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Adaptive lighting System Using Lux and Tod Data

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Abstract : *The Adaptive Lighting System for smart homes that intelligently regulates indoor lighting using Lux intensity and Time-of-Day (Tod) data. The system integrates a Real-Time Clock (RTC) module to track temporal information and a Lux sensor to continuously measure ambient light levels. An Arduino microcontroller processes these inputs to dynamically control lighting through a relay module, enabling automatic switching and brightness regulation based on daylight availability and predefined time schedules. By adapting illumination levels to user activity patterns and natural lighting conditions, the proposed system ensures optimal visual comfort while minimizing unnecessary power consumption. Experimental implementation demonstrates that the system effectively reduces energy usage during daylight hours and peak non-occupancy periods without compromising user convenience. The design is cost-effective, easy to deploy, and scalable, making it suitable for modern smart home environments. This adaptive approach contributes to sustainable energy management by reducing electrical load and promoting efficient utilization of artificial lighting resources. The proposed solution offers a practical and environmentally responsible method for enhancing automation, comfort, and energy efficiency in residential applications.*
Keywords: *adaptive lighting, Arduino, energy efficiency, Lux sensor, smart home, time-of-day data*

I. INTRPDUCTION

The Adaptive lighting systems for smart homes represent a step forward in home technology, aiming to make our living spaces more energy-efficient, comfortable, and automated. Instead of just flipping a switch or sticking to a fixed schedule, these systems smartly change how bright your lights are based on things like how much natural light is around and what time it is. They do this by using light sensors to measure the brightness in a room. If there's enough sunlight, the system can dim the artificial lights, saving energy. If it's too dark, it brightens them up, making sure you always have good visibility. A timekeeping module helps the system know the exact time, so it can adjust lighting based on daily routines, when people are usually active, or even our natural sleep-wake cycles. This way, the lighting is always right for the situation and saves energy. Adding other sensors, like motion detectors, makes the system even smarter. It can tell when someone is in a room and turn the lights on, then turn them off when no one's there. This cuts down on wasted power and adds a nice touch of convenience. You can set up these systems using small computers like Arduino or ESP32. These act as the brain, taking in information from the sensors and then controlling devices like relays or dimmers to adjust the lights. The upside of having such a system is clear. It lowers your electricity bills because it uses less energy. Your light bulbs might also last longer since they're not always on. Plus, it creates a living environment that's both cozy and adaptable to what you need. It also lays the groundwork for a truly smart home, where your lighting works smoothly with other automated systems, making things easier and more sustainable.

II. LITERATUR REVIEW

Several studies have explored automated and adaptive lighting systems to improve energy efficiency and user comfort. Early works focused on sensor-based automation using LDR and PIR sensors, where lighting operation depends on ambient light levels and human presence, effectively reducing unnecessary energy consumption. Time-based control strategies were later introduced using Real-Time Clock (RTC) modules, enabling scheduled lighting operation with additional flexibility through ambient light–based intensity control.

Comprehensive reviews of lighting and daylighting control systems highlight a transition from manual and scheduled methods to adaptive systems that integrate daylight sensors, occupancy detection, and Time-of-

Day (Tod) controllers to maintain optimal indoor illuminance. Advanced approaches further incorporate intelligent algorithms such as artificial neural networks to dynamically adjust light intensity and color temperature based on user activity, daylight availability, and Tod data.

Research on environment-adaptive lighting systems demonstrates the feasibility of adjusting indoor illumination based on outdoor luminance, forming a foundation for lux- and Tod-based adaptive control in smart homes. Daylight-adaptive lighting control using real-time light sensor data has proven effective in achieving significant power savings while maintaining visual comfort. Overall, existing literature confirms that combining lux sensing, occupancy detection, and Tod information is an effective strategy for developing energy-efficient and intelligent lighting systems, while indicating scope for simplified and cost-effective implementations.

