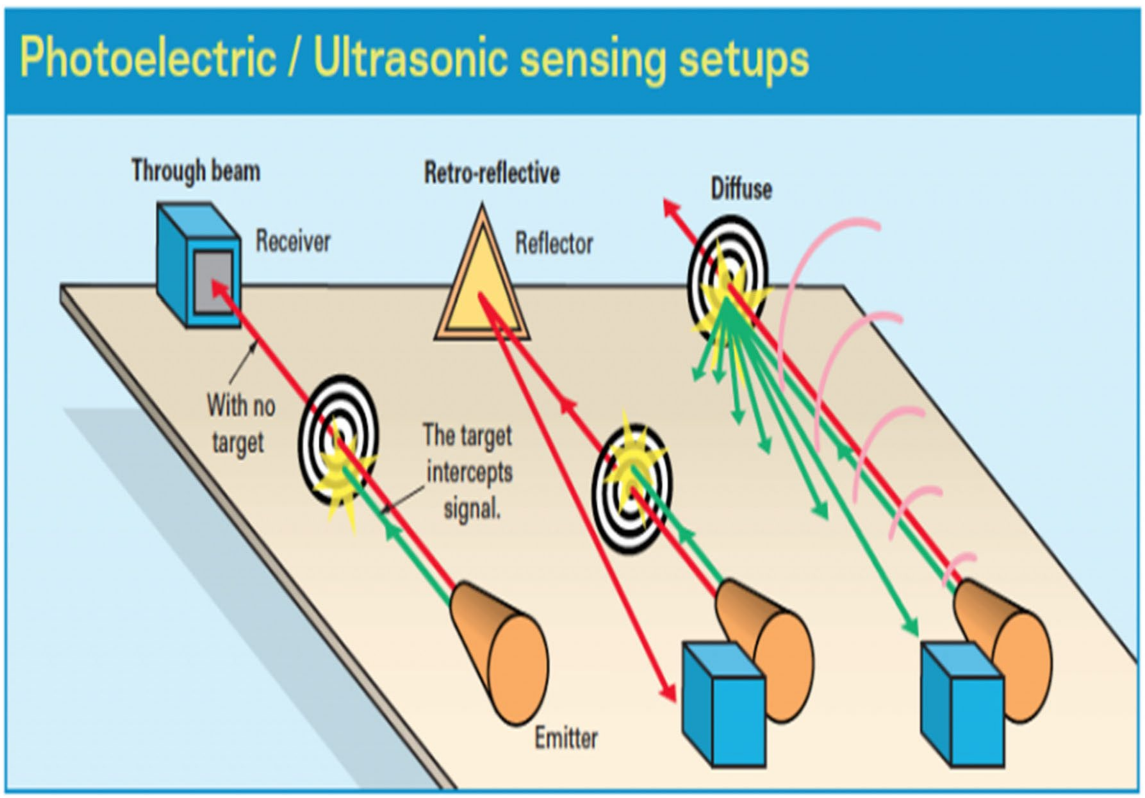
3.2.4.1.3 Magnetic Proximity Sensor

Also known as the Hall-effect sensor is used to detect the presence of magnetic field. The working principle of this sensor is quite simple. If there is a magnetic field in range of the sensor, the magnetic field magnetizes the thin metal plates call the reeds and causes them to touch each other to complete a circuit, then the switch for the sensor's output such as alarm or light will be activated.

Based on the human factor of this project, the magnetic proximity sensor is not suitable to be considered.

3.2.4.1.4 Photoelectric Proximity Sensor

This is a device that can be used to detect the presence of the object using its own light source. The photoelectric proximity sensor usually contains 3 main components which are the light source, amplifier, signal converter, and an output. The light source's main goal is to transmit the light (LED or IR) into the space where an object can either interrupts the light from source or reflects the light back into the receiver with a smaller density. The reflected light is passed through an amplifier to amplify the signal then pass to the converter from for the output. There are 3 modes of photoelectric proximity sensors:



Lasers or sound waves serve as the signal in three setups. In through beam and retro-reflective, the signal shoots from the emitter to receiver until the target cuts it off. In diffuse sensing, the signal diverges until a target moves in and reflects some back to the receiver.

Figure 17: Working Principle of 3 different modes from photoelectronic Proximity Sensing Technologies

Thru-Beam mode: this mode of photoelectric proximity sensor consists of two different housing – one for the transmitter, and one for the receiver. The transmitter is positioned where the light is transmitted directly into the receiver. When the transmitted light is interrupted, the signal in the receiver will signal to activate the output. The range for this mode is quite far, can be up to ten meters away.

Retroreflective mode: this mode of sensor has a similar working principle as the through beam. However, the transmitter and the receiver are in same housing and there will be a reflector which is used to reflect the transmitted light to the receiver. When there is an object which interrupts the light path, the sensor will give an output signal.

Diffused mode: this is the last mode of photoelectric sensing technology. For diffused mode sensing, the transmitter and receiver are in the same housing. The light transmitted from the transmitter will be reflected by some arbitrary angles to the receiver. Some reflected light beams hit the receiver will activate the output for this sensor.

The effective range for this diffused mode sensing is up to one meter. This range is reasonable for a user to use. Whenever the user feels an urge to have a look outside the window, he/she can approach the window to activate it. A downside for this mode of sensing is a dark environment or dark clothing from user can absorb the light from the transmitter which will have no light reflected into the receiver to trigger the output.

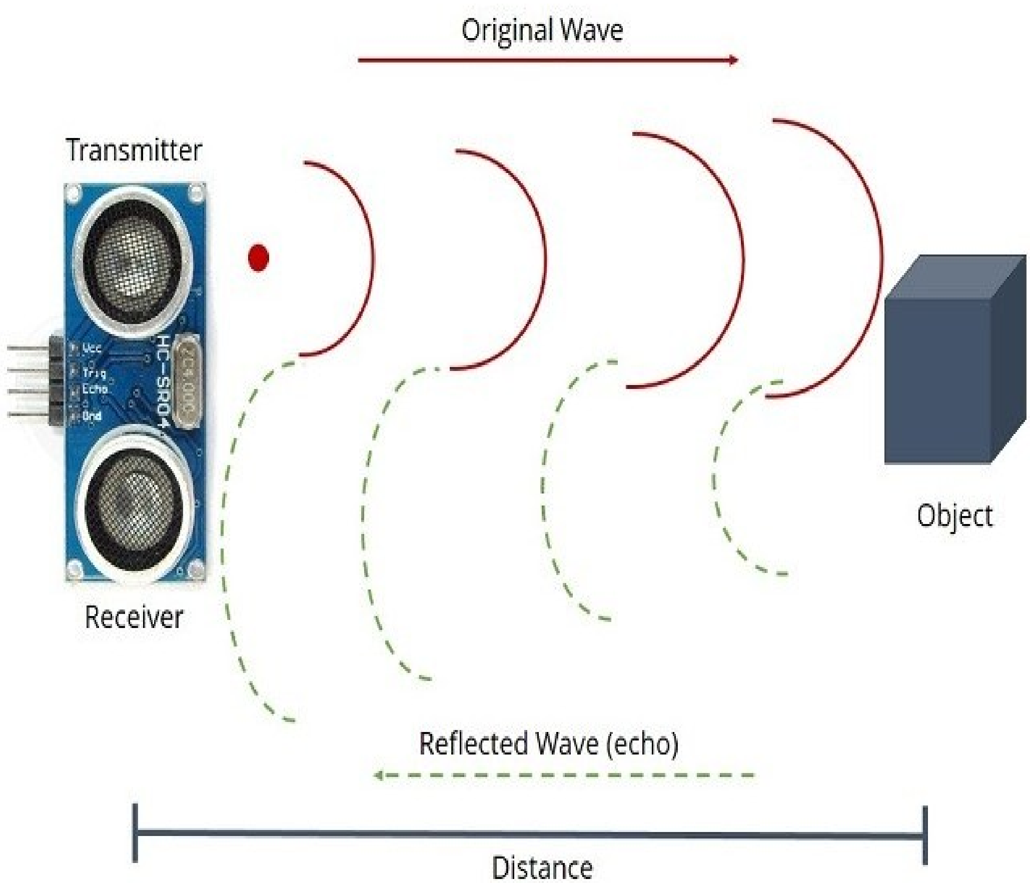


Figure 18: Ultrasonic Proximity Sensor Working Principle

3.2.4.1.5 Ultrasonic Proximity Sensor

The working principle for the ultrasonic proximity sensing technology is similar to photoelectric proximity sensing technology. The only difference is ultrasonic proximity sensor uses ultrasonic sound waves to detect an object instead of light. The ultrasonic sound waves are transmitted from the transmitter then reflects from the object to the receiver in the same housing. The reflected waves will then trigger an output signal to notice there is an object in its range.

The effective range for this ultrasonic proximity sensor is up to four meters which is also reasonable for the scope of this project. When using this sensor, soft clothing or sound absorbing material such as wool in the winter can reduce the effectiveness of the sensor.

3.2.4.2: Proximity Sensor Comparison

The table below summarizes the main characteristics of 5 different proximity sensing technologies researched above to provide a comparison between the technologies for us to choose the best fit proximity sensing devices for our project.

Table 6: Comparison between photoelectric and ultrasonic proximity sensing technologies

Proximity technology	**Inductive**	**Capacitive**	**Magnetic**	**Photoelectric**	**Ultrasonic**
Range	5 - 10 mm	25 mm	70 mm	12 m	4 m
Detectable	Metallic object	Metallic, non-metallic object, fluid	Metallic object	Metallic, non-metallic, object radiates wavelength	Object with simple surfaces
Application	Industrial	Industrial	Industrial	Industrial/Residential	Industrial/Residential
Environment	Suitable for harsh condition	Suitable for harsh condition	Suitable for harsh condition	Not suitable for harsh condition	Suitable for harsh condition but not in vacuum.

Based on the research for different proximity sensing technologies, the applications and effective range of inductive, capacitive, and magnetic proximity sensor are limited and not suitable in the scope of this project. Because both photoelectric and ultrasonic proximity sensing have a longer effective range where the maximum range can be up to ten meters, and this range can be adjustable to be shorter depends on the user's desire. Moreover, for these two sensing technologies, they can sense non-metallic objects which is important because of human factor for the scope of this project. The capacitive sensor can also sense non-metallic object, but it is affected by many factors such as the environment's temperature, different sizes of metallic object and non-metallic objects. With the listed reasons above, only photoelectric, and ultrasonic proximity sensing technologies will be closely analyzed to draw out a conclusion on which sensing technology will be most suitable for this project.

In conclusion, these two sensing technologies were applicable. However, the photoelectric sensor had a slight advantage in its compact size made it easier to be mounted and hidden away for aesthetic reason. Another advantage takes from its cons where the lighting environment in the user's room will be mostly bright enoughfor it to be activated.

Table 7: Comparison between photoelectric and ultrasonic proximity sensing technologies

	Photoelectric proximity sensor	**Ultrasonic proximity sensor**
Range	Up to 12 m	Up to 3m
Price	$ 3 - $ 40	$ 4
Size	45 x 20 x 15 mm	24.03 x 32.34 x 24.66 mm
Power Consumption	0.325 W	0.075 W

3.2.5 Power Delivery Technology

As explained above, the photoelectric proximity sensor has different modes which are thru-beam, retroreflective, and diffuse mode. However, the thru-beam and the retroreflective modes require another housing for receiver for thru-beam mode, and reflector for retroreflective mode. This makes the design become more complicated. In addition, the other receiver housing mounted in the opposite side of the transmitter will activate false or unwanted signal when there are objects pass by in it range. Therefore, the sensors belong to the diffuse mode was closely examined and analyzed to choose out the best fit for the proximity sensor.

3.2.5.1 Power Supply

Nowadays, most electric devices need a power source which can be supplied from a receptacle (AC voltage) or from a portable power source such as battery (DC voltage) or a combination of the two sources above. When DC voltage source is depleted, an AC voltage source can be used to recharge for the continuity of that

DC voltage source. In addition, this project has many different components which use different voltage level.

With the conveniences of the battery such as small and portable, it also has its downside where the power capacity of the battery can pose an issue when the devices work continuously. The battery power capacity is a value with a unit Ah (Amp-hour). This parameter is a main factor to decide the reliability of the battery. Let's assume the battery has the power capacity of 5000 mAh and the devices draws a current of 5 A. The battery can only last in an hour. For this project, the currents drawn by the components are only in milliamp which makes the battery have a longer working life. By using a pretty reliable source such as the AC voltage taken from the house to overcome that issue. Nevertheless, the components in this project use DC voltage where a full rectifier will help bring the sinusoidal wave of VAC to a smooth, almost linear signal that can be considered as VDC.

Therefore, a research for a voltage regulator is also required besides the research for the power source to choose out the most suitable power source and voltage regulator for this project.

3.2.5.1.1 Battery

Battery is pretty familiar to everyone since it plays an important role supplying power to the devices that we are using everyday such as watches, telephones, game console, etc. Therefore, we probably notice that there are 2 type of batteries where one type is one time using only, and the other one can be recharged through the receptacle in our house. Indeed, those two types of batteries are call primary battery (non-rechargeable) and secondary battery (rechargeable).

Primary battery is commonly known as the cylindrical shape cell such as the AAA or AA battery. The primary battery is usually small, lightweight, inexpensive, and quite safe to use. Another advantage of the primary battery is its readiness where a package of many batteries is always ready to use even if they are stored in a long period of time thanks to its shelf life. Specific energy of primary battery is also higher than the secondary one. Specific energy of battery is the capacity of the energy a battery can hold. The chart below shows that primary batteries have a larger specific energy compared to secondary batteries.

Besides the cylindrical shape, primary battery also has a button shape and rectangular shape. Primary battery comes with different sizes such as AAAA, AA, AAA, C, D. The size and shape of the batteries are important since they will take a good amount of area on or outside of the PCB. The nominal cell voltages of the primary battery are usually at 1.5 V, 3.0 V, or 3.6 V depends on the material of the battery. Nevertheless, by choosing the suitable size, shape and nominal cell voltage for the batteries can make the device have a smaller footprint helps with the prototype as well as the aesthetic purpose.

Secondary battery is widely known thanks to Lithium Ion which is mostly used in rechargeable battery for cell phone. The advantage of secondary battery is its rechargeable function where it can save money when used on devices draw higher current. The actual specific energy of secondary batter is close to the rated value when compared to the primary battery, its actual specific energy is pretty low. The discharge rate of secondary battery is also higher than the primary one. The chart below shows the rated and actual specific energy of the primary and secondary battery.

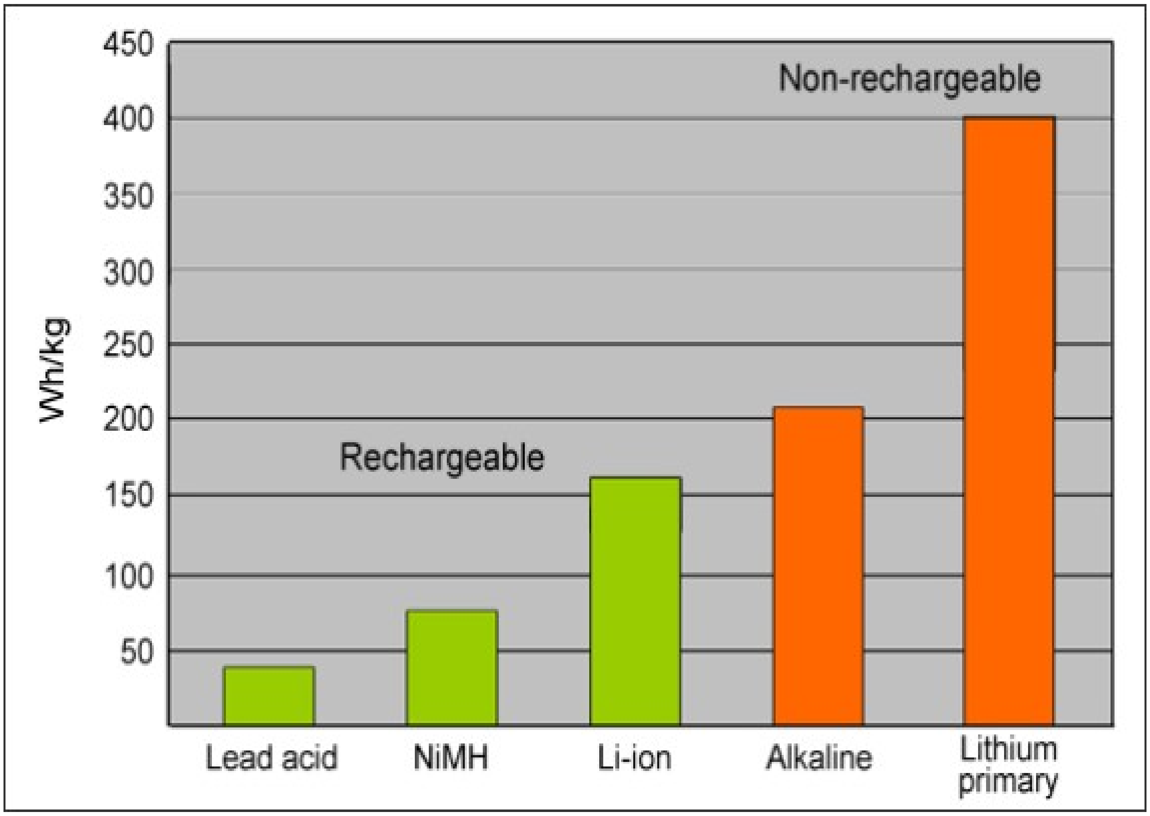


Figure 19: Specific energy comparison of secondary and primary battery. (Need confirmation to reproduce from https://batteryuniversity.com/learn/article/primary_batteries)

Secondary battery comes in various sizes and shapes from button to cylindrical to boxy. The boxy secondary battery mentioned is the lead acid battery which is used in automotive industry. The nominal voltages of secondary battery are usually from 1.2 V to 3.7 V. The nominal voltages of secondary battery are usually from 1.2 V to 3.7 V. The only disadvantage of using secondary battery is it is more hazardous. An overcharged or overheat Li-Ion battery can cause the devices to explode and damage the users. Lead acid/car battery is also dangerous because of its chemical materials. Acid from the battery can leak out over time, an unnoticeable touch to the acid can irritate or burn skin, eyes.

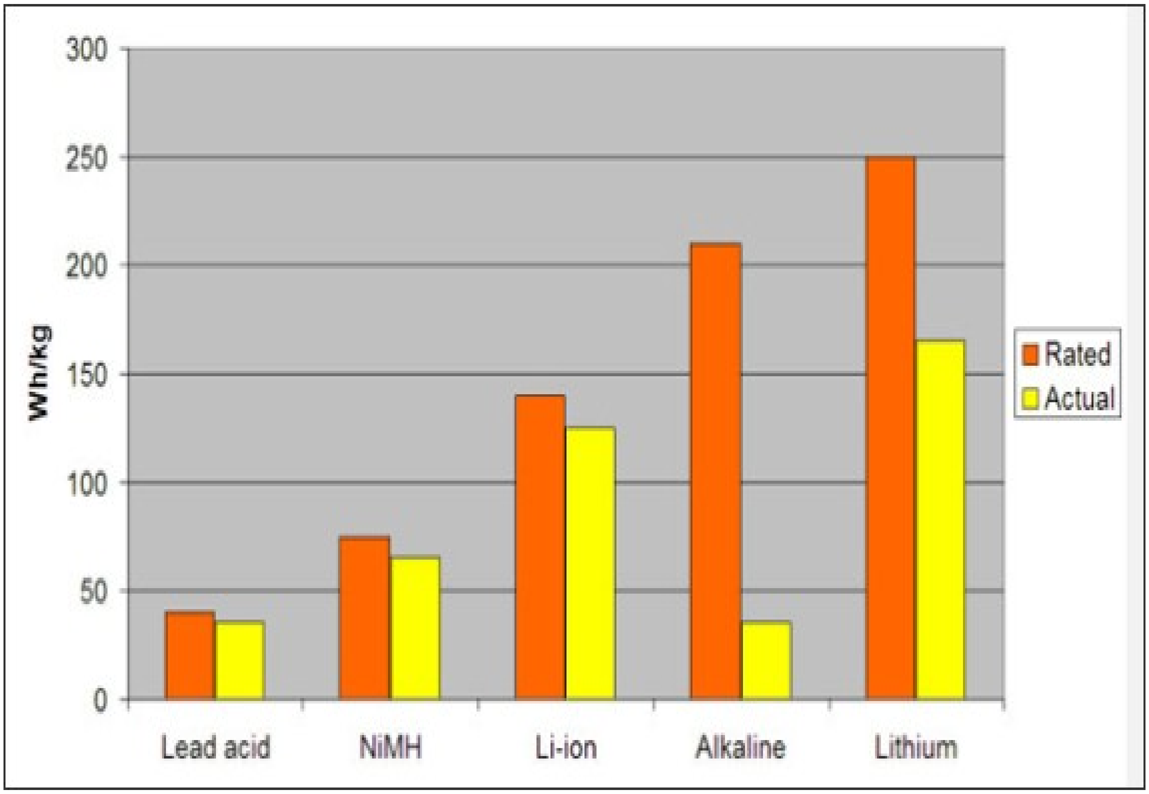


Figure 20: Energy comparison underload. (Need confirmation to reproduce from https://batteryuniversity.com/learn/article/primary_batteries)

3.2.5.1.2 Solar Panel

With today technology, solar panel is used widely due to its price has been decreasing tremendously and it is now coming with many different sizes that suitable for residential usage as well as for small device, project like ours. The main purpose of using solar panel for the project is to improve the sustainable ability of this project where the thermal energy collected from the sun is converted to electric energy which is stored in rechargeable battery.

The focus on solar panel is on the low-wattage panels since the device only requires less than 10 W to operate. The solar panel market provides a variety for choices for mini solar panel where the wattage is from 5 W to 100 W. The smaller the wattage, the cheaper and smaller module the solar panel requires which helps for the budget and the ease of installation/prototype of the project.

The negative point of the solar panel is it entirely depends on the outside weather especially for area or state that has a lot of rainy days or overcast weather such as Florida. Therefore, to ensure the reliability for the solar panel system, a second power source such as household power or another set of backup primary/secondary battery.

3.2.5.1.3 Household Power

Household power is a plug and play source for any ordinary device where it comes with adapter to convert AC to DC voltage. The technology used behind that is developed from diode to build a full bridge rectifier to allow AC voltage to flow in one direction and make it DC voltage.

3.2.5.1.4 Comparison of Power Supply

The table below shows the comparison between the power supply sources from primary battery, solar panel and household power. The comparison was based on this project's characteristic where the need for power is around 6 W.

With the research conducted so far for the power technology that can be used for this project. Household power and primary battery seemed to be well-suited. Household power provides a reliable energy to activate the film on or off. Besides that, a full bridge rectifier can be implemented to convert AC voltage to DC voltage to energize the MCU, switch, relay, etc. Primary battery can be installed as a backup power source due to its shelf life. In case there is an outage in the area, the user can still use the device with the primary batteries as a backup power source.

Table 8: Comparison of Power Supply Technologies

	Battery	**Solar Panel**	**Household Power**
Price/Wh	$ 0.68	$ 0.44	$ 0.011
Area Required	2.48 x 2.28 in	8.6 x 13.8 in	2.76 x 4.5 in
Maintenance required	No	Yes	No
Dependability on weather	No	High	Low

3.2.5.2 Voltage Regulator

As stated above, a research for voltage regulator for a better understanding to choose out the suitable voltage regulator was a must for the project. The voltage regulator is a device used to maintain the output voltage at a certain magnitude that suitable for a particular component without any fluctuation in order to protect the component. There are 3 types of voltage regulator circuit which are linear voltage regulator circuit, Zener voltage regulator circuit, and switching voltage regulator circuit.

3.2.5.2.1 Linear Voltage Regulator

Linear voltage regulator or low dropout regulator is used as a step-down converter by using a transistor. The value of the dropout voltage is the difference between the input and desired output. The difference voltage in the transistor is converted to heat which can heat up the surrounding environment in the assembly. Moreover, that heat is the unusable energy which can drain out the power source faster and make the device unreliable in a continuous working condition.

The linear voltage regulator has some advantages such as it is pretty simple to implement where only a transistor is needed for the circuit. The simplicity of the linear voltage regulator requires only a transistor along with a few passive components such as resistor and capacitor need to be purchased which help drive the total cost of the project down. Since the linear voltage regulator works based on the voltage drop of the transistor so there is no switching from the transistor involved which helps to reduce noise at the output. The noise from the output can make the output unstable which destroy the purpose of voltage regulator.

3.2.5.2.2 Zener Voltage Regulator

Zener voltage regulator where the Zener diode is connected parallelly to the load. This way of connection assure that the load has the same regulated voltage across the Zener diode. The Zener diode working scheme is similar to the regular diode in the forward bias region. However, it also works in the reverse bias region where the Zener breakdown region produces a constant negative voltage as long as the current goes through the Zener diode is in the break down region.

The advantage of using Zener diode is once the Zener is in the break down region, the voltage produces can be up to 200 V with a maximum current to be up to 200A. These values can be used for a variety of different components where they require a significant voltage, current value to operate. Zener voltage regulator has the same issue as with the linear voltage regulator where there will be noise which requires a capacitor to eliminate that noise.

3.2.5.2.3 Switching Voltage Regulator

Switching voltage regulator acts as its name suggest where the input voltage is controlled by an electrical switch to regulate into a smaller portion of energy to avoid the heating problem as the linear voltage regulator. Moreover, unlike linear voltage regulator and Zener voltage regulator, switching voltage regulator can be used to step up or step down the output voltage. Step up voltage regulator can be called boost converter. Step down voltage regulator can be called buck converter. This type of voltage regulator can be handy for the project where from one power source can be converted to different voltage levels for the outputs used for different components.

Because of the working way of switching voltage regulator where the input voltage transferred to the output in a small portion. The energy loss is therefore smaller which makes the switching voltage regulator more efficient than the other types of voltage regulators. Less energy loss also means that the switching voltage regulator is not as hot as the linear voltage regulator. Therefore, heat management is not required. Nevertheless, there is a downside of switching voltage regulator which it is more complicated to build. If an IC is required to be purchased, its price is also higher than the transistor and Zener diode.

The main purposes of switching regulators are saving energy and step up or step-down voltage. However, if the calculated waste energy using linear regulator is not significant, the use of switching voltage regulator is going to be expensive because switching voltage regulator are more expensive. To calculate the wasted energy, the formula:

$$P_{wasted} = (V_{in} - V_{out})\ x\ I_{load}$$

The value for wasted power can be measured once every component for this project is finalized for purchasing. If the wasted power calculated to be less than 1W, the linear voltage regulator and Zener voltage regulator can be implemented.

3.2.5.2.4 Conclusion and Comparison of Voltage Regulators Types

With a knowledge about the voltage regulator researched, each type of voltage regulator has its pros and cons and can be used in different scenarios or applications for the project. The table below summarizes the characteristics of each voltage regulator type.

Table 9: Comparison between voltage regulator types

	Linear Voltage Regulator	**Zener Voltage Regulator**	**Switching Voltage Regulator**
Heat Sink Required	Yes	Yes	No
Price	$ 0.110	$ 0.26	$ 0.55
Efficiency	40%	40%	90%
Power Loss	7 W	7 W	0.7 W
Step Up Voltage Capability	No	No	Yes

With the summary for the voltage regulator in the table above, switching voltage regulator seemed to be the best selection for the project. Switching voltage regulator does not get overheated as the linear and Zener voltage regular. Its efficiency is also higher due to less thermal heat from the energy wasted from regulating the voltage. Although the switching voltage regulator is more expensive than the other two because of its high complexity, there are already built IC for switching voltageregulator which suited our project.

3.2.5.3 Full Bridge Rectifier

Background

The purpose of a Full bridge rectifier is to convert AC voltage into DC voltage by way of a diode bridge. This is done by taking two inputs of the AC Voltage and rectifying them into DC voltage outputs regardless of polarity. An added benefit of this bridge rectifier is that current cannot flow back due to the diode characteristics current cannot flow back.

There will still be some noise generated from rectifying the AC Voltage however this can be rectified with a capacitor (or group of capacitors) set in parallel with the load, greatly reducing the noise.

