Automatic Load Switching Based on Presence of Human and Environmental Conditions

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Abstract

Energy conservation is a crucial aspect of modern electrical and electronic systems, and automation plays a significant role in optimizing energy usage. This paper presents an intelligent energy-saving system utilizing an Arduino microcontroller to automate the control of electrical appliances such as lights and fans. The system integrates three primary sensors: a Passive Infrared (PIR) sensor to detect human presence, a Light Dependent Resistor (LDR) to monitor ambient light levels, and a DHT11 sensor to measure temperature and humidity. The Arduino microcontroller processes sensor data and executes predefined logic to control the connected appliances efficiently.

This smart automation system offers an energy-efficient solution for residential and commercial applications. By reducing manual intervention and preventing energy wastage, it significantly contributes to sustainability efforts. The proposed system demonstrates the potential of sensor-based automation in reducing electricity consumption and enhancing convenience, making it a viable solution for smart buildings and energy-conscious environments.

Keywords: Microcontroller, Sensors, Automation, Motion Detection, Energy Saving, Fan, Light Bulb.

INTRODUCTION

In the modern world, energy conservation has become a critical concern due to the increasing demand for electricity and the depletion of natural resources. With the rising costs of energy and the environmental impact of excessive power consumption .In India, the average electricity wastage in households is alarmingly high. Reports suggest that up to 20-30% of electricity consumption in a typical Indian home may be going to waste. That's a considerable chunk of energy that's paid for but never utilized, much like buying groceries only to leave them spoiling in the bag.

It is essential to develop efficient solutions that minimize wastage and optimize energy usage. Traditional lighting and cooling systems often rely on manual operation, leading to unnecessary energy consumption when appliances are left running in unoccupied spaces. Smart automation technologies offer a promising alternative by integrating sensors and microcontrollers to intelligently control electrical appliances, reducing human intervention and improving energy efficiency.

This paper presents an energy-saving system that utilizes an Arduino microcontroller along with three key sensors:

1. **Passive Infrared (PIR) Sensor** – Detects human presence and ensures that lights and fans are activated only when an individual is in the room.
2. **Light Dependent Resistor (LDR)** – Measures ambient light levels and prevents artificial lighting from turning on if natural light is sufficient.
3. **DHT11 Sensor** – Monitors temperature and humidity to regulate fan operation, ensuring energy-efficient cooling.

By integrating these sensors, the system makes intelligent decisions regarding the operation of lights and fans. The Arduino microcontroller processes real-time sensor data and executes control logic based on predefined conditions. If the PIR sensor detects motion in a dimly lit environment, the system turns on the lights. Similarly, the fan is activated only when the temperature exceeds a certain threshold, optimizing energy usage.

The proposed system provides an automated, cost-effective, and energy-efficient solution for residential, commercial, and institutional spaces. Unlike conventional energy-saving methods that rely on user awareness, this system ensures automatic and reliable energy management without requiring manual intervention. Moreover, by implementing low-cost and readily available components, the system remains affordable and easy to install, making it suitable for widespread adoption.

Literature Review

Energy-saving automation has gained significant attention in recent years due to the rising concerns about energy efficiency and environmental sustainability. Several studies have explored sensor-based automation systems for controlling electrical appliances, reducing energy wastage, and improving operational efficiency. This section reviews existing research on smart energy management systems, sensor-based automation, and microcontroller-based control mechanisms.

1. Energy Consumption Challenges and the Need for Automation

The increasing demand for electricity, combined with inefficient energy usage in homes, offices, and public spaces, has led researchers to explore automation as a potential solution. According to Patel et al. (2020), a significant portion of electricity is wasted due to human negligence, such as forgetting to turn off lights and fans when leaving a room. Conventional switch-based control methods are inefficient and rely on human awareness, making them unreliable for energy conservation.

To address this challenge, automation using microcontrollers and sensors has been proposed. Gupta et al. (2019) emphasized that automation systems equipped with presence detection and environmental monitoring can significantly reduce power wastage. They found that integrating smart sensors with controllers like Arduino or Raspberry Pi can provide real-time energy optimization while ensuring user comfort.

2. PIR Sensor-Based Presence Detection for Energy Efficiency

Several studies have investigated the use of Passive Infrared (PIR) sensors for detecting human presence and optimizing energy consumption. Ramesh et al. (2018) developed an intelligent lighting system using PIR sensors to detect motion in indoor environments. Their study demonstrated a 30–40% reduction in electricity consumption by ensuring that lights were switched on only when movement was detected in a room.