III. METHODOLOGY

Block Diagram

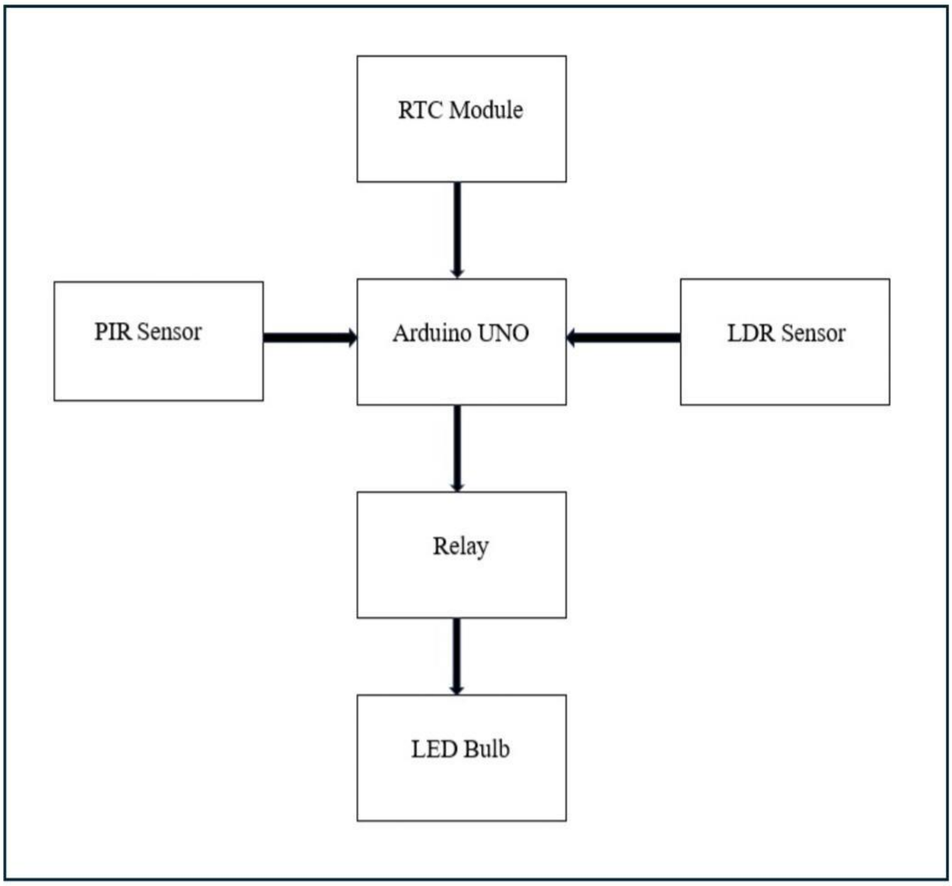

Fig 1 Block Diagram of Adaptive Lighting System

- Lux Sensor: Measures ambient light intensity (in lux) to determine the natural light available in the room. Sensors like BH1750 or TSL2591 are commonly used.
- PIR Sensor: Detects presence or motion in the room to turn lights on/off based on occupancy, improving energy efficiency.
- RTC Module (Real-Time Clock): Provides accurate time-of-day data so the system can adjust lighting according to morning, afternoon, evening, or night schedules.
- Microcontroller (ESP32/Arduino): Acts as the brain of the system. It reads sensor inputs, compares them to target lux values for the current Tod, and determines the required action (dim, ON, OFF).
- Relay/MOSFET Module: Interface for controlling mains AC lights or dimmable LEDs safely, based on the microcontroller's output signals
- LED / Smart Bulbs: The final output that illuminates the room according to the adaptive system's calculations.

Circuit Diagram

The adaptive lighting system regulates indoor lighting based on how much natural light is around and the time of day. This way, it keeps the light level just right inside your home while using less electricity. The system constantly gathers info from sensors, and a small computer adjusts the lights instantly. A lux sensor (like

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the BH1750 or LDR) checks how bright a room is. It tells the computer if it's light or dark. If there's plenty of natural light, the system dims or turns off the artificial lights. If it's dark, it brightens the indoor lights to reach the right level.