Application

With this circuit we will have to take into account a working voltage that has a ripple of less than 100mV. To smooth the voltage further it is necessary to increase the

$$V_{ripplr} = \frac{I_{load}}{f \times C}$$

I_{load} will be the DC load current in amps. The frequency will be pre-determined as it will be double the frequency of the AC Voltage. With this we can vary the capacitance to create the ripple Voltage we need. An off the shelf LM78xx (xx standing for voltage rating)

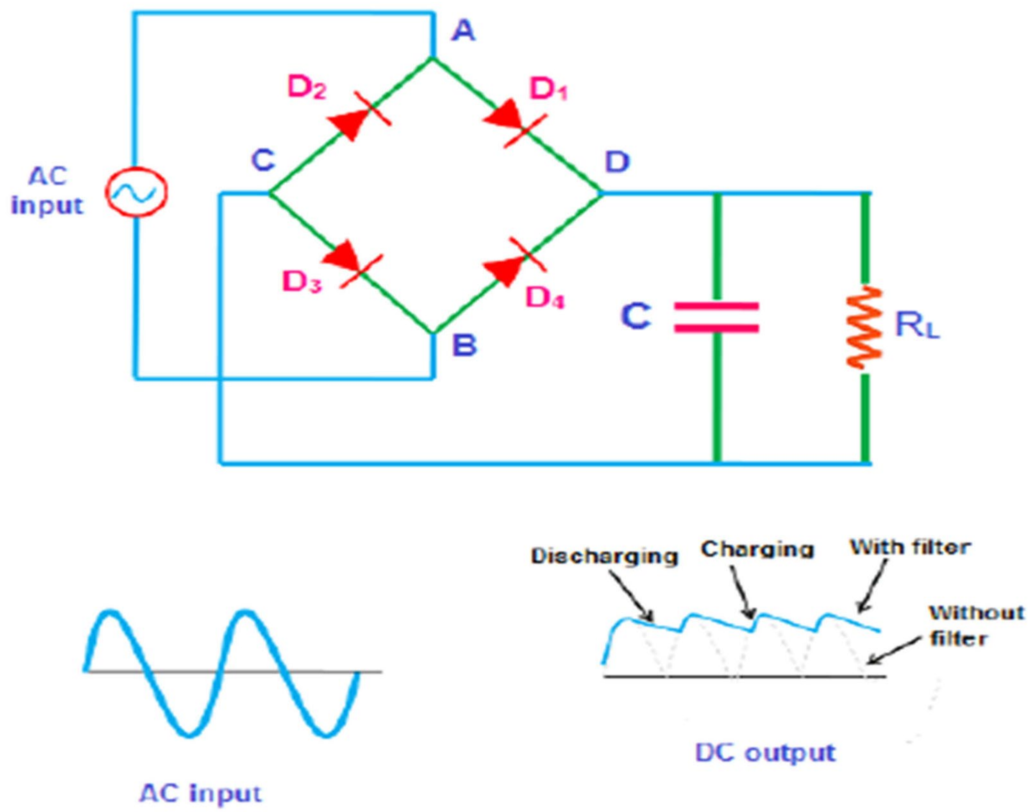


Figure 21: Bridge Rectifier with Filter

X.X.X.X AC to DC

To convert the 60V AC down to the voltage needed to power the rest of the system we will first need a Transformer to reduce the voltage or step it down. At this point we will use a full Bridge rectifier circuit composing afford diodes set in the configuration shown. After this we will use a capacitor and an LM7812 voltage regulator to control the ripple coming out of the full Bridge rectifier. In the circuit diagram this solves our issue in well-defined stages.

Though it is possible to design a voltage regulator from scratch our components are very sensitive to voltage changes and over-voltage can potentially burn out our whole system, that is why we've decided to use a voltage regulator IC. With this we were able to control the whole system with one power source simplifying the design.

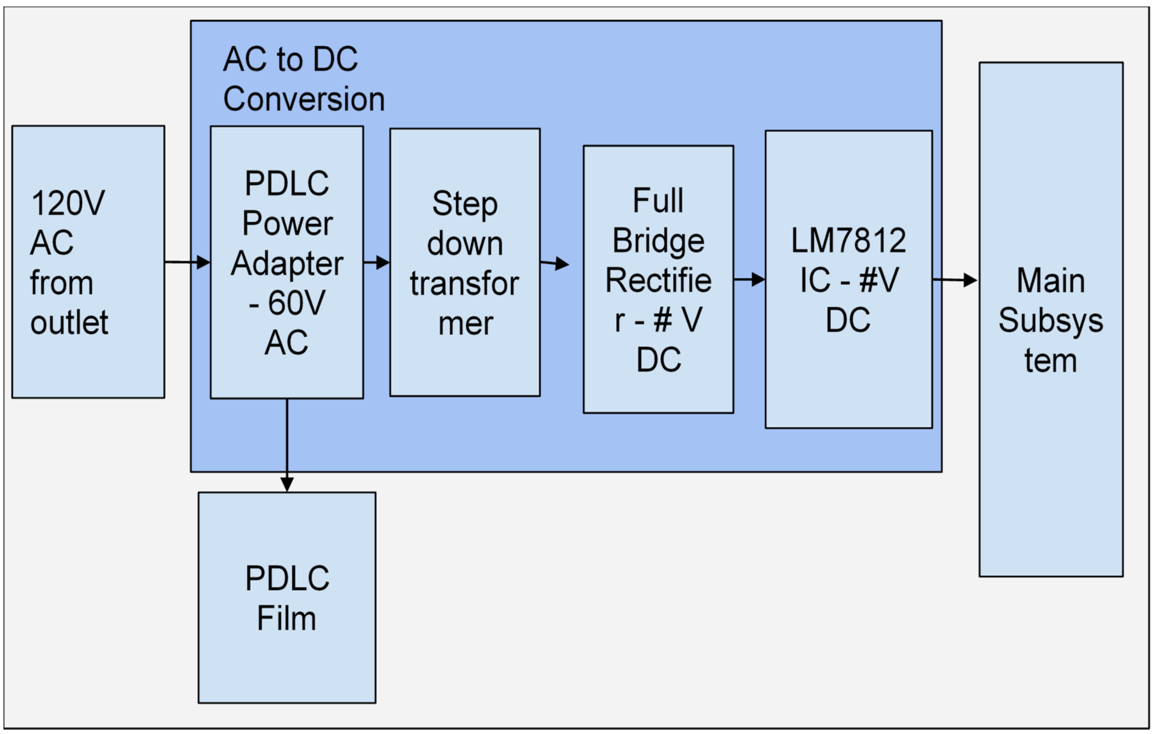


Figure 22: Block Diagram showing 1AC power 2AC step down 3 Full Bridge Rectifier Circuit 4 Ripple Control

3.2.6 Interface Techniques

One of the things we saw as technology increases, is an increased ability to have technology control certain devices. This includes things such as a handclap to turn on lights or asking Alexa to start playing Fermi's Paradox by Avenged Sevenfold on your new stereo system. If the MCU we choose for this project has support for certain technologies, we can include some of those capabilities into this project. This portion explores the various types of input and output that we were implemented into this project.

3.2.6.1 Use of Sensors

The first method of monitoring end user input was through the use of sensors.This is probably the most basic type of End User input this section will cover. Effectively we can have either one, or several sensors monitor for certain input. This input could range from sound, to proximity, to even light. We would define certain actions as certain types of input. For instance, we could have a system where if you are within a certain proximity of the window that we detect with a proximity sensor, we will interpret that as input to open the window. Then when the proximity sensor stops detecting that person within a fixed range, we will interpret that as input for closing the blinds. This is just one example, but there are many other possible applications of this. One of the benefits to using this, is all the code that we would need to run is on the MCU itself. We would not have to concern ourselves with any software running outside of the MCU.

3.2.6.2 Software Web Admin Portal

The second method of monitoring the end user input analyzed camein the form of a software web admin portal. What this will be, is the device will connect to the network of the building. It will then expose a website that it hosts, which end users can log onto. This website will act as an administrator panel, where they can configure certain things. These things could include automatically opening/closing at certain times, statistics on thermal savings, potential diagnostics, and virtually any other relevant piece of information an administrator could want to know (to list off all of them could take dozens of pages easily). This comes with several different advantages, and disadvantages. The first main advantage is that it will greatly enable the end user to easily control and monitor the specifics of how the device operates, so they can tailor it to their performance. The second is that it could greatly assist with troubleshooting problems from the perspective of both End Users, and technicians. However, this does come with some downsides. This device will effectively be a network connected IOT (Internet of Things) device. These devices are infamous for being the target of malicious hackers. In addition to that, there will be additional computation needed to support the website. This is a form of input and output that is commonly used by devices, such as network routers. Also, this website would only be available to the network which the window device is connected to.

3.2.6.3 Phone App

The third method of taking input and output was using an Android phone App Figure 8 shows an example of general functionality of a phone app used as an activation method for the electric blind. An overwhelming majority of Americans have cell phones (current statistics claim 96% of all Americans own a cellphone, with 81%

having a smartphone). With this overwhelming majority of people in America having a smartphone, this would be a form of interfacing that a lot of people could realistically use. Now to implement this, we needed to make a version of the app for both IOS and Android. This is because these are the two main operating systems which run most smartphones.

Beyond that, we orchestrated how we would have the app connect to the window device. This is the method that the phone app uses to communicate with the window device. There are really two types of ways that we could do this, with the main differentiator between them being how far from the device you can be to operate it. We could have the communication interface via a method that requires physical proximity. For instance, this could be over Bluetooth, or over the local computer network. The second method is we can have the window device connected to a server that is exposed to the internet. Then you could connect to this server, which would act as a middleman for communication between the end user and the window device. Using this method, wherever we are in the world, as long as we have an internet connection, we can have an interface with the window device. However, this does come with a caveat. By exposing access to people outside of the house, you will have to have security mitigations in place to prevent unauthorized users from accessing the system. In a worst-case scenario, a malicious actor can gain access to the server, and thus access to a window device in your household. Now these security mitigations wouldn't need to be as stringent if access was restricted to close by end users, since physical proximity in itself is a qualifier for authentication (granted this will need to be looked at, since if you are right outside of the window on the outside, you would be in close proximity but could very well be an unauthorized user). In addition to that, one thing that is a possibility is having multiple methods for communication and making certain ones optional and configurable by the end user.

3.2.6.4 Home Assistant like Amazon Echo or Google Nest

The fourth method of the end user interfacing with the window device was using home assistant. By a home assistant with devices such as Amazon Echo, or Google Nest. These are devices which are in the house, take commands such as voice commands, and then execute subsequent actions. For instance, you can ask Amazon Alexa for a definition for a word, or to turn on lights (configuration needs to be right for that) and those tasks will be accomplished. With Amazon Alexa, there is good support for third party developers to step in and write code to accomplish specific tasks. The same thing is true with Google Home. Utilizing these platforms, we can write code that will allow an end user to utilize these home assistants to interface with the window device.

3.2.6.5 Interfacing using home security system

The fifth method of the end user interfacing with the window device is a bit abstract and automated. We could interface it with a home security system. This could allow a home security system to potentially control the device in the event of let's say an intruder looking through a window. Out of all these listed, this would probably be the hardest to set up for several reasons. The first is that opening and closing the blinds other than the scenario just listed, it's hard to imagine cases where a home security system would benefit from that ability. Likely what could help is if the window would report a breakage in the glass. The second reason is that interfacing this with home security systems would likely require collaboration with the company that produces the home security system.

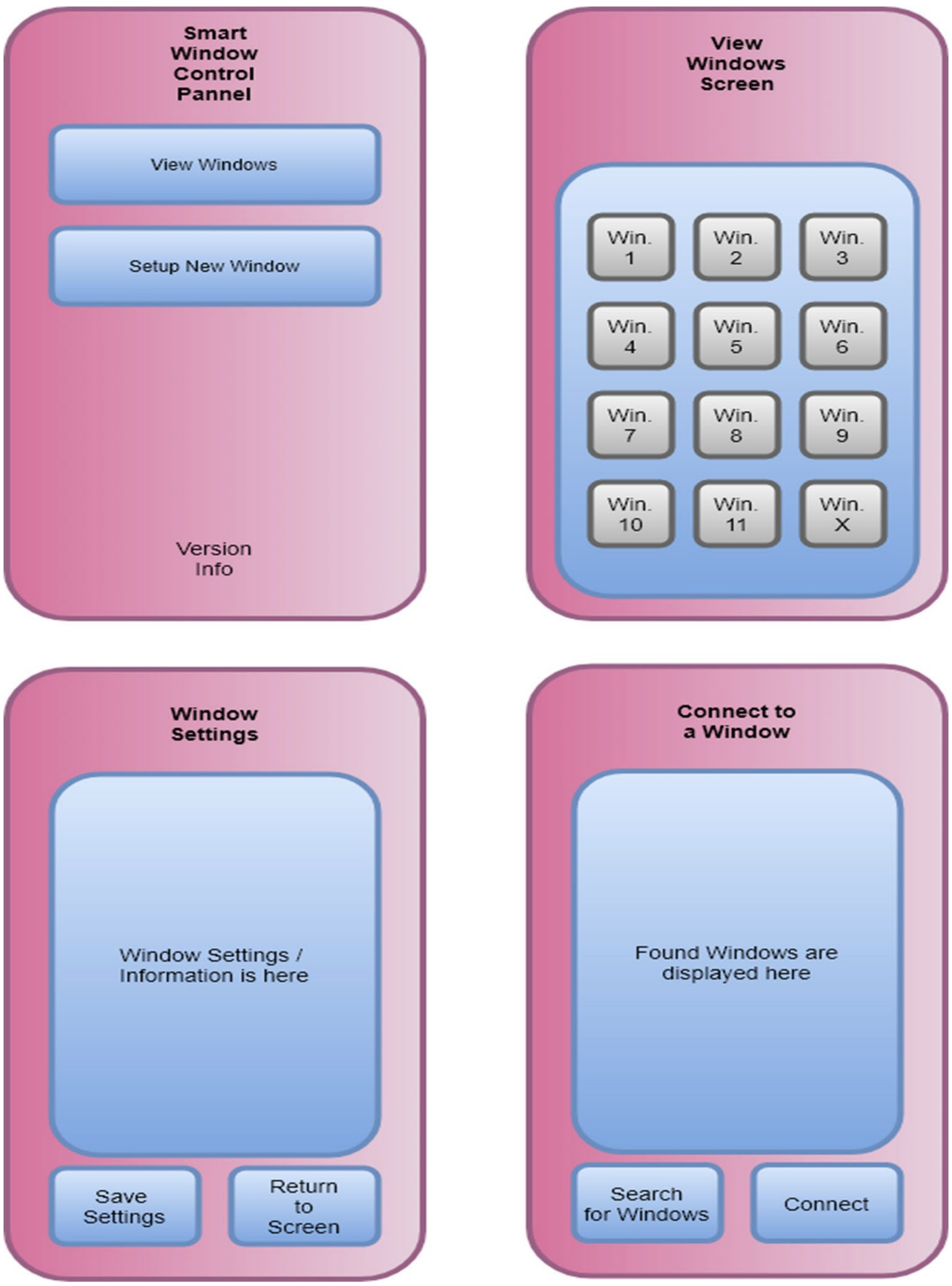


Figure 23: Example of Phone App that can be used as an activation method for the electric blind project

This is because most home security systems are designed to only perform certain actions to protect the house, which likely do not include the capabilities our windowdevice will have. We could potentially have support for home security systems built into the window device, however that would require the manufactures of home security systems to implement it themselves, which is unlikely for a variety of reasons.

3.2.6.6 Remote Control

The sixth method of end user interfacing with the window device is a bit old school. We could just have a remote control. This is a simple form of interfacing, which practically everyone in America could use. This isn't anything super fancy, but it is the most reliable form of end user interfacing with the window device in terms of the end user being able to competently interface with the window device.

3.2.6.7 Comparison of End User Input

The table below goes over the different input methods that can be used by an end user to interface with different devices and projects including the one proposed and designed for this group.

Table 10: End User Input Comparison

Input Method	User Interface	Output Method	Objects Required For Interaction	Connection Types Required
Physical Interaction	Physical	Blind Operation	Human Body	Physical Proximity
Terminal Client	Terminal	Text	Desktop	Network Connection
Desktop App	Graphical User Interface	Graphical User Interface	Desktop	Network Connection
Phone App	Graphical User Interface	Graphical User Interface	Android or IOS Smartphone	Network Connection
Voice Commands	Voice	Either Sound, and/or Blind Operations	Human Body	Network Connection (if speech synthesis is used) and Physical Proximity (in a quiet place)
Alexa Integration	Voice	Either Sound, and/or Blind Operations	Human Body, and Amazon Alexa	Network Connection, and Physical Proximity (in a quiet place)

3.2.6.8 Conclusion

So, we have listed here many different methods of end user interfacing with the window device. Now the beautiful thing behind this, was we could design the device to have support for multiple different types of interfacing techniques. In addition to that, we designed the window device to allow the end user to configure what the interfacing techniques are.

4.0 Components and Part Selection

This section explains the components that were chosen for the parts researched in section 3.0. This section gave a possible components and parts selected for the completion of this project. The last subsection herein gave a table summarizing the components and part selected by the team members.

4.1 Window

4.1.1 Window Frame Selection

So, for this project, we selected a fixed window frame. The reason for this was simple. After careful consideration and research, the window frame really doesn't have a great impact on the core of the project. The core of the project was having a prototype that can prove we have frosted glass that can be turned on and off, andthe technology that interfaces with that. The primary things a window frame type will influence is how the window will open. For this project, the only real way that would influence the project wa the physical positioning of the wiring to the frosted glass. Wiring positioning in this way realistically was an extra feature separate from the core of the project that could be easily configured (easy in comparison to the other challenges of this project). Perhaps later on in future work on this project, we could implement more complex window frames with this project. However, for now, having a fixed window frame was the best, since it eliminated an unneeded complication, that realistically adds little value to the project.

4.1.2 Window Material Part Selection

So, for the material we used for the window frame, wood was chosen. Theprimary reason for this is due to the ease of crafting it. We hammered a nail into it, anddid not have to worry about it shattering, such as with fiberglass or vinyl. In addition to that, itrequires a lot less force to pierce it, versus aluminum. Now while it might not have the bestqualities to be featured in a mass-produced version of this, those qualities are not really relevant to the core of the project. Also, for the amount that we needed to obtain, the price difference was well within our budget.

4.1.3 Comparison of Window Frame Type

The table below enumerates the different window frame types and the necessary comparison that resulted in the part selected for this project. Some of the comparison involves movement type of the window frame, movable space of the window frame, additional space required to open the different window frame types and insulation properties relative to other types of window frame types compared herein.

4.2 Blind

When comparing these motors, they do have the benefit of being lower cost than the electrochromic devices listed, as a downside though there are more maintenance costs in the long term, the need to maintain traditional blinds, and the slow transition state as seen with traditional blinds.

Table 11: Window Frame type comparison for part selection

Window Frame Type	Window Frame Movement Type	Movable Space of Window	Additional Space Required to Open	Insulation Properties (relative to other types)
Fixed	No Movement	None of the Window can move	None	Has the best sealing capabilities, so best insulation properties
Casement	Horizontally Swing Open	All of the Window can move	Space on either the outside, or inside is required to open	Has better sealing capabilities, so good insulation properties
Awning	Vertically Swing Open	All of the Window can move	Space outside of the window is required	Has better sealing capabilities, so good insulation properties
Hopper	Horizontally Swing Open	All of the Window can move	Space both outside and inside is required	Has moderate sealing capabilities, so moderate insulation properties
Sliding	Sliding	Typically half the window can slide	Little additional space is required to open	Has the least best sealing capability, so the worst insulation properties

By keeping blinds, we reduce the opportunity for this system to be installed in various places as once the control system is installed with the smart film configuration the transparency device can be placed and sized to almost any shape of an enclosure. There's also the fact that these motors do not meet some of our engineering requirements as they depend on the blinds themselves to be the transparency device and there will be less controllability as compared to one of the smart film options. As always with mechanical devices they are reliable and consistent in their function but there ends up being I need for maintenance and replacement due to wear in the system. So, we will go with the Smart Film as the “blinds” though they cost more.

Seeing the benefits and cons of the above technologies, smart glass passive devices have many downsides which includes: a lack of control and producing an opposite effect of what our group desires are. This led us to the active smart glass with the following options: electrochromic glass, SPD, and PDLC. It became quickly apparent that PDLC will be our best option going forward. It has the fastest transition time of all the materials which meets one of our engineering requirements, it is easy to replace as any damaged sheet can be removed and reinserted simply by sizing and attaching the electrode, it has the simplest installation and is most user-friendly as there is not a need to have specialized glass inserted.

4.2.1 Smart Film Vendors

This section explains in detail, the two smart film vendors that were considered for this project. The two vendor choices are: Smart Tint and HOHOFILM Smart Film.

4.2.1.1 Smart Tint

Dimensions

Smart Tint's PDLC film goes to a maximum size of 1800mm x 50 m. This is good as it shows that this film will operate the same when scaled up. Another benefit of this film that it is only .35mm thick(verify), which will work well for the simple refined look we are aiming to achieve.

Energy Usage

Smart tint is powered by 60 V AC, this will require us to have a converter and step-down circuit so that our one source of power can power all of our devices. On top of this the film draws very little power at 4 W/m2, this will help in reducing heat created by the system as a whole.

Temperature and Visibility

Thanks to the robust design of the smart film, it can operate in temperatures from 14-140 degrees Fahrenheit. This eliminates the worry of having the film being damaged from continuous light exposure as it stays on the window day after day. A factor toconsider is if the Smart Cling^{TM} Adhesive will be able to withstand long term heat exposure. However, another key performance index we are trying to achieve is tohave the lumens into a room and the with a reduction x% of visibility. Smart tint has been tested to have a light transmittance level of 95-97% when activated and 1-2% when turned off. This exceeds our target by a wide margin giving us room topossibly experiment with dimming which would add to the user experience.

Energy Standards

Another key target we are aiming to achieve is the ability to change a Solar heat gain coefficient, a key performance index the Department of Energy requires for products to be nationally recognized as being energy efficient and ready for installation nationwide. The base film has Solar Heat gain coefficient of .71 in the standard base design, however the next level offers a heat gain coefficient of .1.

Drastically reducing the incoming heat greatly reducing the ambient heat generated in windows.

4.2.1.2 HOHOFILM: Smart Film

Dimensions

HOHOFILM Smart film pdlc comes in a maximum size of 1524mm by 3048mm. This is a rather smaller size as compared to Smart Tint but still allows for scalability for most windows that will be used. This Smart Film by HOHOFILM has a variation in thickness, ranging from 8mm to 22mm. This still should be able to achieve our desired application of being simple and unintrusive.

Energy Usage

HOHOFILM Smart Film also operates at 60 V ac, just as Smart Tint does. This will require a bridge connection that will convert this from AC to DC with the purpose of staying with a main source of power ensuring our system remains as simple as possible. Smart Film also draws more power than other systems at 10 W/m2. This higher draw of power is likely what creates the faster transition time when compared to the other systems.

Temperature and Visibility

Smart Film has a similar operating range of 14-140 degrees Fahrenheit, making it suitable for installation on windows without the concern of the film being damaged from light exposure. Though a continued concern is the lifespan of the adhesive in prolonged heat exposure.

Energy Standards

HOHOFILM Smart film has a light transmittance level of 81% when activated and 10% when turned off in the default state. This is a shorter range than the Smart Tint likely due to the manufacturing process chosen. Though the range is shorter this still does meet our desired light range by a wide margin still giving us room to experiment with different levels of dimming if we desired to go that route. The technical data sheet does not specifically mention what the Solar Heat Gain Coefficient however it does state that 99% of UV light is blocked. This should at least reduce the amount of ambient Heat coming through the window, but it is a downside there is not a specific metric that can measured and/or compared against.

4.2.1.3 Smart Film: Smart PDLC

Dimensions

Magic Film: Smart PDLC comes in sizes starting at 1800m length wise and with an open-ended width but a minimum of 5m and a maximum length that is 50m. This is not advantageous as most windows are much smaller than 5 meters both length and width wise. Furthermore, for this project this is extremely excessive to what our project description is. The thickness of the film is .36mm which is comparable to the other films we have selected.

Energy Usage

Magic Film: Smart PDLC operates at 65V AC which differs slightly from the other two smart film options. This film like the other two will require a bridge connection that will convert this from AC to DC with the purpose of staying with a main source of power ensuring our system remains as simple as possible. This system consumes 3.6W/m^2 which is the lowest of all the systems, this beneficial as every watt we can reduce will help reduce our total system energy and heat.

Temperature and Visibility

Magic Film: Smart has an operating range of -4 - 140 F which is much wider than the other Smart films which is a great benefit as the wider the operating range the more durable the film will be allowing it to be used in more situations and environments. Magic Film: Smart has a light transmittance of 80% when the film is powered on and a light transmittance of 4% when turned off. This is the second widest margin and like the others this range greatly exceeds our desired range.

Energy Standards

Magic Film: Smart PDLC has a Solar Heat Gain Coefficient .79 when it is in the on state and .06 when in the off state. This is encouraging as these numbers are within expected values and would be workable with our project if we decide to use it. This film also states that it has 99% UV blocking which appears to be a characteristic of PDLC film as a technology.

4.2.2 Comparison of Smart Film Vendors

This section gives a table summarizing the comparison of the potential two smart film vendors that could be used for this project.

Table 12: Summary of Smart Film Vendors

	Smart Tint		**HOHOFILM**		**Magic-Film**	
	on	off	on	off	on	off
Operating Voltage	60V AC		60V AC		65V AC	
Power	3-4 W/m^2		10 W/m^2		4W/m^2	
Size	1800mm x 50m		1524mm x 3m		1200-1500mm x 50 m	
Transition time	100 ms	300 ms	2 ms	10 ms	20 ms	60 ms
Visibility	81%	10%	95-97%	1-2%	80%	4%
Operating Temperature	14-140 F		14-140 F		-4-140F	
Solar Heat Gain Coefficient	0.71		not available		0.79	

4.2.3 Conclusion for Blind selection (Smart Film)

As we can see both vendors provided valid options that met our criteria for what the film must achieve. However, when comparing HOHOFILM with Smart Tint there were factors to weigh. The first being how much Voltage is being used to reachthis active state, they both use 60 VAC, however it was seen that Smart tint uses 2 to 3 times less power than the HOHOFILM. Another key feature was the transition time from each state. Here it can be seen that the HOHOFILM is leaps and bounds faster for both states giving it a major lead.

Arguably one of the most important features was the visibility in the different states. We could see here that Smart Tint provides the largest range between the states, even though both films transition within our desired range, it is always beneficial forit to be faster at no significant downside. Lastly Smart Tint was able to provide a measured quantity of the Solar Heat Gain Coefficient one of the key measures when the Department of energy decides how energy efficient glass add-ons are. This is not shown with the HOHOFILM. Overall, with the lower power usage, highervisibility range, quantifiable solar gain coefficient the Smart Tint was the best optionfor the PDLC film.

4.3 Microcontroller Unit

There are three choices of ESP32 MCU to choose from for this project i.e., ESP32 Feather, ESP32 Thing, and ESP32 Koala. Each of the three ESP32 MCU would provide the necessary features (high speed, low power consumption, low cost, built-in Bluetooth, and built-in Wi-Fi) needed for this project.

4.3.1 ESP32 Feather

ESP32 Feather is an ESP32-BASED board from Adafruit that has a USB-to-UART interface and a voltage regulator. Some of the other features of ESP32 Feather are dual-core ESP32 chip, 4-megabyte (MB) of Serial Peripheral Interface (SPI) Flash, tuned antenna, on-board PCB antenna, ultra-low noise analog amplifier, 32-kilohertz (kHz) crystal oscillator, 3 UART (two configured in Arduino IDE and one used for boot loading and debug). This MCU also has a LiPoly battery connector which is a good feature for portable battery powered projects [9]. The power pins on this MCU are Ground (GND), BAT (for optional LiPoly battery), USB (positive voltage to or from micro-USB jack), 3.3V regulator enable pin and 3V output from 3.3V regulator (the regulator can supply 500mA peak but half of that is drawn by the ESP32 chip).

4.3.2 ESP32 Thing

ESP32 Thing is an ESP32-BASED board from SparkFun that comes with a connector for LiPo batteries, which is a good feature for portable battery powered projects [9]. Some of the other features of ESP32 Thing are dual-core ESP32 microprocessor, 4-megabyte (MB) Flash memory, Integrated LiPo Battery Charger. This MCU has an operating range of 3V to 3.6V. This MCU, like the other

ESP32 MCUs has built-in Wi-Fi and integrated dual-mode Bluetooth (classic and Bluetooth Low Energy).

4.3.3 TTGO T-Koala ESP32

This type of ESP32 MCU has a supply voltage of $3.3V$ DC or $5V$ DC; has flash memory of 4MB; built-in Wi-Fi and Bluetooth. Finally, like the ESP32 Thing and ESP32 Feather, ESP32 Koala provides low power consumption, has a battery connector for LiPo battery [10]. Some of the other features of ESP32 Koala include operating voltage of 3.3V, power supply board (USB) of 5V, 500mA maximum charging current, and 4-megabyte (MB) Flash memory, digital-to-analog converter and compatible with Arduino IDE.

4.3.4 Comparison of Microcontroller Unit Selection

The three choices for ESP32 microcontrollers were essentially equally usable for this project and they all met the requirements necessary to successfully complete this project. The three choices i.e. ESP32 Feather HUZZAH32, ESP32 Thing and ESP32 Koala have the same power supply (USB) of 5 volts, same Bluetooth i.e. Classic Bluetooth and Bluetooth Low Energy. Similarly, the three ESP32 MCUs have clock frequency of up to 240MHz, use the same IDE i.e. Arduino and have the same charging current of 500mA maximum. They also have the same memory of 4MB flash memory and 520KB internal SRAM.
However, the key difference that made ESP32 Koala the choice for this project is shown in the table below.

Table 13: Comparison of ESP32 Microcontroller units

	ESP32 Feather HUZZAH32	**ESP32 Thing**	**Esp32 Koala**
Cost	$19.95	$21. 95	$19
Operating Range	3.0 – 3.3V	2.2 – 3.6V	3.3V
Pins	21 GPIO pins 14 Analog Inputs	32 GPIO pins 6 Input Only Pins	34 GPIO pins 5 Input Only Pins

4.4 Proximity Sensor

As explained above, the photoelectric proximity sensor has different modes which are thru-beam, retroreflective, and diffuse mode. However, the thru-beam and the retroreflective modes require another housing for receiver for thru-beam mode, and reflector for retroreflective mode. This makes the design become more complicated. In addition, the other receiver housing mounted in the opposite side of the transmitter will activate false or unwanted signal when there are objects pass by in it range. Therefore, the sensors belong to the diffuse mode will be closely examined and analyzed to choose out the best fit for the proximity sensor.

4.4.1 Diffuse mode IR sensor

4.4.1.1 Sharp GP2Y0A21YK0F

Sharp GP2Y0A21YK0F is the first photoelectric proximity sensor which used the IR light, diffuse mode. This IR sensor can be considered for the project. This sensor is quite compact, its dimension is 29.5 x 13 x 13.5 mm with the effective range is from 10 cm to 80 cm.

