Electric Blind

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***Abstract* — Every day technology becomes a crucial aspect of daily human lives due to its increased integration into everything like workplaces, home, and personal lives. This integration is evident with increased ownerships of devices such as Amazon Alexa, Google home hub, smart devices for cars, home automation. Switch flipping for turning things on and off have been replaced with automated smart devices, verbal command, phone application, or timer. For the project herein, smart technologies are integrated windows, in a meaningful, useful, and automated way using smart films as window blinds and automating the process of opening the blind through human presence and digital application interfaces. Successful integration of these automation technologies for window blinds will prove beneficial for end users with incredible the potential reach due that practically every person in the US uses a window with a blind every day. Similarly, energy saving is another feature of this project that will yield both real monetary savings for the end user, including positive benefits for the environment.**

***Index Terms* — Smart blinds, PDLC, automation, ESP32-WROOM, power.**

I. Introduction

Windows are something that most everyone uses every day. They can be seen in practically every building, house, and apartment. As such the development of an effective window that people value provides an astronomical potential reach. Keeping this in mind, this project aims to achieve the following goals and objective: 1) Remove conventional blinds and replace with smart ones. 2) Meet the engineering specifications listed in section III, 3) develop great teamwork among the engineers working on this project, and 4) produce a successful resulting device that caters to the need of everyone. However, there are a few key areas that need to be addressed for the project herein.

The first key area is safety since the resulting device for this project will be present around people for long durations. The safety considerations must extend past the proper use of the window. For example, considerations need to be made for instances when a kid runs into the window created using the technologies proposed for this project? Extensive research has been done as to all the various types of safety hazards that can arise for the device and numerous effective countermeasures have been set in place to provide safety features.

The second area addressed is efficacy. Not only must the end user receive work from this project which would merit having it, but the end user must be able to effectively use the interfaces provided to successfully interact with the resulting device of the project herein. This is further complicated by the huge array of various applications for windows. The desired capabilities for windows in a small house differ wildly from that of a massive conference center with thousands of windows. As such, all possible use cases (that can be reasonably assumed) have been enumerated and this project was designed in such a way that it can be meaningfully used in those use cases.

The third area addressed is efficiency. The reality is, if the cost associated with this project is too high, nobody will use it. This extends past just the cost of the device itself, but also the power to operate it. One common use case of windows is to assist with temperature control (Air Conditioning), which helps expend less energy (thus lowers the cost of owning it). In addition to that, energy savings directly translate to a positive change for the environment.

The rest of this paper is designed as such: Section II is the background. Section III specified the requirement specifications. Section IV gives the project system components. Section V gives specific and detailed hardware design. Section VI gives the specific and detailed software. Section VII explains the overall hardware and software integration for this project, Printed Circuit Board design. Section VIII gives the results of the system testing and summary of the overall project design. Finally, section IX concludes this paper.

II. Background

In the process of achieving the goals and objectives stated in the introduction section, numerous research effort was put forward by the team members. This research effort included looking into previous electric blind already on the market and creating a plan to make a product that have technological advancements of multiple activation methods of a window blind. Different existing smart blind products were researched and based on those products, different changes and improvements were made to create a unique project herein.

A. 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.

B. 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 the request each project be quoted.

C. 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 the complete removal of conventional blinds and replacement with smart blind.

TABLE I

SUMMARY OF EXISTING SMART BLIND PRODUCTS

Existing Products	Summary
Serena Smart Shades	- Conventional, roller blinds - Bulky installment for blind housing
Dream Glass Blinds	- No digital interface - High cost - Custom order required
Sunshade	- Motorized Blinds - Application Interface

III. REQUIREMENT SPECIFICATIONS

For the successful implementation of this project, some requirement specifications were examined and taken into consideration. The requirement specifications include:

Cost: The goal of the group is to implement a cheap but productive device that can satisfy all the engineering requirements with less than $600. The target budget is set out low because of the modern technology. However, there are many electronics equipment from different companies and suppliers that can drive the cost for the project down.

Time to activate: The time to activate the device is set to be 10 seconds for now although the status of the PDLC film changes quickly where it only takes half a second. However, our group 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.

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.

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.