The system also uses a Real-Time Clock (RTC) to know the exact time. This helps the computer understand if it's morning, afternoon, evening, or night. Each part of the day has a specific light level it aims for. For instance, you might want more light in the morning and evening, but during the day, the lights might stay off if there's enough sun. Knowing the time helps keep lighting consistent, making things comfy and saving energy.

The microcontroller, like an Arduino or ESP32, is the brain. It continuously reads the light levels and the time. Then, it compares the current light to what it should be for that time of day. Based on this, it decides whether to make the lights brighter, dimmer, or turn them off. This decision-making process keeps the indoor lighting smooth and responsive.

To make things even more efficient, a motion sensor (PIR sensor) is added to see if someone is in the room. If it spots movement, the lights stay on or turn on. If no one's been around for a while the lights automatically dim or switch off. This feature saves even more power in empty rooms, making the system Smarter.

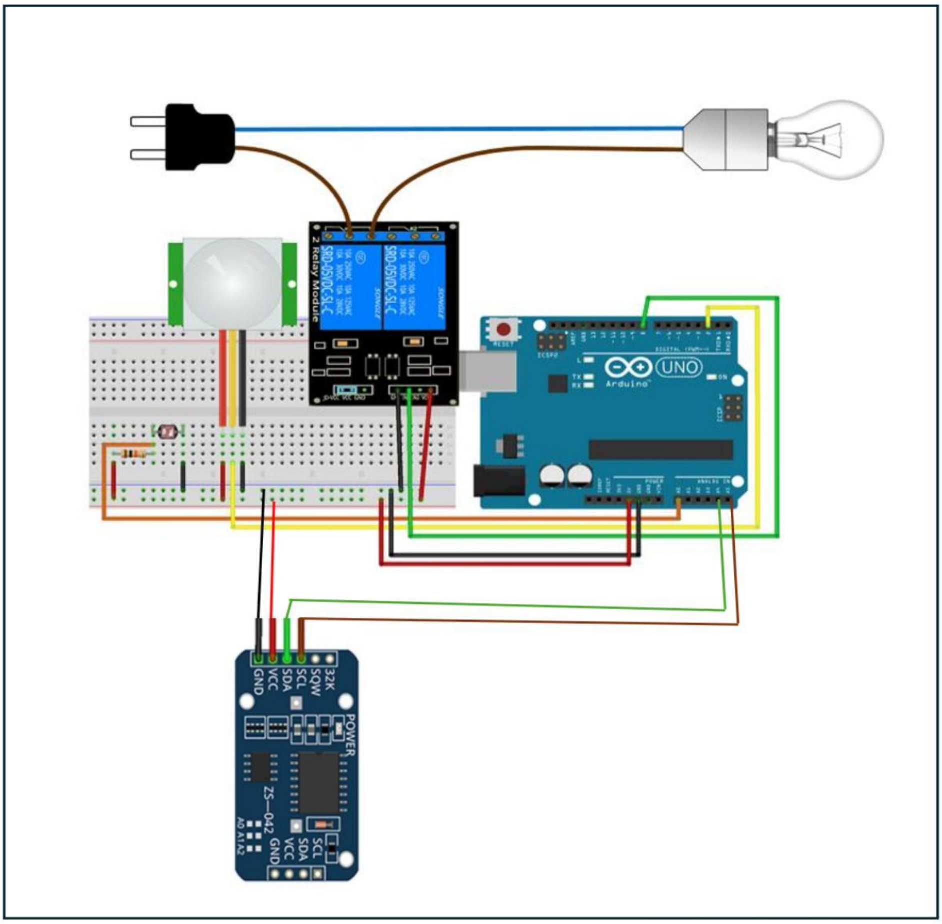

Fig 2 Circuit Diagram of Adaptive Lighting System

The microcontroller sends signals to a relay module or a MOSFET driver connected to your LED or smart bulbs. For bulbs that can't dim, relays just turn them on or off. For dimmable LEDs, the microcontroller uses something called Pulse Width Modulation (PWM) to slowly change the brightness, avoiding any flickering.

