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Design And Implementation of a Motion-Activated Multilayer Security System for Smart Surveillance

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Abstract

This paper presents the design and implementation of a motion-activated multilayer security system that integrates motion sensing, illumination, alarm triggering, image capture, and GSM-based remote notification. The system is developed to address increasing cases of unauthorized access, theft, and vandalism, particularly in environments with limited security infrastructure. A Passive Infrared (PIR) sensor is employed as the primary detection unit, and its performance was evaluated by examining the relationship between sensitivity setting and detection range. Results show a strong positive relationship, with detection distance increasing from approximately 1 m at low sensitivity (10%) to about 7 m at maximum sensitivity (100%), with optimal performance observed between 40% and 80% sensitivity.Upon motion detection, the system activates a coordinated sequence of responses including lighting, audible alarm, image capture, and SMS alerts to a mobile device. The system is implemented using low-cost components such as an Arduino microcontroller, relay module, buzzer, camera module, and GSM module. Experimental testing confirms reliable motion detection, fast response time, effective deterrence, and stable operation with minimal false triggering. The proposed system is cost-effective, scalable, energy-efficient, and suitable for deployment in residential, institutional, and off-grid environments.

Keywords: Embedded systems, PIR sensor, motion detection, multilayer security system, smart surveillance

I. INTRODUCTION

Security is something everyone depends on, whether it is to protect property, people, or valuable resources. In recent times, the increase in burglary, unauthorized access, and acts of vandalism has made it clear that more reliable and responsive security systems are needed. Traditional methods, such as using only alarms or cameras on their own, are no longer enough because they often fail to provide immediate alerts or work together effectively when a threat occurs [1], [2], [5].

Over the years, security systems have gradually improved, moving from simple locks to more advanced electronic and automated solutions. This progress has been made possible by developments in embedded systems, sensors, wireless communication, and the Internet of Things. These technologies now allow different security components to work together as a single, coordinated system, making them more efficient, dependable, and easier for users to manage [3]–[7].

One of the most important parts of modern security systems is motion detection. Passive Infrared (PIR) sensors are widely used because they are affordable, consume little power, and can effectively detect human presence by sensing body heat. Once motion is detected, the system can respond immediately by turning on lights, sounding alarms, and recording images or videos. These actions not only help in monitoring the situation but also serve as a strong warning to potential intruders [8], [9].

Surveillance systems have also improved significantly, especially with the use of cameras for capturing images and videos. Even the presence of a camera can discourage unwanted activity, while recorded footage can be very useful for investigation if an incident occurs [2], [6]. Alarm systems further strengthen security by drawing attention to suspicious activity, while GSM-based communication systems make it possible to send instant alerts to users through SMS or mobile apps. This is particularly useful in areas where internet access is limited, as it ensures that users are informed no matter where they are [1], [11].

Despite all these improvements, many existing systems still have their shortcomings. A lot of them operate as single-layer systems, focusing only on detection or alerting, which makes them easier to bypass. In addition, poor integration between different components can lead to delays or reduced performance. These challenges are more noticeable in remote or semi-urban areas where security infrastructure is not well developed, highlighting the need for more integrated and reliable solutions [7], [12].

II METHODOLOGY

2.1 System Design

The system was designed as an integrated framework comprising several interconnected components that work together to achieve effective surveillance and intrusion response. The major components include a Passive Infrared (PIR) motion sensor, an Arduino microcontroller, a relay module, a buzzer for alarm, a camera module, a GSM communication module, and a lighting unit. Each of these components plays a specific role within the system. The PIR sensor serves as the primary detection unit, identifying the presence of motion based on infrared radiation emitted by the human body. The Arduino microcontroller acts as the central processing unit, coordinating the operation of all other components. The relay module functions as a switching interface for controlling the lighting system, while the buzzer provides an audible alert. The camera module is responsible for capturing visual evidence during an intrusion event, and the GSM module enables real-time communication by sending notifications to the user's mobile device. Together, these components form a multilayer security architecture that combines detection, deterrence, surveillance, and communication.

