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Design and Implementation of an Arduino Uno Based Automatic Lighting Control System Using Passive Infrared (PIR) Sensors

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Abstrak: Di tempat-tempat ibadah seperti masjid, energi listrik sering terbuang percuma akibat sistem penerangan yang tetap menyala dalam waktu lama, terutama di kamar kecil dan area wudhu. Kondisi ini dipengaruhi oleh pola penggunaan yang tidak konsisten serta kurangnya kesadaran pengguna untuk mematikan lampu setelah digunakan. Meskipun menghadapi tantangan tersebut, penerapan teknologi Internet of Things (IoT) di lingkungan semacam itu masih relatif minim, terutama karena kurangnya literasi teknologi dan keterbatasan anggaran. Internet of Things (IoT) mengacu pada jaringan perangkat elektronik yang saling terhubung dan mampu bertukar data serta berkomunikasi melalui sistem terintegrasi. Deteksi gerak sering digunakan untuk mengidentifikasi kehadiran manusia, dengan sensor Passive Infrared Receiver (PIR) sebagai salah satu pilihan yang paling tepat untuk tujuan ini. Sensor ini dikenal luas karena keefektifannya dalam aplikasi pemantauan jarak jauh. Penelitian ini bertujuan untuk mengembangkan sistem kontrol pencahayaan otomatis berbasis IoT yang memanfaatkan sensor gerak guna mendukung efisiensi energi dan menciptakan lingkungan yang ramah lingkungan. Metodologi penelitian mencakup analisis kebutuhan, implementasi sistem, dan tahap pengujian. Realisasi perangkat keras, dikombinasikan dengan pemrograman menggunakan platform Arduino IDE, berhasil mengimplementasikan logika kontrol pencahayaan otomatis sesuai desain. Sistem ini mengintegrasikan sensor PIR dan ultrasonik, dan hasil eksperimen menunjukkan bahwa sistem mampu mendeteksi objek secara akurat dalam jangkauan yang ditentukan serta merespons gerakan manusia dengan cepat dan andal.

Kata kunci: Arduino, Pencahayaan Otomatis, Efisiensi Energi, Internet of Things, Sensor PIR

Abstract: In worship facilities such as mosques, electrical energy is frequently wasted due to lighting systems that remain active for extended periods, especially in restrooms and ablution (wudhu) areas. This condition is influenced by inconsistent usage patterns and limited user awareness in switching off lights after use. Despite these challenges, the application of Internet of Things (IoT) technology in such environments is still relatively minimal, mainly due to insufficient technological literacy and budget limitations. The Internet of Things (IoT) refers to a network of interconnected electronic devices capable of exchanging data and communicating through integrated systems. Motion detection is commonly employed to identify human presence, with the Passive Infrared Receiver (PIR) sensor being one of the most appropriate choices for this purpose. This sensor is widely recognized for its effectiveness in remote monitoring applications. This study aims to develop an IoT-based automatic lighting control system utilizing motion sensors to support energy efficiency and create an environmentally friendly environment. The research methodology includes requirement analysis, system implementation, and testing phases. The hardware realization, combined with programming using the Arduino IDE platform, successfully implements the automatic lighting control logic as designed. The system integrates PIR and ultrasonic sensors, and experimental results demonstrate that it is capable of accurately detecting objects within a defined range and responding rapidly and reliably to human movement.

Keyword: Arduino, Automatic Lighting, Energy Efficiency, Internet of Things, PIR Sensor

INTRODUCTION

The rapid development of technology has led society into an era of modernization. Today, almost all aspects of human life depend on technology, as its presence is designed to facilitate various activities and tasks (Fatimah et al., 2021).

One of the essential needs supporting human activities is lighting. Artificial light sources such as lamps are indispensable elements in many daily activities. However, most lighting systems are still operated using manual On/Off switches. The use of manual switches often causes problems, such as lights being left on or not turned on at the appropriate time due to human negligence, resulting in uncontrolled energy consumption. This condition is consistent with data indicating that approximately 80% of electrical energy waste is caused by human behavior (Rakayama & Firmawati, 2022).

The regulation of electrical equipment, particularly lighting systems, is crucial in energy management efforts in various environments, such as residential buildings, office buildings, and large areas with numerous lighting units. The implementation of automation or control systems for electronic and electrical devices has become an urgent necessity, considering that efficiency and speed are increasingly required across multiple sectors to create systems that are more reliable and user-friendly.