Power Consumption: The PDLC film uses AC voltage with low voltage from 28-48 VAC with a current of 0.2 A which the maximum power usage for the film alone to be around 5W/m2. The power for the film combines with other sensors and MCU of the project would not exceed 20W.

Activation methods: We plan to achieve at least three activation methods for the proposed automation process. The activation methods are a switch which will be the simplest form of activation, human presence using a proximity sensor and digital application interface using a phone application.

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 will be applicable.

Similarly, some marketing requirements for this project are: 1) low-cost, 2) high safety, 3) reliability, 4) ease of use, 5) high and efficient performance, and 6) low power consumption.

TABLE II
REQUIREMENT SPECIFICATIONS

Engineering Specifications	**Marketing specifications**
Power Consumption < 20 Watts	High Safety
Accuracy <= 150cm	Low Cost
Time of Response <= 10 seconds	High reliability
Cost < $600	Ease of use
Idle Time <= 5 minutes	High Performance
PCB dimension <= 4’’ x 4’’ Three activation methods	Low Power Consumption

Finally, three requirement specifications are demonstrated to show the functionality of the product of this project while also achieving the goals and objectives aimed herein. The three requirement specifications are: power consumption < 20 watts, time of response <= 10 seconds and activation methods i.e., switch, human presence, digital application interface.

IV. PROJECT SYSTEMS COMPONENTS

In this section, the details of the project system components are examined. The overall project comprised of window and window frames selection suitable for this project, brief safety concerns, smart film i.e., PDLC as the blind. Microcontroller unit, the overall power delivery technologies, sensors, and interface techniques.

A. Windows and Window Frames

A board made from wood is used as the window in which the electronics of this project will be housed. Similarly, a fixed window frame is used to allow safe and efficient housing of the electronics of this project.

B. Safety Concerns

As with any object that can be expected to see commercial use, the safety of it must be ensured. For this project, extensive research regarding window safety concerns were done, and appropriate countermeasures for were developed this project.

The first set of countermeasures deal with the window frame itself. The window frame will be mounted on a rectangular base, so that the window frame can stand by itself and not topple over. In addition to that, no sharp objects (such as nails) will protrude from the frame. Similarly, all the electronics for the project will be concealed in a protected housing, as so the end user cannot touch any part that might deliver an electrical current to them. This way the end user should be able to touch any part of the frame, and not have a risk of harm.

The next set of countermeasures deal with the material used as the translucent material of the window (typically glass). For this, acrylic was chosen is due to the higher flexibility, and strength. In addition to that, acrylic does not typically shatter in the same manner as glass where it will leave a numerous number of hard-to-see shards that can injure people.

C. Blinds

For the actual mechanism to block light from transferring through the window and achieve the goal of automating window blinds, smart film specifically, Polymer Dispersed Liquid Crystal (PDLC) was chosen due to its high transition time and ease of replacement. This material can switch between transparent and opaque, using an electrical current. This film can be applied to an existing window to allow for the window to switch from transparent and opaque. Similarly, this film also has a simple and user-friendly installation without the need of inserting a specialized glass.

D. Microcontroller Unit (MCU)

The microcontroller unit (MCU) for this project oversaw interfacing the software design of this project with the sensors (proximity sensors and temperature sensors) used for some of the activation methods. ESP32 WROOM-32 was chosen for this project due to its numerous specifications that are beneficial to achieving the project’s goal. The specific specifications that made ESP32 WROOM-32 the go-to MCU are:

Dual core processors: The dual core processor in the ESP32-WROOM32 MCU enabled detection of actions related to the Input/Output pins while also allowing Bluetooth and Wi-Fi communications. This specification allows the creation of different activation methods i.e., Bluetooth and Wi-Fi for digital application interfaces, and gestures captured by the sensors connected to the I/O pins.

Integrated Wi-Fi AND Bluetooth modules: ESP32-WROOM32 has an onboard 2.4GHz Wi-Fi integration and Bluetooth Low Energy (BLE). These features are essential for the digital application interface activation methods which include a phone application and a desktop program.

36 General Purpose Input/Output (GPIO) Pins: These GPIO pins enable connection of numerous components including relays and sensors.

Arduino IDE compatibility: The feature allowed easy integration of the MCU and software aspect of the project herein.