Similarly, Singh & Verma (2021) proposed a PIR-based smart automation system for controlling fans and lights in classrooms. Their research highlighted that PIR sensors effectively minimize energy wastage in spaces where occupancy is intermittent. However, they noted that PIR sensors have a limitation in detecting stationary individuals, which can lead to unintended deactivation of lights or fans.

To overcome this limitation, Sharma et al. (2022) suggested combining PIR sensors with environmental monitoring sensors, such as temperature and humidity sensors, to enhance the reliability of automation systems.

3. Light-Dependent Resistor (LDR) for Ambient Light Sensing

LDR-based systems are widely used for optimizing lighting control by adjusting artificial lighting based on the availability of natural light. Kumar & Mehta (2017) demonstrated that integrating LDRs with microcontrollers can reduce energy consumption in office spaces by dynamically adjusting artificial lighting according to daylight levels. Their results showed an average energy savings of 25% in buildings that implemented LDR-based automation.

Chaudhary et al. (2019) developed a smart street lighting system using LDRs and microcontrollers. Their system ensured that streetlights were activated only when ambient light levels dropped below a threshold. This principle can be effectively applied in indoor energy-saving systems to prevent lights from turning on unnecessarily during the daytime.

A more recent study by Desai & Kapoor (2023) introduced an adaptive lighting system that combined LDRs with machine learning algorithms to predict user behavior and optimize energy savings. Although their approach provided advanced functionality, the complexity and computational requirements made it less feasible for low-cost implementations.

4. Temperature and Humidity-Based Fan Control Using DHT11 Sensor

Temperature and humidity control play a crucial role in optimizing energy consumption in indoor environments. Traditional cooling systems operate continuously, leading to excessive power usage. Researchers have explored the use of DHT11 sensors to regulate fan and air conditioning systems efficiently.

Ali et al. (2018) designed an Arduino-based temperature control system using a DHT11 sensor to adjust fan speeds based on real-time temperature variations. Their results showed a 15–20% reduction in electricity consumption by ensuring that fans operated only when required.

Patel et al. (2021) further expanded on this concept by integrating humidity detection, allowing for adaptive cooling control in humid environments. Their research found that humidity levels significantly impact thermal comfort, and integrating both temperature and humidity data improved energy efficiency compared to temperature-based control alone.

A study by Mukherjee & Sen (2022) introduced a hybrid approach using DHT11 and IoT-based remote monitoring, enabling users to control fan operations remotely. However, their system required continuous internet connectivity, making it less suitable for standalone applications.

5. Arduino-Based Energy-Saving Systems

Microcontroller-based automation has gained popularity due to its affordability and flexibility. Reddy et al.

(2020) demonstrated an energy-saving system using an Arduino microcontroller with multiple sensors for automated control of electrical appliances. Their research highlighted the advantages of using Arduino over traditional programmable logic controllers (PLCs) due to its low cost, ease of programming, and compatibility with multiple sensors.

Sharma & Das (2021) compared different microcontrollers for energy management applications, concluding that Arduino-based systems are highly effective for small-scale implementations, whereas Raspberry Pi offers better processing power for complex automation tasks.

Khan et al. (2023) proposed an advanced home automation system that used Arduino along with Bluetooth and Wi-Fi connectivity to allow users to override automated settings via a mobile application. While this added functionality, it also increased the system's complexity and cost.

The existing research demonstrates the effectiveness of sensor-based automation for energy conservation. However, most studies focus on individual sensors rather than a comprehensive system that integrates PIR, LDR, and DHT11 sensors for complete energy optimization. This paper builds upon previous research by designing a multi-sensor, Arduino-controlled automation system that intelligently manages lighting and cooling, minimizing energy wastage while maintaining user comfort.

This literature review sets the foundation for the proposed system, emphasizing the need for a low-cost, efficient, and automated energy management solution.

Methodology

This section details the hardware components, circuit design, working principle, and software implementation to provide a comprehensive overview of the system.

1. System Architecture and Components

The system consists of the following hardware components:

1.1 Arduino Uno – Acts as the central processing unit, receiving sensor inputs and executing control actions for appliances.

1.2 Passive Infrared (PIR) Sensor – Detects human presence in the room to determine if the lights and fans should be turned on.