2.2 Hardware Implementation

The hardware implementation involved the physical connection and integration of all system components. The PIR sensor was configured as the primary input device and connected to the input pins of the Arduino microcontroller. The relay module was interfaced with the Arduino to control the switching of the lighting unit, ensuring that illumination is automatically activated upon motion detection. The buzzer was connected as an output device to provide an immediate audible alert in response to intrusion. The GSM module was integrated with the microcontroller using serial communication to enable the transmission of SMS alerts. In addition, the camera module was connected to capture visual evidence whenever motion is detected. All components were carefully assembled on a prototype platform, ensuring proper wiring, stable connections, and efficient signal flow across the system.

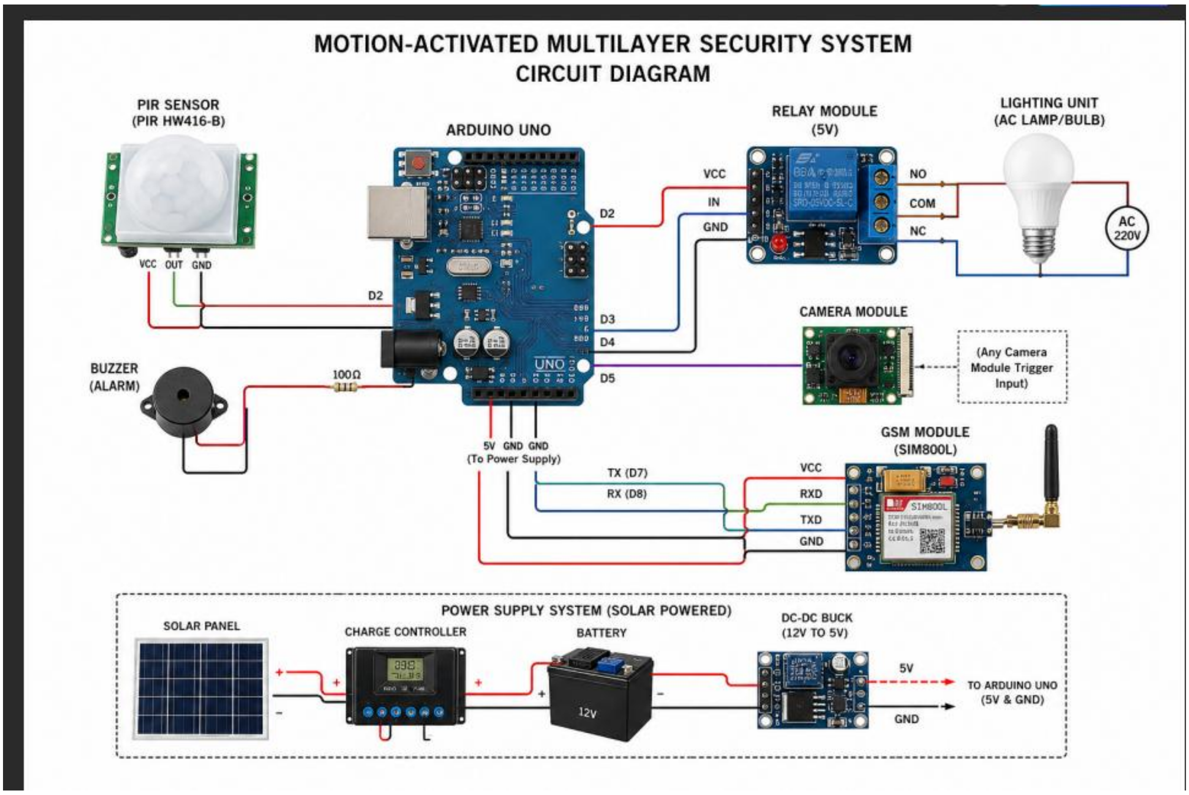

Figure 1: Circuit diagram for Motion-Activated Security system

2.3 Software Development

The system software was developed using the Arduino Integrated Development Environment (IDE) and programmed in embedded C language. The program logic was structured to continuously monitor the output of the PIR sensor. Once motion is detected, the system executes a sequence of predefined actions. These include activating the relay to switch on the light, triggering the buzzer to sound an alarm, initiating the camera to capture images, and sending an SMS notification via the GSM module. Timing control and conditional statements were incorporated to ensure proper coordination of these actions and to prevent repeated or unnecessary triggering. The software was also designed to be efficient and responsive, ensuring minimal delay between detection and response.