Finally, its ability to deliver functionality on industrial environments having ultra-low power consumption made ESP32 WROOM a suitable choice.

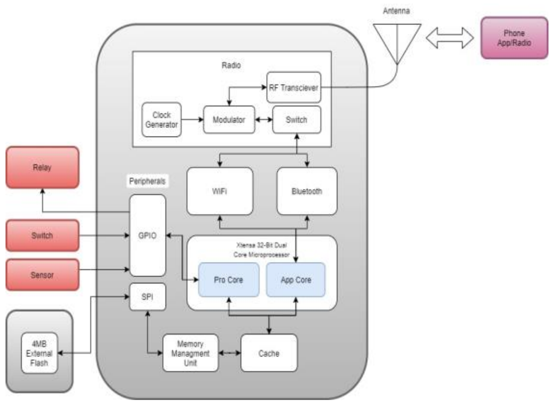

Fig. 1. Inner workings of the MCU ESP32-WROOM32.

E. Proximity Sensors

After extensive research, MCM 287-18001 Passive Infra-Red (PIR) sensor was decided upon herein. The MCM 287-18001 has a wide range for input voltage where it can take the voltage from 5 VDC to 20 VDC which helps power it easier. This sensor was used for the activation method that detects human presence due to the radiation emits from human body to activate the smart film (PDLC) on a window. That was also the main engineering requirement for the project where human is the main aspect to activate the device. The MCM 287-18001 also provides a good detecting distance where it can sense a target up to 7 meters with a wide detection angle up to 110^{o}. In line with the requirement specification of low power consumption, this sensor consumes around 65 mA based on manufacturer's datasheet. However, the actual power consumption of the MCM 287-18001 is half of that with the value of around 39.1 mA.

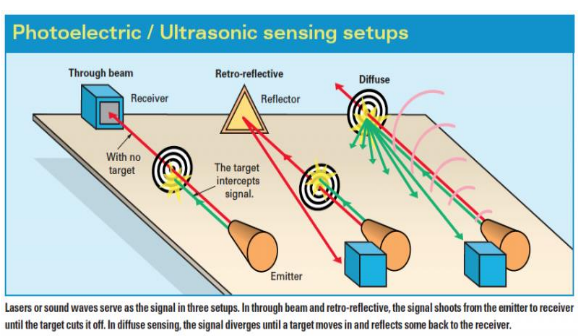

Fig. 2. Different Modes for Photoelectric Proximity Sensing Technology.

F. Power Delivery Technology

An important part for this project is to power the whole device with a reliable power source such as the household power supplied by the grid. Moreover, the PDLC film works with a voltage range from 28 to 48 VAC. Therefore, an AC power source is preferred. Due to low power consumption for this device, a small one phase transformer is used to step down the voltage on the primary side from the outlet with a 120 VAC to a 12 VAC on the secondary side used to power the sensors and the MCU. The transformer used for the project is the Tamura 3FD-424. This transformer can be wired in parallel connection to give an output of 12 VAC and 500 mA or in series connection to give an output of 24 VAC with 250 mA or with center tap to give 2 outputs with 12 VAC and 250 mA for each output. The parallel connection is chosen to be implemented for this project due to its output characteristics.

The voltage used for sensors and MCU is VDC, therefore, the stepped down 12 VAC needs to be converted to 12 VDC by using full wave bridge rectifier. The output from the full wave bridge rectifier has large magnitude ripples which can damage the devices. Therefore, there will be coupling capacitors at the input of two branches of the voltage regulators. The two branches for the voltage regulators are 3.3 and 5 VDC. The 5 VDC branch is used to power all the sensors of the device while the 3.3 VDC branch is used to power the MCU to control the device.

The voltage regulator used for this project is a switching voltage regulator from Texas Instrument model LM2575-ADJ. By using switching voltage regulator, a wide range of input and output can be implemented. More importantly, the efficiency of switching voltage regulator is higher than linear voltage regulator with the efficiency can be up to 90%. The low efficient percentage of the linear voltage regulator causes by the heat dissipated from the drop out voltage. Power lost from drop out voltage combines with thermal resistance makes the linear voltage regulator extremely hot. Thus, heat sink will be required to be integrate and make the whole PCB design bulkier.