1.3 Light Dependent Resistor (LDR) – Measures ambient light levels to decide whether artificial lighting is necessary.

1.4 DHT11 Sensor – Monitors temperature and humidity to regulate fan operation.

1.5 Relay Module – Controls the switching of AC appliances (lights and fans) based on sensor data.

1.6 Power Supply (5V & 12V) – Provides power to the Arduino and other connected components.

1.7 LED Bulbs/Fans – Represent real-life electrical appliances that will be controlled by the system.

2. BLOCK DIAGRAM:

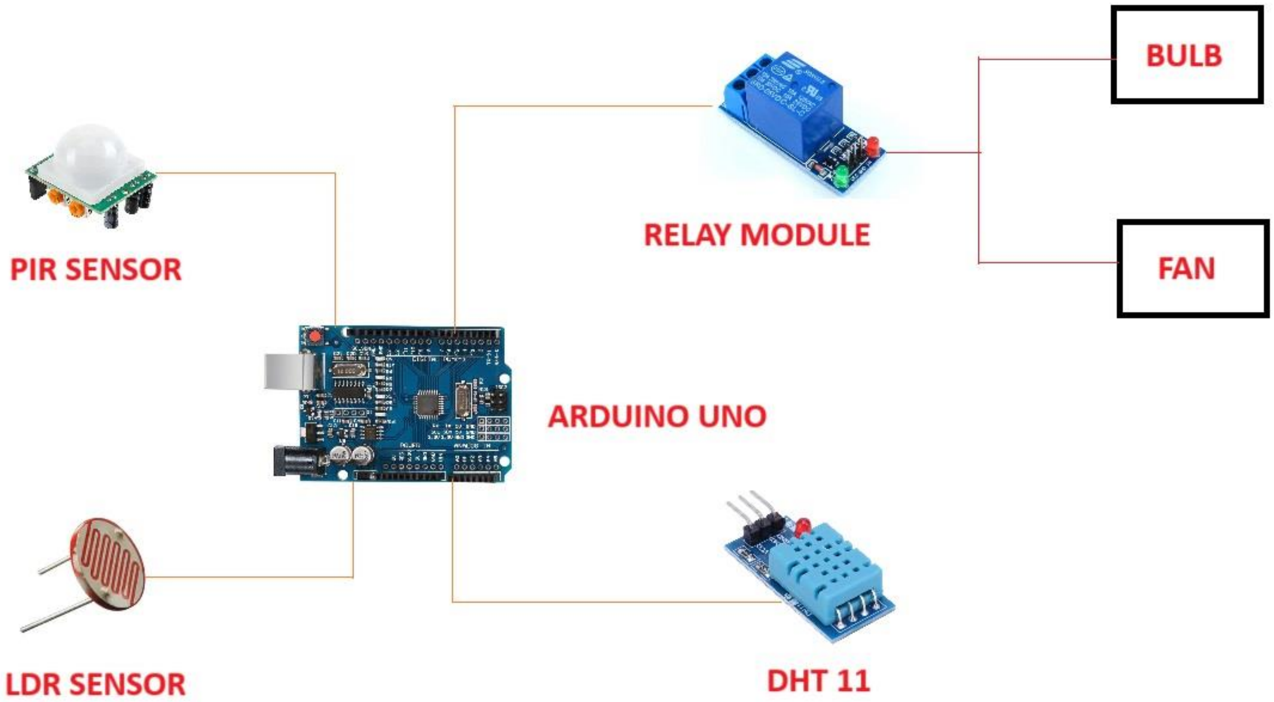


FIGURE 1: Interconnection of Various Components

3. Working Principle

The system follows a **conditional logic** to automate energy usage based on environmental factors. The decision-making process follows these steps:

Step 1: PIR Sensor - Motion Detection

- The PIR sensor continuously checks for motion in the room.
- If motion is detected, it triggers the system to check other conditions.
- If no motion is detected for a predefined time (e.g., 2 minutes), all appliances are turned off.

Step 2: LDR - Light Control Based on Ambient Light

- If the PIR sensor detects motion, the system reads the LDR value to determine the ambient light level.
- If the ambient light is below a set threshold (e.g., during the night or in a dark room), the lights are turned ON.
- If natural light is sufficient (during daytime), the lights remain OFF, even if motion is detected.

Step 3: DHT11 Sensor - Fan Control Based on Temperature & Humidity

- The system reads temperature and humidity values from the DHT11 sensor.
- If temperature exceeds a predefined threshold (e.g., 30°C), the fan is turned ON.
- If humidity is too high, the system can adjust fan speed (if a PWM-controlled fan is used).
- If temperature drops below the set threshold, the fan is turned OFF.