Numerous studies related to lighting automation have been conducted, particularly in residential environments (Darmanto et al., 2020)(Rakayama & Firmawati, 2022)(Mariam et al., 2023). More specifically, several studies have discussed lighting automation for specific areas, such as bathrooms, as reported by (Sonya, 2024)(Kusuma et al., 2024).

However, studies focusing on places of worship, especially mosques, remain limited. Based on observations, many users still forget to turn off lights after leaving the bathroom. This issue is further supported by a study conducted by the Agency for the Assessment and Application of Technology, which indicates that 25–30% of electrical energy usage in places of worship in Indonesia can be categorized as waste due to the lack of optimization according to activity needs. This condition highlights an opportunity for further research.

Through current technological advancements, lighting automation in mosque environments, particularly in bathroom areas, is proposed by utilizing Internet of Things (IoT) technology. One of the commonly used sensors in automatic lighting control systems is the Passive Infrared Receiver (PIR) sensor. The Passive Infrared (PIR) sensor is an electronic detection device used to identify the presence of infrared radiation in its surrounding environment. This sensor operates passively, meaning it does not generate or emit infrared radiation itself, but instead receives and responds to infrared radiation emitted by surrounding objects. This working principle aligns with the characteristics of passive sensors, where any object with a certain temperature emits infrared energy that can be detected by the PIR sensor, enabling the detection of object presence or movement without direct contact (Pambudi et al., 2025)(Arifin & Murdowo, 2025).

The automation of this system lies in the input process received by the PIR sensor. When the PIR sensor detects human activity, it sends a signal to the Arduino. Subsequently, the Arduino processes the signal according to the programmed instructions and sends a command to the relay to turn on the light. Conversely, when no human activity is detected, the system automatically turns off the light.

With this system, lighting no longer depends on human intervention to operate manual switches. Instead, the system functions automatically according to environmental conditions. Through this automation, energy usage efficiency can be improved, starting from places of worship, particularly mosques.

METHOD

The prototype is one of the approaches in software engineering that directly demonstrates how a software system or its components will operate within its environment before the actual construction phase is carried out (Arifin et al., 2025)(Sahid et al., 2023)(Putri Ginting & Desy Nur Utomo, 2024). This method is applied in the design of the automatic lighting control system.

The stages of the prototype method consist of communication, quick plan, modelling quick design, implementation, and deployment delivery and feedback. The communication stage begins with identifying the problems occurring in the research object, followed by designing solutions to address these issues and analyzing system requirements, which are included in the quick plan stage. In the modelling quick design stage, a system design is developed using block diagrams to identify the system model. If the proposed design meets the defined requirements, the process proceeds to the implementation stage, where integration between hardware components and programming languages is carried out to ensure connectivity and functionality. The final stage, deployment delivery and feedback, involves evaluating the implemented system and making improvements if necessary, followed by system deployment so that it can be utilized by users (Purwanti et al., 2021). The stages of the prototype method are illustrated in Figure 1.

