An-Najah National University

Faculty of Engineering and Information Technology

Graduation Project 2

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Bachelor degree in

‘’Telecommunications Engineering‘’

Smart Glass Window

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بِسْمِ اللهِ الرَّحْمنِ الرَّحِيم

قال تعالى: {وَقُلِ اعْمَلُوا فَسَيَرَى اللَّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ
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[آل عمران: 169]

صدق الله العظيم

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Dedication

For our martyrs in our beloved Gaza…

For Our Palestine …

For Our University …

For Our Teachers …

For Our Family …

We Present This Report …

Acknowledgment

- First of all, we thank God for enabling us to complete our research.

-Our ability to accomplish this research is due to the good effort provided by our great university, An-Najah National University.

-We are very grateful to our parents who gave us everything in their lives. We also thank them for pushing us towards success.

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Abstract

To the best of our knowledge, no hardware nor software implementation of a Smart Glass Window system has been carried out in our university, in this project we are planning to accomplish this task.

In this project we will use Arduino IDE software to build an intelligent Smart Glass Window capable of choosing different transparency degrees appropriate for different weather conditions, with and without any human interference in the process.

To build the Project, we first had to face the obstacle of bringing the PDLC from outside Palestine due to the conditions and war that the country is suffering from. The parts of the controller (Arduino) and the inputs of the sensors were assembled and the PDLC module was connected to obtain variable transparency for the PDLC module.

We believe this project will be applied in all aspects of life, from hospitals to cars to homes.

Chapter one: Introduction

1.1 OVERVIEW

The "Smart Glass Window" project introduces an innovative window system that adapts its tint, much like transition lenses, to optimize energy efficiency and user comfort. This technology offers significant potential for various settings, including homes, hospitals, and offices. By dynamically adjusting to external conditions, the smart glass window minimizes energy wastage, conserving energy and enhancing the quality of indoor environments. This project marks a noteworthy advancement in the field of energy-efficient window solutions.

1.2 Statement of the problem

The "Smart Glass Window" project addresses a critical challenge in the realm of energy efficiency and user comfort, particularly in residential, commercial, and medical settings. The problem at hand revolves around the management of heat flow through windows, a major contributor to energy consumption in these environments.

Solar radiation passing through windows is a primary source of heat gain and loss within buildings. Traditional solutions, such as window glazing, offer limited adaptability to changing environmental variables, rendering them inefficient and less responsive to the dynamic needs of occupants.

The key problem is the inability of current window systems to effectively manage heat flow, leading to energy wastage and less than optimal indoor comfort. This issue becomes especially pronounced during periods of intense sunlight, where excessive heat gain forces air conditioning systems to work harder, resulting in higher energy costs.

In summary, the problem statement underscores the pressing need for innovative window systems like the "Smart Glass Window" to effectively regulate heat and light transmission, significantly enhancing energy efficiency and user comfort while mitigating energy waste and associated costs.

1.3 AIMS AND OBJECTIVES

1. Innovation: To innovate and introduce a revolutionary smart window system that transforms the way we manage energy efficiency and user comfort in different environments.

2. Environmental Impact: To contribute to a greener and more sustainable future by reducing energy consumption and waste in homes, offices, and healthcare facilities.

3. Technological Advancement: To advance and integrate cutting-edge technology into everyday life, enhancing the user experience.
4. Energy Efficiency: Develop a dynamic window system that efficiently manages heat flow,

significantly reducing energy consumption and environmental impact.

5. User Comfort: Optimize indoor conditions by dynamically adjusting lighting and temperature control to enhance the comfort and well-being of occupants.
6. Adaptability: Create a versatile and responsive window solution capable of adapting to changing environmental variables, such as sunlight and temperature.
7. Cost Reduction: Minimize energy costs associated with heating and cooling, ultimately providing economic benefits to homeowners, businesses, and healthcare facilities.
8. Versatility: Offer a versatile and applicable solution for a wide range of settings, including residential, commercial, and medical environments.

1.4 Scope of the work

1. Project Initiation: Define project objectives, goals, and success criteria. Assemble a skilled project team.
2. Research: Investigating existing smart glass technologies
3. Materials Selection: Identifying suitable smart glass materials considering properties, durability, cost, and sustainability.
4. Sensor Integration: Determining required sensors (light, temperature, occupancy) and integrating them into smart glass window.
5. Control System Design: Developing a control system that adjusts window transparency based on sensor data and user preferences.
6. Testing and Validation: Rigorously testing the smart glass system under various conditions, gathering data on energy usage, and reliability.

1.5 Importance of the work

In this section we show some of the key points to explain the importance of Smart Glass

1. Energy Efficiency and Sustainability: Reducing energy consumption through efficient control of natural lighting and heat gain. Lowering energy bills and contributing to environmental sustainability by reducing greenhouse gas emissions.

2. Improved Indoor Comfort and Well-being: Providing occupants with control over natural light and privacy. Enhancing visual comfort, increasing productivity, and creating a more pleasant indoor environment.

3. Flexibility in Building Design: Offering architects and designers the opportunity to create dynamic, adaptable spaces. Seamlessly integrating indoor and outdoor environments, especially valuable in commercial buildings.

4. Privacy and Security: Allowing instant switching from transparent to opaque for a high level of privacy. Enhancing security by preventing unwanted visual access to building interiors in various settings.

5. Reduction of Maintenance and Cleaning Costs: Eliminating the need for traditional window coverings like curtains and blinds. Reducing maintenance costs and efforts, with some smart glass technologies being self-cleaning.

Chapter Two: Standards and Constrains

2.1 Standards

Due to a shortage of information in studying standards and protocols, Palestinian projects primarily use IEEE standards. If we wanted to develop this concept into an industrial form, we would use the following protocols: The IEEE 802.15.4s-2018 standard, which outlines a protocol and procedures for in this revision to IEEE Std 802.15.4TM, definitions of MAC-related functions to enable spectrum resource management are covered.

The IEEE 802.15.1: WPAN / Bluetooth Task group one is based on Bluetooth technology. It defines physical layer (PHY) and medium access (MAC) specification for wireless connectivity with fixed, portable and moving devices within or entering personal operating space.

2.2 Constrains

- On economy: the budget limitation was the biggest economical constrain, the high cost of the PDLC glass, which was priced at 3500, due to the cut of salaries and War special situation it was pretty hard to obtain the needed amount of money which was pretty big because our market is restricted to a specific supplier, which lead us to importing from China and Turkey, we resorted to ordering a piece from Amazon It took a month to arrive, during which time we familiarized ourselves with its specifications through practical work.

- On Manufacturability: the design implemented physically but not as it meant to be due to lack of hardware components.

Chapter Three: Methodology

3.1 The used Technology

3.1.1 What Is Smart Glass?

Smart glass, also known as switchable glass, employs advanced technologies to regulate light and provide insulation. The light transmission properties of the glass can be manipulated by light, heat, or electricity. Typically, this involves a transition from translucent to transparent, selectively blocking specific wavelengths of light. This technology finds applications in homes, businesses, and institutions like hospitals, offering enhanced control over light, heat, and privacy. Smart glass contributes to cleaner environments and delivers superior and customizable control compared to manual solutions such as blinds, curtains, shades, and doors.

3.1.2 What are Smart Windows?

Smart Windows refer to windows that utilize specialized glazing materials to manage the amount of light passing through the glass panes. The glazing material, often termed "switchable," exhibits changes in optical behavior when an electrical voltage is applied. This dynamic characteristic allows Smart Windows to adapt their transparency based on external conditions, providing a sophisticated solution for controlling light levels.

3.1.3 Types of Smart Glass

Smart glass technologies can be classified into two main categories: passive and active. In passive technologies, the functional layer responds automatically to environmental changes, with options such as photochromic, which reacts to light, or thermochromic, which responds to heat. These are termed passive because they adjust without the need for an electrical charge, but users cannot manually control changes in tint or opacity.

Conversely, active smart glass technologies respond to electric current, facilitated by a conductive layer. This allows users to control or adjust the glass's functions. Electrified smart glass provides additional functionalities, including emitting light, serving as a display screen, enabling variable settings or patterns across a glass panel, or even harnessing solar power. Active technologies are further categorized into electrochromic, polymer-dispersed liquid crystal (PDLC), and suspended particle device (SPD).

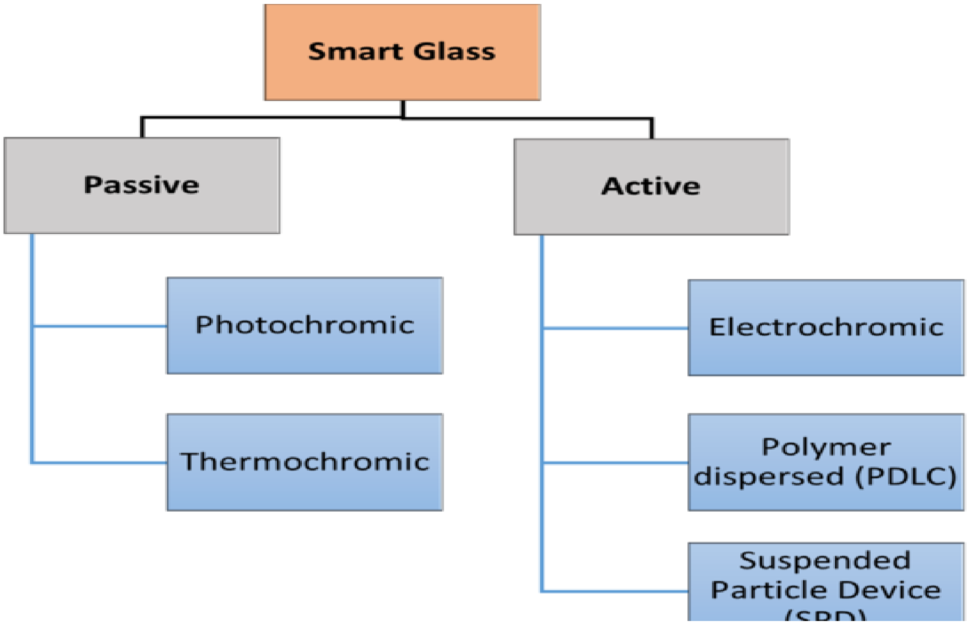


Figure 1-3: The smart glass category including both passive and active technologies.

