LUMISMART

SMART LIGHT FOR SMART TENANTS

LumiSmart: A Smart Lightning System for Texas Tenants

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The increasing global demand for electrical energy presents significant economic and environmental challenges, and energy efficiency has emerged as one of the essential sustainable solutions (U.S. Department of Energy [DOE], 2023). In conventional lighting systems, constant operation even when no lighting is needed results in immense energy waste and increased carbon emissions. Improvements in lighting efficiency, according to recent data from the U.S. Department of Energy (DOE, 2023), could cut national power consumption by as much as 5% a year—huge economic and environmental dividends.

Texas also has to face high energy expenses. Particularly, energy consumption rates in Texas are 14% above the national average per capita, while residential electricity rates stand at 13.15 cents per kilowatt-hour, significantly exceeding the national average of 11.37 cents/kWh (U.S. EIA, 2023).

The economic structure only makes these challenges worse, especially for a young state with a high renter population like Texas. It is considered the second largest state in terms of renter population, with more than 4 million renters (Fechter, 2024). Additionally, these renters bear an unfair energy burden when 30% of income is spent on rent and utilities since approximately 90% of the state's renter households have incomes below $30,000 (Texas Tribune, 2024).

The impact of the current energy price crisis is hitting the middle and lower classes hard. About 40% of low- to moderate-income Texans cannot afford their electricity bills, and nearly 50% struggle to cover their monthly electricity costs Texas Energy Poverty Research Institute [TEPRI], 2024). Comparatively, families, who have an average household size of 3.2 and a median income of $63,826, spend 8.5% of their income on energy spending (Social Security Administration [SSA], 2023).

In general, the growing demand for electric energy and inefficiencies in existing lighting systems contribute significantly to economic and environmental challenges, particularly in states like Texas where energy costs and consumption rates are well above the national average. This burden is borne largely by low- to moderate-income households, especially renters, who face higher utility costs relative to their incomes. Addressing these issues through improved energy efficiency and targeted policy measures is critical to alleviating financial stress and promoting a more sustainable and equitable energy future.

Competitor Analysis

These competitors represent a wide range of smart lighting solutions based on different technological approaches. **Lifx Plus** focuses on Wi-Fi connectivity and LED lighting control with RGB options, offering high customization for home automation. In contrast, **Leviton OSW12-M** and **StarrBot** offer motion-activated solutions using PIR technology, making them practical for energy savings in more traditional or commercial spaces. However, **Omron D6T** introduces an advanced thermal imaging solution, offering more precision in detecting occupancy, which could be valuable in environments requiring high-level detection without relying on motion. Each technology has its own strengths and use cases depending on the needs of the user. The table 1 below shows a detailed comparison between these competitors.

Table 1

Popular direct competitors use advanced technology to detect humans

Product	**Technology Used**	**Description**	**Additional Features and Benefits**	**Approximate Cost**
Lifx Plus Wi-Fi Smart Bulb	Wi-Fi, LED, RGB (Color Changing), Dimming	The Lifx Plus smart bulb connects via Wi-Fi, eliminating the need for a hub or additional equipment. It is a multicolor RGB LED bulb that offers adjustable brightness, customizable color settings, and scheduling via a mobile app. Integrates with voice assistants like Amazon Alexa, Google Assistant, and Apple HomeKit.	- **Wi-Fi Connectivity:** Directly connects to the internet, no hub required. - **Smart Control:** Allows full control via the Lifx app or voice assistant. - **Energy Efficiency:** Offers energy savings through LED technology and adjustable brightness levels. - **Remote Control & Automation:** Can be controlled remotely and scheduled to turn on or off based on time of day.	$40-$50 per bulb
Leviton OSW12-M Occupancy Sensor	Infrared (Passive Infrared - PIR) Motion Detection	The Leviton OSW12-M sensor detects movement through passive infrared technology. When it senses motion within a specified range, it sends a signal to connected lights to turn on, and conversely, it turns the lights off when no movement is detected for a set duration. It's often used in commercial and residential environments for energy savings.	-**Motion Sensing:** Detects motion from body heat and movement. - **Automatic Lighting Control:** Automatically switches lights on or off based on occupancy. - **Adjustable Sensitivity:** Sensitivity and time-out period can be customized based on user needs. - **Cost-Effective:** Low-cost solution for energy efficiency in homes and offices. - **Works with Most Lighting Fixtures:** Compatible with most standard light bulbs and fixtures.	$25-$35 per sensor

StarrBot Motion Sensor Lights	Infrared (Passive Infrared - PIR), Motion Detection	The StarrBot motion sensor light works similarly to other PIR-based systems but is designed for more specific commercial or residential applications. It automatically activates the lights upon detecting motion within its sensor range, ensuring that energy is not wasted in unoccupied spaces. It is typically easy to install and energy-efficient.	- **Motion Detection:** Uses passive infrared technology to detect human movement. - **Wide Coverage Range:** Can cover larger areas for commercial or home applications. - **Energy-Efficient Design:** The system minimizes energy wastage by only turning lights on when needed. - **Customization:** Often has adjustable settings for time delay and motion sensitivity. - **Cost-Effective:** Budget-friendly for both residential and commercial use.	$15-$40 per light
Omron D6T Thermal Sensors	Thermal Imaging (Thermopile Array)	The Omron D6T is a highly sophisticated thermal sensor array that detects temperature changes across a broad area. Unlike PIR sensors, it can detect the presence of individuals even if they are not moving, based purely on body heat. This provides a higher level of accuracy in occupancy detection, particularly in environments where subtle movement may not be detected by traditional sensors.	- **Thermal Sensing:** Uses arrays of thermopiles to detect heat signatures, even in the absence of motion. - **High Precision:** More accurate than traditional PIR sensors, can detect human presence with minimal or no movement. - **Non-Intrusive Detection:** Ideal for situations where privacy is a concern, as it doesn't require detecting motion. - **Advanced Applications:** Suitable for smart homes and offices	$200-$350 (Depending on configuration)

Competitor Evaluation

All of these products use advanced sensor and smart technology to provide enhanced control and functionality. However, this comes at a higher price point, averaging around $40, with some models, like the Omron D6T Thermostat Sensor, ranging from $200 to $350. This cost can be a barrier for low- to moderate-income renters. Additionally, the connectivity features increase the risk of unauthorized access and raise privacy concerns, especially when detailed data about occupants' presence is involved. Furthermore, these devices often require technical expertise to install and set up properly, making them challenging for users without technical skills.

Problem Statement

This project aims to develop an affordable, standalone smart lighting system specifically designed for Texas renters, addressing the challenges of excessive energy consumption and high electricity bills, while providing a user-friendly, easy-to-install solution that fits within tenancy conditions and minimizes the risks associated with connecting technology in shared settings.

Recommendation

After analyzing the advantages and disadvantages of existing technologies and competitors on the market, and considering customer needs, we developed the idea of an integrated lighting system that combines ultrasonic and infrared (IR) technology with an ambient light sensor. This approach maximizes the strengths of each sensor type: Ultrasonic sensors effectively detect larger movements, while IR sensors are sensitive to smaller motions and body heat. Together, these sensors reduce false triggers and improve reliability, ensuring that lights are activated only when necessary. The addition of ambient light sensing prevents unnecessary activation during daylight hours and adjusts lighting based on natural light conditions, adding another layer of energy efficiency.