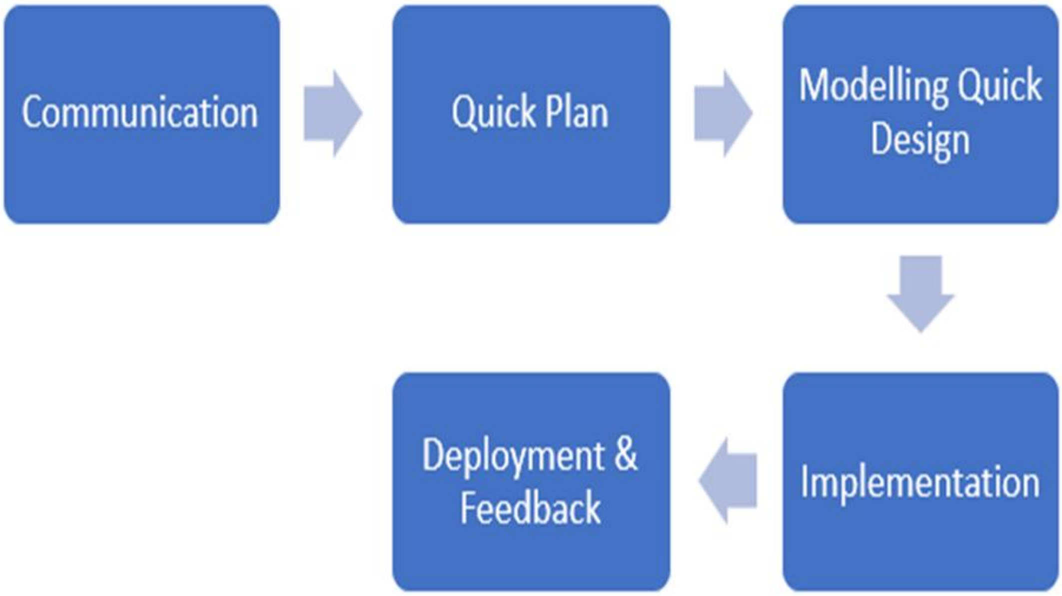

Figure 1. Prototype Method

RESULTS AND DISCUSSION

Communication

Problem identification at this stage was conducted through direct observation at the research location. The results of the observation revealed issues related to inefficiency in electrical energy consumption, particularly in lighting systems in the ablution and toilet areas. A frequently occurring condition is that the lights remain on even when there is no activity in these areas. Therefore, the design of an automatic lighting control system in the mosque environment, specifically in the ablution and toilet areas, is required as an effort to improve the efficiency of electrical energy consumption.

Quick Plan

Based on the proposed problem-solving solution, the process proceeds to the planning stage. In the quick plan stage, the required needs for system design are planned, covering both hardware and software aspects.

The project of an Arduino-based automatic lighting control system using a PIR sensor utilizes several main hardware components without involving a current sensor. The core component of this system is the Arduino Uno, which functions as the main controller to read signals from the PIR sensor and activate the relay module as an electronic switch. When motion is detected, the Arduino sends a signal to the relay to automatically turn on a 220V AC lamp. A breadboard and jumper wires are used to assemble all components without the need for soldering. The system is connected to a computer or laptop via a USB cable, which is used for programming through the Arduino IDE as well as for serial communication with the Processing software. Through Processing, users can visually monitor the lamp status (ON/OFF) in real time.

The Arduino Uno R3 (Figure 2) is a microcontroller board based on the ATmega328P that serves as the central control unit of the system. This board is equipped with 14 digital input/output pins (six of which support PWM), six analog input pins, a USB connection, and an external power jack. In this study, the Arduino reads input from the PIR sensor, processes the logic, and activates or deactivates the relay according to the motion detection conditions. The Uno R3 also transmits data to the computer via serial communication.

Figure 2. Arduino UNO R3

The PIR sensor is an electronic sensor used to detect motion by observing changes in infrared (IR) radiation emitted by objects, particularly the body heat of humans or animals (Hutabarat & Susanti, 2020) (Figure 3). It is referred to as “passive” because the sensor does not generate its own signal; instead, it detects heat radiated from its surroundings. The sensor operates using a pyroelectric element that is sensitive to temperature changes. When a moving warm object is present, the sensor generates an electrical signal. The Fresnel lens on the sensor functions to focus IR radiation onto the detection element, while the internal circuitry processes the signal into a digital output, namely HIGH when motion is detected and LOW when no motion is detected. One of the widely used PIR sensors is the HC-SR501, which is capable of detecting motion at a distance of 3 to 7 meters with a detection angle of approximately 120 degrees, and is equipped with sensitivity and delay time adjustment controls. Due to its efficiency and low power consumption, this sensor is commonly used in automatic lighting systems, security devices, and smart home applications.

Figure 3. Sensor PIR

The PIR sensor has three main pins located at the bottom, namely the ground pin (GND), the output pin (OUT), and the VCC pin. The ground pin (GND) serves as the return current path by connecting the sensor to the ground of the circuit system. The output pin (OUT) produces a digital signal that is either HIGH or LOW depending on whether motion is detected. The VCC pin supplies a DC voltage between 3 V and 5 V, which is required for the sensor to operate.