Photochromic Glass: Photochromic smart glass, akin to the technology used in Transitions eyewear, incorporates a film with photo-sensitive molecules laminated to the inner or outer surface of the glass. These molecules remain invisible until exposed to UV rays, triggering a reaction that alters their structure and changes the transmittance of the glass from clear to darker. The degree of tint is contingent upon the amount of UV exposure, allowing the glass to adapt to varying light conditions. Once UV rays diminish, the glass returns to its transparent state.

Thermochromic Glass: Thermochromic smart glass commonly utilizes an interlayer of polyvinyl butyral (PVB) sandwiched between glass layers. When exposed to sunlight or radiant heat, the glass progressively darkens as the temperature increases. Different materials, such as ceramic coatings, are layered on the inner surface of the glass, effectively trapping heat within the thermochromic layer. This not only keeps the interior of a building or vehicle cool but also provides the added benefit of noise reduction.

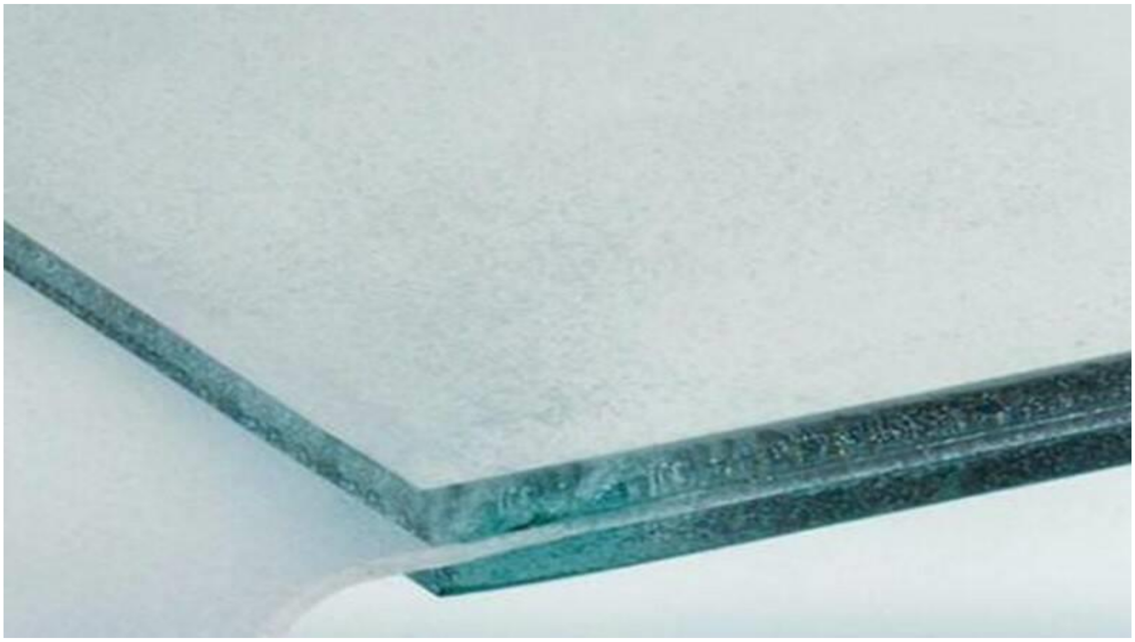


Figure 2-3: Thermochromic glass in production with a PVB layer sandwiched between two glass layers.

Electrochromic Glass: Electrochromic smart glass employs materials that undergo a change in color when an electrical current is applied. In this technology, an electrochromic layer is positioned between glass panels and conducting layers. The application of an electrical charge activates ions within an electrolyte layer, prompting the electrochromic layer to transition from a dark or opaque state to a transparent one. This dynamic process allows for controlled adjustments in the tint or transparency of the glass, offering a versatile solution for managing light and privacy in various environments.

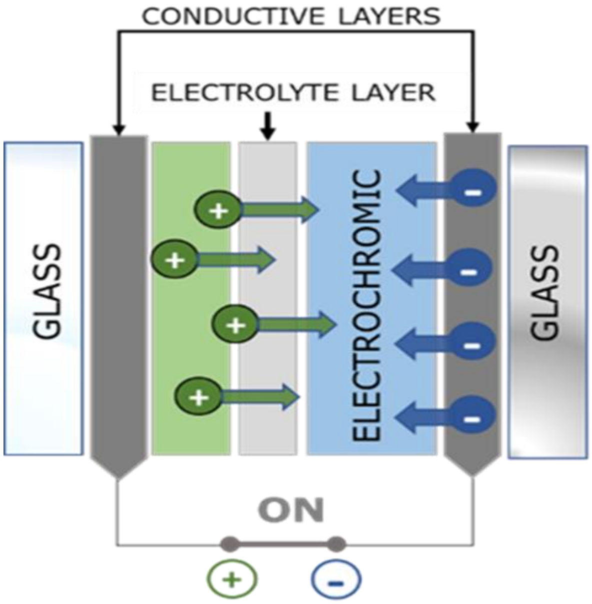


Figure 3-3: Schematic of electrochromic smart glass structure.

3.1.4 How Does Electrochromic Glass Work?

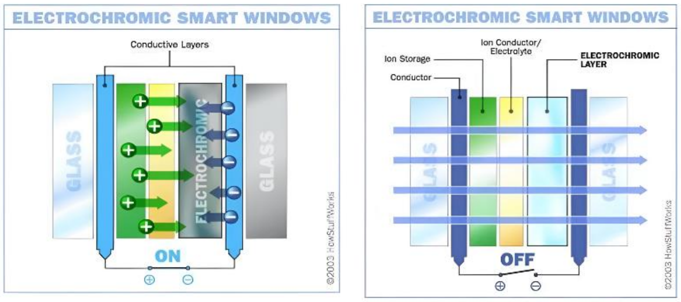


Figure 4-3: How does it work electrochromic glass.

Electrochromic glass operates on the fundamental principle of lithium-ion migration between two electrodes separated by a separator. In its clear state, lithium ions are situated in the innermost electrode. Upon applying a small voltage to the electrodes, these ions travel through the separator to the outermost electrode. In this position, they disperse incoming light, causing the glass to become opaque.

The lithium ions autonomously maintain this opaque state until the voltage is reversed. When the voltage is adjusted, the ions move back to their original position, allowing the glass to seamlessly transition back to its transparent state. This process enables dynamic control over the transparency of the glass, offering a versatile solution for on-demand adjustments to light and privacy.

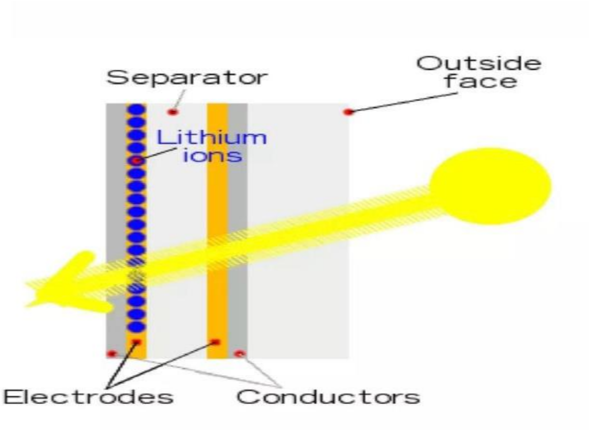


Figure 5-3: How an electrochromic window works.

The glass remains clear without the need for constant electric power; additional electrical input is only required to revert it to its original state. While the transition from clear to opaque used to be a gradual process, recent advancements have significantly reduced the switching time to a mere 2 seconds. Additionally, electrochromic glass is equipped with noise-blocking properties, enhancing its functionality beyond visual adaptability to contribute to a more comfortable and quieter environment.