With our portable design, we offer an affordable solution ideal for households, especially renters, with easy, non-invasive installation and minimal setup. This simple yet highly accurate design also helps renters reduce their energy bills, while providing a cost-effective and technically safe alternative to more expensive, technically vulnerable high-end lighting solutions on the market.

The aim of this solution is to significantly reduce residential electricity consumption by optimizing the use of lighting. By implementing this smart system, tenants can effectively reduce energy costs while contributing to environmental sustainability. The solution supports broader initiatives focused on energy efficiency and ecological responsibility, providing a modern approach to energy management in residential environments.

Project Scope

Target Consumers

Following the previous parts, the main target consumer of this project is Texas tenants.

However, based on their need for an easy-to-install and affordable device, the project can serve well the following types of consumers:

- lower-income households need cost-effective, energy-efficient lighting.
- renters looking for a portable, non-permanent solution.
- college students in dorms or shared living spaces seeking flexibility.
- elderly individuals for improved safety and convenience.
- small business owners in temporary setups like pop-up shops.

Project Location

All data and information in this project was collected for Texas. It is also designed for standard bedrooms in Texas, typically measuring 11 feet by 12 feet (132 square feet) (Stewart, 2017).

Product Functions

To solve the problem stated, LumiSmart focuses on serving the following main functions:

- detecting human presence accurately.
- reducing false detections from a single sensor.
- adjusting light levels to match natural light in the environment.
- easy and non-invasive installation/uninstallation (no additional repair costs due to damage to the rental room).
- no technology connection required (reduces the risk of using complex software and connecting to shared settings).

Executive Summary

Purpose of Project

The Energy Efficient Lighting Project was designed and implemented to meet the growing energy efficiency needs of Texas' approximately 4 million renters, nearly 90% of whom are cost-burdened. Under lease agreements, tenants are typically not allowed to make interior changes to their homes without the landlord's permission and incur additional costs. Additionally, similar products from competitors that incorporate advanced technology are often at high risk of being hacked and invading privacy. Therefore, this safe, affordable, and non-invasive lighting design that incorporates both PIR and ultrasonic technology with high accuracy will meet the enormous needs of Texas' large number of renters.

Methods

An in-depth research about the technology theories were conducted with information gathered from academic sources, such as peer-reviewed articles. In addition, detailed data about the rental unit is carefully collected from reliable sources into the calculation to increase the practicality of the design. We then designed and tested multiple electrical models with different components and coding programs to find the most efficient design on Tinkercad simulation. Finally, we assembled the necessary components to build a visual and dynamic prototype.

Evaluation and Conclusion

PIR sensors are good for detecting motion, while they do not work with static objects. In addition, our affordable PIR sensors have a limited adjustment range. On the contrary, ultrasonic sensors can detect static objects effectively. With the help of potentiometers, we can freely adjust the detection range of ultrasonic sensors to suit the average room size of most tenants. This integration creates the perfect human detection device with high accuracy at low cost to serve the target consumer - Texas renters well.

Project Constraints and Criteria

To ensure that the LumiSmart device can meet industry standards and be competitive in the market, the project constraints and criteria are analyzed in the following table.

Table 2

Basic Requirements for a standard LumiSmart device

Features	Requirements
Budget	$60–$100 budget for a prototype
Safety	● **Materials**: human-friendly and non-toxic ● **Design**: prioritizes safety, with proper insulation and safe circuit

	design. This helps minimize risks such as electrical leakage or electric shock. The enclosure protects the user and prevents damage to household furniture (Kumar et al., 2022).
Durability	The product's estimated lifespan is at least 5 years, compared to the average lifespan of the industry. Particularly, ● Arduino Uno Microcontroller: typical 3 to 5-year range (Arduino Forum, 2017). ● Ultrasonic Sensor: approximately 6 to 8 years (IPMI, 2019). ● PIR Sensor: approximately 5 to 10 years ((Lee & Kim, 2022). ● Light Bulb: an average lifespan of 15,000 to 25,000 hours, approximately 5 to 10 years of regular use (Energy Star, n.d.). ● Potentiometer: ranges from 10,000 to 50,000 cycles (Allelco Electronics, 2024).
Installation	user-friendly, requiring minimal technical skills (1-2 setup steps)
Function	● automatically detects human presence ● automatically dims the light level to match the natural light in the environment ● be able to adjust the detection range of the device

Specifications

Based on the Constraints and Criteria section and the industry standard, the LumiSmart device aims to achieve the specifications' features as shown in the following table.

Table 3

Specifications for a Standard LumiSmart Device

Performance Requirements	
Motion Detection Range: ● Ultrasonic Sensor ● Infrared (PIR) Sensor	● up to 4 meters; effective in a 60-degree field of view; operational both day and night. ● up to 6 meters; effective in a 120-degree field of view; operational both day and night.
Sensitivity	adjustable manually using a potentiometer (Munier, 2022).
Light Output	adjustable brightness through the mobile app.
Color Temperature	not specified, but could be made adjustable via the app.

Power Consumption	estimated at 5 watts during full operation.
Functional Requirements	
Motion Activation	utilizes both PIR and ultrasonic sensors to detect motion and activate lighting automatically (Munier, 2022).
App Integration	no technology connectivity
Power Supply	designed for standard AC outlets (110-240V).
Installation Locations	suitable for installation in living rooms, hallways, offices, and bedrooms.
Environmental Requirements	
Operating Temperature	-10°C to 50°C.
Humidity Range	10% to 90% relative humidity (RH).
Ingress Protection	basic splash resistance; not fully waterproof or heatproof (Munier, 2022).
Safety and Compliance	
Material	constructed with fire-retardant ABS plastic (UL 94 V-0 rating), which prevents flame spread and extinguishes within 10 seconds (Munier, 2022).
User Interface	
Control Options	• Physical Switch: manual control with a toggle or push-button switch. • Remote Control: optional remote control available for distance-based operation without a smartphone.
Status Indicators	• Power Indicator: Green LED. • Sensor Status Indicator: Yellow/red LED for sensor functionality or fault detection.
Maintenance and Durability	
Life Expectancy	Minimum life expectancy of 50,000 hours for LED lights, sensors, and microcontroller, aligning with industry standards (Munier, 2022).
Warranty	1-year limited warranty covering manufacturing defects; excludes damages from improper installation or modifications.
User-Replaceable Components	The bulb and sensors are not user-replaceable; service may be required for component replacement.