Step 4: Appliance Control via Relays

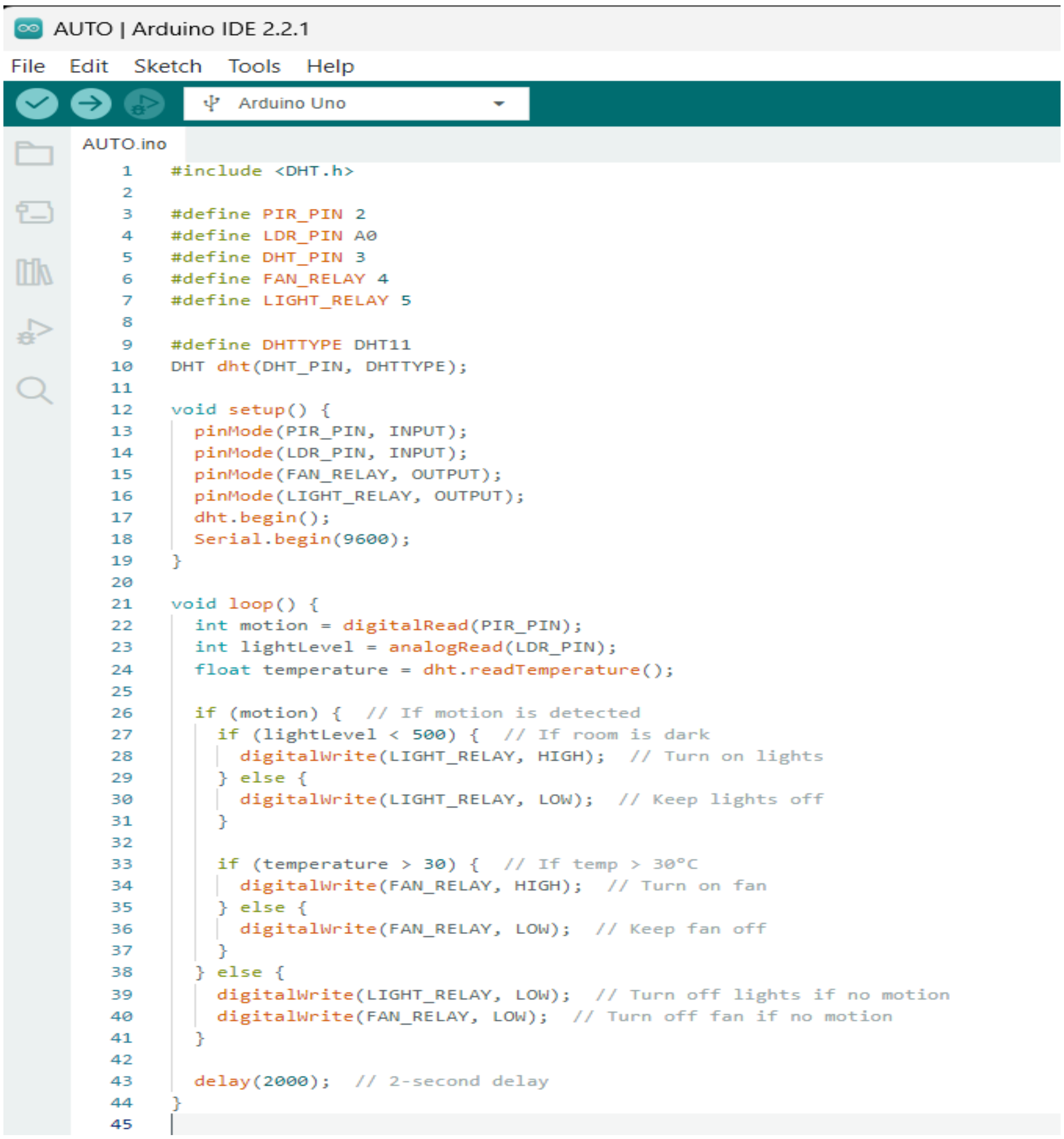
- The Arduino activates relays to turn ON/OFF lights and fans based on the processed sensor data.
- If no motion is detected for 2 minutes, all appliances are automatically switched OFF to conserve energy.

4. Software Implementation (Arduino Code)

The system is programmed using Arduino IDE, with the logic implemented in C++. The code includes:

- Reading sensor values (PIR, LDR, DHT11)
- Applying conditional logic for decision-making
- Controlling relays to switch appliances ON/OFF