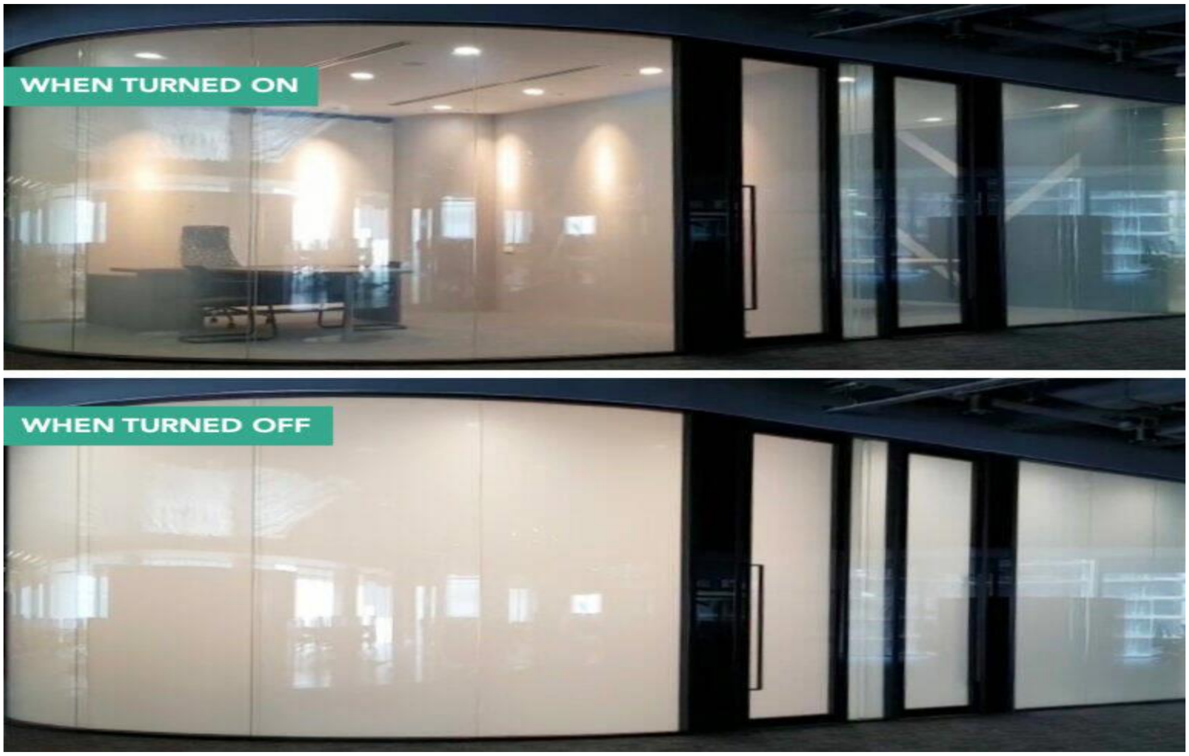


Figure 6-3: Electrochromic switchable partition in an office.

3.1.5 Suspended Particle Devices (SPD)

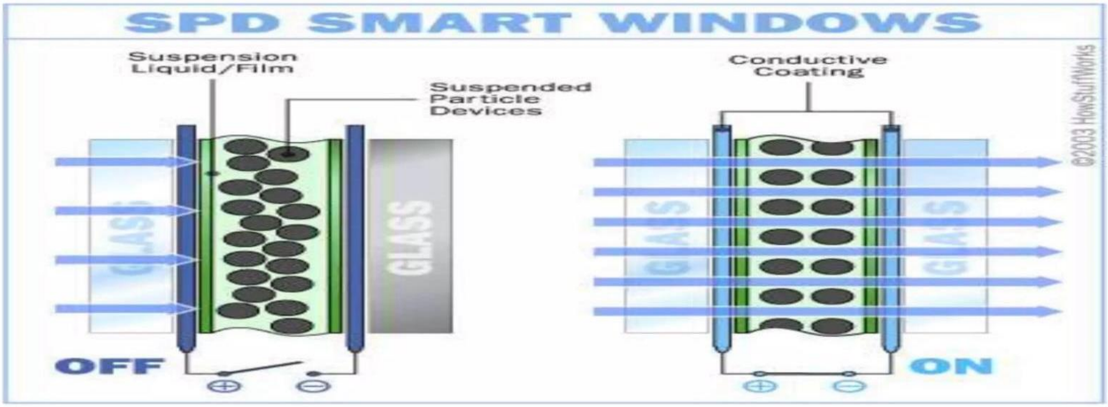


Figure 7-3: SPD-Enhanced Advanced Window Technology.

An SPD window comprises several layers, including two panels of glass or plastic.

These panels are coated with a conductive material. Between the two panes of glass, millions of black particles are suspended within a liquid film, allowing them to move freely. The control device, whether automatic or manual, manages the operation of the SPD Smart Glass.

In the case of suspended particle devices (SPD), a thin film laminate of rod-like particles suspended in a fluid is positioned between two layers of glass or plastic. When the power supply is activated, the rod-shaped suspended particles align, allowing light to pass through and rendering the SPD Smart Glass panel clear. Conversely, when the power supply is turned off, the rod-shaped suspended particles become randomly oriented, obstructing light and causing the glass panel to appear dark (opaque).

The SPD Smart Glass, when in its opaque state, can block up to 99.4% of light. Notably, SPD Smart Glass provides protection from damaging UV rays, whether in the clear or opaque state.

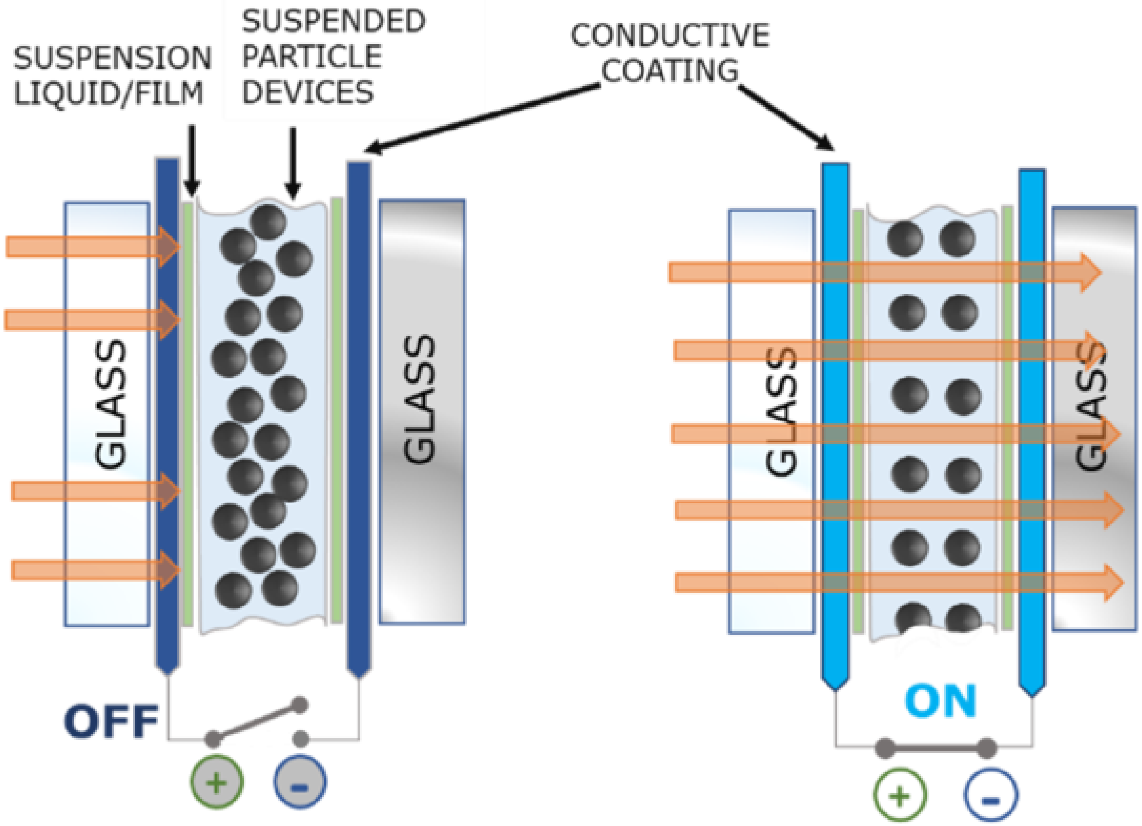


Figure 8-3: Schematic of suspended particle device (SPD) smart glass, in the off and on states.

3.1.6 Polymer Dispersed Liquid Crystal Devices (PDLC):

Polymer Dispersed Liquid Crystal (PDLC) involves micro droplets of liquid crystals encapsulated within a polymer matrix.

In PDLC devices, a liquid mixture comprising both polymer and liquid crystals is positioned between two layers of glass, which include a thin layer of transparent, conductive material. In the absence of applied voltage, the liquid crystal molecules maintain a randomized configuration, refracting incoming light and causing the material to appear opaque.