An Arduino relay is a module used to control high-voltage electronic devices (such as lamps, fans, or pumps) using low-voltage electrical signals from the Arduino (Figure 4). The relay operates like an automatic switch: when the Arduino sends a LOW or HIGH signal to the relay control pin, the module opens or closes the electrical circuit. Generally, the relay is active LOW, meaning that when the Arduino output pin is set to LOW, the relay is energized and the controlled device is activated. The relay module is also equipped with optocoupler isolation to protect the Arduino from voltage surges. Relays are highly useful for developing sensor-based automation systems, such as automatic lighting systems, automatic irrigation systems, and home security devices.

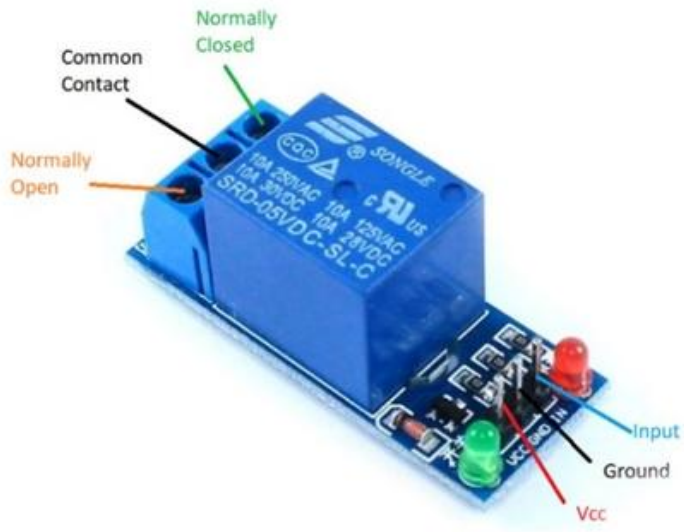

Figure 4. Relay

Jumper wires are flexible cables used to connect electronic components without soldering, particularly on breadboards and Arduino boards. There are three types of jumper wires: male-to-male, male-to-female, and female-to-female, which are selected based on the types of pins being connected. These wires are available in various lengths and colors to facilitate easy identification. Due to their practicality and reusability, jumper wires are ideal for temporary circuit assembly, experimentation, and learning electronic systems.

A 12V power cable is an electrical conductor used to transmit a 12-volt supply from a power source to various electronic devices. This type of cable is commonly used in automation systems, IoT devices, CCTV systems, fans, DC motors, and for supplying power to Arduino modules through the power jack socket or VIN terminal. Cable selection must consider the appropriate wire gauge according to current requirements to prevent voltage drop or overheating. A 12V power cable typically consists of two conductors: positive (red) and negative or ground (black), and is usually made of copper to ensure good electrical conductivity.

Furthermore, regarding software requirements planning, the development of an IoT-based automatic lighting control system requires several software tools, such as Arduino and Tinkercad. The Arduino Integrated Development Environment (IDE) is a cross-platform programming environment (Windows, macOS, and Linux) that provides a code editor, compiler, library management, and a serial monitor for debugging purposes. The Arduino IDE is designed to be accessible to non-specialist users without an electronics background, enabling easy integration with various sensors and actuators in physical computing projects (Setiadi et al., 2022).

In addition, to facilitate the simulation process prior to physical implementation, Tinkercad Circuits is utilized. Tinkercad Circuits is a web-based electronic simulation platform developed by Autodesk (Costaner et al., 2022). It provides a visual interface for interactively designing electronic circuits and offers the capability to simulate Arduino microcontroller behavior in real time (Riskawati et al., 2024). Therefore, Tinkercad serves as an important supporting tool for validating circuit logic and program code without requiring physical components, which is highly beneficial during the early stages of system development. This platform also supports hands-on learning and accelerates design iteration within a safe and efficient environment.

Modelling Quick Design

The design of the Internet of Things based automatic lighting control system consists of two main stages. The first stage involves the design and construction of the hardware, while the second stage focuses on software development. In the first stage, the required components for the lighting control system are assembled. In the second stage, a program is developed to integrate the hardware with the sensors and to create a user interface through the Blynk application. The objective of both hardware and software planning is to determine an optimal design that ensures the system operates efficiently.