Process of Design

Project Design Flowchart

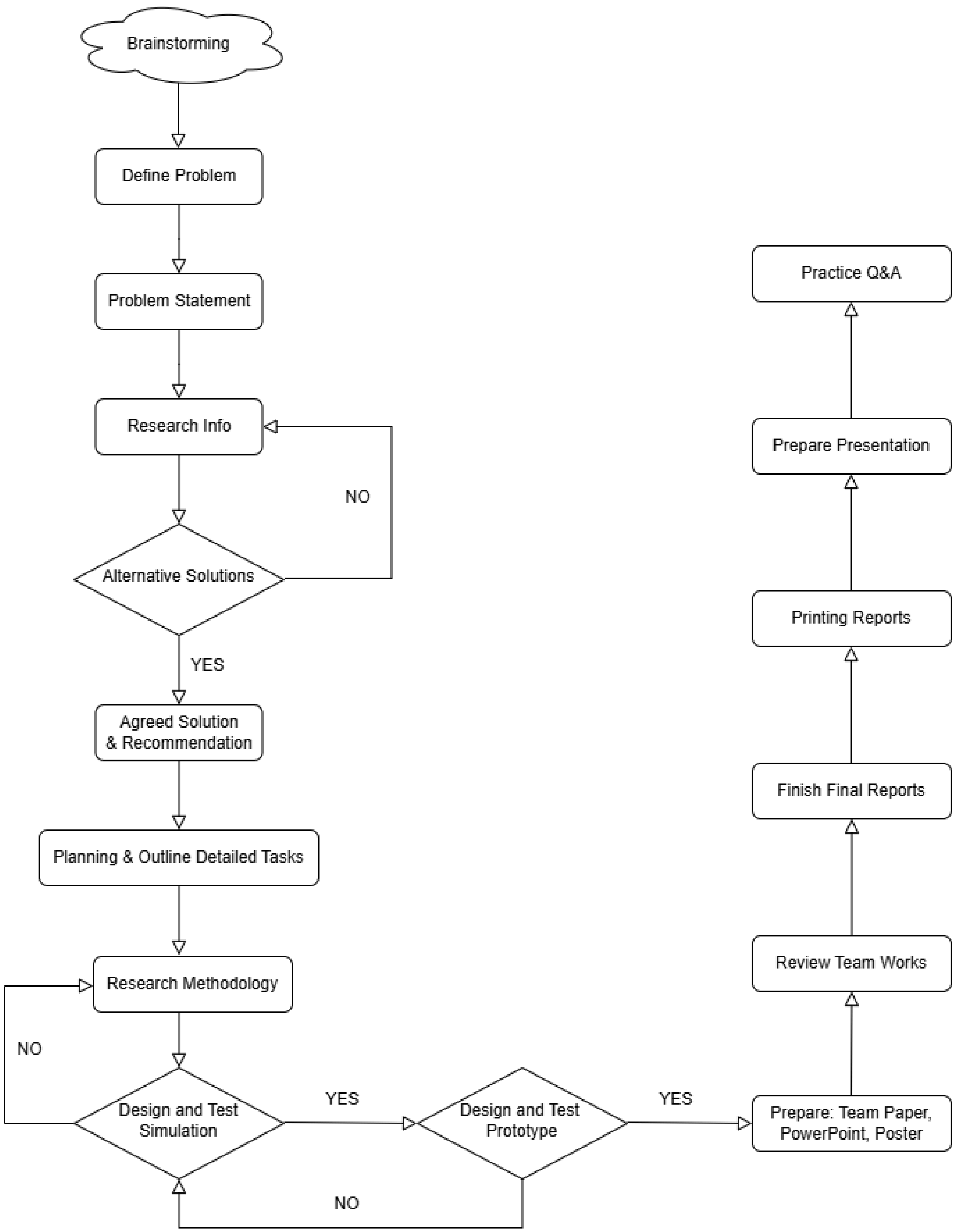

Figure 1. Flowchart for LumiSmart Project

Coding Flowchart

Based on the proposed recommendation, this project comes up with the main components and coding scheme shown below.

Table 4

Symbols for LumiSmart Device's Components Used in The Coding Flowchart

INPUT	
P-signal	Potentiometer signal is manually set by the user to adjust the distance threshold of the ultrasonic sensor.
U-signal	The echo signal of ultrasonic sensor
L-signal	The ambient light level is gotten from the ambient light sensor
PIR-signal	The PIR signal is gotten from the PIR sensor
OUTPUT	
LCD	LCD display
Led	Led light is used to bright your room

The diagram in Figure 2 illustrates the decision-making process for controlling a LumiSmart smart lighting system using integrated sensors. The system takes four inputs: P-Signal (user-set threshold from the potentiometer), U-Signal (echo from the ultrasonic sensor), L-Signal (ambient light level), and PIR Signal (motion detection from the PIR sensor). The process starts by checking if the PIR signal indicates motion (HIGH) and the object is within the user-defined range ([U-signal < P-signal] means the distance of the object is within the distance threshold). If both conditions are met, the system evaluates the ambient light level (corresponding to L-signal). If the L-signal is less than 300 (not enough light in the room), the light will be set to maximum brightness and the LCD will display “Light Bright: Full”. Otherwise, the light will dim, corresponding to the light level and “Light Bright: Dim” will be displayed. If no movement is detected or an object is out of range, the system will turn off the light and the LCD will display "Light Off". This logic optimizes energy efficiency by adjusting the light based on movement, distance and ambient light levels.