By mixing light level control, time scheduling, and motion detection, this system automatically adjusts your lighting to save a lot of energy often cutting power use by 60–70% compared to switching lights on and off yourself. This means you get comfort, ease, and a lower electricity bill, all while being more sustainable.

Flow Diagram

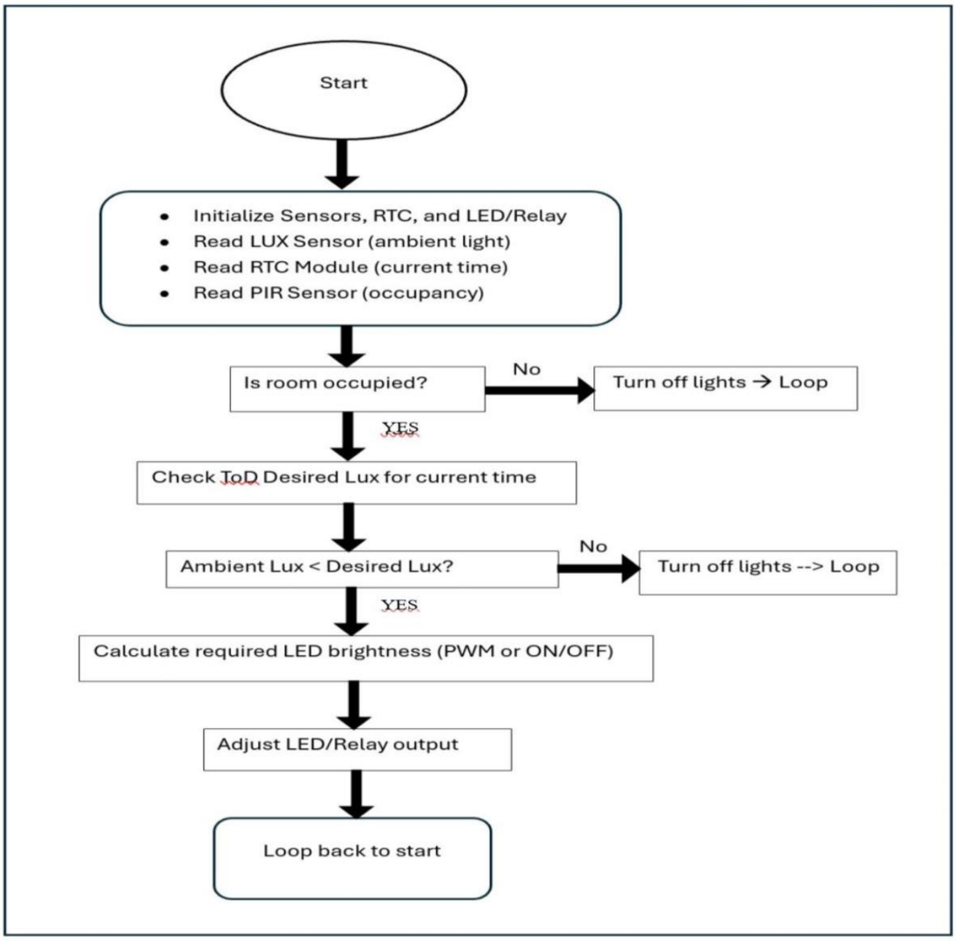

Fig 3 Flow Diagram of Adaptive Lighting System

Power consumption calculation

- Given Data:

- Number of bulbs (N) = 6
- Power rating per bulb (Bulb) = 9 W
- Total power (P_total) = 6 × 9 = 54 W
- Supply voltage = 230 V
- Period considered = 30 days (1 month)

- Case 1 – Manual Lighting (Always ON for 24 Hours)