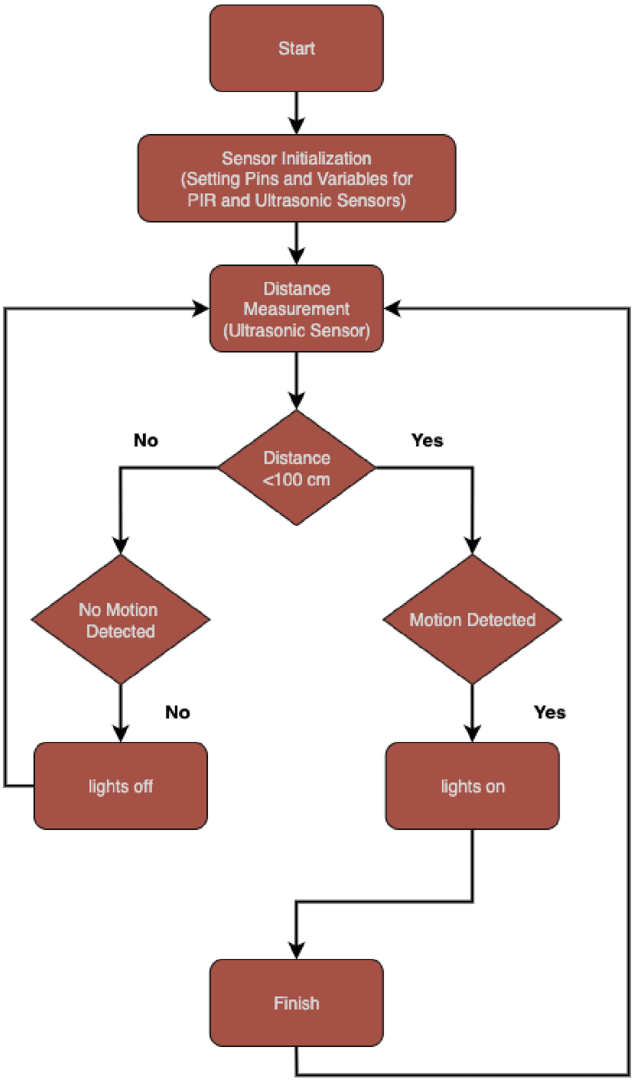

Figure 5. Flowchart System

The system design is presented in the form of a flowchart diagram, as shown in Figure 5. The system integrates two sensors: a Passive Infrared (PIR) sensor for motion detection and an HC-SR04 ultrasonic sensor for measuring the presence of objects within a certain distance (Rakayama & Firmawati, 2022). The process begins when the system is powered on (Start), followed by distance measurement using the ultrasonic sensor. If the sensor detects an object within a distance of less than 100 cm, the system proceeds to check for motion using the PIR sensor. If motion is detected by the PIR sensor, the system issues a command to turn on the lamp. Conversely, if no motion is detected, the lamp remains off. If initially no object is detected within a distance of less than 100 cm, the system does not perform PIR sensor detection and directly maintains the lamp in the off state. After each process is executed, the system returns to the initial state to continuously monitor changes in distance and motion in a repetitive cycle. This workflow enables energy efficiency, as the lamp is only turned on when an object approaches and movement is detected.

The automatic bathroom lighting circuit is designed using the Tinkercad simulation platform, with the Arduino UNO serving as the main controller. When a person enters the detection area, the PIR sensor responds to motion, and the ultrasonic sensor confirms the presence of an object within a range of less than 100 cm. When both conditions are met, the Arduino activates a single-channel relay module, which then turns on a 220V AC lamp. The relay functions as an electronic switch that isolates high-voltage loads from the microcontroller circuit, ensuring safe operation. The circuit is powered by a 5V power supply or directly via the Arduino USB port. When no motion or nearby object is detected, the system automatically turns off the lamp after a predefined delay time. This design is highly suitable for bathrooms or other enclosed spaces, as it supports energy efficiency and provides automatic convenience without the need for manual switches (Attamimi et al., 2022).