To completely control the PDLC through the MCU, relays are used for this project. The relays are solid state relays which used low voltage supplied by the MCU through its GPIO pins. Once the voltage is supplied across control input terminal, the output terminal connected to PDLC film becomes a close contact which completes the circuit and activates the PDLC film. The solid-state relays are preferred other than other types of relays due to no physical contact which can eventually wears the relays in a long time. Another reason is the input voltage used to control the input terminal is low, in this case 3.3 VDC from the MCU.

TABLE III
SUMMARY OF POWER DESIGN

Components	Operating Voltage	Operating Current (mA)	Power Consumption (W)
PIR sensor	5.3	39.1	0.207
MCU	3.3	250	0.825
PDLC Film	65.6	0.069	4.5
Relay	1.25	1.5	0.0019
Light sensor	5.3	34.8	0.184
Temperature sensor	5.3	20	0.106
Total Power Consumption			5.8239

G. Interface Techniques

Development of effective interfaces while keeping in the end users for the product of this project is critical. There are several key areas that were identified which included pinpointing patterns amongst the environments a device like this will use, along with what type of interfaces the end user can be expected to operate. This is because this project aims to develop an interface that the end user can realistically use with minimal effort, and have the interface be able to successfully communicate with the device. For this, four separate types of interfaces were developed, which when combined, will satisfy both requirements for the overwhelming majority. The combination of these input methods will satisfy most use cases, from one device in a home to managing hundreds of windows in a corporate office.

The first interface type used is a sensor. This provide several different types of interfaces that can be used without any additional technologies. The sensors used herein include a proximity sensor, photosynthesis sensor, and temperature sensor. The stimuli these sensors monitor are physical qualities such as light, temperature, and proximity to a solid object. Interfacing with these is as simple as moving a hand in front of the sensor, waiting for nightfall, or waiting for a temperature change. In other words, interfacing with these proved as a simple enough task that practically anyone can do it. In addition to that, these sensors are physically attached to the device itself, so effects on the environment to the operation of the sensors will be minimal.

The second interface type employed is a phone app. For development purposes, an Android app was chosen due to availability of hardware for this project, and its market utilization. Due to the incredible smartphone usage rates among people, expecting not only the end user to possess a smartphone, but the end user having the ability to effectively operate a phone app is far from unreasonable. In terms of how this interface method communicates with the device, Bluetooth networking technology was utilized due that most smartphones have Bluetooth. This networking can function with only the device, and a smartphone, so the effects the environment will have on this interface type are minimal. However due to the physical distance limit of Bluetooth, physical proximity to the device is required.

The third interface type employed is a desktop program. This is a program that runs on a desktop computer, which will require the end user to set up and use the app. This might prove troublesome for technologically illiterate end users. This interface method employs the use of IPv4 networking technology. This will of course require the end user to both have an IPv4 network and configure the device to connect to it (which can be done via Bluetooth). As a result, the environment the device is used in will have some degree of impact as to the practicality of this interface type. However, this interface type allows for one or more people to manage any arbitrary number of devices, so it will excel in applications where the number of devices present in the environment (such as a corporate office) is scaled up. In addition to that, if you can connect to the network, you can manage the windows, so physical proximity is not required.

H. Standards

There are numerous standards that were used for this project to abide by specifications. The standards include:

i. Wireless Connectivity standards specifically IEEE802.1,
ii. Bluetooth Standards i.e., IEEE802.15.1 and
iii. Serial Communication Protocols i.e., Serial Peripheral Interface (SPI), Universal Asynchronous Receiver Transmitter (UART), Universal Serial Bus (USB2.0).

These standards allowed this project to meet the specifications provided for Senior Design projects.

V. 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.

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

The next stage is data transferring between PIR sensor, MCU, and relay. For the device to work, the PIR sensor needs to sense the presence of a target which herein is a human's activity. Once the sensor senses, it sends a TTL output signal to the MCU. The MCU receives the signal will then send a voltage to the relay to close the internal circuit inside the relay. Finally, the relay closes its contact so the main power supply can be delivered to the PDLC film to make it work.