The Sharp GP2Y0A21YK0F uses a 3-pin JST PH connector with 3 pins are V_o, GND, and V_{CC} where the wires are connected to it. This is a great feature since the sensor can be mounted separately anywhere on the window. The wires can be run along the frame to hook up to the power source to activate it. The current drawn from the sensor is low, typical value for it is at 30 mA and the maximum value is at 40 mA. The recommended operating voltage supply has to be from 4.5 to 5.5 V_{CC}. From the information of voltage and current, the calculated power consumption for this mode of IR sensor is low, approximately from 0.14W to 0.22W. Output voltage of this sensor is between 1.65 to 2.15 V. This low output voltage needs to be kept in mind to choose the right relay or switch in order to activate it. The time between every reading is short around 38.3ms with a deviation of 9.6ms. With the sensor short time reading like the Sharp GP2Y0A21YK0F assures the accurate operation whenever there is object within its range.

Last important information for this sensor is its affordability where the price for each sensor is around 10.00 US dollars. The time for delivery is quick where the order can be delivered after one day. This short time delivery is necessary because it can decide the implementable factor of the project.

4.4.1.2 Arduino KY-032

Arduino KY-032 is another IR sensor uses the diffuse mode. This IR sensor is more compact compared to the Sharp GP2Y0A21YK0F with its dimension is 28 x 24 mm, the height of the sensor is not defined but it seems be shorter than the Sharp. The effective range of this IR sensor is from 2 cm to 40 cm. This range is quite suitable for the project, and the shorter the default range, the smaller the typical value for the current of the sensor. In fact, the typical working value for the current of this sensor is around 20 mA, which is 10 mA less compared to the Sharp. The Arduino KY-032 comes with 4 pins interface which are negative pin, positive pin, S pin, and EN pin. With the pins clearly notated on the board makes it easier to configure once the project is put together. Working voltage for this sensor is from 3.3 V to 5 V, it's typical for this mode of small device. The power consumption can be easily calculated from working voltage and working current value where its value is around 0.1 W.

The output signal of this IR sensor is based on the TTL level. TTL stands for Transistor-Transistor Logic, the output TTL level relies on the transistor's switching voltage. The higher the input voltage, the higher the output voltage of the sensor.

For instance, if the input voltage is at 5 V, when the sensor detects an object, the output voltage will low at 0.4 V. If no object is detected, the output voltage will be high at 2.7 V. This IR sensor also has 2 different potentiometers to adjust the range of the sensor and the sensitivity of the sensor where the frequency of the emitting light can be adjusted to match with the frequency of the receiver.

The availability of this sensor is good, a pack of 3 sensors can be bought at around 9 US dollars and the delivery time is around 2 days.

4.4.1.3 CenryKay IR Obstacle Avoidance Sensor

CenryKay IR Obstacle Avoidance Sensor, or CenryKay IR sensor for short. This is another diffuse mode IR sensor variant. The dimension is 31 x 15 mm. The effective range of this IR sensor is from 2 cm to 30 cm which is also considerable for the project. The sensor requires the input voltage of 3.3 V to 5 V. Unfortunately, there is not much information about the working current of this sensor. Hence, the power consumption for this sensor is undetermined. This IR sensor has 3 pins which are V_{CC}, GND, and OUT.

Another unknown is the value for output signal. There is no value indicated, only a short description from the supplier that the sensor can be directly connected to the microcontroller or it can be connected to the 5 V relay. This is inconvenient yet can be tested if this IR sensor can win other sensors to get selected for the project.

The price for this IR sensor is cheap, a pack of 10 sensors can be bought at 12 US dollars and the delivery time is approximately 2 days.

4.4.1.4 Comparison of IR Sensors

After an extent research, there are not too many diffuse mode IR sensors. Moreover, many manufactures have the same sensors with different package values and different prices with not too much of deviation in the price. Therefore, the table below will show the main difference of these IR sensors.

Table 14: Comparison between the IR proximity sensors

	Dimension (mm)	Range (cm)	Power Consumption (W)	Input Voltage (V)	Output Voltage (V)	Price (US Dollars)	Delivery Time (Days)
Sharp GP2Y0A21YK0F	29.5 x 13 x 13.5	10-80	0.22	4.5-5.5	1.65 – 2.15	10	1
Arduino KY-032	28 x 24	2-40	0.1	3.3-5	TTL	9	2
CenryKay IR	31 x 15	2-30	Unknown	3.3-5	Unknown	12	2

With the IR sensor's specifications shown in the table above, the Arduino KY-032 seems to be the best choice for IR sensor type. The sensor is quite small, and it has a good effective sensing range. The supply voltage for the sensor can be chosen between the two values such as 3.3 V or 5 V. By using different voltage level can help implement different components where this sensor can give up the higher voltage range to those other components and save power. The power consumption of this sensor is also low, at 0.1 W. The price for this IR sensor is also cheap where a pack of 3 sensors can be bought with 9 US dollars and they will come to the house in a short waiting time period which is 2 days. The higher the availability of the product, the better because the design need to be implemented as soon as possible.

4.4.2 PIR sensor

The PIR sensor can be called with other names such as Passive Infrared, Pyroelectric or IR motion sensor. This is not necessary a diffuse mode of photoelectric sensing technology, so its working mechanism is different from the IR sensor. Because the PIR sensor also uses the infrared light emits from the target to trigger the sensor so it's worth being investigated. The difference is the PIR sensor does not have a transmitter unit to emit the IR light. Instead of transmitter and receiver, the PIR sensor has the pyroelectric sensor which made from pyroelectric crystal and a lens to widen the range of the sensor. The living organism emits an amount of radiation which can be sensed by this pyroelectric sensor. The sensor receives the emitted radiation when a user enters the sensing range which creates a positive differential change. When the user leaves the sensing range, a negative differential change. The positive and negative changes will trigger the output.

4.4.2.1 MCM 287-18001 PIR

MCM 287-18001 PIR is the one examined for this project. The dimension of this PIR sensor is larger than the diffuse mode IR sensor where its dimension is 24.03 x 32.34 x
24.66 mm. The effective range of this PIR sensor can be up to 7 meters with a supply voltage from 5 to 20 V_{CC}. The output voltage of the sensor is at 3.3 V and it has a built-in voltage regulator which helps with the voltage usage for another device such as switch or relay. The sensor draws a 65-mA current which increases the power consumed compared to the IR sensor. However, the overall power consumption for this sensor is still not significant. The angle to activate the sensor is at 110^o. The PIR sensor has a variable delay time from 5 to 300 seconds with 2 types of triggers. A single trigger will activate the sensor once it senses the target, and the delay time will keep the device working in a desire time, other input from target (user) does not make the device keep working. In contrast, a repeated trigger will take other inputs from target and keep the device working with a desired delay time. There are distance potentiometer and delay potentiometer where user can adjust on his/her desire.

The PIR sensor only costs 2.99 US dollars for a single unit or 10.59 US dollars for a pack of five units. The price is reasonable affordable with the functions it can perform.

4.4.2.2 HC-SR505 Mini PIR Motion Sensor

HC-SR505 Mini PIR Motion Sensor or HC-SR 505 PIR sensor for short. This PIR sensor has a dimension of 40 x 10 x 13mm and it can detect a target up to 3 meters. The voltage supply for this sensor can be used from 4.5 V to 20 V. With the higher value for the voltage supply, the hassle of the sensor is burnt due to high voltage can be ignored. This sensor draws a maximum current with a value around 60 µA. Because of the low current use, the power consumption of this PIR sensor won't exceed 0.12 mW. The output voltage has a value of 0 V for low where no target is detected, and 3.3 V for high when the sensor senses a target in its effective range.

The default delay time of this sensor is around 8s with a deviation of 30%. This also means this PIR sensor does not have the potentiometers to adjust the delay time and the sensing range. The sensing angle of this sensor is at 100^o. Although this PIR sensor does not have the potentiometers, it has trigger modes for the input signal where it can be single trigger and repeated trigger.

The price of this PIR sensor is 3.23 US dollars. The availability of this product is not as good as the other ones. The delivery time takes up to 15 business day which means the product is imported from a foreign country. The delivery process can make the sensor damage and not work as desired.

4.4.2.3 Onyehn PIR

Onyehn PIR this sensor is from a China supplier where it's hard to find a data sheet for the sensor. Once the data sheet is found, not so much information is included. For example, there is absolutely no information about the dimension of the sensor. Based on the picture from the website, the sensor includes a PCB with electrical components which is soldered perpendicularly to the base of the sensor. At the other end, a 3-pin adapter is soldered to the PCB. Fortunately, a picture of the PIR sensor is tested on the breadboard where the sensor is seen taken an approximately 3x3 holes from the breadboard. That helps to know if the sensor size is compact enough to be mounted and hidden away.

This PIR sensor needs a 2.7 V to 3.3 V from the power source. The typical value is at 3 V. the current drawn from the sensor is extremely small with the typical value at only 15 µA. With these values, the power consumption can be calculated at 45 µW which is extremely power efficient. The sensing range of this PIR sensor is up to 5 m. Another inconvenience from this sensor is it does not have any potentiometer so the user can adjust the range and the delay time. Moreover, the default delay time is also an unknown. The sensing angle of this PIR sensor is at 100^o. This PIR sensor does not have different trigger mode for single trigger and repeatable trigger. This is a huge disadvantage if the PIR sensor is chosen to be implemented for this project.

The price for this PIR sensor is at 8 US dollars for a package of 2 units. The sensors can be delivered in approximately 2 days.

4.4.2.4 Comparison of PIR Sensors

These 3 PIR sensors discussed above seem to be the best choices for this type of proximity sensor compared to others PIR sensor in the market where their specifications, prices and availability are quite competitive. The table below will give a summary for the sensors' specification.

The Newark PIR can be clearly seen the best selection for this type of photoelectric sensor. The manufacture has almost every information related to their product which is helpful for buyer. Besides that, the Newark PIR is compact compared to others. The sensing range for this sensor is up to 7 meter which is way over the requirements for this project. However, a big plus is this PIR sensor also has the potentiometer where the users can adjust the different ranges based on their applications and desires. Another useful specification for this PIR sensor is it also has the potentiometer to adjust the delay time up to 300 seconds with a repeatable trigger for the input signal. This means the sensor keeps working as long as it senses the human's activity instead of turning itself of after a certain default delay time like the other sensors. The advantage of having a built-in regulator also helps maintain the voltage level for any component connected to it to make sure that component working right and avoid any damage due to unstable voltage.

Table 15: Comparison between the PIR proximity sensors

	Dimension (mm)	**Range (m)**	**Input Voltage (V)**	**Output Voltage (V)**	**Price (US Dollars)**	**Repeatable TriggerMode**	**Range and Sensitivity Adjustable**
MCM 287-18001	24.03 x 32.34 x 24.66	7	5 - 20	3.3 V with regulator	2.99	Y	Y
HC-SR505 Mini PIR Sensor	40x 10 x 13	3	4.5 - 20	0 - 3	3.23	Y	N
Onyehn PIR	Unknown	5	2.7 – 3.3	Unknown	4	N	N

The Newark PIR can be clearly seen the best selection for this type of photoelectric sensor. The manufacture has almost every information related to their product which is helpful for buyer. Besides that, the Newark PIR is compact compared to others. The sensing range for this sensor is up to 7 meter which is way over the requirements for this project. However, a big plus is this PIR sensor also has the potentiometer where the users can adjust the different ranges based on their applications and desires. Another useful specification for this PIR sensor is it also has the potentiometer to adjust the delay time up to 300 seconds with a repeatable trigger for the input signal. This means the sensor keeps working as long as it senses the human's activity instead of turning itself of after a certain default delay time like the other sensors. The advantage of having a built-in regulator also helps maintain the voltage level for any component connected to it to make sure that component working right and avoid any damage due to unstable voltage.

4.4.3 LiDAR

LiDAR is acronym for Light Detection and Ranging. The working principle of LiDAR is like the IR sensor where the housing has the transmitter and receiver. Instead of transmitting the IR light, the LiDAR transmit a laser light. This laser light will be reflected by the object in its range. The reflected light bounces of the surface of the object and goes into the receiver. In general, LiDAR has a further range compared to the IR sensor thanks to its laser light. Moreover, because the laser focuses on a single point on the target, therefore, the accuracy of LiDAR sensor seems to be more accurate. However, the use of laser light can cause hazardous to user's eyes because of the optical radiation from the laser.

4.4.3.1 TF-Luna LiDAR Module

TF-Luna LiDAR Module is considered for this project. The sensor's dimension is 35 x 21.25 x 13.5 mm. The effective range of this sensor is from 0.2 meter to 8 meters where 90% of the lights is reflective back to the receiver. The accuracy of this sensor is at 6 cm if the target in the range from 0.2 m to 3 m. Field of view (FOV) of this sensor is 2^o.

This sensor requires a 3.7 V - 5 V from the voltage source with a typical value for the current at 70 mA. The maximum value for the current is 150 mA can be ignored because the maximum 8 meters range is not applicable for this project. The power consumption of this sensor is also low where it's around 0.3 W. The output signal of this sensor is TTL level with the communication interface is UART or I2C. This information helps in selecting the microcontroller if the group decides to go with this LiDAR sensor. As mentioned above about the hazardous when using this sensor, a photobiological safety standard must be followed. In particular, Class 1 IEC 60825-1:2014 standard is applied for this sensor.

Due to using higher technology for the light source, the LiDAR modules are more expensive than other type of photoelectric sensor. This TF-Luna LiDAR sensor costs around 26 US dollars for a unit. The availability of this sensor is high with a fast delivery time with 2 days waiting period only.

4.4.3.2 TFmini-S LiDAR Module

TFmini-S LiDAR Module is the next LiDAR sensor to be examined for its specifications. The dimension of this sensor is 42 x 15 x 16 mm. This sensor has a greater sensing range than the TF-Luna where its range is from 0.1 meter to 12 meters. The blind zone is shortened by 0.1 meter. The reflectivity is at 90% with a high accuracy. The deviation for accuracy is only 6 cm if the sensing range is from 0.1 m to 6 m. Field of View (FOV) of this sensor is 2^{o}.

There is only one input voltage can be used for this sensor where its value is at 5 V. Because this LiDAR sensor can sense a further distance, it uses more power where the maximum power consumption is around 0.7 W with a peak current at 200 mA. The working current is also higher where a 140 mA is drawn by the device. The output voltage using the TTL level with the UART or I2C for communication interface.

This LiDAR sensor is more powerful with a sensing range up to 12 m where its price is also higher than the TF-Luna LiDAR sensor. This sensor costs a user 39 US dollars to buy one. The availability of this sensor is also high with a short 2 days waiting period.

4.4.3.3 TFMini Plus – Micro LiDAR Module

TFMini Plus – Micro LiDAR Module is the last LiDAR sensor of this technology is examined. The dimension for this sensor is unknow, but base on the picture from the datasheet shows that the sensor is quite boxy and seems to be bigger than the other sensors. The effective sensing range of this LiDAR sensor is similar to the TFmini-S with 0.1 m to 12 m. However, this LiDAR sensor is more accurate where its deviation for accuracy is only at 5 cm if it detects target in the range between 0.1 m to 6m. Moreover, the FOV of this sensor is also wider with an angle of 3.6^{o}. The wider the detecting range helps reduce the blind zone of the sensor.

This sensor needs a voltage from 4.5 V to 5.5 V to work where it draws a current with a typical value of 110 mA. The maximum current needs to be used to detect anything from 12 m is at 500 mA. The power typical power consumption for this sensor is around 550 mW. The signal output used the TTL with UART communication method only. An extra information is given for this sensor is the pin configuration for the sensor where the pin numbers are mark from 1 to 4. The pins are for Power, Receive, Transmit, and Ground. This information definitely helps out when the sensor is tested.

Final piece of information is the price to purchase it and the availability. This sensor can be purchased with a price of $ 45 US dollars. It’s a little bit more expensive than the other 2 sensors. The sensor will be delivered in approximately 3 days.

4.4.3.4 Comparison of LiDAR Modules

With all the specifications for the 3 different LiDAR sensor listed above, a table will summarize the relevant specifications to draw out the conclusion in picking the best LiDAR sensor for this project.

Table 16: Comparison between the LiDAR proximity sensors

	Dimension (mm)	**Range (m)**	**Input Voltage (V)**	**Output Voltage (V)**	**Price (US Dollars)**	**FOV (degree)**	**Communication Interface**
TF-Luna	24.03 x 32.34 x 24.66	0.2 - 8	3.7 - 5	TTL	26	2	UART, I2C
TFmini-S	42x 15 x 16	0.1 - 12	5	TTL	39	2	UART, I2C
TFMini Plus	Unknown	0.1 - 12	4.5 - 5.5	TTL	45	3.6	UART

It's hard to choose which LiDAR sensor is the best suit for the project since they have similar specifications. To conclude, the basic specification requirements for the project needs to be reviewed where the total design will cost not much than 600 US dollars. Furthermore, the sensor needs to be compact to be installed for the aesthetic reason. According to those specifications, the TF-Luna can be selected as the best suit for the LiDAR technology.

4.4.4 Conclusion for Proximity Sensor Selection

Now, when all the different components of photoelectric proximity sensing technologies were closely examined and compared. The best suitable component waspicked out for each technology will now be compared to each other to choose outthe best components to be implemented for this project.

The specifications listed in the table are the most important ones that come tothe group on agreeing which sensing technology is the best use for the project. First, the dimension is compared due to the aesthetic reason for the project. In addition, the smaller the component, the easier for the group to prototype where a smaller window can be built. These 3 proximity sensors are quite small and impact. The effective sensing range is an important measurement for these sensors. The sensor needs to have a good detection range when a target is close to it to trigger the device work consistently which means the blind zone of the sensor has to be as small as possible where the 3 different sensors qualify for it with the blind zone is under 0.2 m.

Power consumption is also a critical reason where it can decide the reliability of the device. If the sensor uses too much power, the battery life will be reduced it may fail when the user needs to use it. The Arduino KY-302 seems to use the less power to work where the Newark PIR has the average power consumption among the 3. The Newark PIR also comes with a built-in voltage regulator where it can maintain the voltage at 3.3 V for another component or device that directly connected to it. This also helps reduce the number of components to be built on PCB, thus, decrease the dimension of PCB and the cost to produce it.

Table 17: Comparison between proximity sensing components

	Dimension (mm)	**Range (m)**	**Power Consumption (W)**	**Output Voltage (V)**	**Price (US Dollars)**	**Repeatable Trigger Mode**	**Delay Time**
Arduino KY-032	28 x 24	0.2 – 0.4	0.1	3.3 – 5	9	N	N
Newark PIR	24.03 x 32.34 x 24.66	Up to 7	0.33	3.3 V with voltage regulator	2.99	Y	Y
TF-Luna	24.03 x 32.34 x 24.66	0.2 - 8	0.55	TTL	26	N	N

The unique specifications that only the Newark PIR has that the other 2 sensors do not are the repeatable trigger mode and the delay time of the sensor. The repeatable trigger mode is quite useful for this project where human factor plays an important role in it. The reason behind it is the user tends to move around a lot. After the input signal from the user to trigger the sensor and activate the window, the power makes the window become transparent. The movements from the user keeps the sensor sense and send the input signal continuously to keep the window be transparent. The delay time specification is also important. After being triggered, the window will become transparent for a period of time. This delay time can be up to 300 seconds and it can be adjusted. For the other 2 sensors, the window can become transparent once the target is in its range. Once the target leaves, the sensor receives no input signal thus makes the windows become opaque. However, a delay time can be developed by using capacitor to charge the energy in electric field. When the power supply is cut off, the energy in the capacitor can be used to energize the window to maintain the transparency. Nevertheless, the period of the delay time is short compared to the 300 seconds from the Newark PIR sensor.

The final important specification from the sensor is the purchase price for each of them. Both the Arduino-KY032 and Newark PIR are cheap with the price for each unit is around 3 dollars and the availability of them is high where one can have them delivered in a short 2 to 3 days waiting period. The LiDAR sensor is more expensive where its price is about 7 times compared to the other two.

In conclusion, based on the specifications for each different proximity sensor listed above, the Newark PID seemed to be the best photoelectric proximity sensor to be used for this project. Newark PID can sense infrared light emitted from living organism which is human user in the scope of this project. The power consumption from the sensor is also low where it can secure the reliability of the device. Moreover, the repeatable trigger and delay time are also important where they make the window become smarter to interact with human's movements.

4.5 Power Delivery Technology

This section goes into the details involved in the selection of the power delivery technology that would be used in this project. The part selection process for the power delivery technology goes over potential and compatible battery types and voltage regulator types available for this project. The selection process involves comparing the various choices and eventually, selecting the best option for the project herein.

4.5.1 Battery

There are many types of primary battery which are made of from different type of chemicals such as lithium, alkaline, carbon, zinc. Each of the chemical material has different characteristics which make the batteries perform differently. The primary battery will be looked closely with the common brand names with certain chemicals such as lithium, alkaline, and carbon zinc which they can be found easily in any stores in the U.S. as a small package or in bulk.

4.5.1.1 Lithium primary battery

Lithium primary battery has different cell voltage level where it can be 1.5 V, 3.0 V, or 3.6 V. Lithium primary battery comes with variable sizes which help with the saving space and give more degree of freedom in choosing the voltage level. The capacity for this type of chemical is 5000mAh. This value tells that the capacity of this primary battery is not that great which means the battery will run out of power quickly. However, the energy density is quite high with the value of 230 Wh/kg. By using this type of battery, components which require high power usage can be satisfied. Shelf life of this lithium primary battery is quite long with more than 10 years.

Lithium primary battery is quite expensive due to its high shelf life and high energy by volume. Each cell can cost from 1.6 US dollars to 30 dollars depends on the size of battery as well as its capacity.

4.5.1.2 Alkaline battery

Alkaline battery comes with many sizes that everyone is familiar with such as the AA, AAA etc. The cell nominal voltage of alkaline type battery is at 1.5 V. The battery's capacity is 3 times with value of 1500 mAh which is higher compared to the lithium primary battery. On the other hand, the energy density of this battery is half of the lithium one with 163 Wh/kg. Alkaline battery's shelf life is also a half of the lithium primary battery. Alkaline battery is cheaper than lithium one where a pack of 24 AA size batteries only cost 16 US dollars.

4.5.1.3 Carbon Zinc

Carbon Zinc is the last primary battery looked at because of its availability. Carbon zinc battery also comes with the similar size as the alkaline one. The cell nominal cell voltage of this type of chemical is also at 1.5 V. However, the energy density of this type of battery is quite low, around 9 Wh/kg. This battery is suitable to use for components which draw a small amount of current. Because of that, its capacity is the largest compared with the other two where its value is around 30000 mAh. Its shelf life is also another issue where it can only be stored around 2 to 3 years. The price for a unit of carbon zinc battery is also cheap. A pack of 48 units only costs 16 US dollars.

4.5.1.4 Conclusion

After researching for three main types of chemical for primary batteries, a table will summarize their characteristics which makes it easier to compare between the three. The table shows that lithium primary battery seems to be the best fit for the backup power used for this project. The lithium primary comes with variable sizes from as small as the AAA to the 9 volts or D size. Moreover, it also has many voltage levels such as 1.5 V, 3.0 V, 3.6 V and 9 V. These voltage levels are useful in choosing the number of batteries used to power the device which also help reduce the area for battery holder mounted on the PCB. Although the capacity of the lithium battery is not as large as the alkaline and carbon-zinc, it has higher energy density. Higher energy density helps in power components use high load current. Finally, the shelf discharge of lithium primary battery is also high where its life is around 10 years which mean its self-discharge rate is low when the device does not use the batteries. However, upon creation of the project, the battery was decided as a secondary means of power.

4.5.2 Voltage Regulator

Due to high efficiency purpose, switching voltage regulator is preferred. The input will be from 12 V to 15 V after being rectified from the alternating current power source. There are 2 levels for the output which are 5 V and 3.3 V. The 5 V output will be used to power the PIR sensor to get the signal from the user. The 3.3 V output from the voltage regulator was used for the MCU to communicate as wellas give commands to other components.

Table 18: Comparison between primary batteries

	Lithium primary battery	**Alkaline battery**	**Carbon Zinc**
Size	AA, AAA, C, D, 9 Volt	AA, AAA, C, D, 9 Volts	AA, AAA, C, D, 9 Volts
Nominal Voltage	1.5 V, 3.0 V, 3.6 V	1.5 V	1.5 V
Capacity	5000 mAh	15000 mAh	30000 mAh
Energy Density	230 Wh/kg	163 Wh/kg	9 Wh/kg
Shelf life	10 years	5 years	3 years

4.5.2.1 5V Buck Converter

The following sections goes over 3 different 5V buck converter that were choices to be used for this project.

4.5.2.1.1 LM2674

LM2674 this switching voltage regulator has a large range for the input voltage with value from 8 V to 40 V. The output voltages are from 1.21 V to 37 V and are available for fixed voltages such as 3.3 V, 5 V, and 12 V. The maximum load current of this buck converter is 500 mA. This current is enough to power the most current consumption in the project which is the microcontroller. The sensor does not use as much current as the regulator outputs. The switching frequency of this voltage regulator is 250 kHz. This high switching frequency helps with choosing the smaller size for filter components such as capacitor and inductor for the circuit. It also helps to reduce the ripple of the output voltage. This voltage regulator has a high efficiency percentage. Based on the data sheet from Texas Instruments, the efficiency for a 5 V fixed output voltage is 90%. The typical quiescent current for this voltage regulator is only 2.5 mA which really helps to save power usage in when in idle.

One advantage of using this voltage regulator from Texas Instruments is a footprint is also created on their website which is conveniently downloaded to design for the circuit schematics. Moreover, the data sheet also contains a lookup table for values of capacitor, inductor, and Schottky diode for variety of mounting methods such as surface mount or through hole with different manufactures.

The price of this voltage regulator is low, each unit cost around 1.5 US dollars and thousands of them are available for shipping.

4.5.2.1.2 RT7285C

RT7285C is another voltage regular with a wide range input from 4.3 V to 18 V. However, the range of output voltage is smaller compared to the LM2674 with values range from 0.6 V to 8 V with a load current up to 1.5 A. These values can be fit right in our project requirements. The switching frequency is double with the frequency of 500 kHz which means smaller sizes for filter components can be purchased, thus makes the PCB smaller. The data sheet from the manufacture shows the maximum efficiency for the 5 V output from a 12V input voltage with a load current of around 0.6 A is at 93%. The quiescent current for this voltage regulator is at 0.5 mA.

The manufacture of this voltage regulator does not have a large data base and product support like Texas Instruments. The footprint for the component required an extensive search in order to add to a schematic design for the PCB.

This voltage regulator is only 1/10th the price of the LM2674 with a very low stock quantity with only 25 units are available at this moment.

4.5.2.1.3 XRP7659ISTR-F

XRP7659ISTR-F is the last voltage regulator for the research. This voltage regulator is similar to the other ones where it can take in a wide range of input voltage from 4.5 V to 18 V and produce a wide range of output voltage from 0.81 V to 15 V. The load current of this voltage regulator is up to 1.5 A. The big difference of this voltage regulator is its switching frequency. The switching frequency is extremely high at 1.4 MHz which is a plus for PCB schematic design. However, the downside of this high switching frequency is its operating temperature is at $150\,^{\circ}C$, a $25\,^{\circ}C$ higher than other two voltage regulators. Typical quiescent current is at 0.8 mA. The efficiency is around 90% for the 5 V output with load current at 0.5 A. This voltage regulator is around 0.55 US dollar and there are around 4000 units in stock.

LM 2575-ADJ

This is the voltage regulator from Texas Instrument. It has a wide range of input voltage from 4.75 V to 40 VDC. The output current this voltage regulator can produce up to 1 A. the LM 2575-ADJ can output a voltage ranges from 1.23 V to 37V which is way higher than the other regulator listed above. However, the voltages required for this project are 3.3 V and 5 V which stay in the range of the regulated output. The most important characteristic of this voltage regulator is it only operates at 52 kHz. This frequency is quite low compared to the other voltage regulators. Therefore, when the LC filter is implemented, higher values for passive components need to be chosen in order to get rid of the ripple/noise after the voltage is regulated. And because this is a lower frequency voltage regulator, its efficiency is not as high as the other ones. However, the fact of simplicity for testing and soldering score a big point which make us interest.

This product is a little bit pricier than the other ones where it can cost $3.88 per unit and it is highly stock at different vendors.

4.5.2.1.4 Comparison of 5V Buck Converter

To draw conclusion, a small table below shows the characteristics of the three 5 V buck converter researched above.

Table 19: Comparison of 5V Output Buck Converters

	Switching Frequency	Load current	Efficiency – 5V output	Price	Availability
LM2674	250 kHz	0.5 A	90%	$ 1.44	1504 units.
RT7285C	500 kHz	1.5 A	93%	$ 0.155	25 units
XRP7659ISTR-F	1.4 MHz	1.5 A	90%	$ 0.55	3638 units
LM 2575-ADJ	52 kHz	1 A	80%	$ 3.88	1888 units

The table above shows that the characteristics of the voltage regulators are mostly similar to each other where the efficiency is pretty high. The load current is also high enough to power the components in the project. The differences are the switching frequency, availability of the unit as well as the footprint. For that reason, the XRP7659ISTR-F voltage regulator seems to be more attractive due to its 1.4 MHz switching frequency which can be utilized for smaller filter components to make the PCB smaller. There are a lot of available units waiting to be ordered at the vendor website and the footprint for the component is also available on Ultra Librarian and other similar website.

The XRP7659ISTR-F was purchased, however, its dimension was small which posed a problem in soldering stage to test. The LM 2575-ADJ was chosen to replace the XRP. The LM 2575-ADJ gave the expected output values that we expected to use for the project. The output for the 5 V regulated branch is 5.3 V.