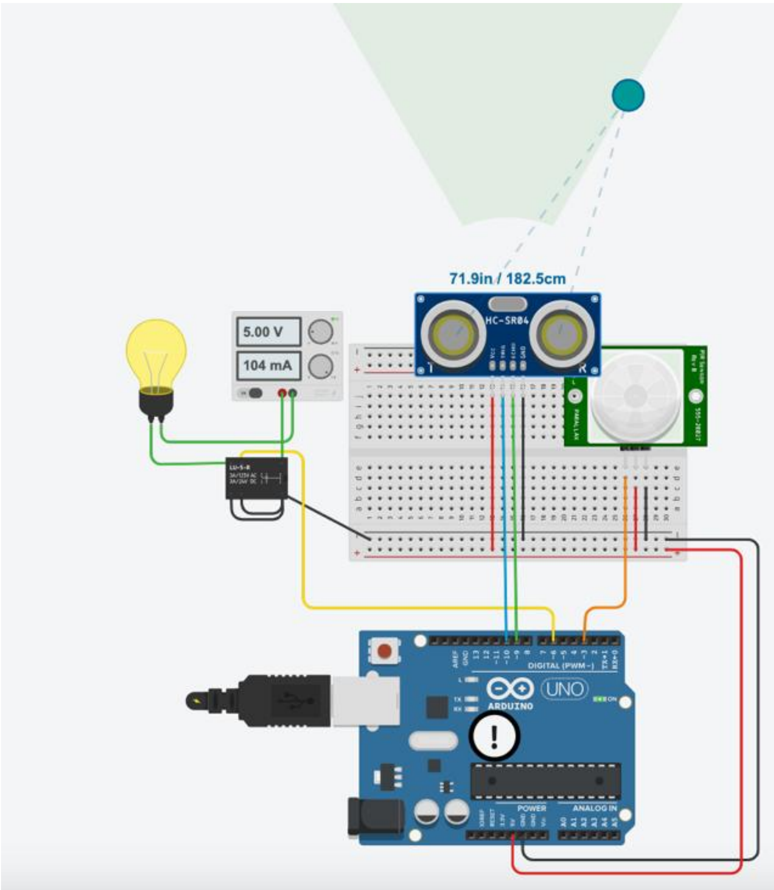

Figure 6. Simulation Design

Implementation

The implementation stage of this study includes the design and realization of an Arduino Uno based automatic lighting system that utilizes an ultrasonic sensor and a Passive Infrared Receiver (PIR) sensor as the primary devices for environmental data acquisition. The system implementation consists of two main components, namely hardware realization and software realization, which synergistically form an integrated microcontroller based automatic lighting control system using the Arduino Uno.

Figure 7. Assembly Result

The hardware realization, as shown in Figure 7, illustrates the structure of the automatic control system developed using the Arduino Uno microcontroller as the central signal processing unit. The ultrasonic sensor functions to measure the distance of objects from the system using the ultrasonic wave reflection method, while the PIR sensor is used to detect human presence through infrared radiation emitted by the human body. The integration of these two sensors supports conditional control logic, in which the lamp is activated only when an object is detected within a radius of less than 100 cm and human movement is simultaneously identified by the PIR sensor.

The purpose of this design is to create a system that is adaptive to environmental conditions while optimizing electrical energy usage. This strategy is particularly relevant for spaces with low usage intensity but requiring instant lighting when human presence is detected, such as bathrooms, corridors, or storage rooms. In addition, the use of economical and easily obtainable electronic components makes this system feasible for implementation at the household scale as well as in public facilities such as mosques at an affordable cost.

Regarding software implementation, programming is employed to ensure that the hardware operates according to the expected inputs and outputs. Figure 8 presents the programming implementation used to regulate the IoT-based automatic lighting control system using the Arduino Uno.

The software implementation is carried out through a coding process using the Arduino IDE platform, which utilizes the C/C++ programming language. The program is developed using a modular approach that includes the initialization of input/output pins, periodic (real-time) sensor data acquisition functions, and the execution of control logic based on input conditions. The main program structure consists of the setup() function for initial configuration and the loop() function as the core of the continuous iterative process that represents the system's dynamic operation.