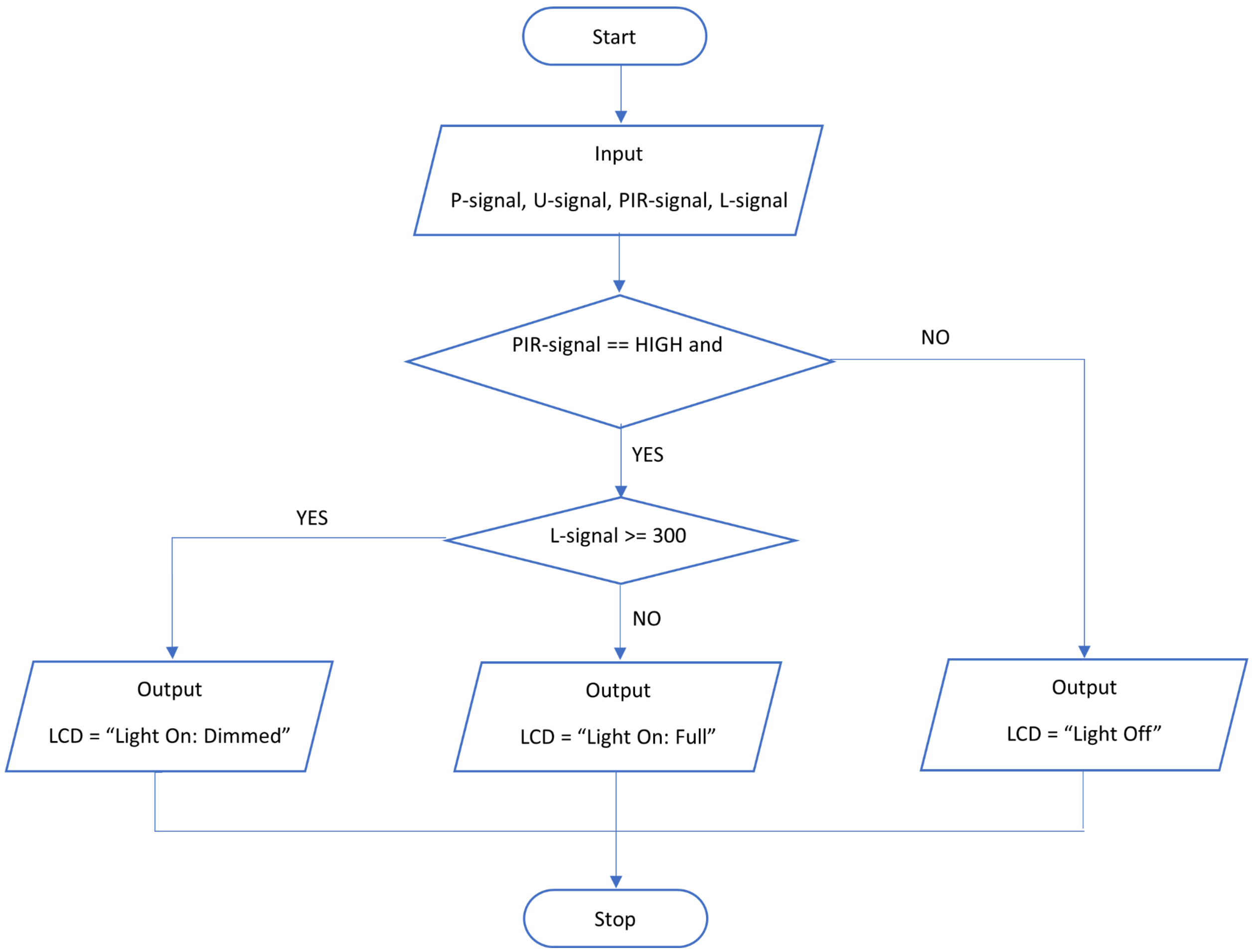

Figure 2. Coding Flowchart for LumiSmart prototype

Methodology

Tinkercad Simulation

To streamline the development process and optimize manufacturing costs, we used the Tinkercad Simulation platform for the initial design phase. By testing out various circuit concepts and coding schemes in a virtual environment, we were able to conduct various engineering testing and design adjustments without the risk of costly physical prototyping. This approach allowed us to efficiently evaluate various electrical components, leading to the final circuit design shown in Figure 3 below.

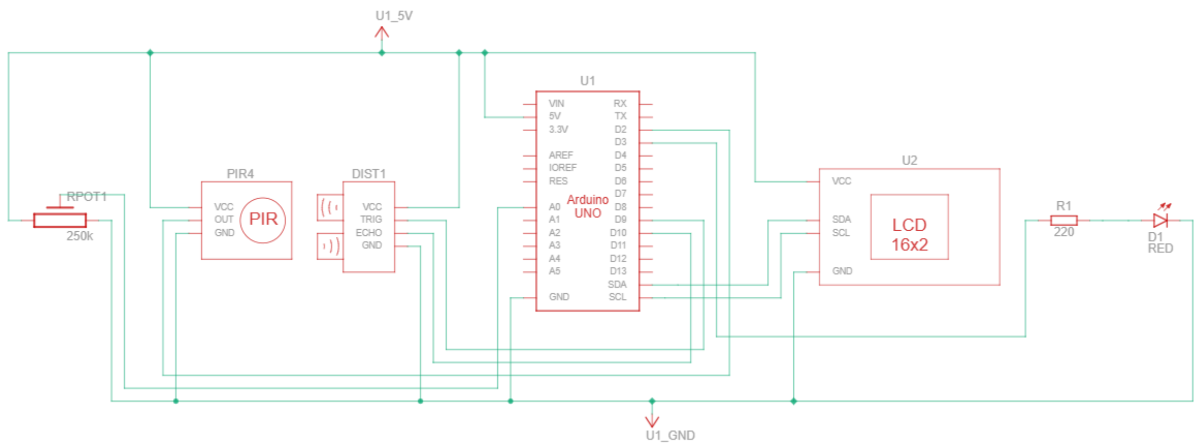

Figure 3. Schematic design for LumiSmart circuit (Source: Tinkercad, 2024).

Main Electrical Components

The LumiSmart prototype has key components that support the core functions of human detection and LED light level dimming as shown in Figure 4 below.

Quantity	Component
1	Arduino Uno R3
1	PIR Sensor
1	250 kΩ Potentiometer
1	Ultrasonic Distance Sensor (4-pin)
1	Red LED
1	220 Ω Resistor
1	MCP23008-based, 32 (0x20) LCD 16 x 2 (I2C)

Figure 4. Component list for LumiSmart circuit (Source: Tinkercad, 2024).

Passive Infrared (PIR) Sensor

Passive infrared (PIR) sensors are widely utilized in motion detection systems due to their ability to sense infrared radiation emitted by warm objects, such as humans. They operate without emitting any energy, hence the term "passive." This section delves into the working principles of PIR sensors, their methodology in detecting human movement, and provides illustrative images to enhance understanding.

Working Principle of PIR Sensors

PIR sensors consist of a pyroelectric material that generates an electrical signal when exposed to infrared (IR) radiation. The sensor is divided into two halves, each sensitive to IR radiation. Under static conditions, both halves detect the same amount of IR radiation from the environment, resulting in no net signal. When a warm object, such as a human, moves across the sensor's field of view, it sequentially activates one half and then the other, causing a change in the differential signal. This signal is processed to detect motion (Zhao et al., 2014).

The PIR sensor's ability to detect human movement is based on three key components:

Pyroelectric Sensor: Detects changes in IR radiation caused by movement.

- Fresnel Lens: Focuses IR radiation onto the sensor and defines multiple detection zones, enhancing sensitivity.
- Signal Processing Circuit: Amplifies and processes the electrical signal to determine the presence of motion.

When a person comes within the detection range of the sensor, the Fresnel lens focuses the infrared radiation emitted by the person on the pyroelectric sensor. This causes a change in the electrical signal, which is then processed as motion by the signal processing circuit (Zhao et al., 2014). The detection process of the PIR sensor is illustrated in detail in Figure 5 below.

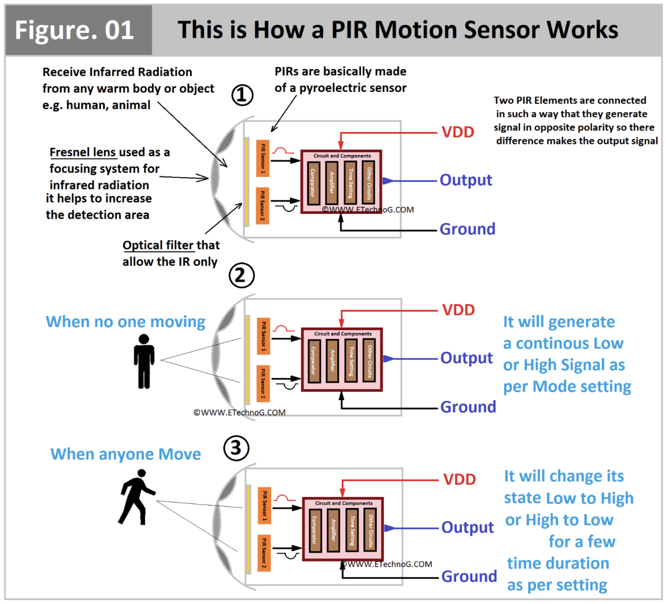

Figure 5. How a PIR sensor works (Source: ETechnoG, n.d.)