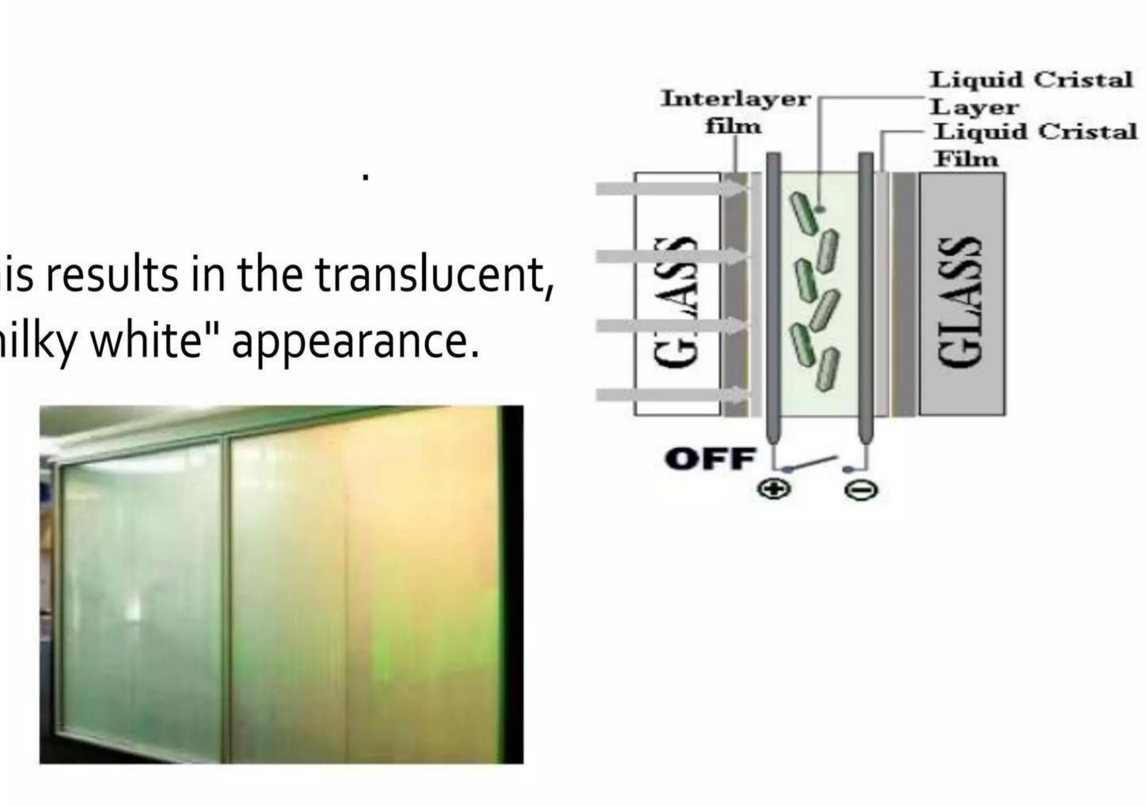


Figure 9-3: PDLC Technology Overview.

When a voltage is applied to the electrodes, an electric field forms between the two transparent electrodes on the glass. The electric field prompts the liquid crystal molecules to align along its direction, effectively allowing light to pass through the now transparent surface.

Figure 10-3: Voltage-Activated Transparency in PDLC.

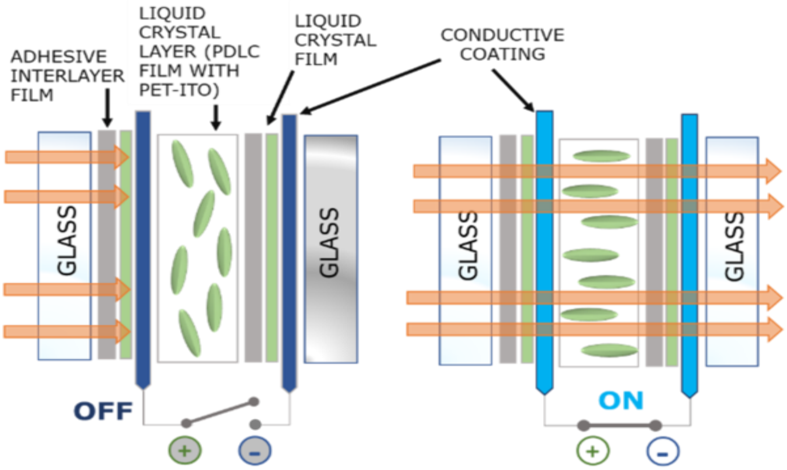


Figure 11-3: Schematic of Polymer Dispersed Liquid Crystal (PDLC) smart glass, in the off and on states.

The degree of transparency in PDLC can be controlled by adjusting the applied voltage. This technology provides a dynamic solution where transparency levels can be altered on demand, offering versatility in managing light and privacy in various architectural applications.

3.1.7 Comparison Between The Three Different Kinds Of Switchable Glass (EC,SPD,PDLC)

	EC	SPD	PDLC
When is transparent?	Switched OFF	Switched ON	
Continuous states between opaque and transparent?	Yes	Yes	No
Requires power to maintain the state?	No	Yes	Yes
Switching speed	Varies depending upon panel size; May take many minutes for large format panels	Several seconds regardless of panel size	Milliseconds regardless of panel size
Light transmission in dark/opaque	SHADING: YES PRIVACY: Typically, some view remains	SHADING: YES PRIVACY: YES	SHADING:
Energy used to operate	Very low	Very low	Very low

Table 1-3: Comparison between the three different kinds of switchable glass (EC, SPD, PDLC).

3.1.8 The Advantages of Smart Glass

1. Light Control: Smart glass provides precise control over the amount of light entering a space. This feature enables customization, allowing users to adjust transparency levels according to their preferences or environmental needs.

2. Energy Efficiency: By regulating the amount of sunlight entering a building, smart glass contributes to energy savings. This controlled approach to natural light reduces the need for artificial lighting, leading to decreased energy consumption and lower utility costs.

3. Ambient Temperature Control: Smart glass can help manage ambient temperature by selectively blocking or allowing sunlight. This feature contributes to improved thermal insulation, helping to maintain comfortable indoor temperatures and reduce reliance on heating or cooling systems.

4. UV Ray Protection: Smart glass is designed to protect occupants from harmful UV rays. By dynamically adjusting transparency, it can limit the penetration of ultraviolet radiation, safeguarding skin and preventing damage to interior furnishings.

5. Low Working Voltage: The technology behind smart glass typically operates at low working voltages, ensuring energy efficiency and safety in its use. This feature makes smart glass a viable and sustainable solution for various applications.

6. Long Life Span: Smart glass undergoes rigorous testing, often surpassing 100,000 cycles in its operational life. This longevity ensures durability and reliability, making smart glass a cost-effective and resilient choice for architectural and design purposes.

In summary, the benefits of smart glass extend beyond more visual adaptability. They encompass energy efficiency, temperature regulation, UV protection, and a prolonged operational lifespan, making smart glass a valuable and sustainable solution for modern spaces.

3.1.9 Applications of Smart Glass

1. Conference Rooms: Smart glass finds valuable application in conference rooms, offering an innovative solution for privacy and adaptability. It allows occupants to transform the transparency of glass partitions, balancing the need for openness during collaborative discussions and privacy during sensitive meetings.

2. Intensive-Care Areas: In healthcare settings, such as intensive-care areas, smart glass can be utilized to enhance patient care. It provides a means to control privacy levels, allowing healthcare professionals to create a more comfortable and adaptable environment for patients.

3. Commercial Buildings, Hotels, and Offices: Smart glass is widely employed in commercial spaces, hotels, and office buildings. It contributes to energy efficiency by controlling the amount of sunlight entering the interiors, reducing the reliance on artificial lighting and HVAC systems. Additionally, it enhances the overall aesthetics of these spaces, providing a modern and dynamic architectural element.

4. Residential Spaces: Smart glass is increasingly being integrated into residential spaces, offering homeowners the ability to control natural light, privacy, and views. It can be applied in windows, doors, or even as room dividers, providing a stylish and functional solution for modern living.
5. Retail Environments: In retail settings, smart glass can be employed for storefronts or display windows. Its ability to transition between transparent and opaque states adds a captivating element to the presentation of products, while also contributing to energy efficiency.
6. Hospitality Industry: Hotels and resorts often utilize smart glass in various areas, from room dividers to bathroom enclosures. This not only enhances the aesthetic appeal but also offers guests the convenience of adjusting privacy levels according to their preferences.
7. Educational Institutions: Smart glass can be applied in educational settings, such as classrooms or lecture halls. It provides flexibility in creating adaptable spaces, optimizing natural light, and enhancing the overall learning environment.
8. Transportation: In the transportation sector, smart glass is used in applications such as automotive sunroofs and windows. It allows passengers to control the level of sunlight entering the vehicle, improving comfort during travel.

Smart glass, with its adaptability and energy efficiency, finds versatile applications in modern architecture. It is transforming spaces in various industries, from offices and hospitals to homes. This technology, capable of converting different glass types into switchable glass, provides flexible solutions. Smart film applications also offer an easy upgrade for existing glass installations, enabling seamless control of privacy through various methods such as wall switches, remotes, smartphones, or voice commands. The dynamic nature of smart glass enhances both privacy and functionality in diverse settings.

Figure 12-3: Smart glass in hospital - versatile privacy solution.

3.2 Comparison between the Smart Glass and Traditional Window Tinting

Smart glass and traditional window tinting serve the common purpose of controlling light and heat entering a space, but they diverge significantly in terms of technology, control, and aesthetics.

3.2.1 Smart Glass

Smart glass, an emerging technology, revolutionizes window treatment with its advanced features.

Users can effortlessly control the intensity of window shading with a simple button press, providing unprecedented control and flexibility.

Integrated directly into window panes, smart glass eliminates the need for labor-intensive manual application of tinting film on individual windows.

The result is a clean, uniform appearance, free from common issues like bubbles or visual defects often associated with traditional film tinting.

While smart glass may entail a higher initial cost, it stands as a compelling alternative for those seeking cutting-edge sensing controls, superior energy efficiency, and a contemporary aesthetic.

3.2.2 Traditional Window Tinting:

Traditional window tinting, a longstanding practice, involves applying tinted film to windows to reduce glare and heat.

Control over tint level is fixed post-application, offering limited flexibility in managing the amount of light entering a space.

The manual application of tinting film on individual windows incurs additional labor costs, and it may lead to visual imperfections.

Although traditionally more cost-effective upfront, traditional window tinting may lack the advanced features and sleek appearance offered by smart glass.

Figure 13-3: Smart Glass vs Traditional Window Tinting.

In conclusion, smart glass emerges as a modern and sophisticated solution, surpassing traditional window tinting in terms of flexibility, integration, and aesthetics. While it may involve a higher initial investment, the benefits in terms of control, efficiency, and visual appeal position smart glass as a compelling choice for those seeking a forward-thinking window treatment option.