4.5.2.2 3.3V Buck Converter

The following sections will go over 3 different 3.3V buck converter that could be possible choices to be used for this project.

4.5.2.2.1 LM2675

LM2675 is an another switching voltage regulator from Texas Instruments which can take in a wide range of voltage input from 8 V to 40 V. The output can be adjusted from 1.21 V to 37 V. The switching frequency of this buck converter is 260 kHz which is not much different from the 5 V buck converter. However, the LM2675 has the output for the load current at 1 A where it doubles the load current from the LM2674 buck converter. The efficiency for 3.3 V buck converter is around 86% which is still high compared to the linear voltage regulator or Zener voltage regulator. The footprint for this buck converter is ready on the Ultra Librarian website which is convenient for the development of the PCB.

There are around 8000 units in stock from Texas Instruments website with the price of 1.92 US dollars. The high availability of the components is preferred because it can save time from looking around from different vendors to order the one that the project need.

4.5.2.2.2 LM2575-ADJ

LM2575-ADJ is a buck converter from Microchip Technology which can take in a wide range of input voltage from 4 V to 45 V. Its output can be adjusted from 1.23 V to 37 V with a load current of 1 A. These characteristics are like the other buck converters above. However, the switching frequency of this voltage regulator is pretty low. Its frequency is only 52 kHz which can pose an issue in making a small size PCB. This is because the lower the frequency, the larger the passive components required to the converter. For instance, the data sheet guides that this buck converter needs an inductor with a value of 330 uH where the one from Texas Instruments only required 47 uH. In addition, the output capacitor for this buck converter has a value of 330 uF while the LM2675 only requires a 68 uF. Another important factor is the efficiency of this voltage regulator which is only at 75% for the 3.3 V output.

4.5.2.2.3 XRP7659ISTR-F

XRP7659ISTR-F can be reviewed to use for the 3.3 V output because this buck converter has a wide range for the output voltage including the 3.3 V. For the input voltage, this buck converter can get the input from either the main power source of the project or can be stepped down from the 5 V output. Moreover, by using the same buck converter with the high switching frequency of 1.4 MHz helps reduce the surface area of the PCB tremendously, where the small values of the components make their sizes smaller. The efficiency of this buck converter for the 3.3 V output is good with 87%.

The availability of this buck converter is extremely high with thousands of units are waiting on one online vendor to be ordered.

4.5.2.2.4 Comparison of 3.3V Buck Converter

With the research on the 3.3 V output voltage from the buck converters above, a small table will summarize their characteristics for the comparison.

Table 20: Comparison of 3.3V Output Buck Converters

	Switching Frequency	Load current	Efficiency – 5V output	Price	Availability
LM2675	260 kHz	1 A	86%	$ 1.92	8000 units.
LM2575-ADJ	52 kHz	1 A	75%	NA	1888 units

XRP7659ISTR-F	1.4 MHz	1.5 A	87%	$ 0.55	3638 units

The table shows that the XRP7659ISTR-F buck converter seemed to be the best fitfor the voltage regulator of this project where its efficiencies are 90% for the 5 V output and 87% for the 3.3 V output. These efficiencies levels can help in utilizing the power source as well as saving it. The high switching frequency helps to shrink the passive components' sizes down to make the PCB smaller. Finally, this voltage regulator only costs 0.55 US dollars for a unit and it is highly available which makes it so easy to order.

Similar to the 5 V regulated branch, the 3.3 V regulated branch was implemented using the LM 2575-ADJ for the same reason. The output of the 3.3 V regulated branch was at 3.4 V. This voltage still stays in the range where the MCU can operate without getting damaged.

4.5.3 Full Bridge Rectifier IC

This section gives the details about 3 different full bridge rectifier IC compared by rating, voltage and current, efficiency and heat rating, IC size and reviews availability and price.

4.5.3.1 MB8S-G

Rating, Voltage and current

This comchip full bridge rectifier has a forward voltage of 1V and a forward current of 0.8 A. This is sufficient for our needs as we are converting 15 V AC to DC which more than exceeds what is required. We also see that there is a max surge current of 35 A, a good feature to have as the spikes seen from the transformer will still be workable. Since full bridge rectifiers are composed of diodes it is important to know what the reverse voltage is. In this chip the reverse voltage is 800 V, even with a surge we should not have to worry about the component being reversed resulting in damage.

Efficiency and heat rating

The efficiency is not stated in this chip but it can be assumed the losses are minimal. The operating heat range of this full bridge rectifier is -55 degrees celsius to 150 degrees celsius. This is greater than the range of the PDLC itself which is satisfactory as we do not want the chip components faulting out before the PDLC.

IC size

As PCB component size is crucial and in turn reducing the size of each component also becomes crucial. With dimensions of 7mm x 4.9mm x 3mm this chip is small which is good for our project.

Reviews, availability, and Price

This chip has high availability with 1894 pieces in stock at the time of writing. This is sufficient enough that we should not expect this amount to be depleted by the time of ordering. The price of this chip is cheap at $0.44, at this price it would be affordable to buy a set so that multiple pieces can be bought as backups without worry.

4.5.3.2 DF1504S-T

Rating, Voltage and current

This diode's incorporated full bridge rectifier has a forward voltage of 1.1V and a forward current of 1.5 A, this is markedly higher than. Nonetheless this is sufficient for our needs as we are converting 15 V AC to DC which more than exceeds what is required. We also see that there is a max surge current of 50 A, which is higher than the other full bridge rectifiers and thus still workable with our system and transformer design. Since full bridge rectifiers are composed of diodes it is important to know what the reverse voltage is. In this chip the reverse voltage is 400 V, even with a surge we should not have to worry about the component being reversed resulting in damage.

Efficiency and heat rating

The efficiency is not stated in this chip but it can be assumed the losses are minimal. The operating heat range of this full bridge rectifier is -65 degrees Celsiusto 150 degrees celsius. This is greater than the range of the PDLC itself which is satisfactory as we do not want the chip components faulting out before the PDLC.

IC size

As PCB component size is crucial and in turn reducing the size of each component also becomes crucial. With dimensions of 8.51mm x 6.5mm x 3.4mm this chip is small which is good for our project.

Reviews, availability, and Price

This chip has high availability with 9725 pieces in stock at the time of writing. This is sufficient that we should not expect this amount to be depleted by the time of ordering. The price of this chip is cheap at $0.46, at this price it would be affordable to buy a set so that multiple pieces can be bought as backups without worry.

4.5.3.3 RDBF32-13

Rating, Voltage and current

This diode's incorporated full bridge rectifier has a forward voltage of 1.3V and a forward current of 3 A, this is markedly higher than. Nonetheless this is sufficient for our needs as we are converting 15 V AC to DC which more than exceeds what is required. We also see that there is a max surge current of 100 A, this is the highest of all the full bridge rectifiers and of course will still be workable with our system and transformer design. Since full bridge rectifiers are composed of diodes it is important to know what the reverse voltage is. In this chip the reverse voltage is 200 V, this is the lowest of all the full bridge rectifiers even with a surge we should not have to worry about the component being reversed resulting in damage.

Efficiency and heat rating

The efficiency is not stated in this chip, but it can be assumed the losses are minimal. The operating heat range of this full bridge rectifier is -55 degrees Celsius to 150 degrees Celsius. This is greater than the range of the PDLC itself which is satisfactory as we do not want the chip components faulting out before the PDLC.

IC size

As PCB component size is crucial and in turn reducing the size of each component also becomes crucial. With dimensions of 8.2mm x 6.85mm x 1.5mm this chip is small which is good for our project.

Reviews, availability, and Price

This chip has high availability with 2273 pieces in stock at the time of writing. This is sufficient enough that we should not expect this amount to be depleted by the time of ordering. The price of this chip is cheap at $0.64, at this price it would be affordable to buy a set so that multiple pieces can be bought as back ups without worry.

4.5.3.4 MB8S-G Comparison of Full Bridge Rectifiers

Table 21: Comparison of Full Bridge Rectifiers

	DF1504S-T	RDBF32-13	MB4S-E3/45
Forward Voltage	1.1 V	1.3 V	1 V
Forward Current	1.5 A	3 A	.08 V
Peak Reverse Voltage	400 V	200V	800 V
Surge Voltage	24 V DC	-	400 V
Surge Current	50 A	100 A	35 A

4.5.3.5 Conclusion for Full Bridge Rectifiers

After comparing these three full bridge rectifiers, the MB8S-G was the optimal choice. Compared to the RDBF32-13 the values for the forward voltage reversal are much better and with the RDBF32-13 have reverse current of 100 A this would be very excessive for our project. We can that the DF1504S-T also has an excessive reverse current while having a significantly lower reverse voltage at 400 V compared to 800 V. Size wise the MB8S-G is the most compact which was crucial when designing a PCB and comes with the added benefit of being the cheapest of all three components. With these factors in mind, we went with the MB8S-G.

4.5.4 Transformer

The purpose of a transformer is to step up or step-down voltage. There are many purposes of this from power transmission to controlling the voltage in a circuit. In this case we are using a center tapped transformer so we can step down the voltage from our power source so that we can safely operate our system without burning out our components.

4.5.4.1 Tamura: 3FD-424

Voltage Rating and Power

With this transformer the primary voltage is rated for 115 VAC on the Primary side, which ensures that we can use this to convert power directly from a wall outlet in the US. On the secondary side it converts to 12V in the parallel configuration and 24V in the series configuration. With these options we will be able to theoretically run this voltage into the voltage regulators safely. With this voltage and a current 500mA in parallel configuration and 250mA in the series configuration this transformer draws 9 VA of power. This should be workable though we will have to be careful to watch for overheating of our system.

Dimension and Casing

This transformer has a dimension size of 41.5mm x 34.83mm x 38 mm. This is on the larger size compared to our other components however this is typical for these types of transformers. Luckily this transformer comes with a through hole mounting type which would allow for easier integration into a PCB.

4.5.4.2 Triad Magnetics: FD4-24

Voltage Rating and Power

With this transformer the primary voltage is rated for 115 VAC on the Primary side, which ensures that we can use this to convert power directly from a wall outlet in the US. On the secondary side it converts to 12V in the parallel configuration and 24V in the series configuration. With these options we will be able to theoretically run this voltage into the voltage regulators safely. With this voltage and a current 500mA in parallel configuration and 250mA in the series configuration this transformer draws 9 VA of power. This should be workable though we will have to be careful to watch for overheating of our system.

Dimension and Casing

This transformer has a dimension size of 60.45mm x 31.75mm x 35.05 mm. This is slightly larger than the Tamura Transformer. A major downside of this transformer is its mounting style. With the chassis configuration it will make it more difficult to integrate into our PCB design requiring extra space overall to fit.

4.5.4.3 Conclusion on Transformer.

For all of the components these transformers shared many similarities, so the decision came down to ease on implementation. For the Tamura transformer though it is not a surface mount component is it through hole which was the next bestoption, on top of this, the Triad transformer is larger which will increase the real estate that our system occupies. As these two factors will have significant weight when selecting components, we decided on the Tamura 3FD-424

4.6 Summary of Components and Parts Selection

The table below gives a summary and overview of the parts selected for this project and their prices. The table shows the parts and components that were decided upon by the team members based on the conditions explained in the parts and components section of this paper. The decision was made based on cost (since the team members are on a tight budget), availability and ease of procurements, compatibility, and capability of each of the parts and components for the successful completion of the project.

Table 22: Summary of Parts selection and Prices

Component	Part Selected	Price
Window Frame	Fixed window frame	$20
Blind	Polymer Dispersed Liquid Crystal (PDLC)	$50 per panel
Microcontroller Unit	TTGO T-Koala ESP32 ESP32-WROOM32	$19
Proximity Sensor	MCM 287-18001	$2.99
Voltage Regulator (Switching Regulator)	LM2575-ADJ 5V Output Buck Converter LM2575-ADJ 3.3V Output Buck Converter	$ 0.55 $ 0.55
Full Bridge Rectifier	MB4S-E3/45	$0.41/chip
Transformer	Tamura 3FD-424	$9.40

5.0 Standards and Design Constraints

This section goes over some of the related standards and design constraints that pertain to this project. Section 5.1 will go over some related standards for wireless connectivity, software design (programming languages used herein), power supply, serial communication protocols. Section 5.2 will go over some possible design constraints that could be encountered during this project.

5.1 Standards

This section goes over the related standards used for this project including wireless connectivity standards (Wi-Fi standards, Bluetooth standards, proximity sensor standards), Serial communication protocols (I2C standards, SPI standards, UART standards, USB standards) and programming languages (used herein) standards.

5.1.1 Wireless Connectivity Standards

Wireless connectivity allows communication between different devices while also allowing access to different products like a computer allowing its user to connect to social media using Wi-Fi connection. Wireless connectivity will be used in this project to allow communication between the electric blind and various automation process developed herein. Therefore, it is necessary to understand the various standards associated with the various types of wireless connectivity that would be used herein.

5.1.1.1 Wi-Fi Standards – IEEE 802.11

Wi-Fi is collection of wireless network protocols that functions using radio frequency technology based on the IEEE 802.11 specifically a set of medium access control MAC and physical layer PHY protocols for implementing wireless local area network communications. Invented and released for consumers in 1997, Wi-Fi became an integral part of keeping people connected at home, small offices and in public by allowing connection of smart devices to broadband internet using wireless transmitters and radio signals. IEEE 802.11, which was the basis for Wi-Fi standards refers to a collection of standards that define communication for wireless local area networks (WLANs). Following the creation of IEEE 802.11, a basic specification for Wi-Fi was introduced which eventually gave rise to the creation and introduction of Wi-Fi for home use in 1999.

Generally, Wi-Fi uses radio frequency technology i.e., a frequency within the electromagnetic spectrum for radio wave propagation, to communicate data that run on two main ISM radio bands: 2.4 gigahertz (GHz), also known as IEEE 802.11b and 5 gigahertz (GHz), also known as IEEE802.11a. After many years, advancement in technologies led to faster speed and stronger Wi-Fi connections and numerous versions of Wi-Fi. The most recent version enabled significant increase in data without the need for higher bandwidth. Some of the different versions of Wi-Fi include: 802.11a, 802.11b, 802.11n (which is Wi-Fi 4), 802.11ac (which is Wi-Fi5) 802.11ax (which is Wi-Fi 6) etc.

Table 23: Comparison of Wi-Fi standards based on speed and Radio frequency ranges

Wi-Fi Standard	Speed (how much data can be transmitted by the network)	Radio Frequency
802.11a (Wi-Fi 2)	54Mbps but usually around 6 to 24Mbps	5GHz
802.11b (Wi-Fi 1)	11Mbps	2.4 GHz
802.11d	Usually combined with other networks like 802.11ad	
802.11g (Wi-Fi 3)	54Mbps	2.4 GHz
802.11n (Wi-Fi 4)	100Mbps	2.4 GHz and 5GHz
802.11ac (Wi-Fi 5)	160Mbps	5GHz
802.11ax (Wi-Fi 6)	3Gbps	2.4 GHz and 5GHz

The IEEE 802.11 standards that are the basis for Wi-Fi will be further explored in this section. The 802.11 MAC sublayer protocol provides a simplified version of the physical layer to the logical link control sublayer and upper layers of the OSI network. The OSI model, Open Systems Interconnection Model), describes the function of a networking system. The OSI Model has 7 layers used to describe a network architecture: Physical Layer, Data Link Layer, Network Layer, Transport Layer, Session Layer, Presentation Layer and Application Layer. 802.11 Physical Layer (PHY) is the lowest layer of the OSI model that is mainly concerned with transmitting raw unstructured data across the network. The physical layer also holds physical resources like cabling, adapters, modems, and network hubs.

For this project, Wi-Fi would be used for one of the automation methods that involved opening and closing the electric blind with a phone app.

5.1.1.2 Bluetooth Standards – IEEE 802.15.1

Bluetooth, originally known as a short-link radio technology, was initiated in 1989 by Nils Rydbeck at Ericsson Mobile in Lund Sweden. Bluetooth wireless communication technology was put forth by IEEE 802.15.1 standard. Bluetooth, while it was standardized by IEEE 802.15.1, is no longer maintained by IEEE but rather by the Bluetooth Special Interest Group (SIG). Bluetooth is a low or short-range wireless technology used for transferring data between devices (like smartphones and other smart devices) over short distances using Ultra-High Frequency radio waves. WLAN and Bluetooth both operate in the same 2.4GHz frequency bands but they use different signaling method that prevents interference between both signals. Bluetooth is used for its low power consumption and ease of connectivity and re-connectivity among devices. These features of Bluetooth allow applications of wireless control and communication between a mobile phone and a handsfree headset, compatible car stereo system, smart locks, intercom, wireless speakers and many more devices.

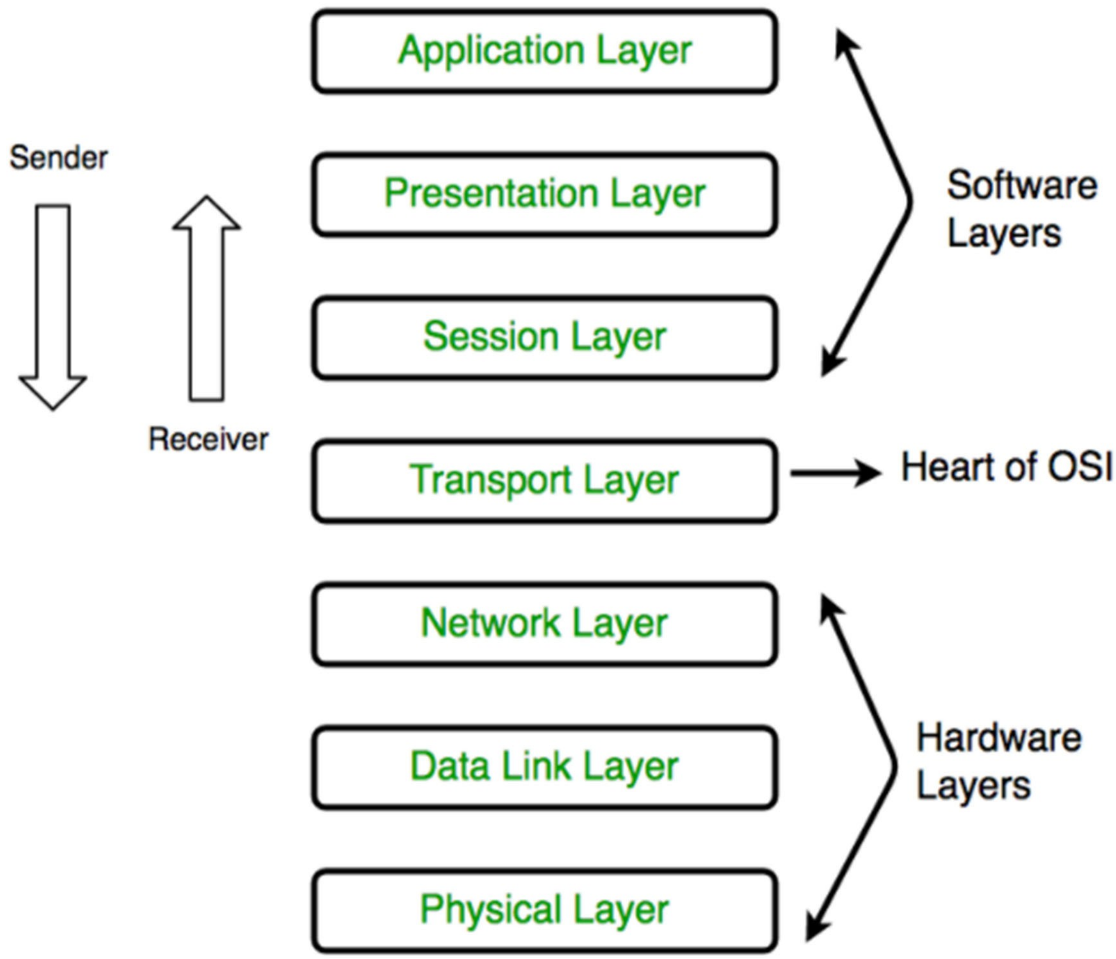


Figure 24: Layers of Open Systems Interconnection (OSI) model

5.1.2 Serial Communication Protocols

A serial communication protocol is what is used for embedded devices to communicate. For this project, we will be using UART (Universal Asynchronous Reception and Transmissions). The primary reason for this, is that the board will be programmed using an Arduino board. The default serial communication protocol used for Arduino boards is UART. Arduino already has a lot of libraries built in which will abstract away a lot of that functionality to nice and simple API calls, which send a receive data. Underneath these API calls is realistically just UART transmission. As such, API calls will be used which will effectively communicate using UART.

5.1.2.1 Serial Peripheral Interface (SPI)

Serial Peripheral Interface (SPI) is a four-wire serial bus communication interface that is specifically used for short-distance communication in embedded systems because of high speed signals. SPI was designed by Motorola in 1979 for serial and full-duplex data protocol. While there are no formal standards specifically designated to SPI, SPI has been implemented in numerous designs because of its advantages that include: SPI is faster than asynchronous serial, and it supports multiple peripherals like temperature sensors, analog-to-digital converter sensors, control devices, real-time clocks, communications and many more peripherals.

SPI bus generally specifies four logic signals which are: SCLK (Serial Clock which is output from master), MOSI (Master Out Slave In which is data output from master), MISO (Master In Slave Out which is data output from slave) and CS (Chip Select which is often active low, output from master). Note that, since there are no formal standards for SPI, different names can be used to identify the four logic signals stated and shown in the figure below, which shows a single master to single slave basic SPI bus example.

As shown in the figure, the master is the device that generated the clock signal (SCLK) and data is transmitted between the master and slave using the synchronization of the clock signal generated by the master. Similarly, in SPI, the master selects the clock polarity and clock phase where CPOL bit selects and sets the polarity of the clock signal during idle state, and CPHA bit selects and sets the clock phase.

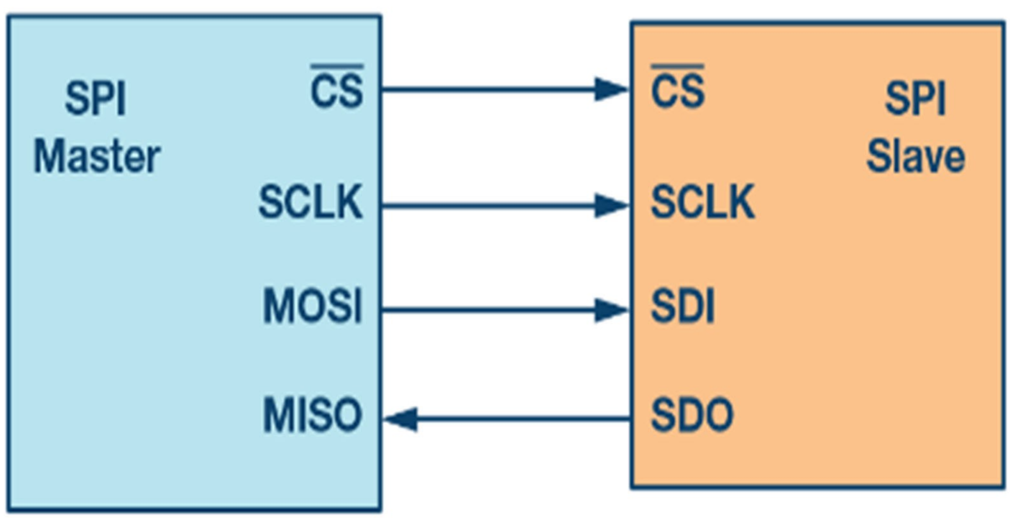


Figure 25: Basic SPI single Master and Single Slave configuration

Table 24 shows the different SPI modes that can happen with CPOL and CPHA bit selection.

Table 24: 4 SPI Modes with CPOL and CPHA bit selection

SPI Mode	CPOL	CPHA	Clock Polarity in Idle State
0	0	0	Logic Low
1	0	1	Logic Low
2	1	1	Logic High
3	1	0	Logic High

5.1.2.2 Inter-Integrated Circuit (I2C)

Inter-Integrated Circuit, popularly called I2C, is a synchronous multi-master, multi-slave serial communication bus that was designed by Philip Semiconductor (known as NXP Semiconductors) in 1982. Although I2C was designed by NXP, various companies like Texas Instruments, Intel and others have created and introduces subsets of I2C and compatible I2C devices. I2C bus is generally comprised of the following features: serial data line (SDA) and serial clock line (SCL), masters that can operate as transmitters or receivers, masters generate bus clock and initiate communication on the bus, and slaves respond to commands in the bus. Finally, each slave device has a unique address on the bus. Figure 26 shows I2C bus specifications.

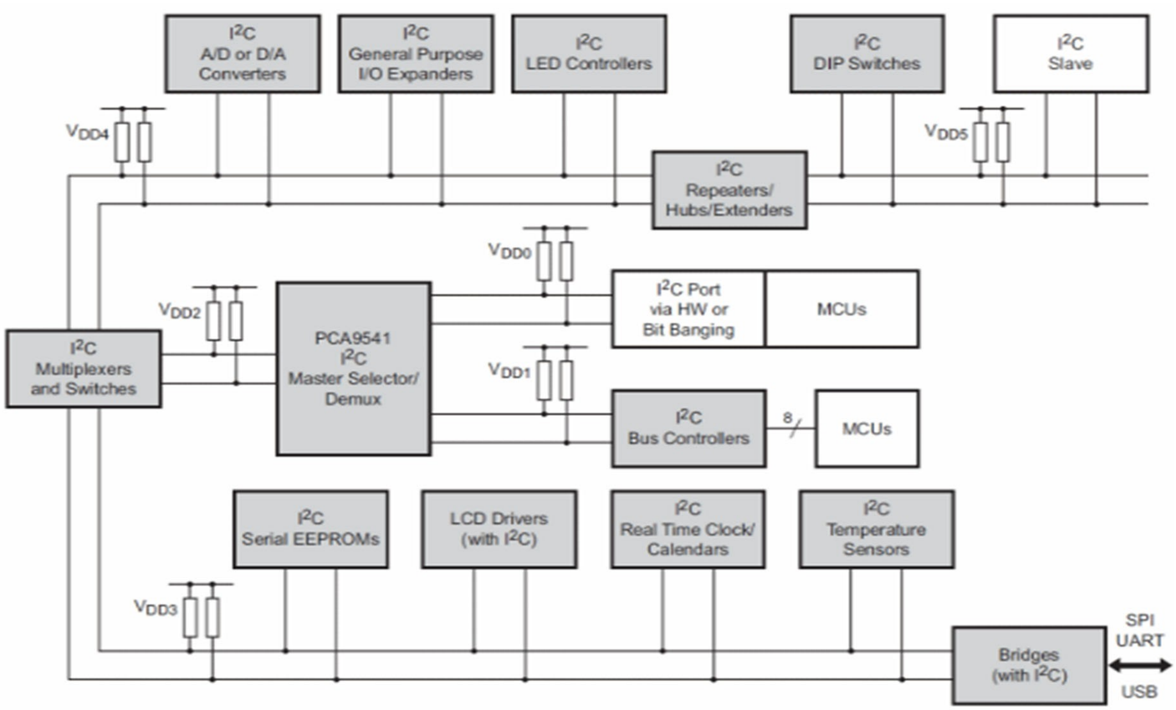


Figure 26: I2C Bus specifications

I2C will be beneficial for this project because of its extremely low current consumption.

5.1.2.3 Universal Asynchronous Receiver Transmitter (UART)

The first Universal Asynchronous Receiver Transmitter (UART) was designed by Gordon Bell of DEC and it was designed as an entire circuit board called line unit. UART is an asynchronous serial communication standard that contains a clock generator, I/O shift registers, control logic, buffers FIFO buffer memory and many other optional components. UART enables communication using two wires to allow bidirectional simultaneous transmission. A basic UART allows robust, moderate speed, full-duplex communication. Unlike SPI and I2C, no clock signal is required for UART because the user provides UART hardware which would be needed for timing information. The figure below gives a brief overview of the UART communication protocol where start bit (logic low) is the first bit of UART that indicates data line leaving idle state and last bit of UART stop bit (logic high).

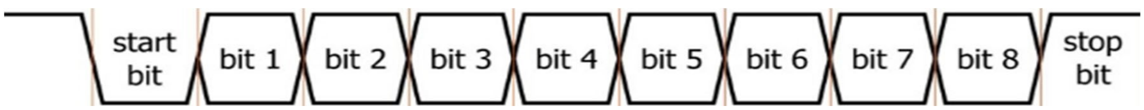


Figure 27: UART Communication Protocol

5.1.2.4 Universal Serial Bus (USB)

Universal Serial Bus standards was released in 1996 and is maintained by the USB Implementers Forum (USB-IF). USB was designed by various designers including Microsoft, IBM, Intel, NEC and more. The USB standards gives the specifications and protocols that allow connection between numerous devices and enables communication between them. Over the years, there have been different versions of USB specifications (generally known as the generations of USB) as shown in table below including the speed improvement per generation.

Table 25: Generations of USB specifications

USB Version	Year Released	Improvement/Speed
USB1.1	September 1998	Low Speed: 1.5 Mbps High Speed: 12 Mbps
USB2.0	April 2000	High Speed: 480 Mbps
USB3	September 2007	4.8 Gbps
USB3.1	November 2008	10 Gbps
USB3.2	September 2017	10 – 20 Gbps
USB4	August 2019	Up to 40 Gbps

The microcontroller that would be used for this project uses USB for its power supply.

5.1.3 Programming Languages

So, for the programming language we are going to use, we will be using the Arduino Programming Language. This is because the board we are working with is designed to be programmed using that programming language. In addition to that, both the programming language and the Arduino IDE are designed in such a way where a lot of tasks are abstracted away. As a result, this will assist with programming the board.