Ultrasonic Sensor

In the LumiSmart system, a single-probe ultrasonic sensor plays a key role in detecting presence and controlling lighting based on distance. The sensor works by emitting ultrasonic waves and measuring the time it takes for the echo to return after reflecting from nearby objects, a principle known as time-of-flight measurement.

The ultrasonic sensor consists of a piezoelectric transducer that acts as both a transmitter and a receiver as shown in Figure 6. When an electrical signal is applied, the transducer vibrates, emitting ultrasonic waves typically at a frequency of around 40 kHz. These waves propagate through the air until they encounter an object, where they are then reflected back to the sensor. The transducer then switches to receiving mode, collecting the reflected waves. By calculating the time interval between emission and reception, the system determines the distance to the object, since distance is proportional to the time it takes for the echo to return (Toa & Whitehead, 2021). Using a single converter simplifies design and reduces costs, making it an efficient solution for smart lighting applications.

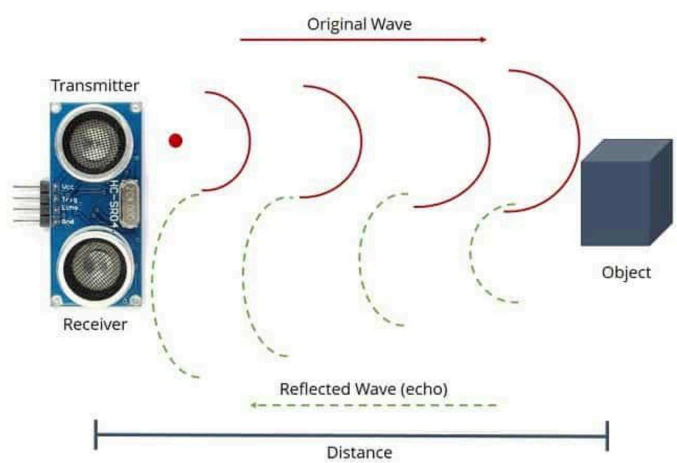

Figure 6. How an ultrasonic sensor works (Source: Dubey, 2020).

Ambient Light Sensor (ALS)

In the LumiSmart device, the ambient light sensor is a key component that measures the ambient light intensity to adjust the brightness of the LEDs accordingly. This sensor works by detecting the ambient light level via an analog input and providing a corresponding analog value. The system uses this value to determine whether the room is bright enough or needs more light.

When both the PIR and ultrasonic sensors detect motion and proximity, the system evaluates the ambient light level.

- If the ambient light level is above a threshold, showing that the room is bright enough, the system dims the LED light to save energy.
- If the ambient light level is below the threshold, indicating that the room is dark, the system will increase the brightness of the LED light to increase visibility.

This dynamic adjustment ensures optimal lighting conditions while supporting energy savings.

Potentiometer

In the LumiSmart lighting system, the potentiometer serves as a crucial component for manually adjusting the distance threshold of the ultrasonic sensor. This adjustment allows the device to change its sensitivity to object distance, thus increasing the ability to adapt to various room sizes and user preferences.

A potentiometer is a three-terminal resistor (shown in Figure 7 below) with sliding or rotating contacts that forms an adjustable voltage divider. By adjusting the potentiometer, users can change the input voltage, which the Arduino reads as an analog value ranging from 0 to 1023. This value is then mapped to a specific distance range, allowing real-time adjustment of the distance threshold for the ultrasonic sensor. For example, in a small room, a lower threshold can be set to detect nearby objects, while in a larger space, a higher threshold might be more necessary (Kumar et al., 2022).

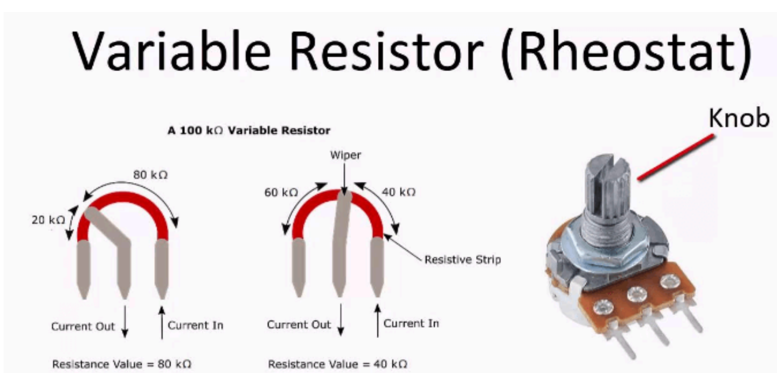

Figure 7. Potentiometer as a Variable Resistor (Source: Allelco Electronics, 2024).

The Functioning Principle

The integration of ultrasonic, PIR and ambient light sensors in a smart lighting system enables efficient and reliable control of the lighting system based on multiple environmental signals. The microcontroller continuously reads data from all three sensors, making decisions based on the following logic.

Motion Detection with PIR Sensor

When the PIR sensor detects movement, it triggers a flag indicating the presence of a person.

Object Distance with Ultrasonic Sensor

The Ultrasonic Sensor checks for objects or obstacles within a preset distance threshold. If an object is detected within range, it confirms the presence of a person.

Ambient Light Adjustment

The ambient light sensor measures the current light level. If the light level is lower than the threshold (in this case, the threshold is half the average rental room size), the system decides to turn on the LED lights.

Summary

By integrating PIR sensors and ultrasonic sensors into the LumiSmart smart lighting system, the power of both technologies can be used to provide more reliable detection as illustrated in Figure 8 below. PIR sensors provide rapid motion detection through infrared sensing, while ultrasonic sensors continuously monitor presence, even when the individual is not moving (Murata Manufacturing Co., Ltd., 2019). The ambient light sensor further refines the system by adjusting the brightness of the lights based on the amount of natural light, thereby optimizing energy usage and maintaining consistent illumination levels. This combination improves the energy efficiency of the system and reduces the likelihood of false positives by ensuring the lighting responds to the actual human presence.