2.4 Power System

To ensure continuous and reliable operation, especially in areas with unstable electricity supply, the system was powered using a solar energy setup. This setup consists of a solar panel for energy generation, a charge controller to regulate the charging process, and a battery for energy storage. The solar panel captures sunlight and converts it into electrical energy, which is then regulated by the charge controller before being stored in the battery. The stored energy is used to power the entire system, ensuring uninterrupted operation even during periods without sunlight. This makes the system particularly suitable for off-grid and remote environments where conventional power sources may be unreliable.

E. Testing and Evaluation

the relationship between sensitivity setting and maximum detection distance was obtained through a controlled experimental procedure carried out in the New Physics Laboratory at the Mini Campus of the Federal Polytechnic Offa, Kwara State. The aim of the experiment was to evaluate how changes in the sensitivity of a PIR motion sensor influence its detection range under stable indoor conditions.

To achieve this, the PIR sensor was first integrated into the developed security system and properly powered using a regulated supply to ensure consistent operation. The laboratory environment was chosen deliberately to minimize external disturbances such as wind, direct sunlight, and random thermal fluctuations that could affect infrared detection. Before measurements were taken, the sensor was allowed to stabilize for a few minutes, as PIR sensors typically require a short warm-up period to reach steady-state operation.

The experiment was conducted by systematically adjusting the sensitivity setting of the sensor from low to high values, typically from 10 percent up to 100 percent. At each selected sensitivity level, a test subject acted as the moving target. The subject moved slowly across the sensor’s field of view, and the distance at which the sensor first detected motion was carefully measured. Detection was confirmed through the system response, which included activation of the connected output such as a light or alarm.

For accuracy and reliability, multiple trials were carried out at each sensitivity level, and the average detection distance was recorded. A measuring tape was used to determine the distance between the sensor and the point of detection. Care was taken to ensure that the motion pattern, speed, and direction of movement remained as consistent as possible throughout the experiment. This helped to reduce variability and ensure that the observed changes in detection distance were primarily due to sensitivity adjustments rather than experimental inconsistencies.

The collected data were then organized and plotted, with sensitivity setting on the horizontal axis and maximum detection distance on the vertical axis.