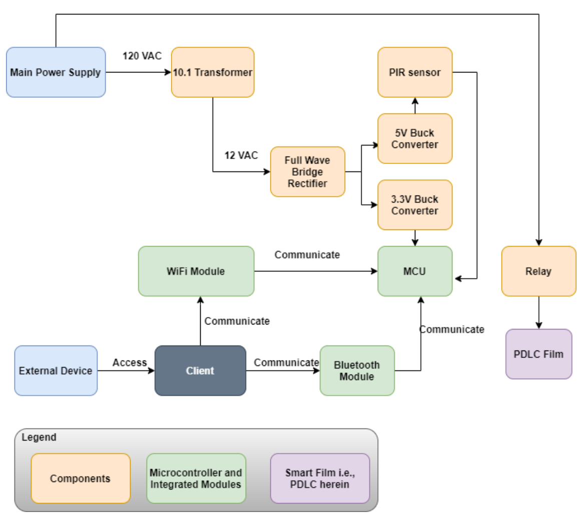

Fig. 3. Overview of the software design

Table IV shows the overall component selection that enabled the successful implementation of the designs herein.

TABLE IV
SUMMARY OF COMPONENT SELECTION

Components	
Window Frame	Fixed Window Fame
Blind	Polymer Dispersed Liquid Crystal
Microcontroller Unit	ESP32-WROOM32
Proximity Sensor	MCM 287-18001
Voltage Regulator	LM2575-ADJ
Full Bridge Rectifier	MB4S-E3/45
Transformer	Tamura 3FD-424

VI. SOFTWARE DESIGN DETAILS

For the programming environment we used, we choose the Arduino IDE. This provides several key advantages. Operations such as reading analog input from a pin are abstracted away to API calls, which simplifies the software development process. In addition to that, the Arduino open-sourced community is a relatively large community. This provides us with a lot of resources to aid with the development process, and a lower bar of entry for new software developers to join the project (which will give us increased potential for third party features support).

So, for the software, there are two primary functions. They are controlling the state of the PDLC film, along with reading and interpreting the various inputs. For this, functionalities are modularized into singular functions that can be called. This will greatly simplify the process of software development.

For software design, various software development methods were employed to ensure software quality. The first method used is the use of a software linter, which is a piece of code which will perform static analysis on a code base to check for low quality code. The second method employed is adherence to the Arduino Code style guideline to ensure code is written in a uniform fashion (to help ensure code readability). The third method used is documentation, both in the form of software comments and external markdown files (will provide great assistance with code readability). The fourth method used is the use of a version control software (we used git), to help ensure proper software development.

So, with managing various types of inputs, one problem encountered is conflicting inputs. This is when multiple different inputs specify different window behavior. To effectively mitigate this problem, an input privilege scheme was designed. Different inputs are assigned different privilege levels, with each one being higher or lower than every other privilege level. If an input specifies a certain functionality, we will check if there is a conflict with a higher privilege level, and if there is a confliction the higher privilege level will override the lower privileged signal.

There are two primary communication types the software must read and interpret. These are input from sensors, and network input. For scanning in data from sensors, we utilize Arduino API functions for scanning in both digital and analog signals. These APIs are used to read in the value, and interpret the value based upon what input it is and execute any necessary actions. For scanning in network data, a custom network protocol was defined for this project's software design (detailed in external docs). This is to help ensure effective and efficient communication. This protocol operates over both Bluetooth, and UDP. UDP was utilized for IPv4 networks over TCP, since it will enable the leveraging of multicast messages to find the device on an IPv4 network, when the IP address is not known (to help improve the end user experience).

Lastly, most of the code base for this project does not run on the MCU. It deals with the various interfaces associated with this project. For the web application interface, a LAMP application was created. For the Desktop App, an application that utilizes a Python3 GUI was used. For both the web and desktop apps, they utilize a python3 backend to handle communication with the device.

VII. Overall Integration 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 to create a working prototype of the project herein.

The block diagram in Fig. 4 shows the overall integration of this project from hardware to software design and the communication that allowed the activation methods to interact with the smart film.