5.1.3.1 Arduino Integrated Development Environment (IDE)

Arduino IDE is a software platform that developed by Arduino Software written in C and C++. Arduino IDE can be used on the following operating systems: Windows, Linux and macOS. Arduino IDE has become very popular that the platform can be used to build and upload codes to other microcontrollers like ESP32 Koala used for this project. Arduino IDE is licensed under GNU Lesser General Public License (LGPL), a free-software license that allows developers to use and integrate Arduino IDE. Another license for Arduino IDE is GNU General Public License (GPL), which is a series of widely used free-software license that allows users to run, study, share and modify Arduino IDE (or other software with this license).

5.1.3.2 C Programming Language

C is a procedural programming language designed by Dennis Ritchie in 1972 at Bell Labs. C was designed and developed as a system programming language to be used for structured programming. This programming language was influenced by languages such as FOTRAN, Assembly and more. C has also been used as the foundation for other languages such as C++, Java, JavaScript, and lots more. Over the years, there have been numerous developments of C standards as shown in the table below:

Table 26: C standards enumerated by year of development and major changed

Year of Development	C Standard	Changes and New features
1972	Creation of C	implemented in assembly language
1978	K&R C	introduced standard I/O library
1989/1990	ANSI C and ISO C	resulted in the standardization of C
1999	C99	introduced features like inline functions and new data types.
2011	C11	added more features like type generic macros and multithreading
2017	C17	introduced technical corrections to C11

The latest C Standard is expected to be a standard revision with development year yet to be determined. ISO/1EC 9899:2018 specifies the representation of C programs, syntax, constraints, and semantic rules for C programming language. The document also explains and specifies the restrictions and limits imposed on the usage and implementation of C programming language.

C is researched and detailed herein because C is used in Arduino IDE to build the microcontroller used in this project, ESP32 Koala board.

5.1.3.3 C++ Programming Language

C++ is a multi-paradigm, general purpose programming language designed by Bjarne Stroustrup in 1985. C++ was created as an extension of C programming Language. Over the years, C++ became an object-oriented programming language with functional features added to enable low-level memory manipulation. C++ programming language is standardized by the International Organization for Standardization (ISO). While C++ programming language and C programming language are closely related, both languages have significant difference that set them apart from the other.

Over the years, there have been numerous C++ standards created under ISO standards. Generally, these standards added new features, technical reports and specification to older C++ standards.

5.2 Possible Design Constraints

Realistically, the most pressing design constraints were the ones that led to it being an excellent product. This was explored in great details earlier in the paper. However, to quickly recap they include cost, ease of use, energy savings, safety, aesthetic, and more. The technology used for the design is called Polymer Dispersing Liquid Crystal (PDLC) film or switching film. This material currently is on the more expensive side when compared to Conventional blinds. Another constraint is ensuring that the inputs and outputs of the blinds (on/ off) arereadable to the microcontroller used for designing the system for the electronic blinds. Another constraint is ensuring that the pee strips can be powered withthe relevant power source whether that be a solar panel or a hard wire into a plug. Another constraint will be sourcing all of these materials needed to build the designsystem with a global pandemic going on. Currently one year into this global pandemic Supply chains are still disrupted. Ensuring that the PCB, microcontroller, solar panel, PDLC film, and miscellaneous components arrive on time will be crucial in completing this project. Along with this, learning on the go how to interface these different components to achieve the goal of this project will be essential.

This section goes into brief details for each of the constraints that are possible in this project from cost constraints (student funded project) to safety constraints which could arise from the components used for the project and how this could affect or possibly affect the end users for this project.

5.2.1 Economic (Cost) Constraints

Cost constraints for this project involved the budget created for the completion of this project. Since this project is student-funded, the cost constraintis very limited. The cost constraints did not only mean the money needed for thematerials (which has been projected to be maximum of $600), but cost constraints herein also comprised of the individual labor cost for the team members, the vendors that parts and components are procured from, and quality control. The team members of this project have decided to dedicate as much time as needed for the completion of this project. Various vendors will be reached out to and usedto allow for flexibility and readily procurement of the necessary parts and components needed for this project in a timely manner.

Manufacturing these units in mass reduced the price. However, producing the prototype was expensive. Buying the device for the transparent/opaque feature proved expensive. On top of that we interfaced it with our own PCB, possible relays and power supply which required specific components. Additional research was required to satisfy these concerns.

5.2.2 Ease-of-Use Constraints

The device created from this project will be marketed as an easy-to-use project which makes the process of opening and closing a blind automated (since that is the main goal and objective herein). If the goal is met, then the resulting device from this project will allow numerous ranges of end users due to the multiple automation methods employed. The constraints that could arise for end users is the very wide of users that could potentially use the device and product of this project. While it is impossible to cater to all the end users of this project, the electric blind will have a product that can be used by most end users and also include safety factors to enable easy and safe usage.

5.2.3 Energy Saving Constraints

Heating it will be important to check to see if our system design has a satisfactory u-factor as deemed by the US Department of energy. The U-factor is defined by defenestration of the window. “The U-factor is a measure of the rate of heat flow through glazing products; the lower a U-factor, the less heat will flow through the window. In the United States, U-factors are reported in Btu/(h·ft2·°F), and typically range between 0.2 to 1.2 Btu/(h·ft2·°F).”

To maximize energy savings, we followed the standard set by the departmentof energy that suggested that your product have a low solar heat gain coefficient or SGHC. They also recommend having tints of some kind, with this project we should be able to meet both recommendations. If in the future our product is determined to me energy star ratings the users will be able to qualify for rebate from certain utilities for having these products, on top of the savings in energy. Along with measuring the SHGC we should also measure the visible transmittance also known as VT. This is the amount of visible spectrum or light that passes through a glazing unit is usually the values range between 0 and 1, with below .5 being a noticeable reduction in the amount of light transmitted. With our unit we should be able to vary the visible transmittance depending on the opaqueness setting currently enabled. Our goal remained within the recommended range for the Southern Region of the US.

5.2.4 Time Constraints

This constraint refers to the project's schedule for the completion of the project which includes implementation, testing and delivery of the final project meeting all the requirement specifications given above. This is a major constraint that needed to be carefully investigated by the team members which is what led to the creation of project milestones in Chapter 8 of this paper. The project milestone was divided into two: senior design 1 milestones and senior design 2 milestones. By following the carefully created milestones, there was a higher probability of tackling time constraints and successful project delivery by the end of senior design 2. By following and meeting the deadlines created for the two milestones, it was possible to meet the time constraints for this project.

WINDOWS			
CLIMATE ZONE	U-FACTOR[1]	SHGC[2]	
Northern	≤0.27	Any	Prescriptive
	=0.28	≥0.32	Equivalent Energy Performance
	=0.29	≥0.37	
	=0.30	≥0.42	
North Central	≤ 0.30	≤ 0.40	
South Central	≤ 0.30	≤ 0.25	
Southern	≤ 0.40	≤ 0.25	

SKYLIGHTS		
CLIMATE ZONE	U-FACTOR[1]	SHGC[2]
Northern	≤ 0.50	Any
North Central	≤ 0.53	≤ 0.35
South Central	≤ 0.53	≤ 0.28
Southern	≤ 0.60	≤ 0.28

Air Leakage ≤ 0.3 cfm/ft2

[1] Btu/h ft2·°F
[2] Solar Heat Gain Coefficient

Figure 28: Performance criteria for windows and skylights based on ratings certified by the National Fenestration Rating Council (NFRC)

5.2.5 Safety Constraints

Safety was an essential aspect of this project because the team members wanted to create a product that meets safety requirements and enables wide end user usage. However, since this project doesn't store any personal information of the user, then there is no need to implement HIPAA (for safe usage of personal information).

6.0 Project Design

This section goes into full detail, the project design i.e., the hardware design details, and the software design details.

6.1 Project Hardware Design Details

This section gives the hardware design details for this project. The details include hardware block diagram that shows the step by step process of the hardware design used herein. The process includes power supply, then data transfer between PIR sensors, microcontroller unit and relay.

6.2.1 Hardware Block Diagram

To have a general idea and a step for the overall project, a blueprint of the project was deployed. Similarly, our group came up with the block diagram for the hardware design so we can follow the stages. The block diagram also makes keeping track with the process easier.

The first stage of the project's hardware design was developing power supply. The main power supply from a 120 VAC household power which was stepped down to a12 VAC from a transformer with 10:1 ratio. The voltage on the low side of that transformer was then rectified by a full wave bridge rectifier to convert the alternatingcurrent to the direct current with a value of 12 VDC. From this step, the 12 VDC voltage was now regulated by 2 two switching voltage regulators to a 5 VDC used forthe PIR sensor. The other switching voltage regulator regulated to a 3.3 VDC to power the main microprocessor control unit (MCU).

The next stage was data transferring between PIR sensor, MCU, and relay. In orderfor the device to work, the PIR sensor needed to sense the present of a target whichis a human's activity. Once the sensor sensed, it sent a TTL output signal to theMCU. The MCU received the signal will then send a voltage to the relay to close the internal circuit inside the relay. Finally, the relay closed its contact so the mainpower supply could be delivered to the PDLC film to make it work.

6.2 Project Software Design Details

This section discusses the software portion of the project. Our code ran on an Adafruit ESP32 Feather board. Effectively this code had one job. To input and interpret end user input and operate the frosted glass accurately in accordance with the end user's input. For this, there are three main jobs it had. That is managing end user input and output, effective interpretation of that input, and operation of the frosted glass. We go into detail as to how the software effectively accomplished all those tasks. Figure 12 gives theflowchart of the overall project software design used herein.

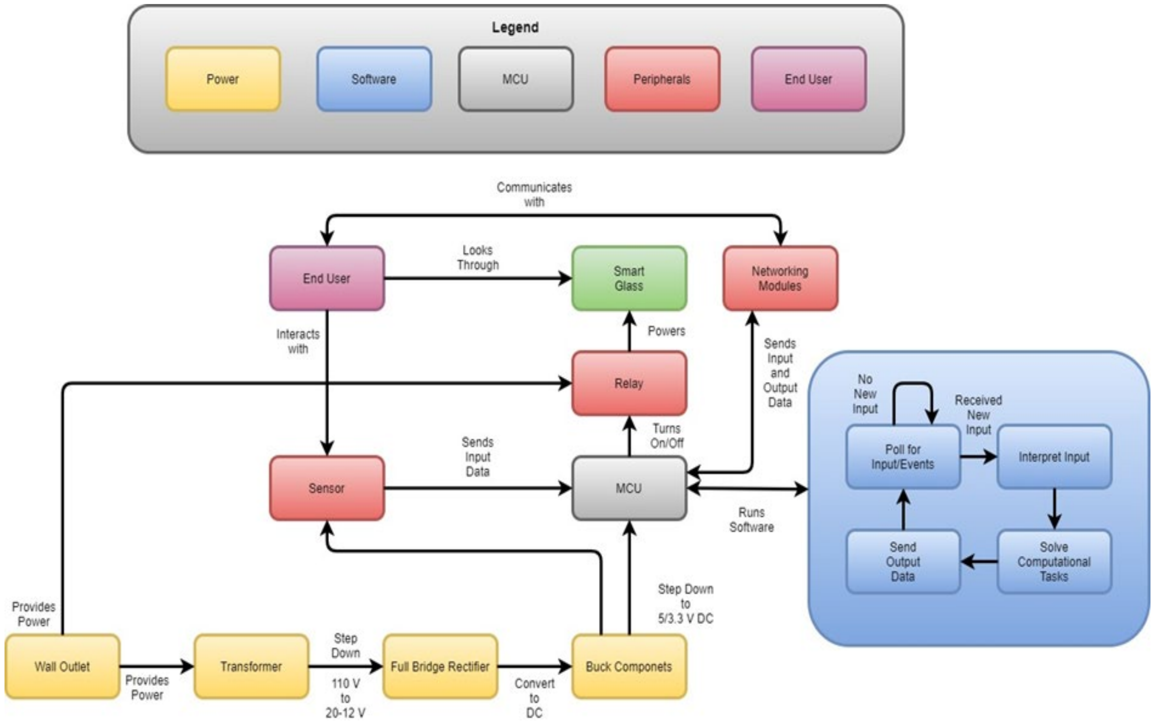


Figure 29: Hardware Block Diagram

6.2.1 Input Software Design

6.2.1.1 End User Input

The potential methods of input for end users is practically infinite. However, they primarily fall under two separate categories. Input derived from sensors, and input derived from network data. We plan on having at least one input method from each category. The reason for this is because if we have a functional form of input for a category, getting subsequent input forms is significantly more achievable. Since the purpose of this project was to prove the functionality of the idea, having at least one type of functional input for each category was sufficient.

6.2.1.2 Sensor Input

For a sensor, we utilized a proximity sensor. We used polling to utilize this sensor. The code utilization of the sensor looked as such: First in the setup function, we defined the pins used to communicate with the sensor. Then with every iteration of the primary function, which is looped infinitely, we read the value recorded by the sensor. From a software perspective, the sensor always output by numerical values which signify the distance to an object it detects. If it is within a certain range, we open the blinds. This range is a range that we define, and it signifies the distance in front of a window we want an end user to be to trigger this event. If the value read in from the sensor is not within the range, and the glass is not frosted, the glass will be frosted.

6.2.1.3 Network Input

This is input derived from another computer sending this device data. For this, we planned functionality for both Bluetooth and Wi-Fi support. The reason for these two methods is both methods have drawbacks. Bluetooth requires physical presence near the device, and a device with Bluetooth capabilities. Wi-Fi requires wireless authentication to the network to talk to any other computers (since this device doesn't have a keyboard, providing that input without a pre- existing connection will prove difficult).

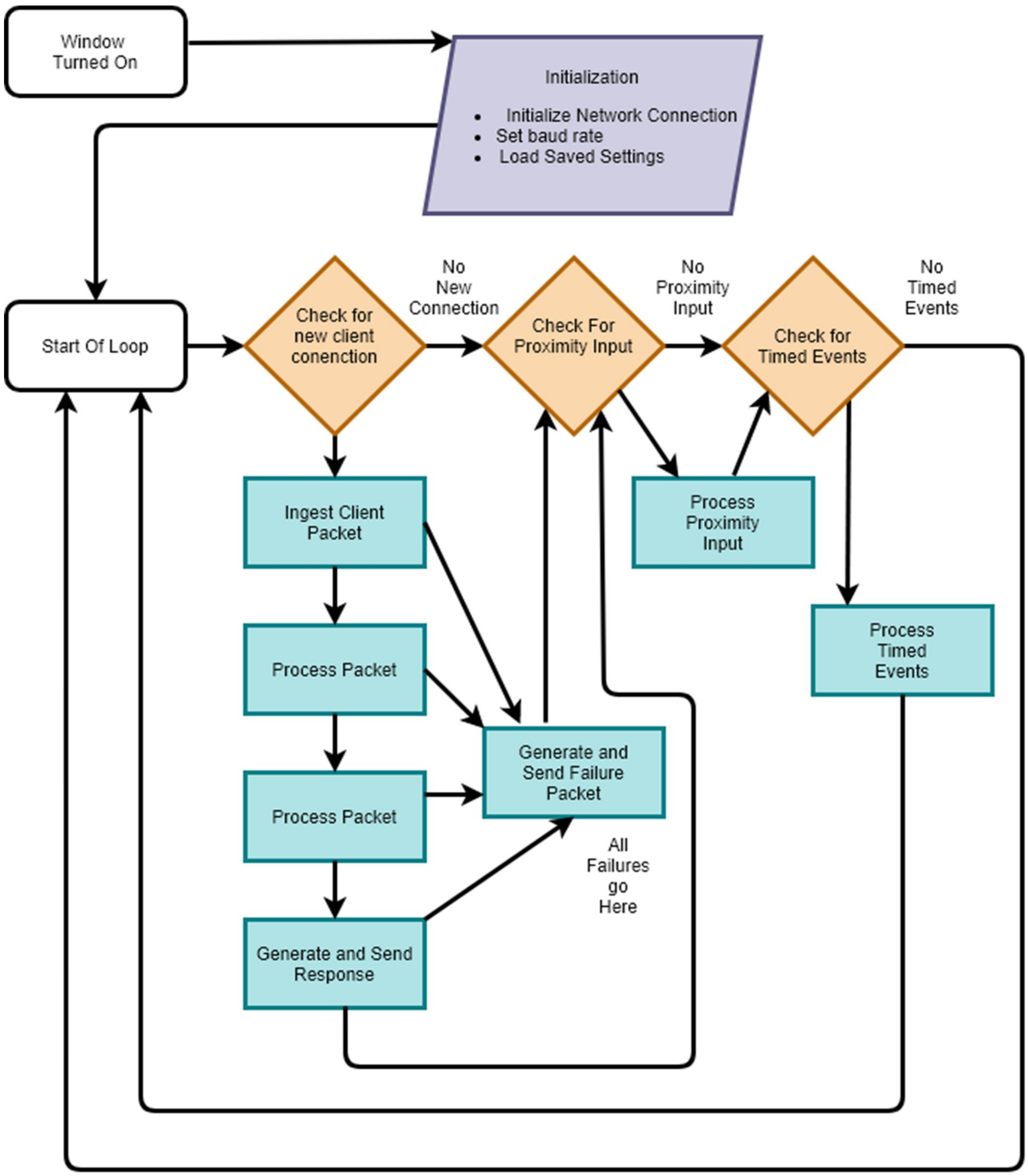


Figure 30: Overview of Software design

By having these two communication methods together, we overcome the disadvantages. The Wi-Fi method negate the physical proximity requirement, if you are on a network that can reach the device. Bluetooth does not require authentication (it assumes physical proximity is authentication), so you can first connect to it with Bluetooth to specify the Wi-Fi connection specifics.

In terms of the client that will communicate with the device, we have twoplanned. One is a python3 script that is run on a computer. This resemblea client that can be run from a computer. It will encompass all the components of such a client, except for a GUI. That is realistically just Window Dressing that can easily be applied later (this is just a prototype meant to act as a proof of concept). The second type of client is an app on an Android phone. This acts as a proof of concept to use a cellular phone as a client to communicate with the device, which added significant value.

Over Wi-Fi, we used TCP as the protocol to transfer the data. This is because the two main options available to us are TCP and UDP. The primary tradeoff for using TCP is that we get higher reliability of correct network data transfer (since network data isn't always correctly transmitted), in exchange for a minor performance hit. For this application, we value correct data transmission over a slight performance increase, so we went with TCP. The port it listens onwill be a defined port within the unassigned range of TCP ports, as to minimize thechance of some other program accidentally communicating with this device.

In addition to that, communicating over Wi-Fi over a network posed one problem. Chances are when the client tries to connect to the device, it will not know it's IP address. This was solved by sending a predefined packet that is multicasted. This made its way to the board, to which the board will reply. Then the client and the server knew each other's IP addresses, and were able to communicate via unicast.

6.2.1.4 Network Protocol

So, this section we discuss the protocol used to actually transmit the data. We made a custom network protocol to accomplish this. This seemed like a complicated process, but realistically it was fairly simple for this, considering that there wasn't much complexity in the information transmitted. The preceding paragraphs will detail some of the specifics of this protocol, which is primarily packets.

There were effectively be two types of packets. These are requests, and acknowledgements. The requests are sent by the client to the server, and the acknowledgements were sent from the server to the client. The server in this instance are defined as the board which runs the code for the window glass frosting device.

For the requests, these packets comprise of four different sections. These sections are Packet Size, Number of Requests, Requests Content, and a Checksum. The Packet Size was a two-byte value, that is the size of the total packet in bytes. The number of Requests was a one-byte value, which signified the number of requests that are composed in the packet. The fact that there is a 2-byte value for the packet size, and a one-byte value for the number of requests, means that the maximum packet size is 65535 bytes, and the maximum number of requests is 255. Both 1- and 2-byte values was interpreted as unsigned integers.

The Requests Content section was a variable length section. This meant that it could be 10 bytes, 100 bytes, or more (unlike all other sections, we don't know the size of this section). This section is where we specify what we want from the requests. It consisted of several individual units called requests. These requests had four sections. The first was a one-byte unsigned integer, representing the size of the single request. The second section was be a 2-byte value representing the type of request (this limited the amount of different requests we could have to 65535, which should be way more than plenty). The third section was the data itself of the request. The third was a two-byte terminator, with a specified value representing the end of the request (every terminator will be the same value). Now we did not specify every potential data of the request

The final section of the packet is the checksum. This is a two-byte value. This value is calculated using all bytes of the packet except for the checksum. Thisway every byte of the packet has a direct influence on the checksum. The purpose of this checksum is to help ensure correct data transmission over the network. It is calculated when the packet is sent and sent with the packet. Upon receipt of the packet, a new checksum is generated from the packet, and compared to the checksum that is sent. If they are equivalent, then that lends a lot of credibility to the idea of correct network data transfer. If it isn't, then it knows that there was an incorrect transmission of network data, and it begins the retransmission process. This consists of the server sending the client a packetwith a request requesting a retransmission, and the client will retransmit the packet. If this fails three times, the connection is aborted.

Now for acknowledgement packets. This effectively becomes packets with a single request in the request content. This singular request specifies either a correct receipt of data, or incorrect receipt of data. We have the potential to expand upon this in the future. To help illustrate all this information, here is a diagram detailing the information like what you would see in an RFC.

One last thing about this protocol. While we have laid out the framework surrounding it, we did not assign Enum values yet, or granularly describe how all functions will occur such as specifying the window to be unfrosted. This is because, the framework is designed to be modular. We can add or remove various functionalities by adding or removing request types. We do this without making major overhauls to the protocol itself. This project has the potential for a lot of various types of interactions, such as setting a time for it to be open, disabling sensor functionality, specifying network credentials and more.

```
Packet

+--------------------------+
|       Packet Size        |
+--------------------------+
|       Number of Requests |
+--------------------------+
|       Requests Content   |
+--------------------------+
|       Checksum           |
+--------------------------+

Packet Size: 2 byte unsigned integer representing size of total packet.

Number of Requests: 1 byte unsigned integer representing number of requests.

Requests Content: Section composed of Requests.

Checksum: 2 byte checksum value for data integrity.

Request:

+--------------------------+
|       Request Size       |
+--------------------------+
|       Request Type       |
+--------------------------+
|       Request Content    |
+--------------------------+
|       Request Terminator |
+--------------------------+

Request Size: 1 byte unsigned integer representing the size of the request.

Request Type: 2 byte unsigned integer representing the request type.

Request Content: The content of the Request.

Request Terminator: A 2 byte specified value representing the end of the request.
```

Figure 31: Detailed information similar to RFC

This saves us time in the long run with having to redesign the network protocol and the code base for dealing with network traffic. In addition to that, on top of that it has layered checks for ensuring correct data transfer over a network, which isn't something you can rely on.

6.2.2 Frosted Glass Control

So, another primary functionality of the software is to turn the window glass frosting on or off. This means that we need to alternate between sending a current through the part of the window with the frosting, and not. From a software perspective, this is extremely simple. We set the output on one pin toon to send the current through the window and make the window translucent. To make the window opaque, we set the output to off which will cut off the current.

6.2.3 Arduino Coding Implications

Now we program this board utilizing the Arduino IDE. This comes with several implications. First off, it abstracts away some of the specifics of programming the board. This effectively makes it easier to code. In addition to that, Arduino has become a major platform used by many people out there. This makes the potential for possibly allowing third party developers to write their own functionality for this project easier. This is already commonly done with platforms such as Amazon's Echo, which allows for anyone to write their own code, and use it. This is a major plus since it has the potential to turn into programmers contributing free code and functionalities. Also, this type of feature is a major selling point for many products amongst tech enthusiasts.

6.2.4 Code Quality Control

Code quality control is a subject of great importance to any code base. It can be the difference between software that effectively achieves its purpose or sits in the corner untouched by anyone. Especially in team projects where you will have multiple people contributing to the code, due to the different ways people can write code, if proper Code Quality Controls are not implemented and followed, things can turn south quickly. In various software engineering roles, I have seen this be the sole deciding factor between making and breaking various products which have had a lot of resources poured into developing that. In addition to that, another thing I have seen in my professional experience, is that due to a lack of experience (most Electrical Engineers don't see anywhere near the same level of programming training in their degrees and careers), Electrical Engineers can be notorious for writing bad quality code. Since this group is primarily Electrical Engineering focused, this is even more important.

One of the first things we discuss is the Coding Style. This is of importance, primarily for code reading and comprehension. This might not seem like much, however any codebase that is used in any real capacity, the code is read many times more than the code is written. As such, ease of code comprehension for any engineers working with the code base is critical to productivity. There is an absurd amount of different ways you can write code, and depending on what your coding experience is, certain ways can be much easier to read than others. Having one uniform standard way of writing code could greatly reduce time spent reading code. In addition to that, another major issue I've seen in terms of bad code comprehension, is when engineers misread code. This leads to the engineer having an incorrect model in their head of how the code operates. Following this, it is a fairly simple jump to the engineer writing code with faults or bugs in it. This can easily lead to monumental issues later down the line. To help combat these issues, we will use a standard guideline, which defines a set of standards on how to write the code. Since we are coding on the Arduino platform, we will simply use the Arduino style guideline defined here (https://www.arduino.cc/en/Reference/StyleGuide). What realistically is important here isn't which style guide we choose if we choose one.

Another piece of our plan to ensure quality code is version control. This allows us to effectively manage having potential multiple people contributing to a code base. For this we have different branches (which are just copies of the code base, with some differences). When an engineer is working on a particular feature of functionality, they do so on their own branch. Upon completion of that branch,we then merge the branch with the master branch. The master branch is the copy of the code base that is deemed to be the official production copy of the codebase. If this was a product, it would be the copy of the code base we would have the customer using. This allows the engineers to have an environment where theycan effectively develop code that initially has faults, bugs, or issues with it (as a lotof code does initially, but those faults will all be rectified as a part of the development process). They can develop this code while not causing the master copy to be in an inoperative state, which is critical to any code base that sees any real use. In addition to that, every change that is made to every branch will be recorded, and have its own separate version assigned to it. The benefit of doing this, is if for some reason our controls fail and buggy code is introduced to a branch, or even our master branch, we can revert the code base back to the last known good version. To achieve all of this, we use the version control utility git, which has the functionality to achieve all of this. We store the code in a git repo on github.com, which is designed to handle storage of git repos (and will give all engineers access to it, wherever they have an internet connection).

The next piece of our code quality plan is a manual code review. This code review occurs whenever code is being merged with the master branch. This code review involved the Software Engineer in our group manually reviewing the codeto ensure that it meets the standard. This group member has a tremendous amount of experience writing quality code, both in University classes, Engineering jobs, and from personal projects (which is why he has the credentials to do this). This type of code review is standard practice for many code bases, ranging from Google Chrome to the Linux Kernel. It makes it so that if a mistake were to enter the code base, there will have to be multiple points of failure for realizing that mistake exists. In addition to that, this will be a critical step since we will not have unit testing or continuous integration in place. A large amount of code bases employs the use of automated testing to help ensure quality of new code. For this project's code to operate, it requires physical components. Due to resource problems, we will not be able to have automated testing. As such, the manual code review for new code being merged into the master branch, is even more critical.

The final piece of our code quality plan is to employ the use of code linters. A code linter is a piece of software that will perform a manual code review of code. It can check for issues ranging from deviations from a style guideline, to actual software vulnerabilities and bugs. The software linter we will be using is Arduino Lint detailed here https://blog.arduino.cc/2021/01/13/detect-problems-with-your-arduino-projects/ . Mandatory code linting will only occur on code that is being merged into the master branch.

7.0 Overall Integration, PCB design and System Testing

The overall integration of window manufacturing plan, power system, microcontroller unit and software would be detailed in this section. The overall PCB design would be detailed with schematics. Lastly, this section will show the system testing process undertaken by the team members in an effort to create a working prototype of the project herein.

7.1 Window Manufacturing Plan

So, this part details our plan for actually manufacturing the window. We tried and made this as simple, and adjustable as possible. That way, it allowed us to cope with any potential problems that might manifest itself. The plan is effectively this. We constructed via cutting 2X4 wood pieces. These pieces were purchased from a local hardware store, along with any additional screws, nuts and bolts. We had a piece of acrylic that acts as the transparent material. We chose this, since it is more durable, cheap, and readily available. We purchased this piece off of amazon instead of a hardware store, since they had good pieces that met this requirement.

For constructing the wooden frame, we cut off four pieces of the 2X4 such that it surrounded the perimeter of the piece of acrylic. We used a table saw (volunteered by a group member) to cut small grooves that ran the perimeter of the acrylic. The acrylic rested within these grooves. We attached brackets that extend to two pieces, in each of the four corners, on both sides (8 brackets in total). These brackets had two holes, one for each piece they connect. We drilled a hole into the wood, and inserted a bolt through each hole, which was fastened with a nut and a washer. This allowed us to construct the frame, but also take it apart and then subsequently put it back together using all of the parts, and with simple household tools, in a relatively simple process. The need for this might arise due to an unforeseen problem that gives us the need to. The piece of acrylic was inserted into the frame, in the groove. This design allowed for the acrylic to have some slight wiggle room, but it was not able to fall out (which gave us a margin for error). Since our project was about implementing technology with frosted glass and not the window, simplifying the window frame was a big help with the project. The groove in the pieces of 2X4 were similar to the figure below.

Now lastly, for the pieces of electronics that were be implemented in this project, we constructed a board out of wood which we mounted the electronics to. This is because for this project, we realistically can just run wires to the window (which our frame would easily allow for that) and have all of the electronics be on its own board separate from the window frame. This simplified the design, allowing us to focus on the core of the project.