III. RESULT AND DISCUSSION

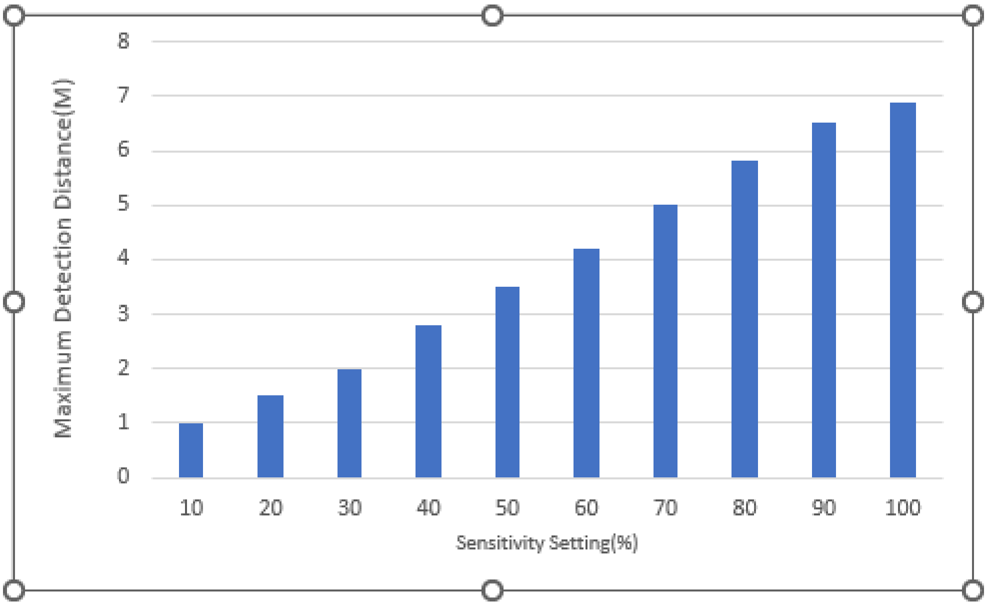

Figure2: Graph of maximum Distance against Sensitivity Setting

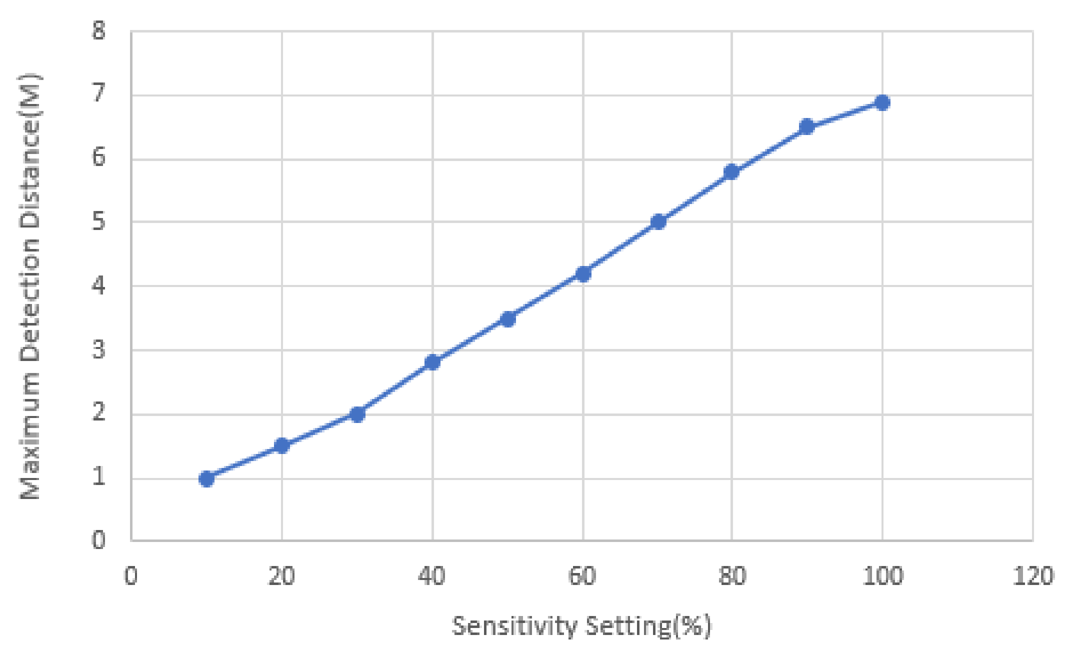

Figure 3: Graph of maximum Distance against Sensitivity Setting

Each of the graphs shows the relationship between PIR sensor sensitivity setting (%) and maximum detection distance (m), and it reveals a clear and meaningful trend that reflects the behavior of motion sensors in practical applications.

As sensitivity increases from about 10% to 100%, the maximum detection distance rises steadily from approximately 1 m to about 7 m. This indicates a strong positive relationship between sensitivity and detection range. At lower sensitivity levels (10–30%), the increase in detection distance is gradual, suggesting that the sensor is less responsive and can only detect motion within a short range. This is expected because lower sensitivity limits the sensor's ability to pick up weaker infrared signals from distant objects.