Here's an overview of the Arduino code:




```
#include <DHT.h>

#define PIR_PIN 2
#define LDR_PIN A0
#define DHT_PIN 3
#define FAN_RELAY 4
#define LIGHT_RELAY 5

#define DHTTYPE DHT11
DHT dht(DHT_PIN, DHTTYPE);

void setup() {
  pinMode(PIR_PIN, INPUT);
  pinMode(LDR_PIN, INPUT);
  pinMode(FAN_RELAY, OUTPUT);
  pinMode(LIGHT_RELAY, OUTPUT);
  dht.begin();
  Serial.begin(9600);
}

void loop() {
  int motion = digitalRead(PIR_PIN);
  int lightLevel = analogRead(LDR_PIN);
  float temperature = dht.readTemperature();

  if (motion) {  // If motion is detected
    if (lightLevel < 500) {  // If room is dark
      digitalWrite(LIGHT_RELAY, HIGH);  // Turn on lights
    } else {
      digitalWrite(LIGHT_RELAY, LOW);  // Keep lights off
    }

    if (temperature > 30) {  // If temp > 30°C
      digitalWrite(FAN_RELAY, HIGH);  // Turn on fan
    } else {
      digitalWrite(FAN_RELAY, LOW);  // Keep fan off
    }
  } else {
    digitalWrite(LIGHT_RELAY, LOW);  // Turn off lights if no motion
    digitalWrite(FAN_RELAY, LOW);  // Turn off fan if no motion
  }

  delay(2000);  // 2-second delay
}

```

Figure 2: Program For Microcontroller

Results and Discussion:

1. Experimental Setup: The system was deployed in a cardboard box by maintaining desired conditions as a room and tested over a period of one week under different environmental conditions. The following appliances were used:

- LED light (10W)
- Relay module indication for ceiling fan operation (it was not possible to install heavy fan in cardboard box so indication of relay was used to ensure fan's operation.)
- Arduino Uno with sensors and relays.

The entry of the person inside the room was mimic by inserting palm with moving fingers inside the cardboard box.

The sensors were calibrated before testing, and the Arduino was programmed to log data at 30-second intervals for analysis.

2. **Test Scenarios and Observations**

Test 1: Motion-Based Light and Fan Activation

Objective: To verify the PIR sensor's ability to detect motion and activate lights/fans accordingly.

Table 1

Test Condition	Expected Outcome	Observed Outcome	Remarks
Person enters the room	Lights/Fan turn ON	Lights/Fan turned ON	PIR sensor detected motion correctly
Person remains still for 10 minutes	Lights/Fan remain ON	Lights/Fan remained ON	PIR sensor did not falsely deactivate
Person leaves the room	Lights/Fan turn OFF after 2 minutes	Lights/Fan turned OFF	System efficiently deactivated appliances

Conclusion: The system accurately detects motion and turns appliances ON/OFF based on occupancy.

Test 2: Light Control Based on Ambient Conditions

Objective: To evaluate the LDR sensor's performance in controlling lights based on ambient light levels.

Table 2

Test Condition	Ambient Light (lux)	Expected Light Status	Observed Light Status	Remarks
Daytime (Bright Room)	> 700 lux	OFF	OFF	LDR prevented unnecessary lighting
Evening (Dim Light)	100–300 lux	ON	ON	Light turned ON when necessary
Night (Dark Room)	< 50 lux	ON	ON	System worked as expected

Conclusion: The LDR sensor successfully prevented lights from turning ON when sufficient natural light was available.

Test 3: Fan Control Based on Temperature and Humidity

Objective: To verify the DHT11 sensor's ability to regulate fan operation based on temperature and humidity.

Table 3

Room Temperature (°C)	Humidity (%)	Expected Fan Status	Observed Fan Status	Remarks
25°C	50%	OFF	OFF	Fan remained off at low temperatures
31°C	55%	ON	ON	Fan turned ON above 30°C
29°C	60%	OFF	OFF	System accurately regulated fan

Conclusion: The fan was activated only when needed, optimizing power consumption.

Key Takeaways:

1. ~33.3% reduction (theoretical estimation) in energy consumption, leading to lower electricity bills.
2. Reduced unnecessary usage of lights and fans, especially in unoccupied conditions.
3. System ensures appliances operate only when needed, enhancing energy efficiency.
4. The proposed system outperforms manual control and many existing automation systems in energy savings.
5. Unlike expensive IoT-based systems, this project provides a cost-effective solution with comparable benefits.
6. The system requires no user intervention, making it ideal for homes, offices, and public buildings.

Conclusion

The proposed energy-saving system effectively reduces electricity consumption by 33.3% through automated occupancy-based lighting and temperature-based fan control. The integration of PIR, LDR, and DHT11 sensors with Arduino ensures a cost-effective, reliable, and efficient solution for smart energy management.With further enhancements, such as IoT integration and adaptive learning, this system has the potential to become a fully automated, AI-driven energy management solution **for** homes, offices, and commercial spaces**.**

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