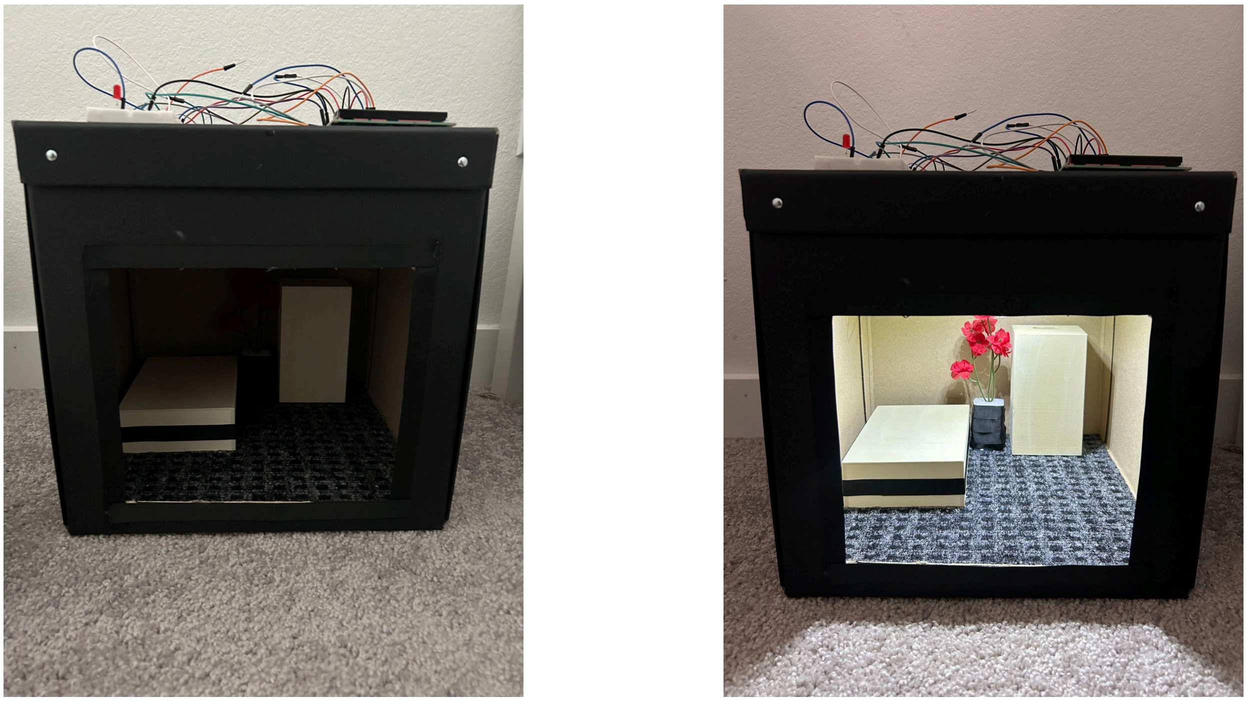

Figure 8. Illustration of LumiSmart prototype in action

Technical Implementation

The sensors are connected to the Arduino microcontroller using predefined pins:

PIR sensor connects to digital pin 2, reads as a binary input (HIGH/LOW).

- Ultrasonic sensor uses digital pins 9 (trigger) and 10 (response) to measure distance.
- Ambient light sensor connects to analog pin A0, providing a variable voltage based on light intensity.
- LED light is connected to pin 3, uses PWM (Pulse Width Modulation) for dimming.

The microcontroller's loop function continuously reads sensor data and makes decisions based on adjusted thresholds. The LCD display provides real-time feedback on the status of the system, showing whether the light is on or off and the current light level. The Figure 9 below shows the circuit model of the prototype of LumiSmart light system.

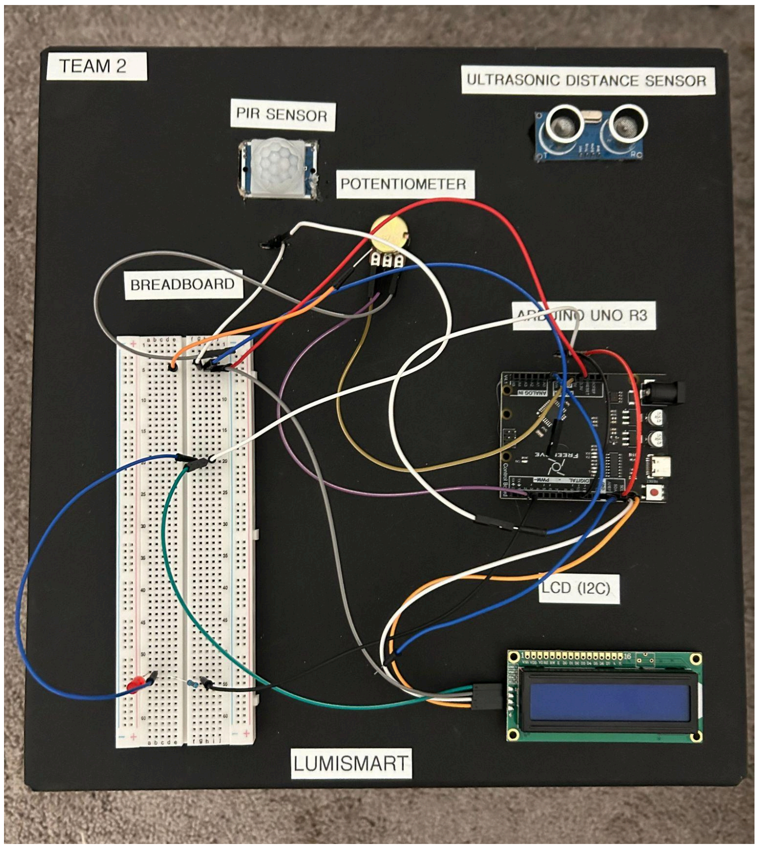

Figure 9. The Circuit Model of The Prototype of LumiSmart Light System

Calculations

Distance Threshold Measurement

By calculating a distance threshold based on real room size, the system is adjusted to the actual occupancy size, improving efficiency and responsiveness. According to data from the

Scope section, an average standard rental room can be approximated with an area of about 132 square feet.

1 square foot = 0.092903 square meters.

Area in square meters = 132 × 0.092903 = 12.26 (m^2).

Assuming the room is approximately square-shaped, we can calculate the side length of the room using the formula for the area of a square:

$$\text{Side length} = \sqrt{\text{Area}} = \sqrt{12.26} \approx 3.5\,\text{meters}$$

The Distance Threshold in the code is defined as half the length of the side of the room due to the central location of the LumiSmart device on the ceiling of the room.

$$\text{Distance\_Threshold} = \frac{\text{Side length}}{2} = \frac{3.5\,\text{m}}{2} = 1.75\,\text{m}$$

In the Arduino code, this threshold value is approximated and set to 178 cm for practical purposes. This small adjustment ensures that the sensor can reliably detect objects in typical room sizes, taking into account variations in the actual room layout and sensor accuracy.

Working Principle of Ultrasonic Distance Measurement

The HC-SR04 ultrasonic sensor measures distance using the principles of sound wave propagation. It consists of a transmitter and a receiver. The transmitter emits an ultrasonic pulse at a frequency of 40 kHz, which travels through the air. When the pulse hits an object, it is reflected back to the receiver. The time the pulse is reflected is recorded and the distance is calculated using the formula:

$$\text{Distance} = \frac{\text{Time} \times \text{Speed of Sound}}{2}$$

The speed of sound in air is about 343 meters per second at room temperature. The division by two accounts for the round trip time of the pulse (Kumar et al., 2022).

Implementation in Smart Lighting System

In the LumiSmart device, the HC-SR04 is connected to an Arduino microcontroller. The Arduino triggers an ultrasonic pulse and waits for a response. By measuring the response time, the system calculates the distance to the nearest object. If the measured distance is lower than a predefined threshold (adjustable via a potentiometer), it indicates that an object or person is nearby. This information, combined with the motion detection from the PIR sensor, will activate the LED. The light intensity is further adjusted based on ambient light readings, providing an efficient and adaptive lighting solution.

Scheduling

A detailed timeline is noted in Figure 10 below to show the time from idea to completion of a LumiSmart prototype.