3.3Block Diagram

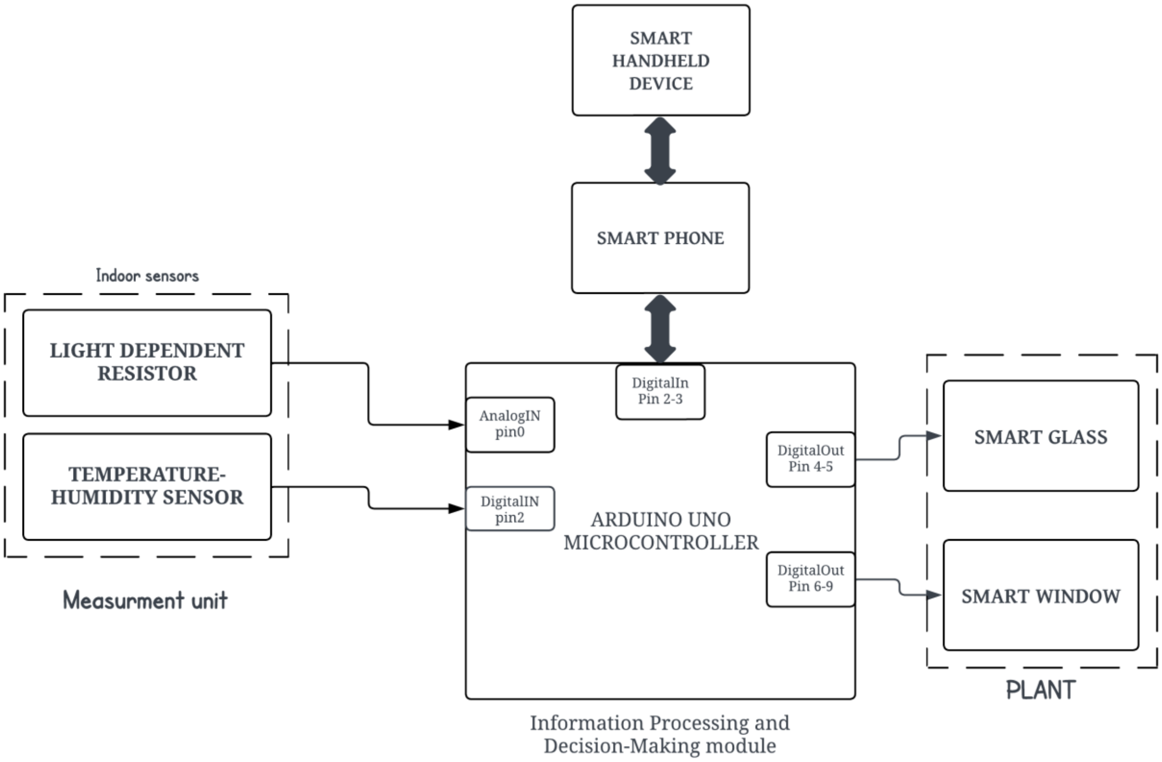


Figure 14-3: Smart Window Block Diagram.

3.3.1 Block Description

The block diagram illustrates a sophisticated system powered by an Arduino UNO microcontroller, integrating a diverse range of sensors and devices tailored for both indoor and outdoor applications. Indoor sensors, such as a Light Dependent Resistor (LDR), Temperature Humidity Sensor. Notably, Smart Glass and a Smart Window have been introduced as innovative elements, ensuring adaptability to changing environmental conditions. These smart components, controlled by the Arduino, enable seamless automation based on sensor inputs. An Information Processing and Decision-Making Module processes this data, dynamically influencing the state of the smart glass and smart window. Additionally, a handheld device allows convenient remote control, making this versatile system ideal for applications in smart home automation and environmental monitoring, offering enhanced control and efficiency.

3.4 Software Implementation

The software used in this project, Arduino IDE. This is an application written in C and C++. Programs can be written and uploaded to Arduino boards. In this project we will use 2.3.2 version.

```
void setup() {
  // put your setup code here, to run once:

}

void loop() {
  // put your main code here, to run repeatedly:

}
```

Figure 15-3: Arduino IDE interface

3.4.1 Arduino Languge

Arduino programming language can be divided in three main parts: functions, values (variables and constants), and structure.

Functions: For controlling the Arduino board and performing computations.

Variables: Arduino data types and constants.

Structure: The elements of Arduino (C++) code.

3.5 Software Design

3.5.1 Transparency control in defferent weather conditions

Figure shows the flowchart of the proposed model. Here, once system starts, the Arduino is measuring the data from sensors and the transparency is adjusted based on the commands given to the Arduino.

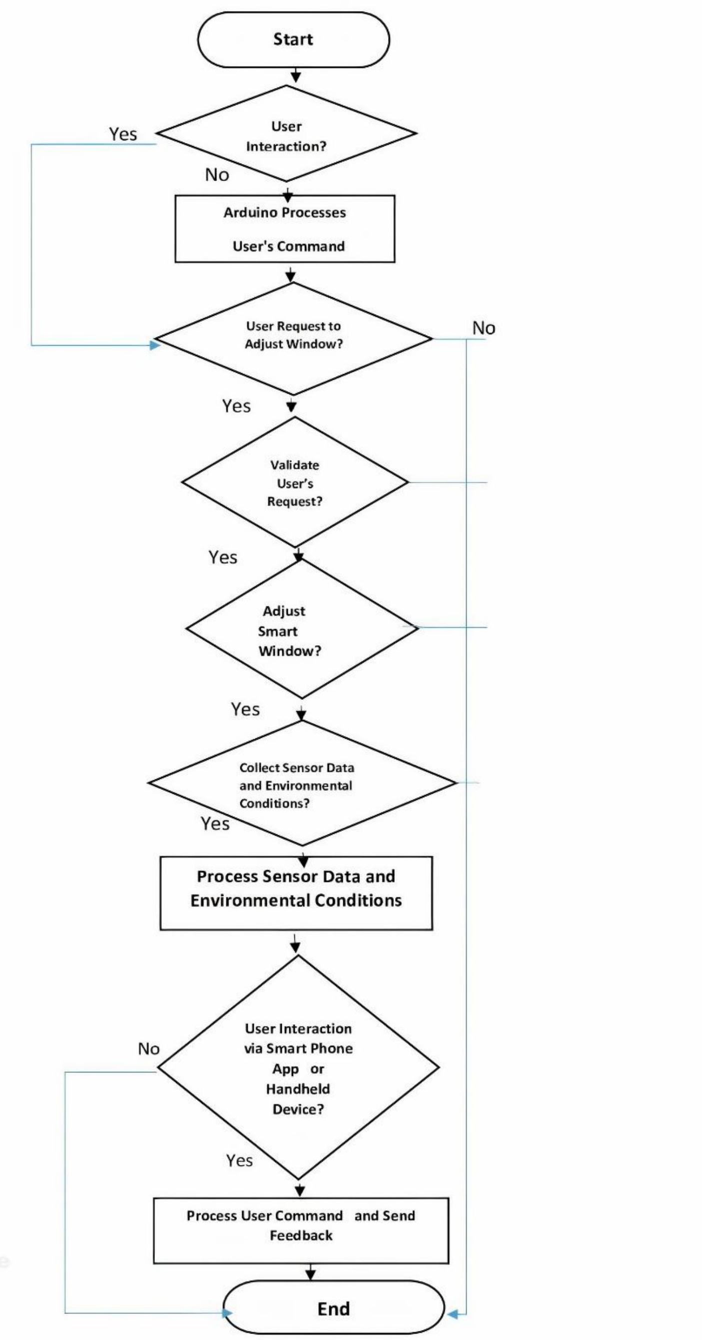


Figure 16-3: Project Flow Chart.

3.5.2 Arduino Code

```
#include "DHT.h" //DHT sensor library
#define DHTTYPE DHT22             // DHT 22 (AM2302), AM2321

const int LDRPin = A0;            // A0 Pin connected to LDR
const int PDLCControlPin = 3;     // D3 Pin connected to IRF740 Gate through a resistor (220Ω)
const int DHTPin = 2;             // D2 Pin connected to DHT22 data


DHT dht(DHTPin, DHTTYPE);

void setup() {
  Serial.begin(9600);             // Initialize serial communication for debugging
  pinMode(PDLCControlPin, OUTPUT); // Set PDLC control pin as an output

  // Set PWM frequency to ~14kHz on pin 3 (using Timer2)
  TCCR2A = 0;
  TCCR2B = 0;
  OCR2A = 113;
  TCCR2A |= (1 << WGM21) | (1 << WGM20);
  TCCR2B |= (1 << CS20);

  dht.begin();                    // Initialize DHT22 sensor
}

void loop() {
  // Read the value from the LDR (0-1023)
  int lightIntensity = analogRead(LDRPin);

  // Read temperature and humidity from DHT22
  float temperature = dht.readTemperature();
  float humidity = dht.readHumidity();

  // Check if any reads failed and exit early (to try again).
  if (isnan(temperature) || isnan(humidity)) {
    Serial.println("Failed to read from DHT sensor!");
    return;
  }

  // Map light intensity to PWM value (190-255)
  int pwmValue = map(lightIntensity, 0, 1023, 255, 190); // Lower limit set to 190
  if (pwmValue < 200){
    pwmValue = 205;
  }
```

```
  // Adjust transparency based on temperature and humidity
  if (temperature < 20 && humidity < 60) {
    pwmValue = 255; // Fully transparent for low temperatures and moderate humidity
  } else if (temperature >= 20 && temperature < 25 && humidity >= 60) {
    pwmValue = map(lightIntensity, 0, 1023, 255, 205); // Adjust transparency based on light intensity and high humidity
  } else {
    pwmValue = map(lightIntensity, 0, 1023, 255, 200); // Default transparency level with lower limit
  }

  // Debug output to check LDR values, temperature, humidity, and PWM value
  Serial.print("Light Intensity: ");
  Serial.print(lightIntensity);
  Serial.print("\tTemperature: ");
  Serial.print(temperature);
  Serial.print(" °C\tHumidity: ");
  Serial.print(humidity);
  Serial.print(" %\tMapped PWM Value: ");
  Serial.println(pwmValue);

  // Apply PWM value to the MOSFET gate to control the PDLC film transparency
  analogWrite(PDLCControlPin, pwmValue);

  delay(2000); // Fixed delay of 2000 milliseconds (2 seconds)
}
```

3.6 Hardware Design

3.6.1.1 Arduino UNO R3 Microcontroller

- Description: The Arduino UNO acts as the central processing unit, managing communication and coordination between all connected devices. It interprets data from sensors and executes commands to control various components within the smart system.