Figure 32: Initial Window Manufacturing Plan

7.2 Hardware Design Integration

7.2.1 Hardware Schematics and Design Procedure

The design procedure of for the project are carefully explained in this section. There are many free firmware which can assist user in designing the Printed Circuit Board (PCB) on the market at this moment. However, Eagle CAD firmware is trusted and used for this project due to the UCF's study plan. UCF designs a full course which is called Junior Design where students learn how to use this firmware from designing schematic for the design, transferring the schematic design into a board layout to ordering all kind of components through many different vendors in the USA.

There were several steps for this process. The first step was to design the circuit with components on the schematic layout of the Eagle CAD. The Eagle CAD's library contains many different components' symbols and footprints from resistor, capacitor, to switch, pin header, etc. However, there are some components that require an outside search to be placed in. With that in mind, whenever a component is chosen for the project, we try to search for its symbol and footprint from some website such as Ultra Librarian and SnapEDA. The already built symbols and footprint will cut a good amount of time for the design since we do not have to create the symbol and footprint from scratch. Moreover, mistakes can be made which create more difficulties in designing the PCB and for the whole project.

Once the schematic for the design was completed, Eagle CAD transferred that schematic layout to board layout. The board layout was used to arrange components on the PCB and make traces between the components. As stated above, this stepcan only be achieved once the components' footprints are ready.

With the two stages identified from the block diagram, the project needed different modules such as the power supply module which provided power for the whole project to operate. From the power module, there were two subsystems need to be designed. The first subsystem was the step-down in AC voltage and conversion from AC to DC voltage. The second subsystem for the power module was voltage regulator from the stepped down, converted DC voltage to maintain a specific voltage level to power each of the component.

The other module was the microcontroller schematic design. This subsystem helped the device become smarter by making the device work automatically with the present of the user without physical operation. With the selection of the microcontroller which includes the Bluetooth module and Wi-Fi module, the implementation of the microcontroller helps the user control the device through an user interface through a phone in case the user is not in the working range of the sensor.

7.2.1.1 Power Module

Voltage Regulator (5 V Buck Converter)

As decision in the Part Selection chapter above, the switching voltage regulator LM2575 was chosen to be used for the 5 V buck converter for the project. However, when the voltage regulator was purchased, it only came by itself without any other passive components. To demonstrate its ability to step the 12 VDC down to 5 VDC, we designed a complete circuit. Fortunately, the LM2575 came with a data sheet where the manufacturer has typical diagrams that suit each application.

Upon completing the circuit diagram, we followed the manual from the manufacturerto search for the passive components that are recommended for the switching voltage regulator. Then, the schematic was implemented as the figure below.

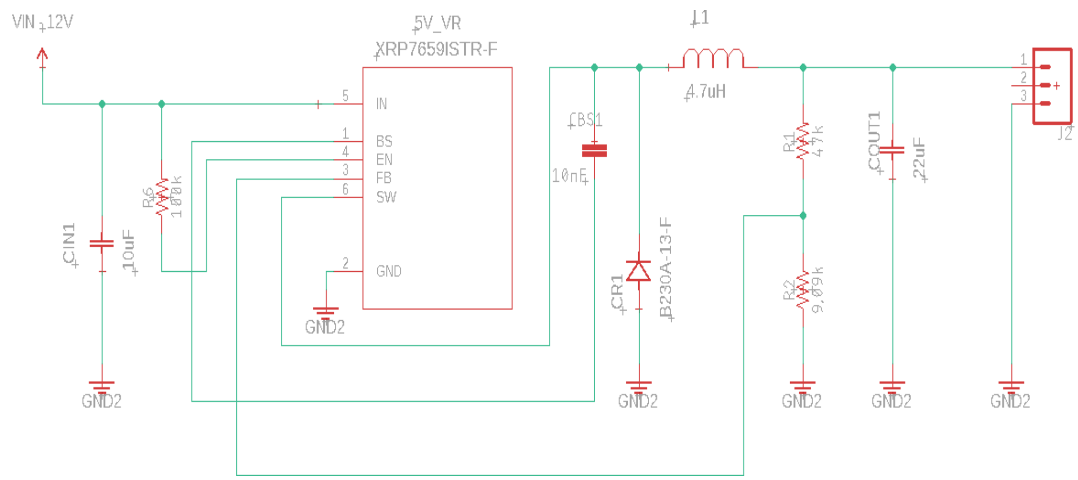


Figure 33: 5V Buck Converter

With the schematic above, the input was a 12 VDC from the full wave bridge rectifier. Then, it is connected to the IN pin of the switching voltage regulator. The CIN with a 10 uF is suitable for the purpose of the converter where the input can be stepped down to 5 V. The coupling capacitor COUT with a value of 22 uF and the 4.7 uH inductor have a purpose of filtering out the noise from the switching operation of the voltage regulator. The noise needs to be filtered out because it can affect the working principles of the components.

Because this is an asynchronous switching voltage regulator. Therefore, instead of two MOSFETs, this switching voltage regulator has one MOSFET for the high side and one Schottky diode for the low side of the switching voltage regulator. The Schottky Rectifier diode (CR1) implemented in the design is another switchin the switching voltage regulating scheme. For this manufacturer, the Schottky diode is recommend with a value 2A/30V. This is the characteristic of the Schottky diode in its reverse region where it operates. The Schottky diode is placed at SW pin which is the switch output pin from the manual. A default 10 nF capacitor is recommended to be put at the BS pin to drive the MOSFET inside the regulator. The EN pin

To decide the output voltage, the manufacturer came up with typical applications for the output with a 12 VDC input. The typical output voltages are 1.8 VDC, 2.5 VDC, 3.3 VDC, and 5.0 VDC. With those desired outputs, the manufacturer already sets up a lookup table for the values for the resistor R1 and R2. In this 5 VDC output voltage, the values for R1 and R2 are 47 kΩ and 9.09 kΩ accordingly. A connection between the two resistors and FB pin is needed. The reason for that is if the voltage of the FB pin is over 0.972 V, the over voltage protection of the switching voltage regulator is triggered. Another case is if the voltage of the VB pin is below 0.25 V, the short circuit protection is activated. These activities are designed to protect the switching regulator in abnormal working conditions.

A pin header with 3 pins in connected to the first pin to the 5 VDC regulated voltage. The third pin was connected to ground. The second pin was saved for an integrated schematic where that pin will be connected to the MCU. The purpose of the layoutabove for the pin header was because the PIR sensor has three pins which are the positive pin to get the power supply, the negative pin to be connected to the groundand one trigger pin which is the output of the sensor after it senses a target in its range. With the pin layout for the pin header explained above, the PIR sensor canoperate and sends output signal to the MCU.

3.3 V Buck Converter

The 3.3 V buck converter schematic is similar to the 5 V one due to only one type of switching regulator XRP7659ISTR-F is chosen for the project thanks to its abilities and its price. The whole setup for the schematic is identical to the 5 V buck converter. However, at the output pin, there are changes in the values for resistors. The values change for resistor R1 and R2 are denoted as R4 and R4 in the 3.3 V buck converter because this is a different voltage regulator module that are built in the same integrated but shown separately. The values for R3 and R4 are 43 kΩ and 14 kΩ respectively. The resistance of the resistors was calculated with the formula:

$$R2 = \frac{R1}{\frac{V_{out}}{0.81V} - \square}$$

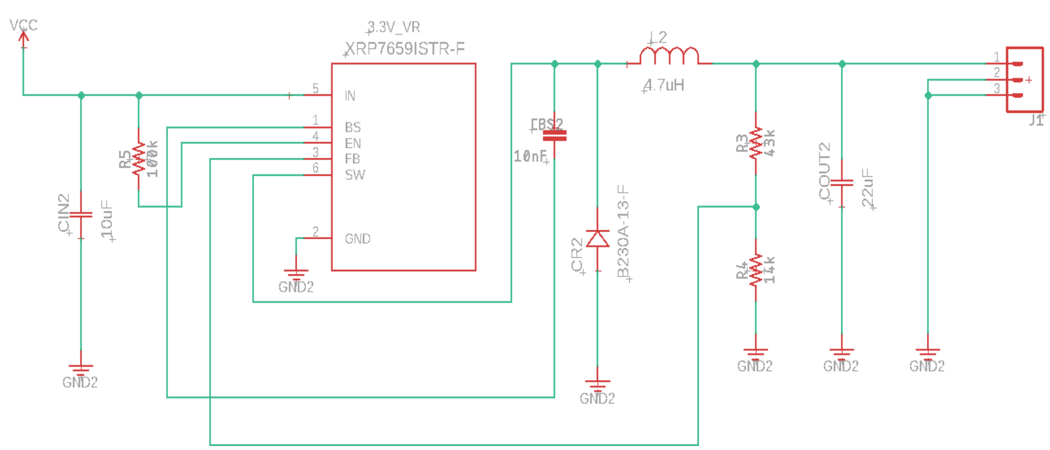


Figure 34: 3.3V Buck Converter

With the resistance R1 can be chosen arbitrarily, the resistance for R2 was calculated. For the schematic of the 3.3 V buck converter, we followed the manual for those resistance's values. However, we tested different resistance for the resistors and recorded the behavior for each switching voltage regulator.

At the output of the switching voltage regulator, a 3-pin header was connected. Theplan for the pin header was using the first pin to connect to the MCU for power supply. The second and third pins were jointly connected to ground with the ground pin of the MCU.

7.2.1.2 Testing Plan

PIR Sensor

As discussed in the part selection, the MCM 287-18001 PIR sensor was chosen for the project.The PIR sensor has 3 pins for Power Supply, Ground and Trigger. The Trigger pin is the output pin of the sensor which sends the TTL output signal to MCU. With thepin layout shown in the manual, we solder the 3 wires to the pins to test the PIR sensor on the breadboard. The two red wires are soldered to the Power Supply and the Trigger pins. The black wire is soldered to the ground pin of the PIR sensor.

The PIR sensor has a wide voltage range for operating from 5 to 20 VDC. Therefore, we use a battery holder with four battery slots to hold the alkaline primary batteries at this point of the testing plan with the total voltage of 6 VDC. Then we use the Digilent Test Kit provided from UCF to test the output of the PIR sensor. Red alligator clip is clipped to the red wire of the Trigger pin and the black wire is clipped to the Ground pin of the PIR sensor in order to give out the output signal on the test kit. The picture below shows the testing circuit for the PIR sensor.

The sensor supposes to send a TTL level signal from the Trigger pin. The high level is produced once there is a target in its range. The high TTL level from this output pin is a 3.3 VDC where the low TTL level is at 0 VDC with no target in its range. The output recorded from the Trigger pin shows that the output voltage when a hand is placed in the sensor's range is at around 3.3 V which satisfies our expectation. However, this output voltage is only kept at a certain time depending on the time delay adjustment of the sensor which means that the sensor only takes one input and produces one output for a short amount of time.

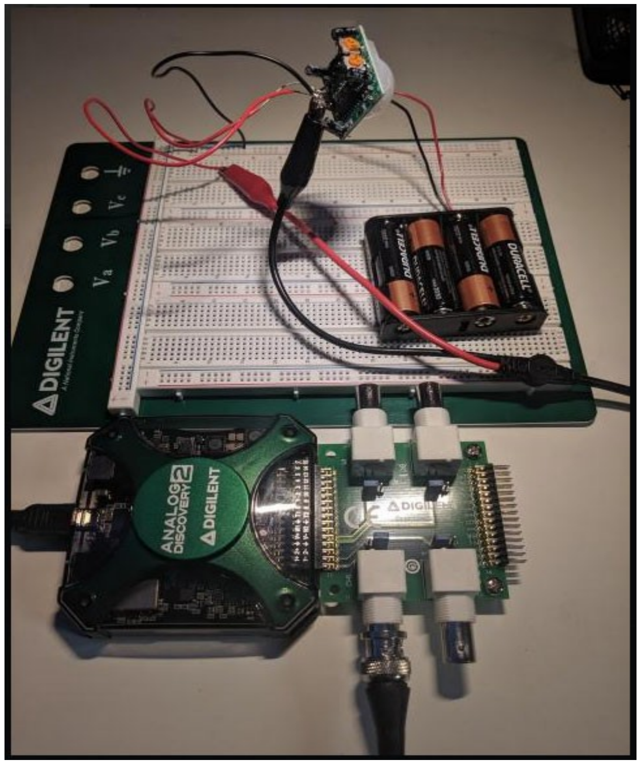


Figure 35: Testing circuit for PIR sensor

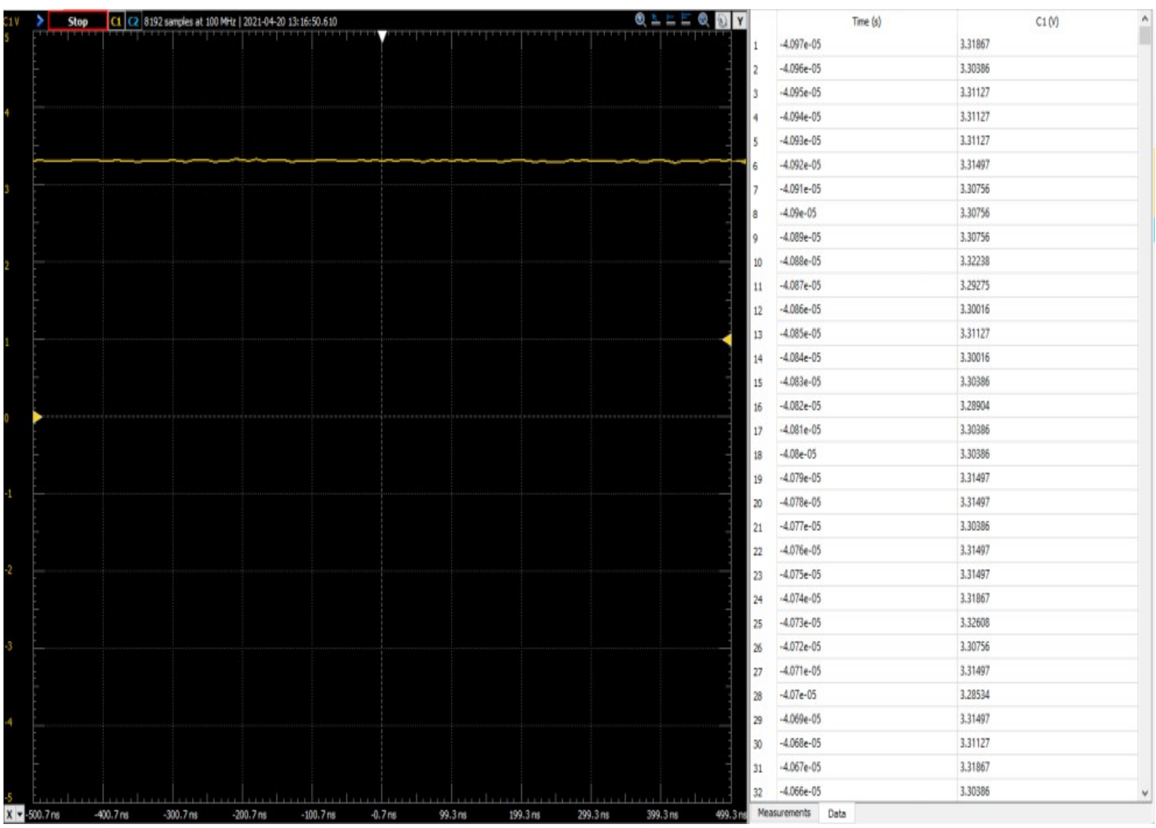


Figure 36: Output recorded from the Trigger Pin

The MCM 287-18001 PIR sensor has a repeatable trigger mode which according to the manual, the sensor has already come with a jumper set. Recall that the repeatabletrigger mode of the PIR sensor allows it to continuously take in inputs from the target and hole the TTL level at high. However, after receiving the sensors and examining them, we realize that none of the sensors come with the jumper set. Wedecided to improvise by soldering the two spots High and Medium on the PIR sensor's PCB for the repeatable trigger mode.

Figure 37: PIR sensor (Jumper missing - solder to activate repeatable trigger mode)

Once that soldering part was done, we tested the PIR sensor again following the procedure above. The only difference in this test was we kept moving our hand back and forth in the sensor's range to see if the output from the sensor is kept at 3.3 VDC continuously as shown in the Figure 37 above. If the sensor sense no more input from the user, the output kept for an adjusted time then turns to0 V.

7.2.2 Power System Integration

As previously considered in our project, we decided to use a split in the power source for our design. With this, we created two district branches for the power and could more easily identify which subsystems were being affected by a problem. Alongwith this it was much easier troubleshoot what subsystem is being affected by a problem since they are powered sequentially. Given the importance of the MCU there are many subsystems before allowing us more steps to test and verify the outputs before potentially firing the MCU.

7.2.2.1 PDLC Film Power (ON/OFF)

Given the importance of the PDLC, it was crucial that this perform as described in the datasheet. In this step, we tested the timing and transparency of the PDLC film and it's off and on State. Given as the film itself satisfies at least two of the criteria of our project and be a crucial part in at least two more, we made sure that it was performing to the standards set in the datasheet.

You can see in the picture that the film is in its off State, no voltage being in put into the film that it appears rather opaque and obscures all objects in between the film on both sides of the window.

Film in the ON state

When we applied the voltage, we see that in this example the car and tree immediately become visible in less than half a second of activating the switch achieving the two requirements of transitioning from transparent to opaque in less than 10 seconds and having a visibility difference I'm greater than 80% in a given state.

With this, we confirmed two of the goals of our project the next was controlling the two sections of the film independently, using the sensor input to control the on-and-off state of the film, allowing an input from a digital platform to control the film, and if possible, varying the visibility of the film using a potentiometer. So far this looked very promising andwas moving us in the right direction to achieve the set-out goals of this design.

Figure 38: Smart Film (PDLC) in OFF state

Figure 39: Smart Film (PDLC) in ON state

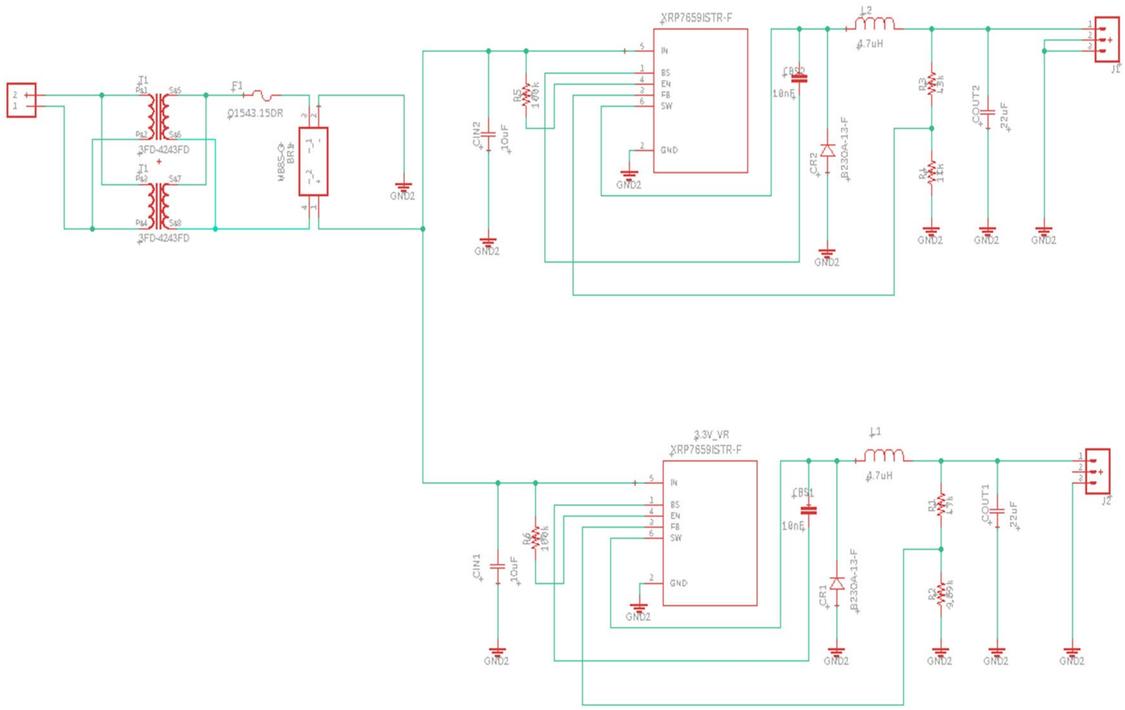


Figure 40: Overall Power Integration Schematic

7.2.2.2 Branch containing Smart Film Voltage.

With this design, we gradually implemented our building blocks to step down and convert voltage. In one branch, the voltage change from first 120V AC to 60V AC 60HZ which fed into the Smart Film, giving and an output rangingfrom 24V AC to 48V AC. We confirmed this seen below with the Oscilloscope.

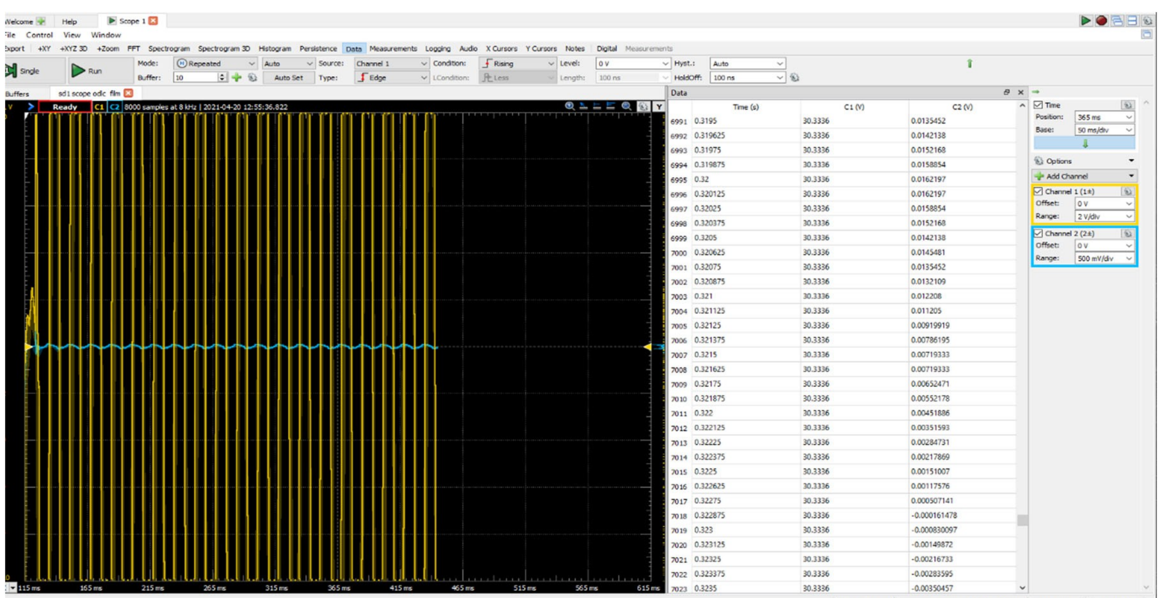


Figure 41: Oscilloscope showing 30V AC reading from Smart Film (PDLC)

This was an acceptable value based of the data sheet. With this reading, we were less concerned about spikes or dips as the values hovers in the middle of the given range. The next challenge we undertook was implementing a way to have both PDLCsheets operating within the acceptable range, while also meeting the given data specifications and our project requirements.

7.3 Microcontroller Integration

This section goes into the details of overall testing process of the microcontroller unit chosen for this project, ESP32 Koala. This section details the programming MCU testing process, MCU Schematic, and ESP32-WROOM chip schematic created for the PCB design overview.

7.3.1 Programming MCU Testing

So, we needed to validate that we could program the Microcontroller unit to effectivelycarry out the functionalities that we want. To do this, we wrote sample softwareprograms that exhibit key functionalities we needed. For this, we wrote three different pieces of code. The first piece of code demonstrated simply blinking the board. This demonstrated several things. First off, it proved that we could loadcode onto the board (which isn't always a given). The second thing is that it provedthat we have basic control over the pins on the board. The second piece of code we have, would be one that has simple serial communication between the computerand the device. This proved that we could count on having functioning serial communication with our software applications. The third piece of code we have, was having the MCU communicate with a python3 application running on my PC. This communication was over the network, with the MCU utilizing WI-FI.This proved that we could rely on not only having the MCU connect to a networkand transmit data over it, but we can have a client on a separate device receive this data. Of course, we configured the test, to ensure that both the MCU and the client can both send and receive data. For all three tests, we had pieces of evidence that they were successfully completed. So, this was the first test.For this, we have a picture of the MCU blinking the LED.

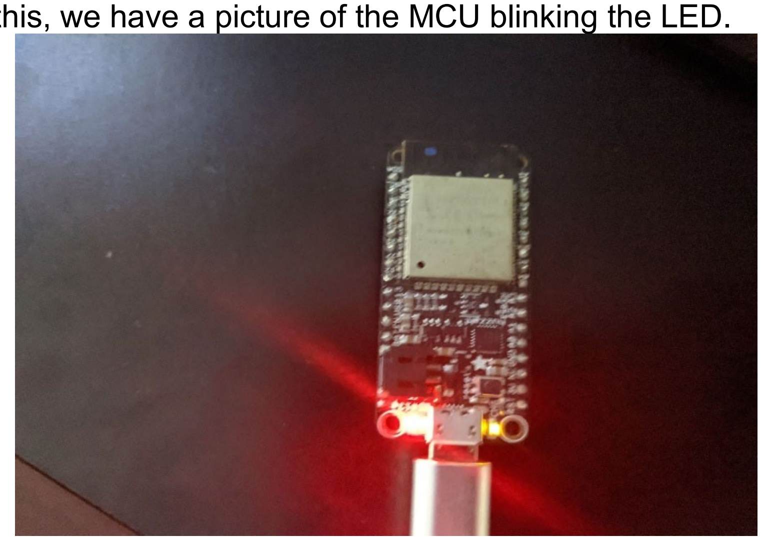


Figure 42:MCU testing – blinking of LED

So, for the second test, we show a screenshot of the serial monitor. This is output from the MCU, to the PC via serial communication. There are two messages being sent intermediately, “No one’s” and “laughing now”.

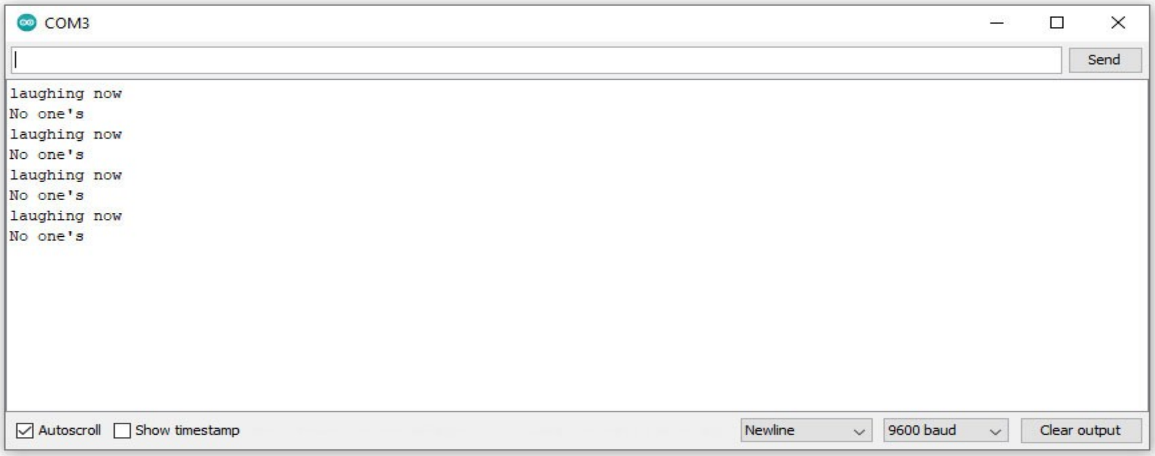


Figure 43: MCU output of two messages to PC via Serial Communication

So, for the third test, here is a screenshot from the perspective of the desktop client as evidence that this test was successfully complete. This is just simply printing the data that it receives from the MCU.