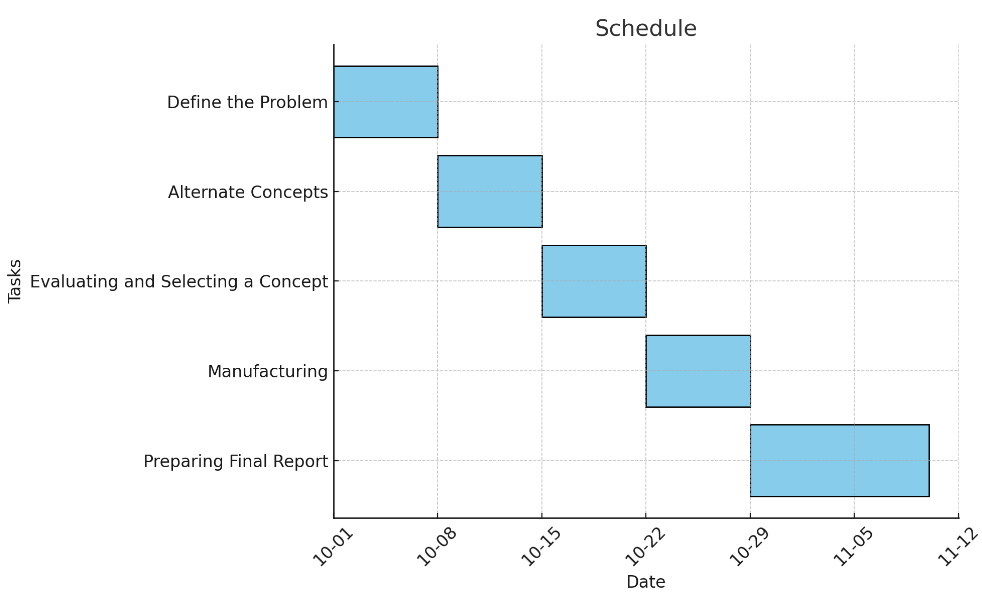

Figure 10. Design Schedule for LumiSmart Prototype

Prototype Production Cost

The table 5 below shows the actual prototype cost to create a LumiSmart prototype with the actual detailed price of each component.

Table 5

LumiSmart Prototype Cost for Components

Component	Estimated Cost	Source
Arduino Uno	$3.28	AliExpress
LCD display	$6.99	Amazon
HC-SR04 Ultrasonic Sensor	$0.39	AliExpress
Potentiometer	$0.34	AliExpress
Bread Board	$0.53	AliExpress
Led light bulb	$1.00	AliExpress
Wires etc.	$0.99	Ebay
Total Prototype Cost	$13.38	

Mass Production and Estimated Selling Price

Mass Production Cost

Plastic Shell for the LumiSmart device

The estimates shown in the table below are based on a production volume of 100,000 units and can vary depending on specific design requirements and market conditions (Munier, 2022).

Table 6

Estimated Component Cost per Unit of Housing of LumiSmart Device

Component	Estimated Cost per Unit
Material (ABS/PC)	$0.50 - $1.00
Manufacturing (Injection Molding)	$0.50 - $1.00
Tooling Amortization	$0.10 - $0.20
Total Estimated Cost	$1.10 - $2.20

In the prototype, the LCD screen is necessary for product testing, but in practice, the user does not need to know the technical information about the distance threshold and the "Light On/Off" status displayed on the LCD screen. In the table below, the LCD cost is eliminated and the plastic case is added for mass production.

Table 7

Estimated Mass Production Cost per Unit for LumiSmart Device

Component	Estimated Cost	Source
Plastic Shell	$1.5	Estimated
Arduino Uno	$3.28	AliExpress
HC-SR04 Ultrasonic Sensor	$0.39	AliExpress
Potentiometer	$0.34	AliExpress
Bread Board	$0.53	AliExpress
Led light bulb	$1.00	AliExpress
Wires etc.	$0.99	Ebay
Estimated Total Mass Production Cost per Unit	$8.03	

Estimated Selling Price

In the electronics and smart home markets, typical profit margins range from 30% to 50% for consumer products (Kotler & Keller, 2016).

However, for a new product entering the market at a low price point like LumiSmart, an initial profit margin of around 30% may be more realistic, allowing for competitive pricing while still covering costs and generating a profit. Over time, as LumiSmart gains more market share and the brand becomes more recognizable to customers, mass production costs may decrease due to economies of scale and profit margins may increase to 40% or more.

$$\text{Profit Margin} = \left(\frac{\text{Selling Price} - \text{Cost}}{\text{Selling Price}}\right) \times 100$$

With a profit margin of 30% and an estimated total mass production cost per unit of $8.03, we can calculate a selling price of $10,439 based on the profit margin formula above. We then set an attractive price for each LumiSmart device at $10.99, which is much cheaper than the competitors we analyzed in the Competitor Analysis section.

Idea Potentials

Competition Analysis

Before launching the product to the market and convincing potential investors to invest in this project, a detailed SWOT analysis was conducted as shown in the table below to assess the potential of the LumiSmart device.

SWOT Analysis

Table 8

SWOT Analysis to Compare LumiSmart Device and Direct Competitors' Devices

Strengths	Weaknesses
● **High accuracy** comes from the integration of multiple sensors in human detection, even with minimal movement. ● **Energy efficiency**: with the function of automatically adjusting light levels during the day ● **Affordable price**: for the Texas low-to-middle-income tenants, compared to competitor products which average $40 and can go as high as $350 (Competitors section). ● **Easy and non-invasion installation:** the system does not require any complicated setup and app installation. ● **Easily removable:** without affecting the interior of the house. No extra charges for tenants. ● **Safe and low risk of hacking or private data leakage:** based on no data of human presence or technology connectivity exists.	● **Technical complex:** Designing a system with many sensors is complex and requires a high level of organization and calculation. ● **No technology connectivity:** not compatible with smart home systems and no advanced technology connectivity (wifi, bluetooth, etc.) leaves the devices with limited functionality to support higher demands. ● **Limitations in small production and high initial cost:** hard to find good materials, limited options in components, and cannot deal a better price for production costs. ● **Technological challenges**: Sensor calibration and accuracy issues in different environments (e.g., high humidity or extreme temperatures) may impact performance and user satisfaction.
Opportunities	**Threats**
● **Market relevance:** Texas households have higher energy costs than the national average, providing a solution that fits the region's needs (U.S. EIA, 2023). ● **Growing of global movements**: to promote energy conservation and electricity savings, like Earth Hour, World Energy Efficiency Day, International Energy Efficiency Day, World Environment Day, Climate Action Summit, etc. ● **Tax incentives**: Eligibility for energy efficiency rebates and tax incentives can make the product more attractive to cost-sensitive consumers (US Department of Energy). ● **Potentials of smart home market:** annual growth rate (2024-2029) of 10.17%, and a projected market volume of US$250.6bn by 2029 (Statista, 2024).	● **Competitive market**: Strong competition from established products such as the Lifx Plus, Leviton OSW12-M, and Omron D6T with similar features may limit market penetration (Competitors section). ● **Economic factors**: A current economic downturn or financial stress for Texas renters may reduce spending on unnecessary home upgrades, limiting market potential (Fechter, 2024).

Product potential evaluation

Despite some challenges related to technology connectivity and limited manufacturing capacity, this product effectively addresses the needs of the target market: low- to moderate-income renters in Texas looking for a portable, easy-to-install, and affordable smart lighting solution with high detection accuracy for rental properties.