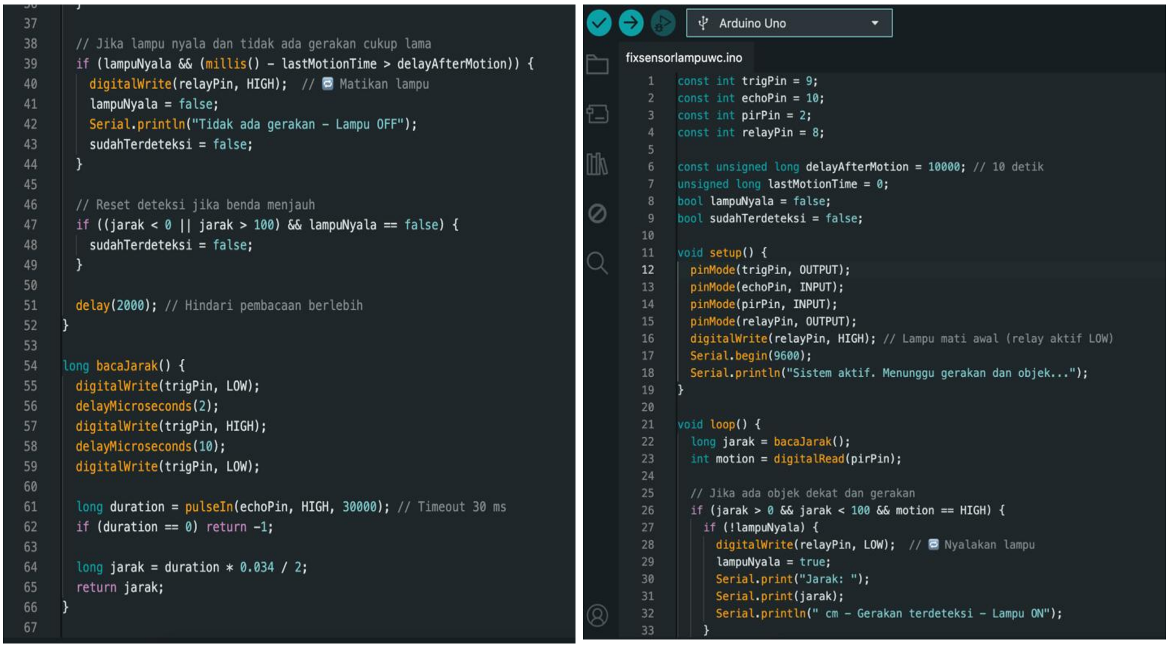

Figure 8. Arduino's Code

Figure 8 illustrates the software implementation in the form of source code used to control the lighting system automatically. The implemented logic ensures that the digital output (lamp) is activated only when both conditions are simultaneously met, namely the presence of an object within a specified distance range and the detection of motion. By not involving wireless communication protocols or network-based devices, the system offers advantages in terms of response speed, local reliability, and ease of maintenance and replication.

Overall, the realized system demonstrates the capability to perform lighting automation efficiently and effectively. This approach also contributes to the development of sensor-based control systems without dependence on external infrastructure and supports energy-saving efforts through the utilization of microcontroller-based automation technology.

Deployment and Feedback

After the implementation process was completed, the next stage involved deployment at the research site. This deployment process consisted of the direct installation of the automatic lighting system in the bathroom area. Figure 9 shows the results of the installation of the IoT-based device in the bathroom.

Figure 9. Installation Automatic Lighting

Subsequently, the feedback stage was carried out through testing to evaluate the performance of the Arduino-based automatic lighting control system using a PIR sensor. The testing focused on the PIR sensor to determine whether it was able to operate properly, particularly in detecting users within the bathroom area. Table 1 presents the results of the PIR sensor testing. The test was conducted to analyze the lamp's response to distance conditions, where the system was configured so that within a range of up to 100 cm, the lamp would turn on when the presence of a human entering the bathroom was detected.

Table 1. PIR Sensor Test Results

No	Distance	Lamp Status
1	10 cm	On
2	20 cm	On
3	30 cm	On
4	50 cm	On
5	100 cm	On

The results show that the IoT-based automatic lighting control system, integrating both sensors, functioned as intended. This confirms that the research objective to design an IoT-based automatic lighting system as a green technology solution for a place of worship was successfully achieved.

CONCLUSION

Based on the design and implementation of the Arduino Uno microcontroller-based automatic lighting system using Passive Infrared (PIR), it can be concluded that the system operates effectively and efficiently in controlling restroom lighting. The system is designed to automatically switch on the light when an object is detected within 100 cm and human body movement is detected. The hardware implementation demonstrated stable system performance even without wireless network or internet connectivity, making it an ideal solution for spaces with limited connectivity. From the software perspective, using the Arduino IDE as the programming platform provides flexibility and ease in developing and modifying the system. The C/C++ code structure is accessible to users with both technical and non-technical backgrounds, increasing the potential for replication and further system development. Therefore, this automatic lighting system not only contributes to improved comfort and energy efficiency but also shows strong potential for wider application in enclosed automation scenarios requiring smart and independent control systems.

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