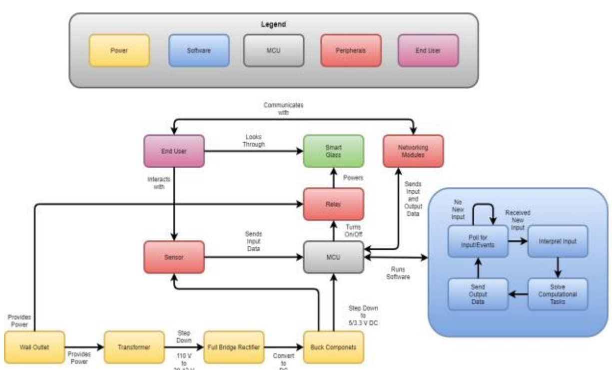

Fig. 4. Overall Integration of hardware and software design.

With the two stages identified from Fig. 4., the project needs different modules such as the power supply module which can provide power for the whole project to operate. From the power module, there are two subsystems need to be designed. The first subsystem is the step-down in AC voltage and conversion from AC to DC voltage. The second subsystem for the power module is voltage regulator from the stepped down, converted DC voltage to maintain a specific voltage level to power each of the component.

The other module is the microcontroller schematic design. This subsystem helps 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 can also help 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.

VIII. Results

For this project, various Engineering Requirements were stated, which if met, should signify that the core functionality of this project is working.

The first requirement specified was regarding the cost of the project. While this requirement is not the most exciting, it is of utmost importance (since if the cost of this window is too high for the market to bear, it will experience miniscule usage). The requirement initially specified that the cost per unit cannot exceed $600 per device. The current bill of materials has the price per unit below that (due to the price impact of the variability for the different window applications, it has hard to state an exact price).

For the time to activate, the requirement for it was that this operation takes no longer than 10 seconds. Upon testing various methods of operating the window, the average time is around 1-3 seconds, which is within the acceptable operating range (as shown in the demo video).

One of the requirements created was efficiency. For this requirement, the window device must be able to block out at least 90% of the incoming light upon the window becoming opaque. The film used for the project will block 95% of incoming light upon becoming opaque. In addition to that, the device can turn the film to max opaqueness, so as a result, less than 10% of light can come through the window when it is opaque. As such, this requirement is satisfied.

(a) (b)

Fig. 5. Smart Film (PDLC) (a) OFF state (b) ON state

The next requirement is power consumption. For this requirement, the maximum power consumption should not exceed 20 watts. After constructing and operating the device, total power consumption of the device is below 20 watts as shown in Table II. As such, this requirement has been met.

With the activation method requirement, as initially specified that there will be at least three methods for the end user to provide input to operate the window. As of now, four separate input methods have been successfully tested, which the end user can provide input to operate the window. In addition to that, verifying and implementing other input methods is in progress.

For the Activation Range requirement, it was specified that an input method that is functional must be at a distance less than 50 cm from the window. This is satisfied with the proximity sensor input method (human presence). This was verified by simply placing a human hand 5cm from the proximity sensor which allowed a user to successfully operate the window.

IX. Conclusion

So, in conclusion, windows are something that a lot of people use. various parts of what makes a good window was identified, designed, and successfully tested to create a new design for windows. This is one which contains new features and technologies which offer real world value for a large array of practical applications. As such, technology into windows was implemented in a real and meaningful way that people can realistically use.

However, there were limitations to this project that can be implemented into future works for this project. This project was student-funded which did not leave room for elaborate design. Similarly, this project was proposed, designed, and implemented in less than 6 month which led to time constraints for the engineers.

The Engineers

Adedoyin Adepegba is an electrical and computer engineer student who also participated in undergraduate research. She plans to continue her education by earning a master's degree in computer engineering from UCF.

Joshua Forrest is a Senior electrical engineering student with a focus in the power and renewable track at the University of Central Florida. Joshua has interest in supply chain management and power system sales specifically in the developing hydrogen and renewable energy market. After successful internships at Pepsico, Gatorade, and Mitsubishi Power Systems America and a contractor position at Siemens Energy. Joshua is weighing his options between Amazon, Honywell, and Siemens Energy.

Ryan Meinke is both a software and a security engineer. After college he hopes to apply his skills in both software engineering and security to work on cool projects which deliver meaningful and real capabilities and effects to the world.

Tien Tran is a senior student of the electrical engineering department at University of Central Florida. Tien Tran interests in power industry where he was working at Florida Municipal Power Agency as an Electrical Engineer intern. After graduation, he will be working full-time at Enercon Services as a Distribution Engineer working primarily with Non-Hardening project.

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