Conducting in-depth research to explore scalable manufacturing methods can help reduce manufacturing costs and simplify technical complexity. Regarding potential technological issues, necessary upgrades can be considered based on feedback from post-purchase surveys.

To address competitive threats posed by established companies in the market, additional market research should be conducted to identify the unique preferences of the target segment, allowing for the development of appropriate marketing strategies for this niche market. Economic challenges can be mitigated by emphasizing the energy-saving benefits of products, especially in awareness campaigns tied to important environmental events, such as Earth Hour.

Challenges and Obstacles Encountered in Project Implementation

Developing a low-cost, standalone lighting system that automatically adjusts based on room occupancy presents numerous challenges. These challenges span technical, financial, and team collaboration aspects, especially for engineering students with limited experience. Several obstacles were encountered throughout the project, including but not limited to the integration of different technologies, time constraints, and the learning curve associated with new concepts.

Time Constraints

The team had to balance the demands of their coursework, extracurricular activities, and the project. This balancing act created significant time constraints, particularly when they encountered unexpected challenges. The project required extensive trial and error, which added to the time required to complete it. Time management became a critical skill as the team had to adjust their schedules and prioritize tasks effectively.

Budget Limitations

The project's budget was another limiting factor. The smart bulbs and sensors used in the system were costly, and the team had to make trade-offs between the performance and price of various components. The budget constraints led to compromises, such as opting for less expensive motion sensors that may not have been as accurate or reliable as higher-end models. Team Collaboration and Communication Issues.

Team Work

Effective teamwork is essential for the success of any engineering project, but the team faced challenges in communication and collaboration. Sometimes, roles were unclear, leading to misunderstandings about who was responsible for specific parts of the project. Additionally, the team had different levels of experience, which led to disagreements on the best approach to solving problems. There was also the challenge of ensuring that everyone stayed on track and remained motivated throughout the project's duration.

Uncertainty about Final Product

As the project neared completion, the team faced uncertainty about whether the system would meet their expectations or work reliably in different environments. Factors such as lighting conditions, sensor placement, and Wi-Fi interference could all affect performance.

Conclusion

The Energy Efficient Lighting Project offers an innovative solution to the growing energy consumption and associated costs faced by Texas renters, many of whom are burdened with high utility bills. By developing an affordable, portable, and homeowner-friendly smart lighting system that combines PIR and ultrasonic sensors for precise detection, the project addresses the need for energy efficiency in rental homes. The system not only reduces unnecessary energy consumption but also minimizes environmental impact by reducing carbon emissions, in line with national energy efficiency goals outlined by the U.S. Department of Energy. Furthermore, non-technology connectivity is a simple yet secure solution for renters who must access shared internet. Through rigorous design and testing, this project has demonstrated the potential to make energy-saving technology accessible to low- to middle-income households, promising meaningful savings for both users and the environment.

Discussion and Direction for Future Research

Device Options

This project mainly deals with the selection of devices that would be able to control occupancy lighting effectively. Among these, three appropriate options of devices-sensing bulbs, intelligent switches, and smart plugs-offer various features over which a decision is to be made towards the realization of the project objectives.

The smart bulbs have chosen advanced functionalities for which they are a very popular choice in automated lighting systems. These are Wi-Fi-enabled bulbs, such as the Lifx Plus, which can control brightness, color, and even schedule lighting from afar through an app or by using a voice assistant. Possibly the biggest positives of smart bulbs are the amount of variability they offer; one can create a range of illuminating effects with them that adjust based on user preference. The catch is, these bulbs tend to be pretty pricey and are only as good as the underlying Wi-Fi network they operate over. The other thing with smart bulbs, while they boast of a raft of advanced features, the software keeps getting updated, and there can be some incompatibility with other smart home devices.

The Leviton OSW12-M are super affordable and are smart switches. These devices replace traditional light switches and can be combined with motion sensors for automatic lighting depending on whether a room is occupied. Compared to smart bulbs, smart switches are considerably easier to install and usually cheaper, though they offer less advanced customization-color and brightness-than their bulb counterparts. This reduced flexibility makes them better suited for applications requiring simple on/off control, like hallways or bathrooms. Another limitation could be the fact that smart switches work only with fixtures that are hardwired directly into the switch, which further limits application.

Another inexpensive device that can turn traditional lamps and appliances into smart, remotely controlled devices is smart plugs. One could plug a normal lamp into a smart plug and further automate the lighting based on occupancy or set schedules.

Being the cheapest among the three and quite easy to set up, smart plugs extend far fewer functionalities than smart bulbs. They indeed lack color-changing capabilities and usually are able to control just lamps or appliances plugged into them. Because of this, they are perfect for simple uses but would not be perfect for a user who needs more flexibility in his/her lighting setup. Enhanced Accuracy: Motion Sensors versus Thermal Detection

Occupancy Detection

Of these, occupancy detection is the key driver for the reduction in energy wastage. Conventional motion sensors are usually infrared radiation-based movement detectors and are one of the most frequently deployed devices in the case of smart lighting. Limitations of motion sensors include that they cannot detect occupants who might be sitting still or moving very slow. Changes in infrared radiation due to the operating environment enhance accuracy in thermal sensors like Omron's D6T for detecting the presence of a target by detection. Unlike motion sensors, which require actual movements to detect, thermal sensors can detect heat emitted from the human body and therefore detect the presence of a person with no motion. This further improves the system's reliability in cases that involve little movement.

However, such thermal sensors are way more expensive and need a much higher degree of integration than current motion sensors. These sensors may require complex calibration, to detect only the key body heat of a person and dismiss influences of the ambient temperature, such as drafts, warm appliances, and the like.

Environmental Impact

Another key factor that will be undertaken in the project is reducing environmental impact through minimizing energy use. This is going to reduce energy consumption by the use of smart lighting systems, taking into consideration whether the lights are turned on or off depending on need. Though there must be considerations about the environmental footprints that the devices will generate, manufacturing and electronic component disposal, such as smart bulbs, switches, and plugs, contribute to electronic waste that may be damaging to the environment. Minimum environmental impact by incorporating energy-efficient components; for instance, the usage of LED bulbs is supposed to minimize energy use and result in increased life compared to normal incandescent bulbs. Besides that, the system should be durable, modular, recyclable, and reduce waste. Efforts toward the use of eco-friendly materials during the production of the devices will go a long way in ascertaining that the system stays as green as possible throughout its life cycle.

Future Directions

This project evaluates smart lighting solutions by comparing the features, costs, and limitations of sensing bulbs, smart switches, and smart plugs, alongside occupancy detection methods like motion and thermal sensors. Smart bulbs offer the most customization but at a higher cost, while smart switches and plugs present more affordable yet simplified options. By utilizing advanced sensors, particularly thermal ones, the project aims to enhance occupancy detection accuracy, thus reducing energy wastage. Alongside functionality, the project also prioritizes environmental sustainability through energy-efficient components and recyclable designs, contributing to a minimal ecological footprint. Ultimately, this exploration highlights how smart lighting can combine user convenience with energy savings, suggesting that future developments focus on increasing affordability and integration to expand accessibility.

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