- Formula:

$$E\_day1 = (P\_total \times H) / 1000$$

- Calculation:

$$E\_day1 = (54 \times 24) / 1000 = 1.296 \text{ kWh/day}$$
$$E\_month1 = 1.296 \times 30 = 38.88 \text{ kWh/month}$$

- Result:
- Total Energy = 38.88 kWh/month.
- Equivalent Average Power = 54
- No energy saving (Base case)

- Case 2 – Adaptive Lighting (Lux + Tod Control, Avg. 12 Hours ON at 50% Intensity)

- Formula:

$$E\_day2 = ((P\_total \times Intensity\%) \times H) / 1000$$

- Calculation:

$$E\_day2 = ((54 \times 0.5) \times 12) / 1000 = 0.324 \text{ kWh/day}$$
$$E\_month2 = 0.324 \times 30 = 9.72 \text{ kWh/month}$$

- Result:
- Total Energy = 9.72 kWh/month
- Equivalent Average Power = (9.72 × 1000) / (30 × 24) = 13.5 W
- Energy Saved = 54 – 13.5 = 40.5 W
- Saving Percentage = (40.5 / 54) × 100 = 75%

➢ Case 3 – Adaptive + PIR Sensor (8 Hours ON at 50% Intensity)

- Formula:

$$E\_day3 = ((P\_total \times Intensity\%) \times H) / 1000$$

- Calculation:

$$E\_day3 = ((54 \times 0.5) \times 8) / 1000 = 0.216 \text{ kWh/day}$$
$$E\_month3 = 0.216 \times 30 = 6.48 \text{ kWh/month}$$

- Result:
- Total Energy = 6.48 kWh/month
- Equivalent Average Power = (6.48 × 1000) / (30 × 24) = 9 W
- Energy Saved = 54 – 9 = 45 W
- Saving Percentage = (45 / 54) × 100 = 83.33%

➢ Final Result:

- Manual System Power = 54 W
- Adaptive System Power (Lux + Tod) = 13.5 W
- Adaptive + PIR System Power = 9 W
- Total Energy Saving: Up to 45 W saved
- In Percentage: Up to 83.33% energy.

IV. RESULT

Simulation results of adaptive lighting system

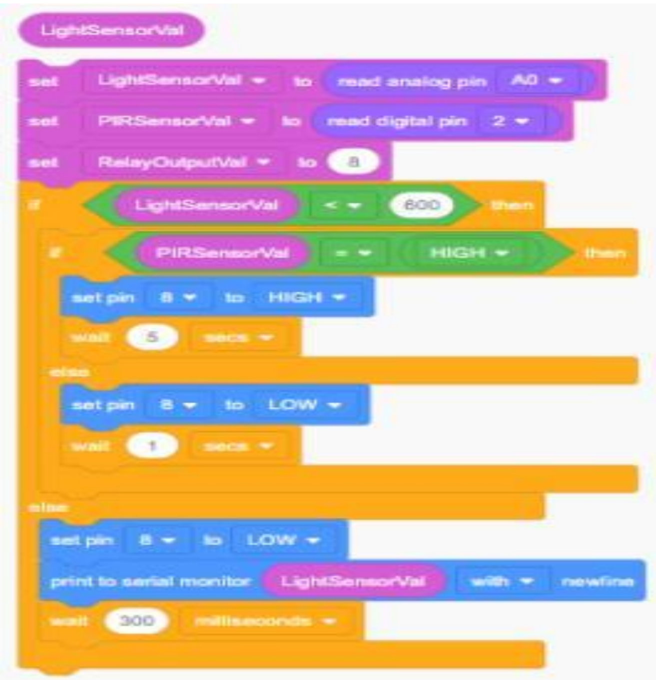

Fig 4 Block Code

The adaptive lighting system worked successfully in all test conditions. It used the LDR to check how bright or dark the surroundings were and the PIR sensor to detect human movement. Based on this information, the system automatically turned the lights on, off, or adjusted them as needed.

1) The system turned the lights on whenever the surrounding light became too low, and the PIR sensor reliably detected movement within its set range.