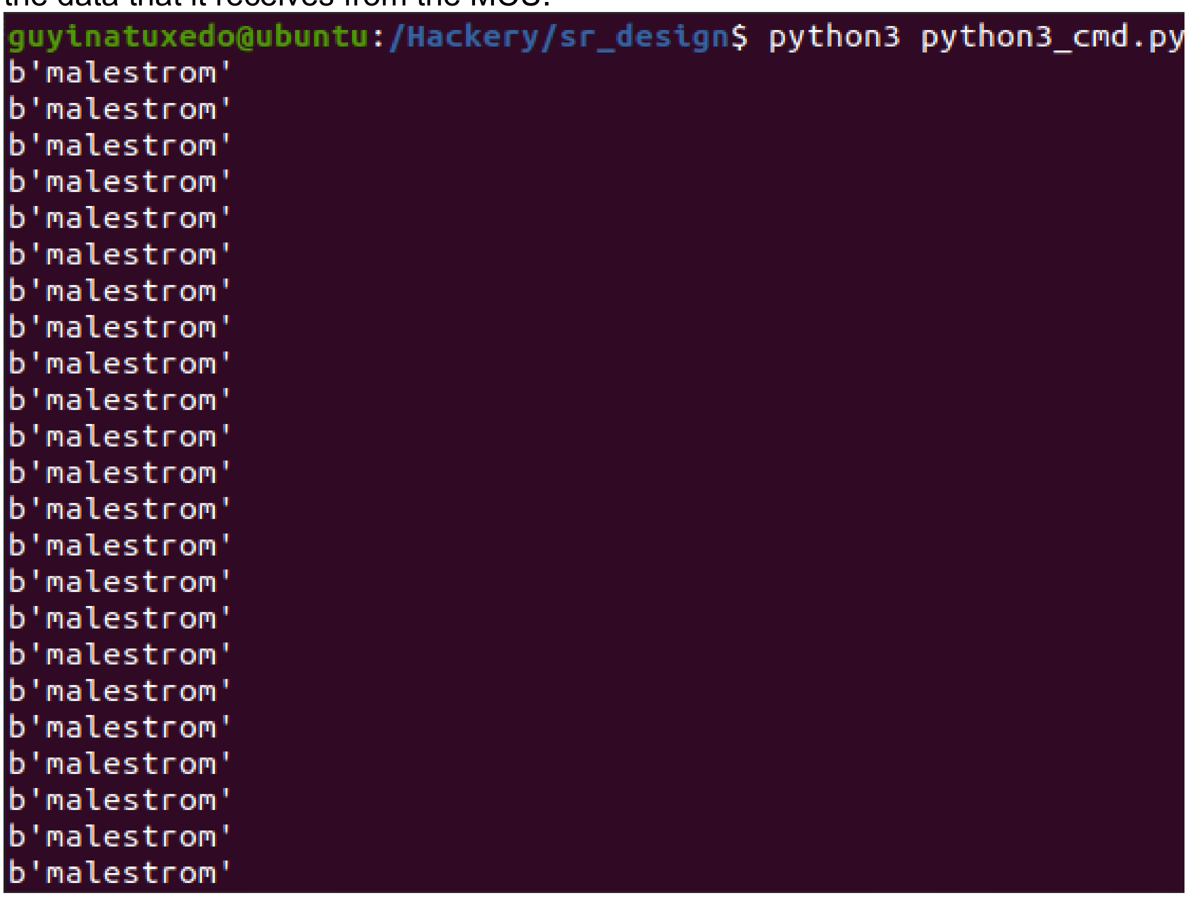


Figure 44: Message received from MCU

7.3.2 Microcontroller Unit Schematic

So, this next portion is a brief schematic of the MCU used herein. There are two pictures: one of the top-view, and one of the bottom-view. The reason for this, the picture of the top detailed some of the major components of the MCU. The bottom picture detailed the important pins (I choose the bottom for this, since the pins protrude more from the bottom, and the components in the top picture are only visible from the top).

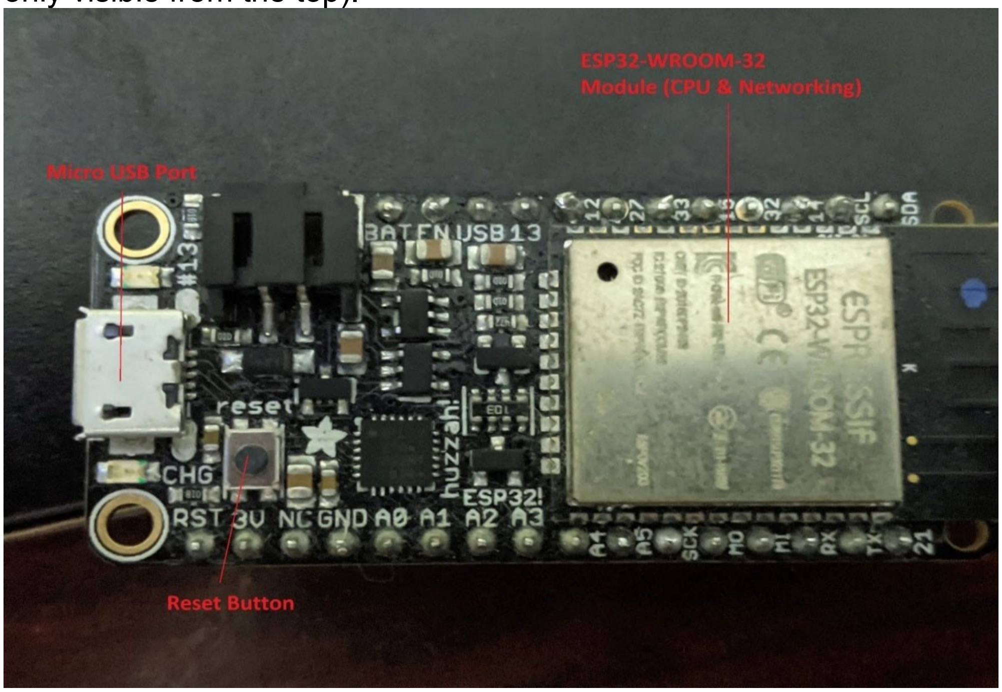


Figure 45: Microcontroller Unit top view

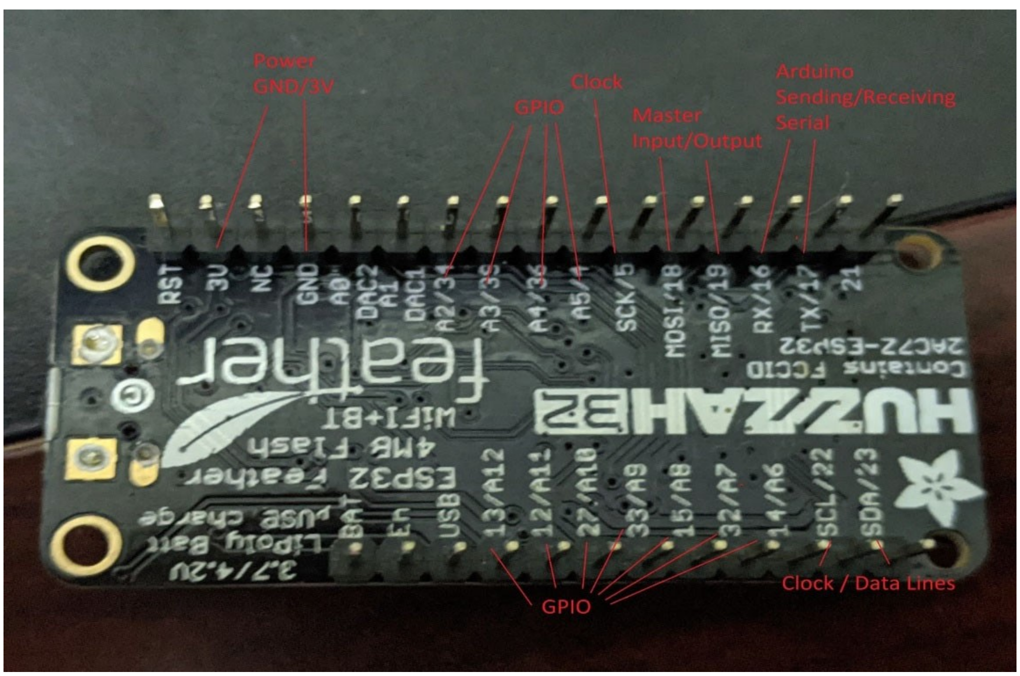


Figure 46: Microcontroller Unit bottom view

For the integration of the microcontroller unit into the PCB design for this project, a schematic was created for the microcontroller unit specific chip, ESP32-WROOM. This chip was designed unto the PCB for initial testing of the overall integration of the project.

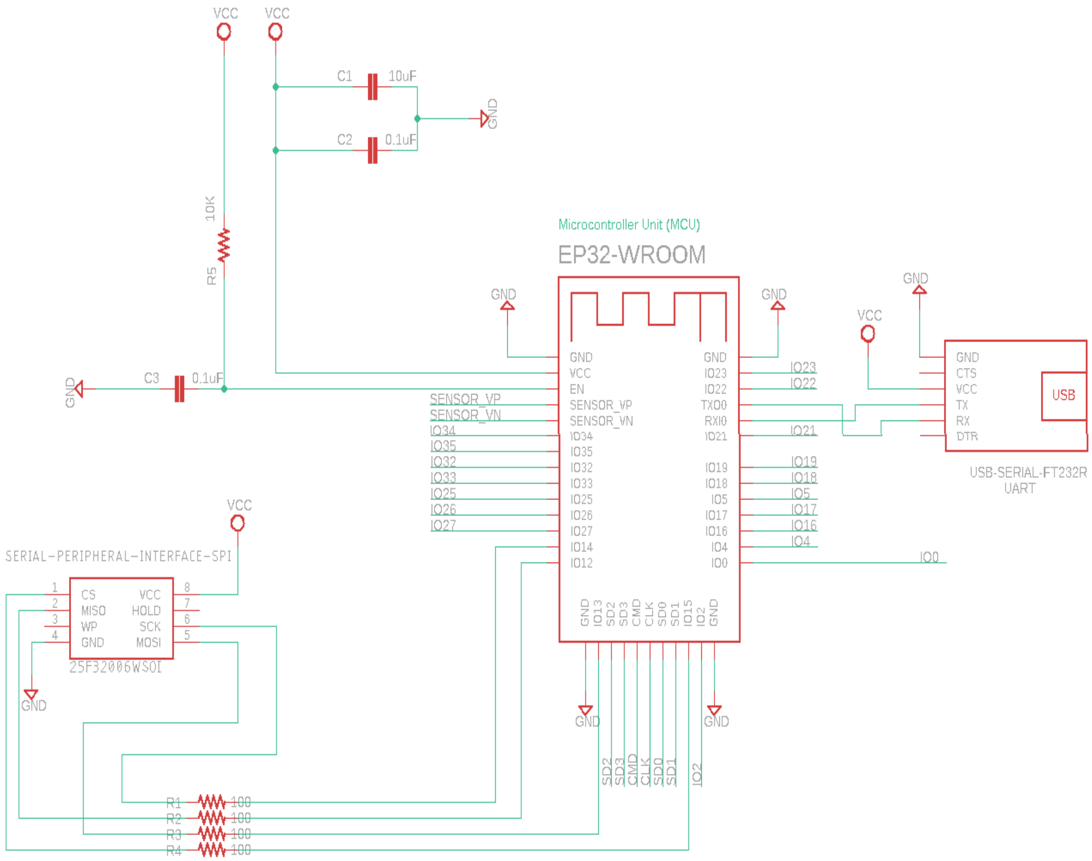


Figure 47: Schematic for ESP32-WROOM

7.4 Software Integration

The first figure below shows the request transmission diagrams that shows the progression of requests in the software integration. After request transmission is began, then the next step is request generation section that involves different loops and decisions made based on different conditions. Following that is packet generation and transmission. Then the result was transmitted to the device in use.

The second figure shows the request reception diagram which shows how the request transmission is received by the device in use. The process involves beginning data reception to the device in use, then proceeds with packet reception and integrity checks. This process involves series of loops that are chosen based on different conditions. Then the next process involves request consent paring and servicing, which involves different loops that are taken based on different conditions.

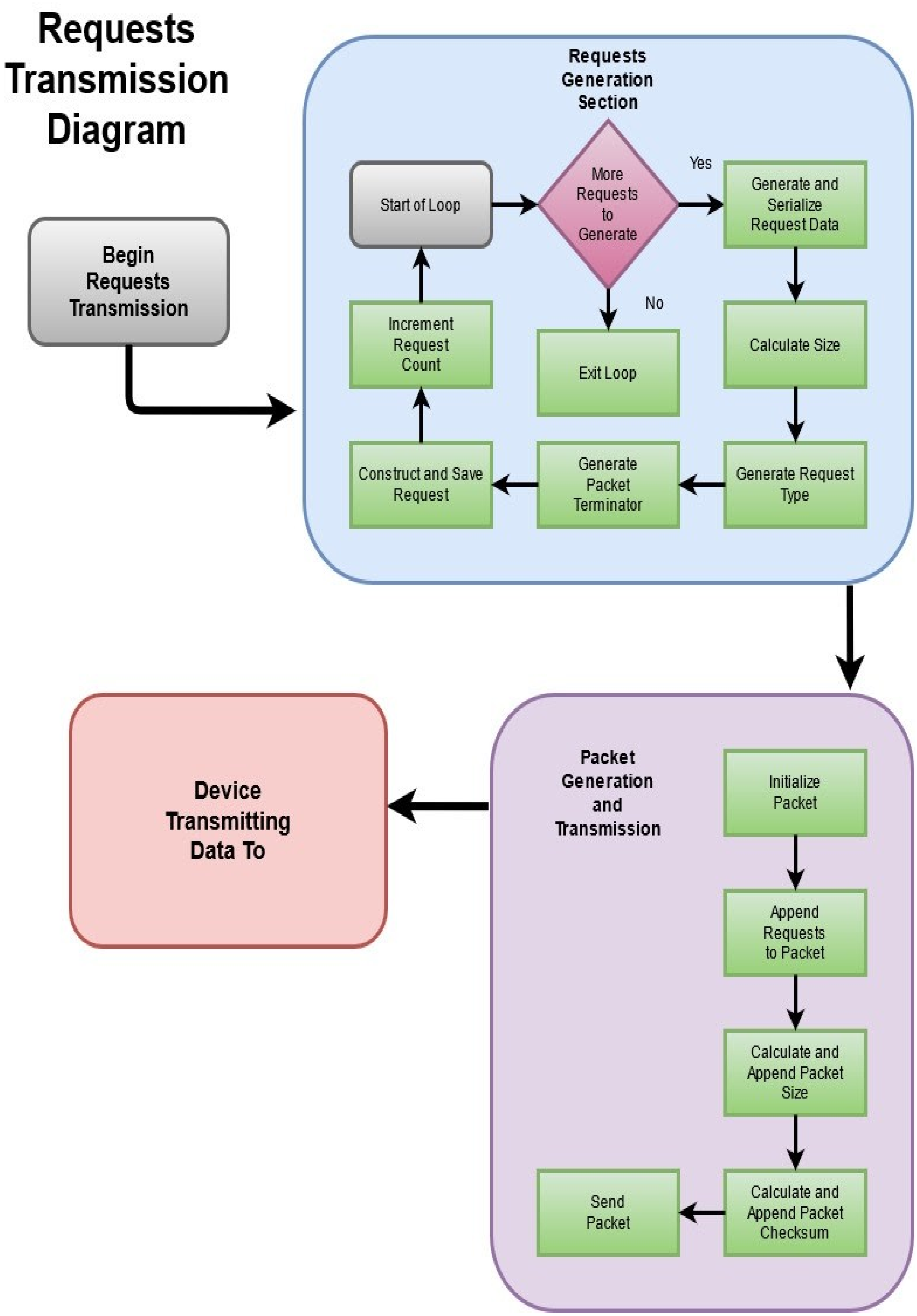


Figure 48: Request Transmission Diagram

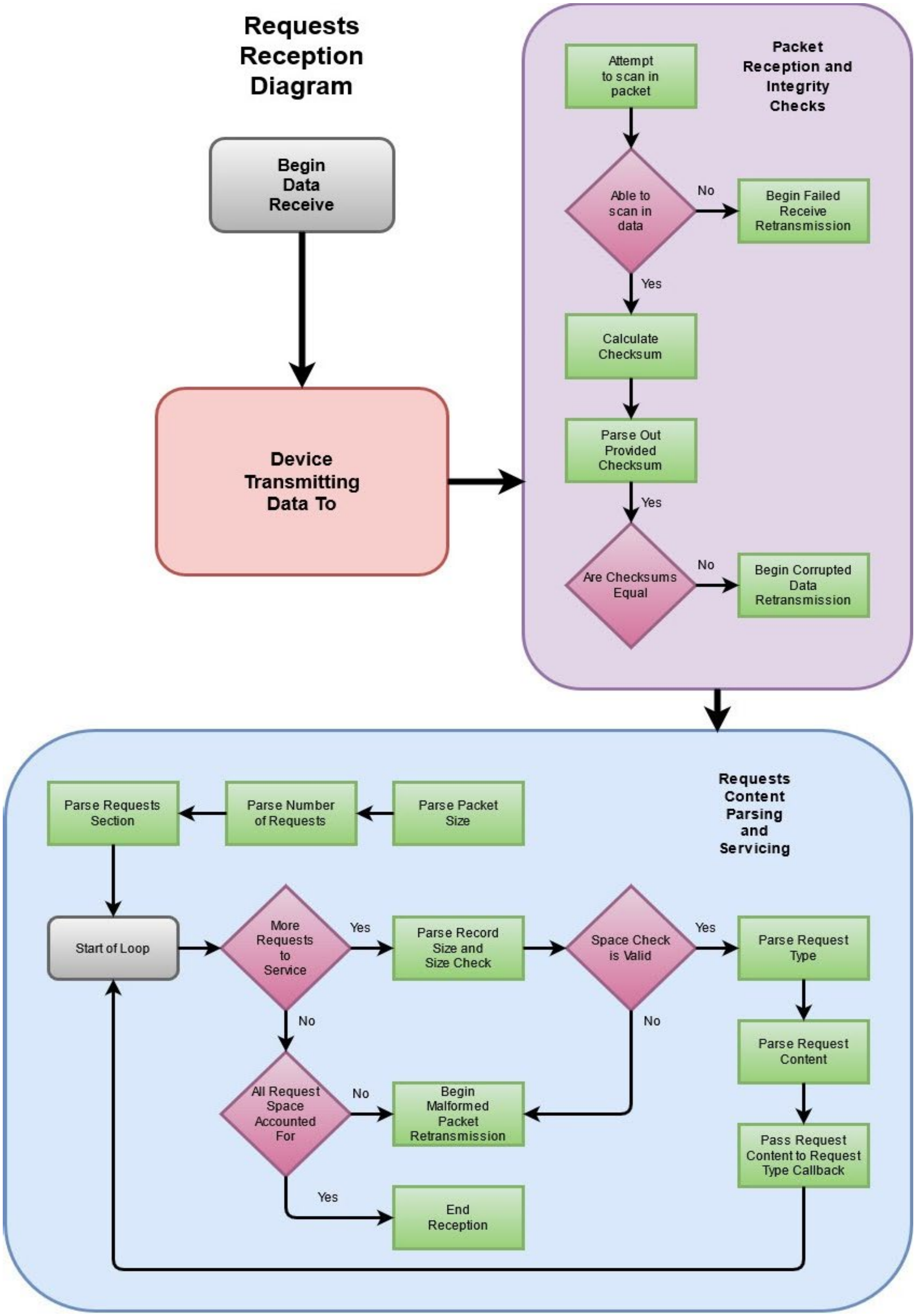


Figure 49: Request Reception Diagram

7.4.1 Networking Trade Off table

This table briefly describes some of the tradeoffs between various Networking technologies that we implemented at various stages in the network communication. The two main factors are performance, and data integrity insurance.

Table 27: Networking Trade Off

Technology	Performance Impact	Integrity Impact
TCP Protocol	Additional computations lead to worse performance.	This ensures that both the sender and the receiver are ready to transmit data, which helps greatly with ensuring proper data transmission.
UDP Protocol	Less computations required lead to better performance.	No check for sender and receiver being ready to transmit data, will sometimes cause incorrect data transmission.
Checkums	Additional computations lead to worse performance.	Will allow for a mechanism for the receiver to detect certain data transmission errors and correct them via retransmission.
Size Checks	Additional computations lead to worse performance.	Will allow for a mechanism for the receiver to detect certain data transmission errors and correct them via retransmission.

7.4.2 Programming Languages

The table below briefly describes the tradeoffs between various different programming languages and environments that could be used with the MicrocontrollerUnit (MCU), ESP32 Koala, chosen or this project.

Table 28: Programming Language of MCU Trade Off

Programming Language / Environment	Performance	Abstraction
Micro python	Python interpreter causes lower performance.	Highest level of abstraction.
Arduino IDE	Due to C utilization greater than Micropython, however greater abstraction puts it behind Esp-idf.	Moderate level of abstraction, some Microcontroller specifics are abstracted away.
Esp-idf	Greatest performance.	Lowest level of abstraction.

7.5 Overall Printed Circuit Board (PCB) Schematic

The figure below shows the overall PCB schematic that was used in this project. The schematic shows power supply block (which would be an outlet), transformer, full bridge rectifier, connected to a PIR sensor, Voltage regulator (3 volts and 5 volts) all connected to the ESP32-WROOM-32 microcontroller chip. The PCB schematic also shows the overall connection to the smart film (PDLC film).

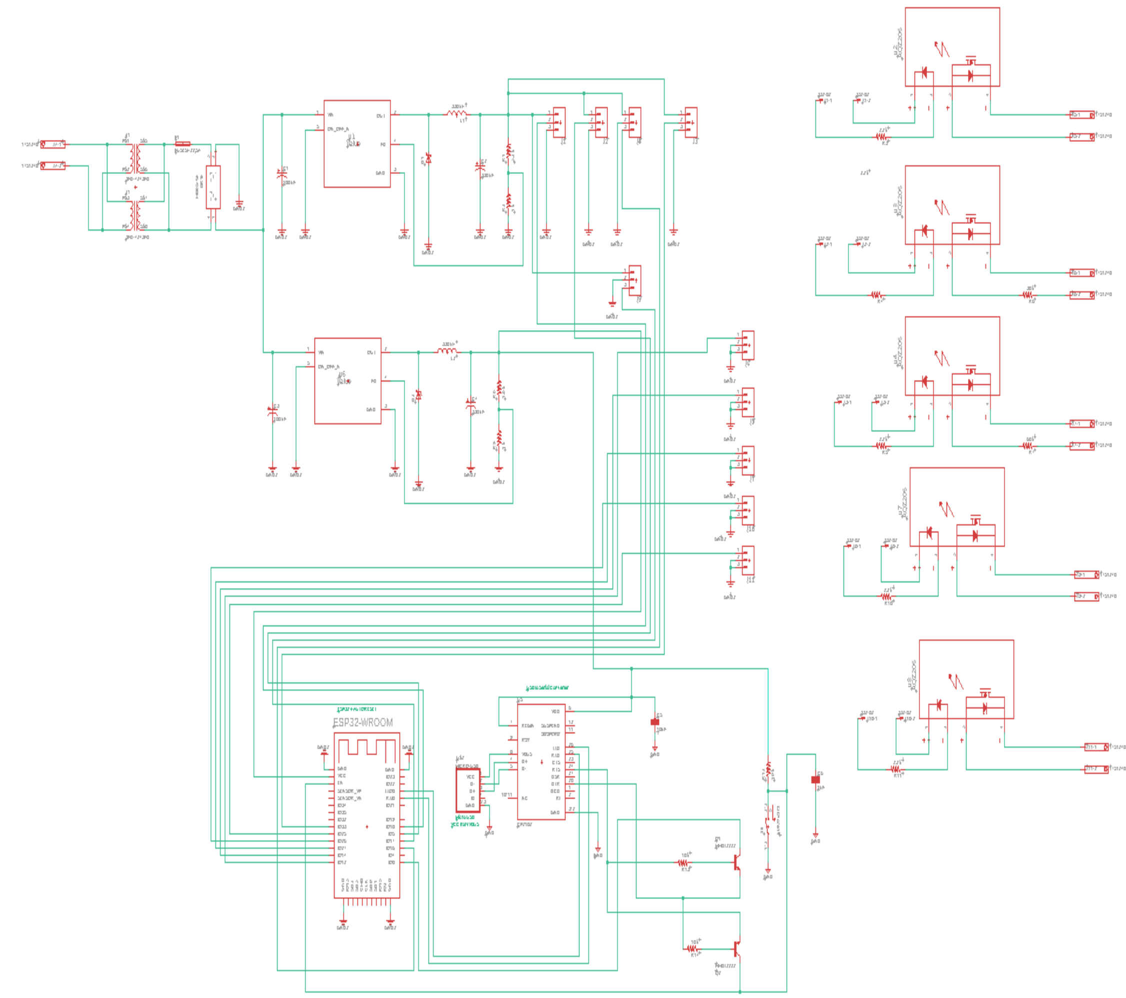


Figure 50: Printed Circuit Board (PCB) Schematic

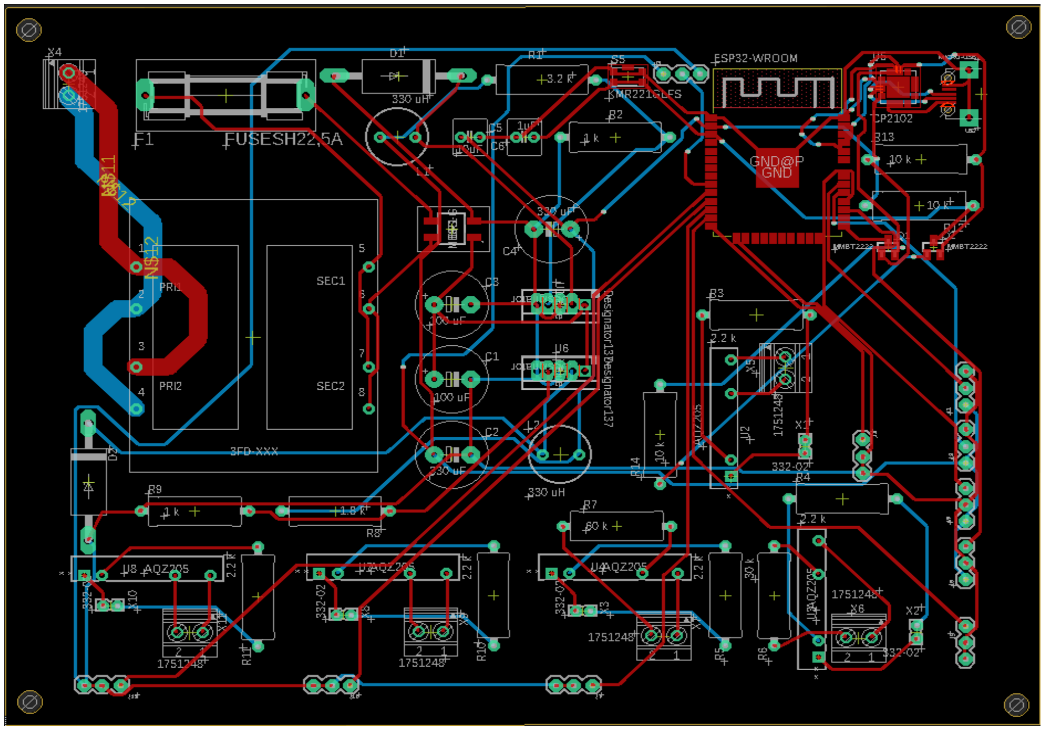


Figure 51: Printed Circuit Board (PCB)

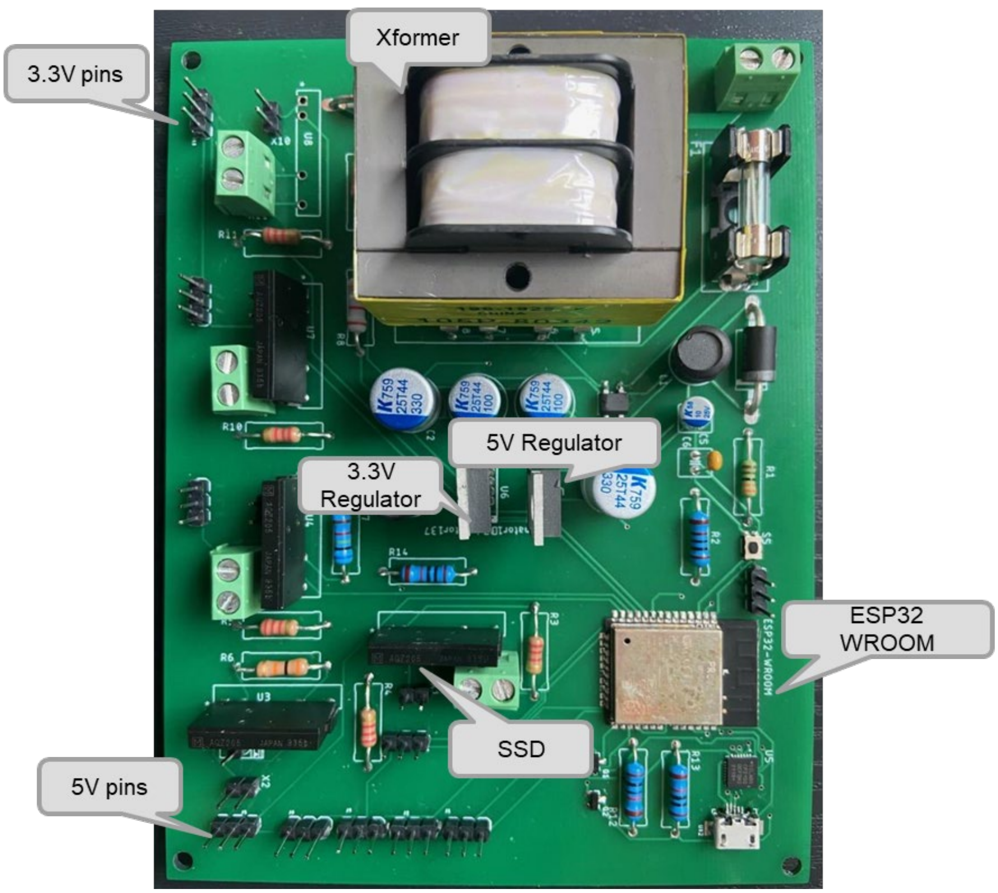


Figure 52: Printed Circuit Board (PCB) – Physical Board

8.0 Administrative Content

This section shows the budget and finance used for this project, milestones created and followed to enable efficient time management for the team members, and important deadlines and deliverables created for this project

8.1 Budget and Finance

This section discusses the overall cost for completing the project herein. Section 8.1.1 shows the initial project estimate created when the project was chosen. After extensive research, section 8.1.2 shows the final project budget used to complete the project herein.

8.1.1 Initial Project Budget (Estimate)

In the budget estimate of this project, you can see that we are estimated to spend around $450. However, this is a generous estimation. We believed we can get the PDLC film cheaper, if we decide to go this method, another example is the PCB. As this was our first time generating our own PCB and we were not sure with theexact components we needed, we decided to go with an inflated cost on the fabrication cost, which also includes the parts for set fabrication. At the end of ourchart, there was an additional feature total. We decided to add this so that we wouldhave an estimate of what it would cost to add these additional features. We plan to split the cost of this project equally four ways with each member having to agree on the components before we decide to pay. There was a document to track allthe suggested options, so we had a record on what was chosen and the reason.