- Key Information: The Arduino UNO has multiple digital and analog pins for connecting to sensors and devices, enabling both input and output operations. It serves as the brain of the smart system.

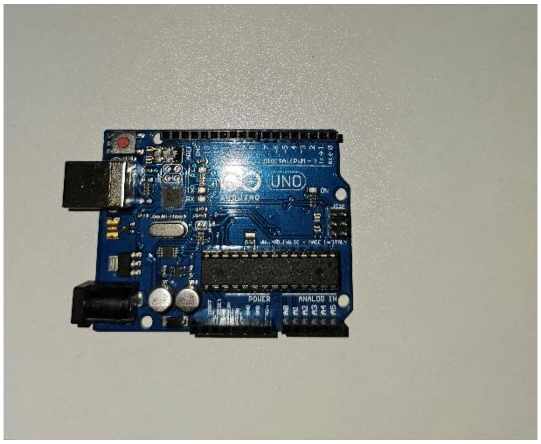


Figure 17-3: Arduino UNO Microcontroller.

3.6.1.2 PDLC module

- Role: The main component that adjusts its transparency based on the voltage applied. It is used to create the smart glass effect.

- Description: PDLC (Polymer Dispersed Liquid Crystal) film that can change its state from opaque to transparent when an electric current is applied.

Figure 18-3: PDLC Module

3.6.1.3 PDLC Driver

- Role: Supplies the necessary voltage to the PDLC module to control its transparency.

- Description: A device that converts the control signals from the Arduino to the appropriate voltage and current needed by the PDLC film.

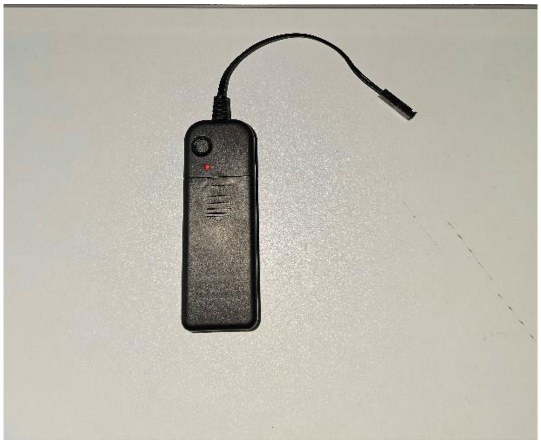


Figure 19-3: PDLC Driver

3.6.1.4 Mobile App (Smartphone)

- Description: A dedicated mobile application transforms our smartphone into a control interface for the smart system. It enables users to interact with the Arduino UNO, providing a user-friendly means to monitor and adjust connected devices and sensors remotely.

Figure 20-3: Mobile App (Smartphone).

3.6.1.5 Light Dependent Resistor (LDR)

- Role: Measures ambient light levels, allowing the system to adjust the PDLC transparency based on light conditions.

- Description: A resistor whose resistance decreases with increasing incident light intensity. It is used in light sensing applications.

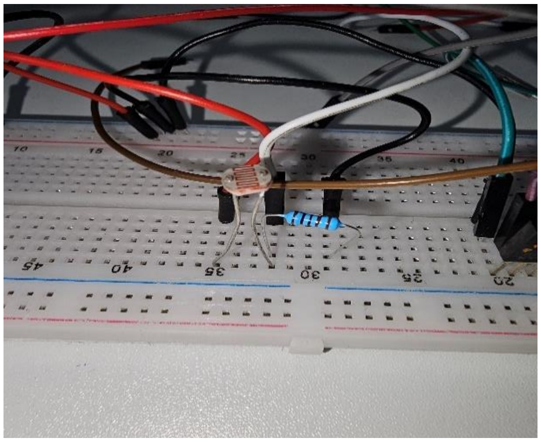


Figure 21-3: Light Dependent Resistor (LDR).

3.6.1.6 DHT Sensor

- Role: Measures temperature and humidity, providing environmental data to the Arduino.

- Description: A sensor that outputs digital signals corresponding to the temperature and humidity levels. Often used for weather monitoring and home automation systems.

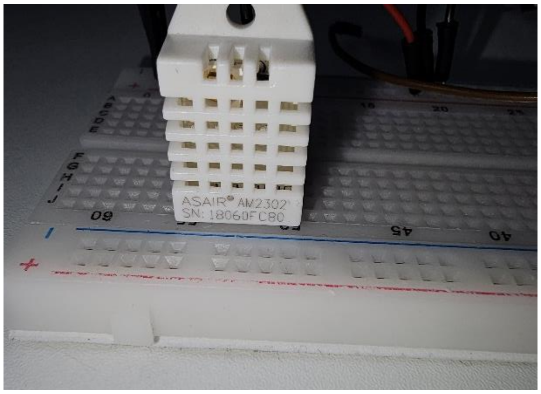


Figure 22-3: Temperature Humidity Sensor (DHT22)

3.6.1.7 Transistor BD137

- Role: Acts as a switch or amplifier in the circuit, used to control higher currents or voltages for the PDLC driver.
- Description: A NPN bipolar junction transistor that can handle moderate currents and voltages.

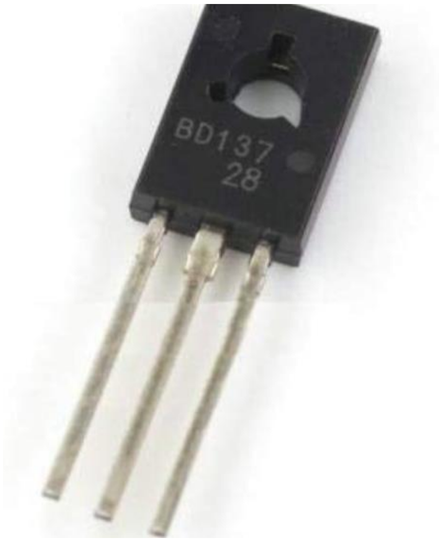


Figure 23-3: BD137 Transistor

3.6.1.8 Breadboard

- Role: Provides a platform to build the circuit without soldering. It allows easy connections and modifications.
- Description: A rectangular plastic board with a grid of holes, used to connect components and wires to build circuits.

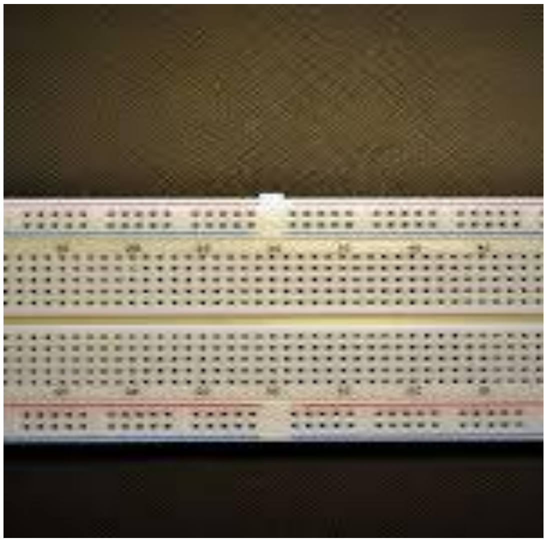


Figure 24-3: Breadboard

3.6.1.9 Power Supply

- Description: Device providing electrical energy to the system for proper functionality.
- Role: Ensures a stable and reliable power source to drive the electronic components of the system.

Figure 25-3: Power Supply.

3.6.1.10 Resistors

- Role: Used to limit current and drop voltage in the circuit.
- Descriptions:
  - 560 Ohm Resistors: Two resistors used in the circuit, typically for current limiting or voltage division.
  - 1K Ohm Resistor: Used in the circuit, potentially for biasing the transistor or as a pull-down resistor.

Figure 26-3: 560 OHM Resistor

Figure 27-3: 1 KOHM Resistor

3.6.1.11Jumper Wires (Male-to-Male and Male-to-Female)

- Role: Used to connect different components on the breadboard and to the Arduino.
- Description: Flexible wires with connectors on both ends, used for making temporary connections between components on a breadboard.

Figure 28-3: Jumper Wires

3.6.1.12 USB Cable A to B

- Role: Provides power to the Arduino and allows for programming and communication with the computer.
- Description: A standard USB cable used to connect devices like the Arduino to a computer for data transfer and power.

Figure 29-3: USB cable A to B

3.6.1.13 Bluetooth Module HC-05

- Role: Provides wireless communication between the Arduino and other Bluetooth-enabled devices.
- Description: A Bluetooth module that enables serial communication over a wireless connection. It operates at 2.4GHz, has a range of up to 10 meters, and supports both master and slave modes. It communicates with the Arduino via serial (UART) interface, making it easy to send and receive data wirelessly. Commonly used for remote control and data transfer applications.