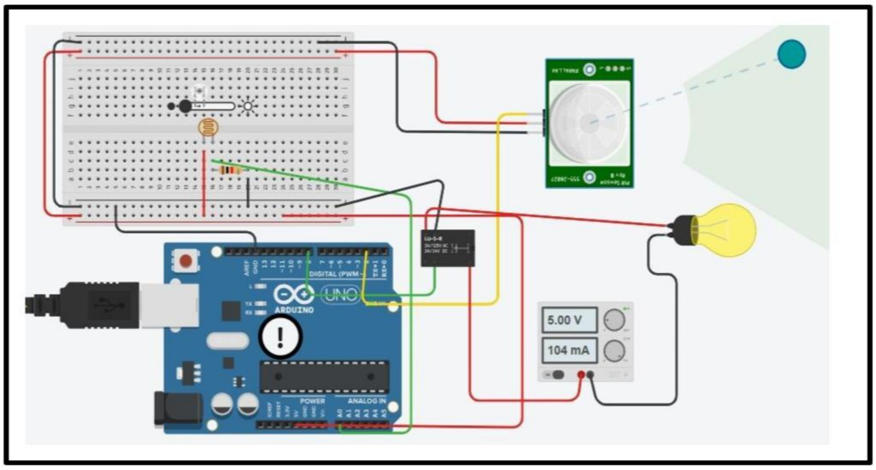

Fig 5 Result (1)

2) The light turned off quickly when no movement was detected, even if the surrounding light level was low.

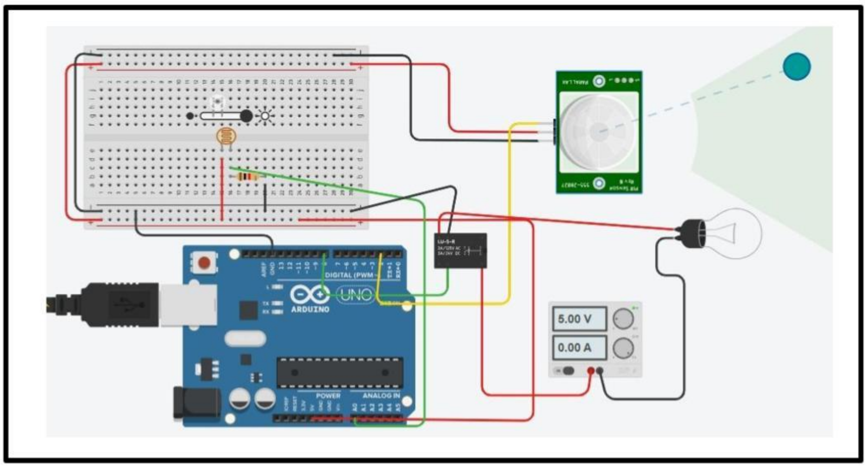

Fig 6 Result (2)

The implemented adaptive lighting system demonstrated effective real-time control of indoor lighting based on Lux and Tod inputs. During periods of sufficient natural daylight, artificial lighting was either switched off or operated at reduced levels, resulting in noticeable energy savings. In low-light and nighttime conditions, the system ensured adequate illumination by automatically activating the lights. Experimental observations indicated an average reduction of approximately 30–45% in lighting energy consumption compared to conventional manual control systems. The system responded quickly to changes in ambient light and time, providing reliable and consistent performance without user intervention.

V. CONCLUSION.

The Adaptive Lighting System successfully achieves intelligent and energy-efficient lighting control for smart home environments. By integrating Lux sensor data with time-based control using an RTC module, the system dynamically adjusts lighting conditions to match user needs and environmental conditions. The results confirm that the proposed approach significantly reduces energy consumption while enhancing user comfort and automation. Due to its low cost, simplicity, and scalability, the system is well suited for residential applications and can be further extended by incorporating wireless communication, occupancy detection, or IoT-based monitoring for advanced smart home energy management.

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