Table 29: Estimated Budget

Component	**Cost**
PDLC film	$150
PCB	$150
Controller	$50
Proximity sensor	$15
Solid State Relay	$15
Miscellaneous (wires, frame, etc.)	$70
Total	$450
Solar panel	*$150*
Additional Feature Total	*$600*

8.1.2 Final Project Budget and Finance

After extensive research, this section gives the actual cost and budget used in the completion of this project.

Table 30: Final Project Budget and Finance

Component	Part	Quantity Used	Cost
Window Frame	Fixed window frame	1	$20
Blind	Polymer Dispersed Liquid Crystal (PDLC)	1	$129.67
PCB board		1	$2.70
Microcontroller Unit	TTGO T-Koala ESP32	1	$3.80
Proximity Sensor	MCM287-18001 PIR sensor	1	$2.99
Components	Resistors, Capacitors, Schottky diode, inductors, headers, jumpers	Multiple	$15.76
Voltage Regulator	LM2575	2	$7.76
Full Bridge Rectifier	MB4S-E3/45	2	$0.65
Transformer	Tamura 3FD-424	$9.40	$10
Light Sensor		1	$1.50
Temperature Sensor	DS18B20	1	$5.99
Relays	AQZ205	5	$57.10
Total			**$257.92**

8.2 Project Milestones

This section focuses on the project milestones that allowed the completion of this project. The milestones are categorized into two: 1) Senior Design 1 milestones (focuses on the selection of project, research, hardware and software of the project design and prototyping), while 2) Senior Design 2 (focuses on the actual designing and testing of project device). Table 25 goes over Senior Design 1 milestones and Table 26 goes over Senior Design 2 milestones.

Senior Design 1 milestones focus on the project selection for the team members. This process involved realizing the team goals and working toward creating a project that met these goals. Next, initial group project identification led to the brainstorming of project ideas and deciding as a group on which project best met the expectations of everyone involved. Senior Design 1 milestone proceeds to show the timeline of research done for the project, parts and components selection for the completion of the project, hardware and software design details included in the final paper submission. If the senior design 1 milestones are successfully followed and met, then the team members expect to have a prototype ready by the May.

Table 31: Senior Design 1 Milestones

Milestone	Description	Duration	Dates
Group Formation & Project Selection	Divide and Conquer v1	3 weeks	Jan. 18 – Feb. 5
	Divide and Conquer v2	1 week	Feb. 6 – Feb.12
Document Submission: Initial Group and Project Identification (Divide and Conquer v1)			Feb. 5
Document Submission: Divide and Conquer v2			Feb. 12
Technology Investigation	Hardware: - Power Supply - PCB Design - Sensor selection Software	3 weeks	Feb. 13 – Mar. 5
60 Page Draft	Divide and Conquer v2 Revision	4 weeks	Mar. 6 – Apr. 2
Document Submission: 60 Page Draft			Apr. 2
100 Page Report	60 Page draft Revision	2 weeks	Apr. 2 – Apr. 16
Document Submission: 100 Page Report			Apr. 16
Final Document	100 Page Revision	1 week	Apr. 16 – Apr. 27
Document Submission: Final Document			Apr. 27
Components Acquisition	Order parts and components - Initial component testing		

Senior Design 2 milestones focuses on the actual designing and implementation of the design details given in the Senior Design 1 final document. Similarly, Senior Design 2 milestones shows the design process shown in Senior Design 1 milestones being implemented. If the milestones are followed, by the end of Senior Design 2, the project should be implemented, tested and a working product should be available for this project.

Table 32: Senior Design 2 Milestones

Milestone	Description	Duration	Dates
Prototyping	Initial Prototyping	2 weeks	May 1 – May 14
	Complete Prototype Ready for testing and Debugging	2 weeks	May 14 – May 31
Testing and Debugging - **Test components** - **Debug outputs**		4 weeks	April
Finalize Project - **Final testing and debugging and Demo Creation**		4 weeks	May
Final Project Documentation - **Create Final Presentation**		2 weeks	July
Final Presentation			July 26

8.2.1 Important Deadlines

These deadlines helped the team members stay on track with the main goal of providing a completed project prototype for the project proposed herein.

- February 5th - Initial Group and Project Identification (Divide and Conquer)
- February 12th – Updated Divide and Conquer document
- April 2nd – 60 Page Draft Senior Design 1 Document
- April 16th – 100 Page Senior Design 1 Report
- April 27th- 120 Page Senior Design 1 Final Document
- June 18th – Critical Design Review
- July 6th – Midterm Demo
- July 16th – Review Committee and 8-page Conference Paper
- July 25th – Final Presentation Submission
- July 26fh – Final Presentation

8.3 Division of Labor (Work distribution)

So, for this project, there is a wide range of tasks involved with this project. However, they primarily fall into four separate categories. These four categories are: Software Engineering, Electrical Engineering, Computer Engineering, and miscellaneous. The miscellaneous category is realistically a catch all category, for tasks that realistically don't require any specialty to accomplish. The first three tasks, however, realistically require expertise in that area in order to effectively accomplish the task well. Our group makeup consists of four different engineers, with specialties in these areas. These specialties were developed both from a range of experiences including classes and industry work experience (with each group member possessing both). As shown in the block diagram:

- Tien and Joshua have a lot of experience with Electrical Engineering, so theywill handle tasks regarding that.
- Adedoyin has incredible expertise with designing chips, and working with computer engineering, so she will handle Computer Engineering tasks.
- Ryan has experience developing, analyzing, and working with software so he will handle any Software Engineering tasks.

For the miscellaneous task, that will be handled with volunteers. This is because the bandwidth individual members must accomplish work varies from week to week, so this will enable us to accomplish those tasks as quickly as possible.

Adedoyin Adepegba – Lead on Microcontroller and Administrative Content

Joshua Forrest – Lead on PCB Design and Testing

Ryan Meinke – Lead on Software engineering

Tien Tran – Lead on Power Delivery and Circuit Assembly

9.0 Conclusion

From the Inception of this project, there was a defined list of goals with the following being crucial to target; transitioning from transparent to opaque in less than 10 seconds, at least one end user inputs in proximity, and the system will be able to interface with a digital application. With these tangible goals in mind, there were others such as energy efficiency and safety that it played a big role in guiding our research and design of this project. As we were able to hone in on our objectives we've decided that a polymer dispersed Liquid Crystal film or PDLC will be used to control the transparency and opaqueness of our window. This has an added benefit of being controlled entirely buy voltage which address is one of the major safety concerns of traditional blinds by removing the chords and panels which present major choking hazards. With another ideal being intuitive use, we have implemented a PIR sensor to capture the human direct interface which removes the need to press a button that other people have pressed. It also has the added benefit of only activating the window when someone is in a set proximity.

As we designed, our system became apparent that we would have to work with both ac voltage and DC voltage based purely on the components that we chose. The major AC component being the PDLC film it was easy to set up that branch and have the film powered, the trickier part will arise when we create the AC to DC branch using a full Bridge rectifier and voltage regulators to give the required voltage of our components. The major concern going forward with this branch will be providing reliable DC voltage that will not Spike and burn out the components/ chips that we have ordered. There's also the added concern of how to integrate the Transformer which is quite sizable compared to the surface mount devices in a way that the traces are not overloaded. Code quality can be the sole difference between a project or a product seeing widespread use, or simply ignored. We have thoroughly discussed in previous sections the Software Engineering practices which we will employ, in order to ensure code quality.

After totaling all our components prices, we came in under our estimated budget. This is a great achievement for our team as gives more financial power to work with a project we had already planned to be cost effective. As this project has come to a head, our team has worked well together deliver the necessary deliverables and completing are given tasks without much conflict. Based on the interaction we've had this semester, we were able to deliver a completed prototype in the summer semester even given the shortlength and continuous supply chain disruptions due to COVID-19

Appendix

A1 Copyright Permissions

Primary battery

Tien Tran
Tue 3/30/2021 1:47 PM
To: batteryu@cadex.com

Hi BatteryU,

I'm Tien Tran from University of Florida. I'm a senior year student and currently working on my Senior Design project. I wonder if I can have your permission to reproduce the 2 figures which are Figure 1: **Specific energy comparison of secondary and primary batteries.** and Figure2: **Energy comparison underload.** from the article BU-106: Advantages of Primary Batteries. I hope you can grant me the permission for my project. Thank you very much.

Best Regards,

Tien Tran

Reply | Forward

Inductive proximity sensing

https://www.electronicshub.org/applications-of-inductor/

Tien Tran
Sun 4/11/2021 11:18 AM
To: Leona Lee <elktros@gmail.com>

Leona,

Thank you so much and I will definitely do that.

Best Regards,

Tien Tran

Reply | Forward

Leona Lee <elktros@gmail.com>
Sun 4/11/2021 11:17 AM
To: Tien Tran

Yes, you can do that.

Please give credit back to us in link format.

Admin
Leona Lee
electronicshub.org
Facebook | YouTube | Pinterest | Instagram

Tien Tran
Sun 4/11/2021 11:15 AM
To: elktros@gmail.com

Dear Electronic Hubs,

First of all, thank you for having such as great website that explains the electronics knowledge clearly. I am working on a senior design project and looking for a nice diagram that can explain the idea of my writing. Fortunately, I came across one of the articles in your website and found that you have a very well-explained diagram of the inductive sensor. I wonder if you can grant me permission to use that diagram in my paper?

Thank you so much and I look forward to hearing from you.

Best Regards,

Tien Tran

Capacitive proximity sensing

https://www.motioncontroltips.com/what-are-capacitive-proximity-sensors/#:~:text=The%20way%20a%20capacitive%20proximity,that%20generates%20an%20electric%20field.

sent through website but no response

ultrasonic proximity sensing

https://randomnerdtutorials.com/contact/?contact-form-id=1233&contact-form-sent=103126&contact-form-hash=96c0a540eeadd8b4cfbdd8ce6e7c8a0112a0e888&_wpnonce=717283c27a#contact-form-1233

RS Rui Santos <rffsantos16@gmail.com>
Tue 4/13/2021 10:40 AM
To: Tien Tran

Hello Tien,
Yes, you can use that 1 diagram, but please include a link to the original post as a source.

Thank you for your patience.
Rui

On Sun, Apr 11, 2021 at 6:08 PM Tien Tran <support@randomnerdtutorials.com> wrote:
Name: Tien Tran

Email Address: trantm@knights.ucf.edu

Confirm Your Email Address: trantm@knights.ucf.edu

Subject: asking for permission to reproduce a diagram

Describe Your Question Briefly: Hi Random Nerd Tutorials,

I'm working on a Senior Design project and I'm looking for a diagram/schematic that depicts a working principle of an ultrasonic proximity sensor. Fortunately, I came across your website and found the one diagram that well-explained the idea of how an ultrasonic proximity sensor work. I wonder if I could have your permission to use that diagram in my report?

Thank you so much and I look forward to hearing from you.

Best Regards,

Tien Tran

I'm not submitting a technical question about my project: Yes

Photoelectric proximity sensing tech

https://www.machinedesign.com/automation-iiot/sensors/article/21831577/proximity-sensors-compared-inductive-capacitive-photoelectric-and-ultrasonic

sent but has no response

CITATION REQUEST

https://www.serenashades.com/products/#smart-roller-shades

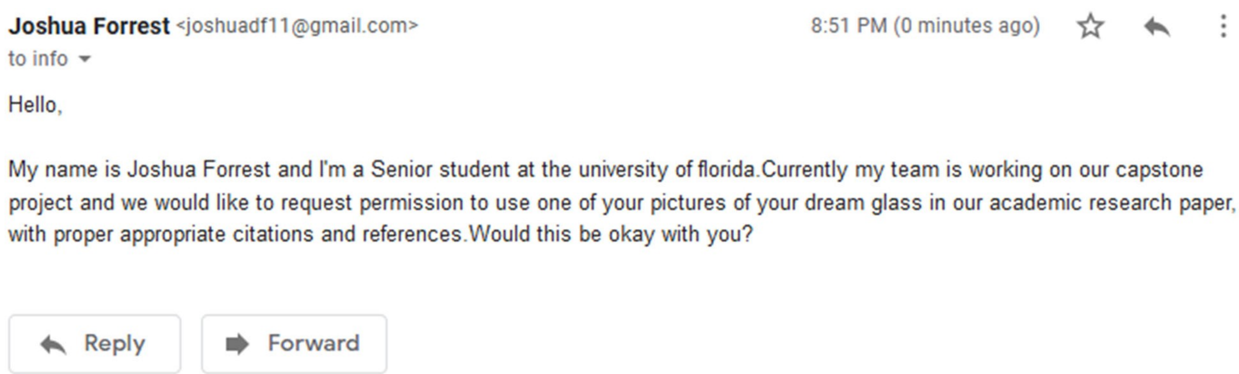
Request for student to use picture on your site

Joshua Forrest <joshuadf11@gmail.com> 8:48 PM (1 minute ago)
to info

Hello,

My name is Joshua Forrest and I'm a Senior student at the university of florida.
Currently my team is working on our capstone project and we would like to request permission to use one of your SerenaShades in our academic research paper, with proper appropriate citations and references.
Would this be okay with you?

https://www.dreamglassgroup.com/product/dreamglass-smart-blinds/



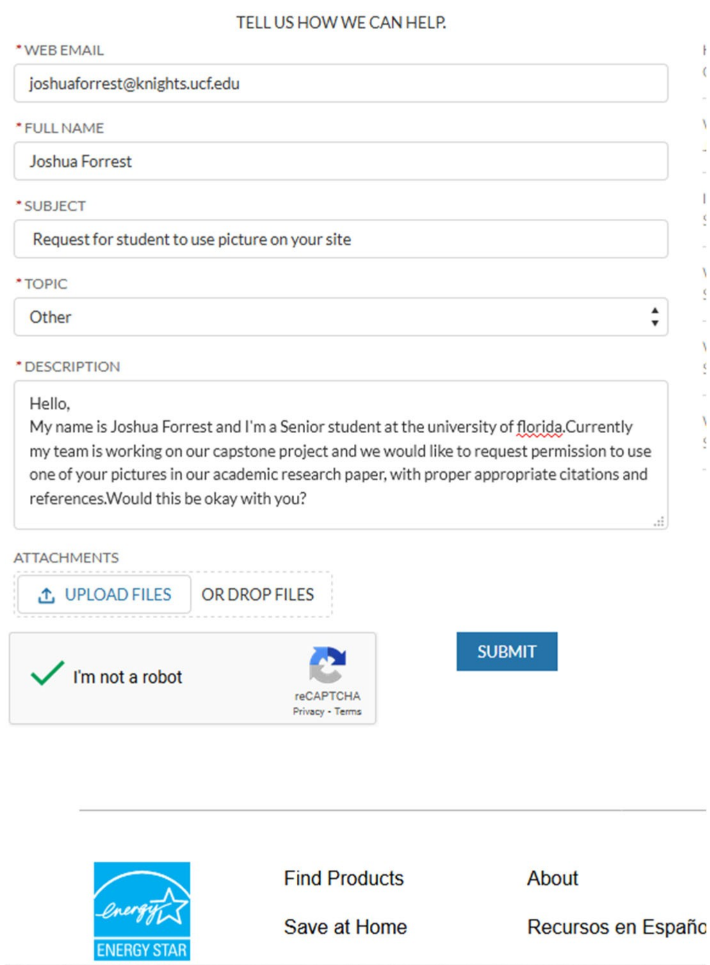
Joshua Forrest <joshuadf11@gmail.com> 8:51 PM (0 minutes ago)
to info

Hello,

My name is Joshua Forrest and I'm a Senior student at the university of florida.Currently my team is working on our capstone project and we would like to request permission to use one of your pictures of your dream glass in our academic research paper, with proper appropriate citations and references.Would this be okay with you?

Reply Forward

https://www.energystar.gov/products/building_products/residential_windows_doors_and_skylights/key_product_criteria



TELL US HOW WE CAN HELP.

*WEB EMAIL
joshuaforrest@knights.ucf.edu

*FULL NAME
Joshua Forrest

*SUBJECT
Request for student to use picture on your site

*TOPIC
Other

*DESCRIPTION
Hello,
My name is Joshua Forrest and I'm a Senior student at the university of florida.Currently my team is working on our capstone project and we would like to request permission to use one of your pictures in our academic research paper, with proper appropriate citations and references.Would this be okay with you?

ATTACHMENTS
UPLOAD FILES OR DROP FILES

I'm not a robot reCAPTCHA Privacy - Terms

SUBMIT

ENERGY STAR

Find Products About
Save at Home Recursos en Españo

https://continuingeducation.bnpmedia.com/article_print.php?C=1641&L=544

Name *

Joshua — First

Forrest — Last

Company *

UCF

Phone *

(000) 000-0000

Email *

joshuaforrest@knights.ucf.edu

Location *

Florida

Business Type *

Residential

Technical Question *

My name is Joshua Forrest and I'm a Senior student at the university of florida.Currently my team is working on our capstone project and we would like to request permission to use one of your pictures of your infographics in our academic research paper, with proper appropriate citations and references.Would this be okay with you?

A2 References

[1] AuCM3029 data sheet. Analog Devices, Inc., March 2017
[2] Ada, L. "PIR Motion Sensor Overview." from https://learn.adafruit.com/pir-passive-infrared-proximity-motion-sensor.
[3] Adafruit. "Adafruit HUZZAH32 - ESP32 Feather." Retrieved March 04, 2021, from https://learn.adafruit.com/adafruit-huzzah32-esp32-feather/overview
[4] AliExpress (2010). "HOHOFILM CUSTOMIZED Smart Film Window Smart PDLC Magic Switchable Transparent white customized." Retrieved March 03, 2021, from https://www.aliexpress.com/item/1005001429520198.html?spm=2114.12010612.8148356.4.f92
[5] Alliance, N. H. S. (2018). "Safety Issues with your Home's Windows." Retrieved February 17, 2021, from https://staysafe.org/safety/windows/.
[6] Alonzo, R. J. (2009). Electrical codes, standards, recommended practices and regulations: an examination of relevant safety considerations, William Andrew.
[7] Amazon. "HOHOFILM Electronic PDLC Smart Film A4 Sample PDLC Switchable Smart Film Electric Smart Glass Film(21cmx29.7cm)." Retrieved March 03, 2021, from https://www.amazon.com/HOHO-Electronic-Switchable-Electric-21cmx29-7cm/dp/B07428XTF7/ref=psdc_16136296011_t2_B077P4QJT1.
[8] Amazon (1996). "DFRobot DF15RSMG 360 Degree Standard Servo Motor (20kg) for RC Robot." Retrieved March 16, 2021, from https://www.amazon.com/DFRobot-DF15RSMG-Degree-Standard-Servo/dp/B014L5CBBA.
[9] Anish. K, R. B., Avaneet Ranjan (2020). "Peripheral Interface Controller (PIC)." Retrieved February 21, 2021, from https://www.circuitstoday.com/peripheral-interface-controller-pic.
[10] Arduino. "Arduino Software (IDE)." Retrieved April 23, 2021, from https://www.arduino.cc/en/guide/environment.
[11] Artistry, E. (2020). "Mircrocontroller Unit [MCU]." Retrieved February 21, 2021, from https://embeddedartistry.com/fieldmanual-terms/microcontroller-unit/.
[12] Battery University. "Learn about Batteries." from https://batteryuniversity.com/learn/article/battery_definitions.
[13] Ben Farris, P. F., Blake Loeb, William Tyback (2017). SkyLight Glass.
[14] Conor Ferrinf, A. R., Terrell Richardson, Miloud Ennemar (2019). SunShade: 1-137.
[15] Council, N. S. (2021). "Windows are Vital to Survival, but Keep Safety in Mind." Retrieved February 17, 2021, from https://www.nsc.org/home-safety/safety-topics/child-safety/window-safety.

[16] Custom Power. "Battery Chemistry Chart for Primary and Secondary Batteries." from https://www.custompower.com/battery-chemistry-chart.

[17] Diksha (2017). Retrieved March 04, 2021, from https://www.engineersgarage.com/electronic-projects/constant-12v-power-supply-for-led-circuits-part-4-13/.

[18] Dhaker, P. (2018). "Introduction to SPI Interface." Volume 52: 1-5.

[19] Electronics Hub. "Applications of Inductor." Retrieved March 10, 2021, from https://www.electronicshub.org/applications-of-inductor/.

[20] Electronics Notes. "What is a Microcontroller MCU: embedded systems." Retrieved February 21, 2021, from https://www.electronics-notes.com/articles/digital-embedded-processing/embedded-systems/what-is-embedded-microcontroller-mcu.php.

[21] Electronics Notes. "USB Standards: USB1, USB2, USB3, USB4 - Comparison and Capabilities." Retrieved April 1, 2021, from https://www.electronics-notes.com/articles/connectivity/usb-universal-serial-bus/standards.php.

[22] Electronics Tutorials. (2021). "Full Wave Rectifier." Retrieved March 04, 2021, from https://www.electronics-tutorials.ws/diode/diode_6.html.

[23] Energy.gov. "Insulation." Retrieved February 17, 2021, from https://www.energy.gov/energysaver/weatherize/insulation.

[24] Epec Engineering Technologies. e. E. "Battery Chemistry." from https://www.epectec.com/batteries/chemistry/.

[25] ESPRESSIF (2015). "ESP 32." Retrieved February 20, 2021, from https://www.espressif.com/en/products/socs/esp32.

[26] Feller Robyn. M, “Smart Glass Solutions for Interior Commercial Structures.” Continuing Education Center. April 2019. Accessed Feb. 09, 2021. http://static1.squarespace.com/static/57653afc15d5db346154a776/t/5775756e37c5816f7a896ae3/1467315584003/I-FILM%E2%84%A2+INSTALL.pdf/

[27] Firmcodes Firmware Developers. "Introduction of PIC Microcontoller." Retrieved February 21, 2021, from http://www.firmcodes.com/microcontrollers/pic/introduction-of-pic-microcontroller/.

[28] ForcePoint. "The OSI Model Defined." from https://www.forcepoint.com/cyber-edu/osi-model.

[29] GeeksForGeeks. (2020). Retrieved March 27, 2021, from https://www.geeksforgeeks.org/layers-of-osi-model/.

[30] glass.com (2021). "Electrochromic Glass." Retrieved March 02, 2021, from https://info.glass.com/glass-dictionary/electrochromic-glass/.

[31] Group, D. G. (2005). "Dream Glass Smart Blinds." Retrieved February 22, 2021, from https://www.dreamglassgroup.com/product/dreamglass-smart-blinds/.

[32] Huang, B. "Logic Levels." from https://learn.sparkfun.com/tutorials/logic-levels/ttl-logic-levels.
[33] ISO. "ISO/IEC 9899:2018 Information technology - Programming Languages - C." Retrieved April 20, 2021, from https://www.iso.org/standard/74528.html.
[34] I2C Info. "I2C Info – I2C Bus, Interface and Protocol." Retrieved April 02, 2021, from https://i2c.info/i2c-bus-specification.
[35] Keim, R. (2016). "Back to Basics: The Universal Asynchronous Receiver/Transmitter (UART)."
[36] LUTRON, S. b. (2016). "Smart Roller Shades by Serena." Retrieved February 21, 2021, from https://www.sparkfun.com/products/13907.
[37] Machine Design. "Proximity Sensors Compared: Inductive, Capacitive, Photoelectric, and Ultrasonic." from https://www.machinedesign.com/automation-iiot/sensors/article/21831577/proximity-sensors-compared-inductive-capacitive-photoelectric-and-ultrasonic.
[38] Marshall Brain, T. V. W. a. B. J. "How WiFi Works." Retrieved March 31, 2021, from https://www.howstuffworks.com/about-author.htm#brain.
[39] Matters, S. (2021). "Windows: Hazard Related Topics." Retrieved February 17, 2021, from https://www.aisolutions.co.uk/community/Knowledge/Topic/119/1004/Windows.
[40] McAfee, B. (2014). "The Most Common Ways Burglars Enter the Home." Crime Prevention Blog. Retrieved February 17, 2021, from https://www.cpss.net/about/blog/2014/05/the-most-common-ways-burglars-enter-the-home/.
[41] Menke, H. "Basic Operating Principle of an Inductive Proximity Sensor." from https://automation-insights.blog/2014/03/05/basic-operating-principle-of-an-inductive-proximity-sensor/.
[42] Mitrokostas, S. (2019). "10 Dangerous mistakes to avoid during a fire." Retrieved February 17, 2021, from https://www.insider.com/what-not-to-do-in-a-fire-2019-7.
[43] Moermond, J. "What is a Capacitive sensor?". from https://automation-insights.blog/2017/06/07/what-is-a-capacitive-sensor/.
[44] NetSpot. "Explaining WiFi Standards." Retrieved April 23, 2021, from https://www.netspotapp.com/explaining-wifi-standards.html.
[45] Nick Gromicko, C., Kenton Shepard (2006). "Burglar-Resistant Homes." Retrieved February 17, 2021, from https://www.nachi.org/burglar-resistant.htm.
[46] Nugent, Stephen. “Precision SPI Switch Configuration Increases Channel Density.” *Analog Dialogue*, May 2017.
[47] Office of Energy Efficiency & Renewable Energy. “Purchasing Energy-Efficient Residential Windows, Door, and Skylights.”

https://www.energy.gov/eere/femp/purchasing-energy-efficient-residential-windows-doors-and-skylights/

[48] Phidgets (2016). "Sensors." Retrieved March 05, 2021, from https://www.phidgets.com/?tier=3&catid=24&pcid=21&prodid=340.

[49] Physical Computing. "ESP32: Intro to the ESP32." Retrieved April 21, 2021, from https://makeabilitylab.github.io/physcomp/esp32/esp32.html.

[50] "Proximity Sensor." https://www.amazon.com/Arduino-Proximity-Sensor/s?k=Arduino+Proximity+Sensor/

[51] Purple (2014). "The History of WiFi." Retrieved May 29, 2021, from https://purple.ai/blogs/history-wifi/.

[52] Random Nerd Tutorials. "ESP32 Pinout Reference: Which GPIO pins should you use?". Retrieved April 22, 2021, from https://randomnerdtutorials.com/esp32-pinout-reference-gpios/.

[53] Random Nerd Tutorials. "UltraSonic Proximity Sensing Contact ". Retrieved April 12, 2021, from https://randomnerdtutorials.com/contact/?contact-form-id=1233&contact-form-sent=103126&contact-form-hash=96c0a540eeadd8b4cfbdd8ce6e7c8a0112a0e888&_wpnonce=717283c27a#contact-form-1233.

[54] Random Nerd Tutorials. (2013). "100+ ESP 8266 Node MCU Projects, Tutorials and Guides with Arduino IDE." Retrieved February 21, 2021, from https://randomnerdtutorials.com/projects-esp8266/.

[55] SafeAtLast (2020). "Burglary Statistics 2020 (Infographic) - How Safe Is Your Home?". Retrieved February 17, 2021, from https://safeatlast.co/blog/burglary-statistics/.

[56] Santos, S. (2020). "ESP 32 Development Boards Review and Comparison." Retrieved February 20, 2021, from https://makeradvisor.com/esp32-development-boards-review-comparison/.

[57] Savage, K. "House Damage Caused By Hail Storms." Retrieved February 17, 2021, from https://homeguides.sfgate.com/house-damage-caused-hail-storms-87142.html.

[58] SecurAmerica (2013). Home Burglary Awareness and Prevention. jsu.edu. J. S. University: 1-10.

[59] SparkFun. "ESP32 Thing Hookup Guide." Retrieved April 21, 2021, from https://learn.sparkfun.com/tutorials/esp32-thing-hookup-guide.

[60] SparkFun. "SparkFun ESP 32 Thing." Retrieved March 16, 2021, from https://www.sparkfun.com/products/13907.

[61] SmartTint. (2021). "LOW VOLTAGE 1 Square Foot Sample / Power Supply / Smart Cling™ SELF-ADHESIVE / FREE SHIPPING USA and Canada Only." Retrieved March 03, 2021, from https://shop.smarttint.com/LOW-VOLTAGE-1-Square-Foot-Sample-Power-Supply-Smart-Cling%E2%84%A2-SELF-ADHESIVE-FREE-SHIPPING-USA-and-Canada-Only_p_675.html.

[62] "Solid State Relays." https://www.amazon.com/Solid-State-Relays/b?ie=UTF8&node=6374820011/

[63] TinyTronics (2014). "LilyGO TTGO T-Koala ESP 32-WROVER." Retrieved March 01, 2021, from https://www.tinytronics.nl/shop/en/platforms/ttgo/lilygo-ttgo-t-koala-esp32-wrover.

[64] Tjensvold, J. M. (2007). "Comparison of the IEEE 802.11, 802.15.1, 802.15.4 and 802.15.6 wireless standards." 1-7.

[65] Tri=Tonics. "What is a Photoelectric Sensor?". from https://www.ttco.com/what-is-a-photoelectric-sensor.

[66] Tutorials Point. "Electronic Circuits - Regulators." from https://www.tutorialspoint.com/electronic_circuits/electronic_circuits_regulators.htm.

[67] United States Department of Labor. "Winter Weather." Safety and Health Topics. Retrieved February 17, 2021, from https://www.osha.gov/winter-weather/hazards.

[68] Usach, Miguel. AN-1248 Application Note: *SPI Interface*. Analog Devices, Inc., September 2015.

[69] WatElectronics.com (2019). "What is PIC Microcontroller and Its Architecture." Retrieved February 22, 2021, from https://www.watelectronics.com/pic-microcontroller-architecture-and-applications/.