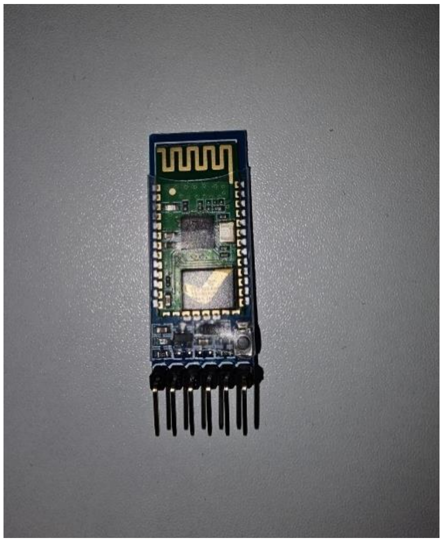


Figure 30-3: Bluetooth Module

3.6.2 Design

Smart Glass Window Project the Smart Glass Window system uses an Arduino Uno to control the transparency of a PDLC module based on environmental conditions. The system includes a DHT sensor for temperature and humidity, an LDR for ambient light, a Bluetooth module for wireless control, and a BD137 transistor for power regulation. Resistors and jumper wires connect components on a breadboard. The Arduino processes sensor data to adjust the PDLC module's transparency, ensuring optimal light and privacy. Users can also control the window remotely via Bluetooth

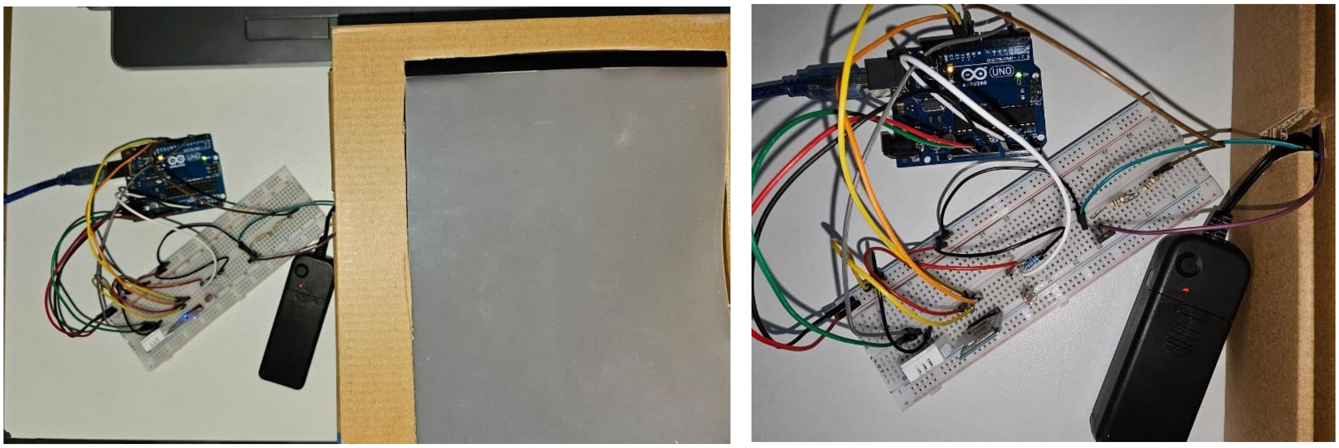


Figure 31-3: Project Design

Chapter Four: Smart Glass Landscape and Comparative Analysis

4.1 Smart Glass Manufacturers

In the realm of smart glass industry, six standout manufacturers lead the way with cutting-edge technologies and solutions.

Manufacturer	Description
Gauzy	Offers smart glass solutions for large-scale commercial projects, automotive, and aerospace industries.
Gentex	Known for innovations in smart glass technology.
Halio	Provides smart glass solutions and has an exclusive agreement with Marvin Windows for residential applications.
Raven Window	Focuses on developing smart glass technology for various applications.
SageGlass	A manufacturer specializing in dynamic glass solutions for energy efficiency and comfort.
View	Known for its smart glass technology used in commercial buildings.

Table 1-4: Manufacturers of Smart Glass.

4.2 Market segmentation

the global market for smart glass and windows is segmented by technology, application, and region. This includes diverse applications in architectural, automotive, aircraft, and consumer electronics sectors across North America, Europe, Asia Pacific, Latin America, Middle East, and Africa.

4.2.1 By Technology The market includes both active technologies (like Electrochromic, PDLC, SPD) and passive technologies.

Technology Type	Examples
Active	Electrochromic, PDLC, SPD
Passive	Tinted, isolated

Table 2-4: technology types of smart glass.

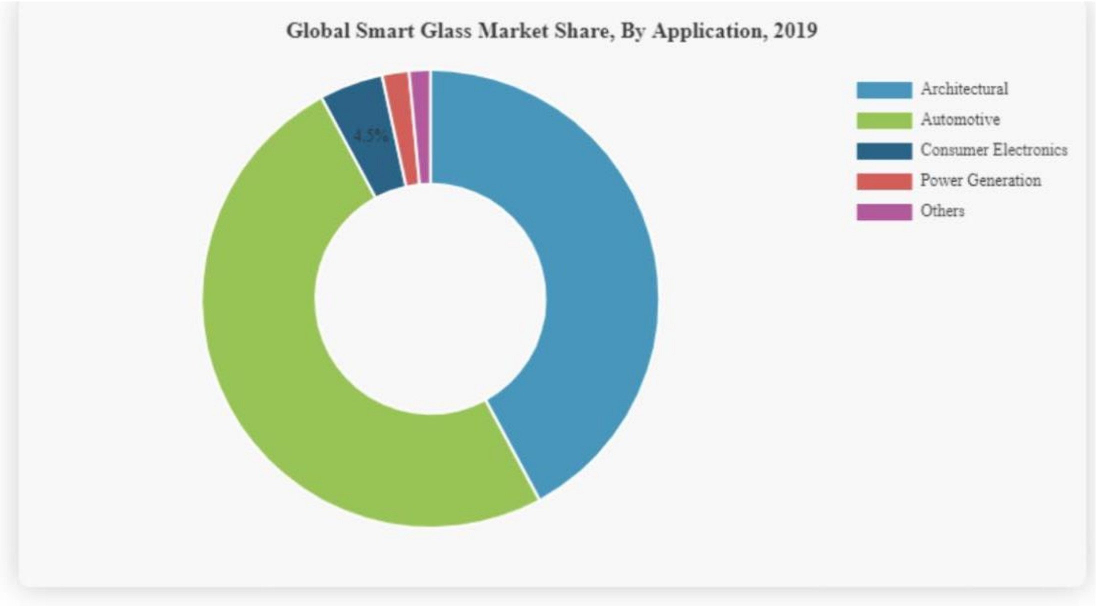


Figure 1-4: Smart Glass Market Segmentation by Application, 2019.

The distribution of smart glass applications. The largest market share is held by architectural applications, followed by automotive, consumer electronics, power generation, and other sectors, signifying the diverse utility of smart glass across industries.

4.2.2 By Application Applications span architectural, automotive, aircraft, consumer electronics, and other sectors.

Application	**Description**
Architectural	Buildings, offices etc.
Automotive	Vehicle windows
Aircraft	Airplane windows
Consumer Electronics	Smart devices and displays

Table 3-4: Application of Smart Glass.

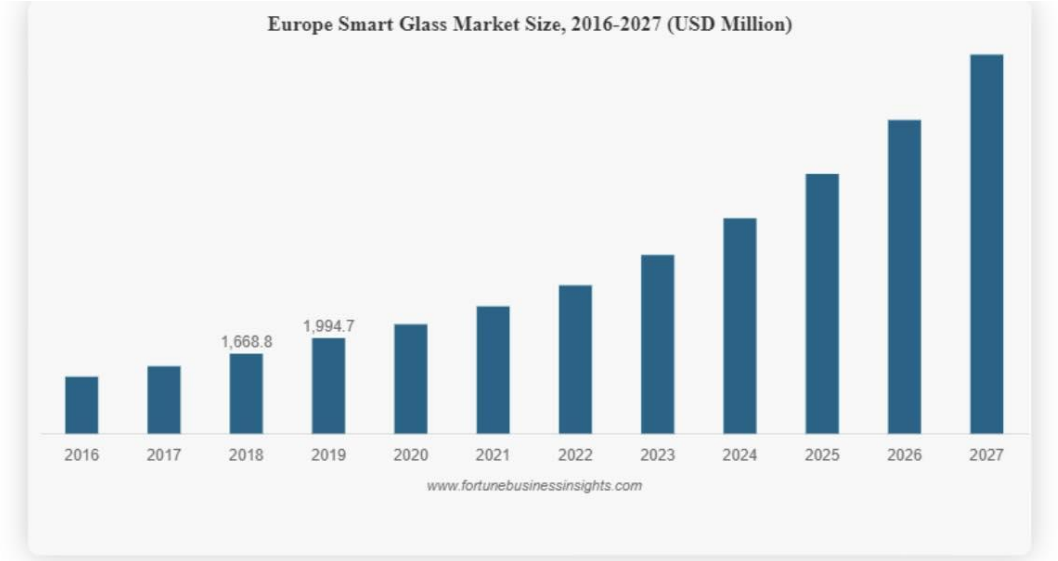


Figure 2-4: Growth Trajectory of the European Smart Glass Market.

4.2.3 By Region North America and Europe are mature markets, while Asia Pacific shows the fastest growth. Opportunities are also identified in the Middle East, Africa, and Latin America.

Region	**Market status**
Europe	Mature Market
North America	Mature Market
Asia Pacific	Fastest growing region
Middle east & Africa	Expected to create significant opportunities
Latin America	Emerging market with growth potential

Table 4-4: By Region market segmentation

4.3 Cost Comparison with Traditional Windows

Smart glass and windows are more expensive than traditional glass and windows, which impacts market expansion. However, the benefits they offer, such as energy efficiency, may justify the higher costs in certain applications.

Aspect	**Smart Glass**	**Traditional Windows**
Cost	Higher initial cost	Lower initial cost
Energy Efficiency	Higher (controls light and heat transmission)	Lower
Technology	Advanced (Electrochromic, PDLC, SPD, etc.)	Basic
Applications	Architectural, Automotive, Aircraft, Consumer Electronics	Residential and Commercial buildings
Market Growth	Expected to grow significantly in the next decade	Stable, with moderate growth
Innovation	High (ongoing advancements in materials and technology)	Low to moderate (limited to design and materials)

Table 5-4: comparison between Smart Glass and ordinary window

4.4 Future of Smart Glass (SWOT Analysis)

1. **Strengths** The innovation in smart glass and window materials and manufacturing technologies are creating new market opportunities.

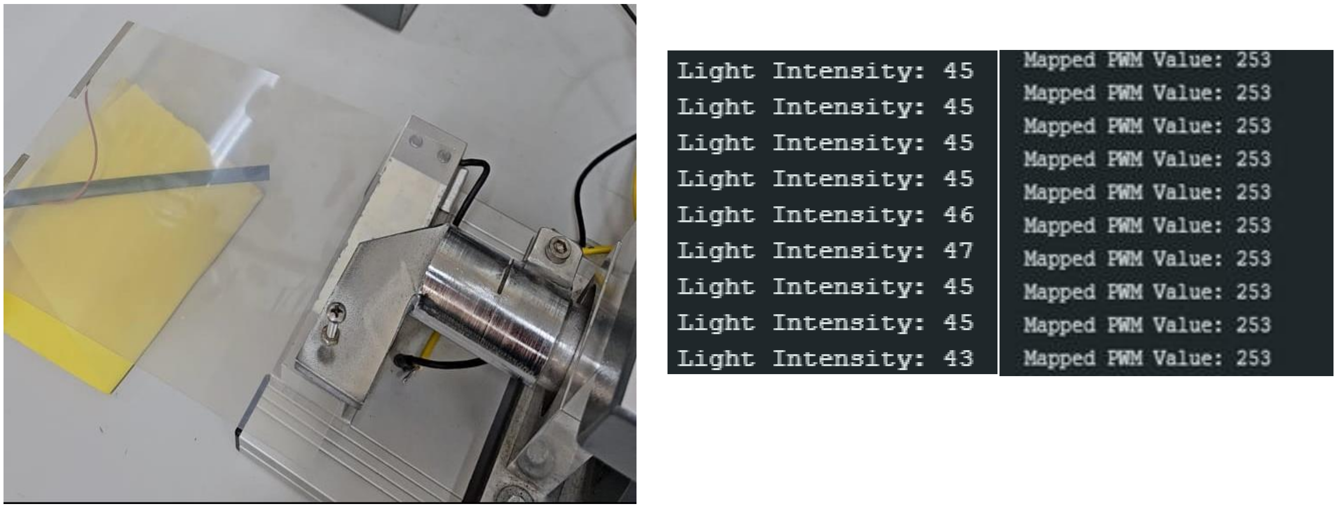
2. **Weaknesses** High costs of smart glass products compared to traditional glass and windows are a significant hindrance to market growth.

3. **Opportunities** There are substantial growth prospects in regions like Asia Pacific, Middle East, Africa, and Latin America.

4. **Threats** Market threats were not directly outlined in the report but could include technological competition and evolving consumer preferences.

Chapter Five: Results and Analysis

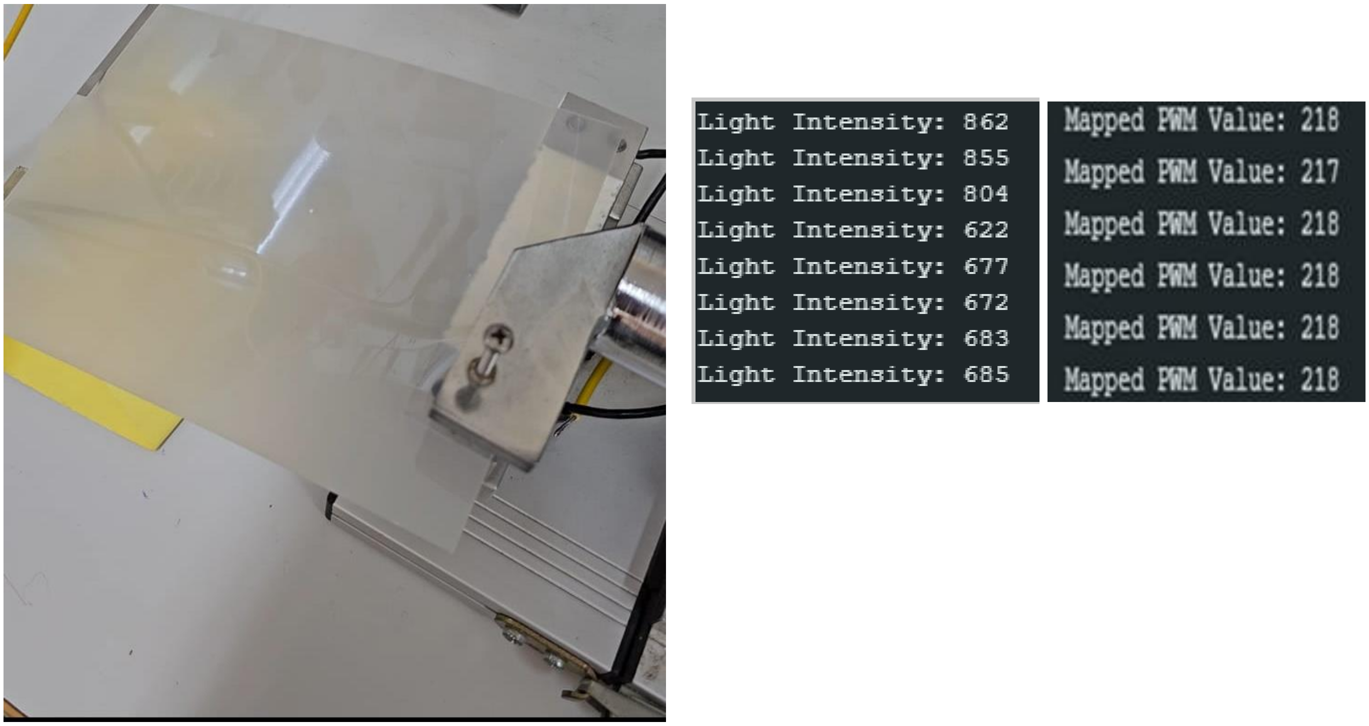
This chapter will include the results and discussion of our project.



```
Light Intensity: 45
Light Intensity: 45
Light Intensity: 45
Light Intensity: 45
Light Intensity: 46
Light Intensity: 47
Light Intensity: 45
Light Intensity: 45
Light Intensity: 43
```

```
Mapped PWM Value: 253
Mapped PWM Value: 253
Mapped PWM Value: 253
Mapped PWM Value: 253
Mapped PWM Value: 253
Mapped PWM Value: 253
Mapped PWM Value: 253
Mapped PWM Value: 253
Mapped PWM Value: 253
Mapped PWM Value: 253
```

Figure 1-5: High transparency conditions



```
Light Intensity: 862
Light Intensity: 855
Light Intensity: 804
Light Intensity: 622
Light Intensity: 677
Light Intensity: 672
Light Intensity: 683
Light Intensity: 685
```

```
Mapped PWM Value: 218
Mapped PWM Value: 217
Mapped PWM Value: 218
Mapped PWM Value: 218
Mapped PWM Value: 218
Mapped PWM Value: 218
```

Figure 2-5: Low transparency conditions

- The figures 1-5 caption confirms that the displayed transparency level is high, corresponding to the high PWM values and low ambient light intensity. This setup demonstrates the effectiveness of the PDLC film in adjusting its transparency based on sensor input, maintaining low transparency in low light and temperature conditions.

- This figures 2-5 demonstrates the system's response to high ambient light intensity by reducing transparency, which is reflected by the lower PWM values compared to previous conditions. The image and data confirm the effectiveness of the PDLC film in adjusting its opacity based on sensor input, ensuring low transparency under high light intensity conditions.

Chapter Six: Conclusions and Recommendation

6.1 Conclusions

The Smart Glass Window project faced high costs and logistical challenges due to the limited availability of PDLC glass, requiring expensive imports. Technical issues arose from the high voltage needs of the PDLC, which were only discovered during implementation. Despite these challenges, the project successfully demonstrated adjustable transparency based on environmental conditions.

6.2 Recommendations

For future projects, thorough research and planning are essential to understand component requirements and availability. Exploring local suppliers and alternatives can mitigate costs and import issues. Detailed documentation and small-scale prototyping can help identify technical challenges early, ensuring smoother project execution.

Project Demo

https://drive.google.com/drive/folders/19xut8mul-swanWSMGKvo0sYLRhiEtJC6?usp=sharing

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