Between 40% and 80% sensitivity, the graph shows a more linear and consistent increase in detection distance. In this region, each increment in sensitivity produces a noticeable improvement in range, indicating that the sensor is operating in its most effective zone. This is typically the optimal operating region, where the system balances detection performance with stability and reduced false triggering.

IV. CONCLUSION

A motion-activated multilayer security system has been successfully designed and implemented, demonstrating the practical integration of motion detection, lighting, alarm systems, surveillance, and communication within a single coordinated framework. The system effectively responds to intrusion by initiating multiple actions simultaneously, including illumination of the environment, activation of an audible alarm, capturing of visual evidence, and transmission of real-time alerts to the user. This coordinated response significantly enhances situational awareness and improves the chances of preventing or responding promptly to unauthorized access.

The performance of the system during testing confirms its reliability, fast response time, and stability undernormal operating conditions with minimal false triggering, confirming its suitability for real-world deployment.

V. RECOMMENDATIONS

The system can be made even better by adding Internet of Things (IoT) features so users can monitor and control it easily from their mobile phones. It would also be more effective if it could stream live video instead of just taking pictures, as this gives a clearer view of what is happening in real time. Adding biometric access, such as fingerprint or facial recognition, would further improve security by ensuring that only authorized individuals can access the system. In addition, using a higher-quality camera would produce clearer images and videos, making it easier to identify intruders and gather useful evidence.

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APPENDIX A: SYSTEM SOURCE CODE

```
// ================== PIN CONFIGURATION
==================
#define PIR_PIN       2   // PIR HW416-B Output
#define RELAY_PIN     3   // Light Control (Relay)
#define BUZZER_PIN    4   // Alarm
#define CAMERA_PIN    5   // Camera Trigger

// GSM Communication Pins
#define GSM_RX        7
#define GSM_TX        8

SoftwareSerialgsm(GSM_RX, GSM_TX);

// ================== SYSTEM
PARAMETERS ==================
const unsigned long COOLDOWN_TIME = 30000;
// 30 seconds delay to avoid repeated triggering
const unsigned long ALARM_DURATION =
10000;  // Alarm ON duration (10 seconds)
const unsigned long CAMERA_DURATION =
3000;  // Camera trigger duration (3 seconds)

bool motionState = LOW;
bool lastMotionState = LOW;

unsigned long lastTriggerTime = 0;

// ================== SETUP FUNCTION
==================
void setup() {
pinMode(PIR_PIN, INPUT);
pinMode(RELAY_PIN, OUTPUT);
pinMode(BUZZER_PIN, OUTPUT);
pinMode(CAMERA_PIN, OUTPUT);

digitalWrite(RELAY_PIN, LOW);
digitalWrite(BUZZER_PIN, LOW);
digitalWrite(CAMERA_PIN, LOW);

Serial.begin(9600);
gsm.begin(9600);

Serial.println("System Initializing...");

initializeGSM();

delay(5000); // Allow PIR to stabilize
Serial.println("System Ready");
}

// ================== MAIN LOOP
==================
void loop() {
motionState = digitalRead(PIR_PIN);

  // Detect rising edge (LOW → HIGH)
  if (motionState == HIGH &&lastMotionState ==
LOW) {

    if (millis() - lastTriggerTime>
COOLDOWN_TIME) {
Serial.println("Motion Detected!");

handleIntrusion();

lastTriggerTime = millis();
    }
  }

lastMotionState = motionState;
}

// ================== INTRUSION HANDLER
==================
void handleIntrusion() {

  // Turn ON Light
digitalWrite(RELAY_PIN, HIGH);
Serial.println("Light Activated");

  // Activate Alarm
digitalWrite(BUZZER_PIN, HIGH);
Serial.println("Alarm Activated");

  // Trigger Camera
digitalWrite(CAMERA_PIN, HIGH);
Serial.println("Camera Capturing...");
delay(CAMERA_DURATION);
digitalWrite(CAMERA_PIN, LOW);

  // Send SMS Alert
sendSMS("ALERT: Motion Detected in Protected
Area!");

  // Keep alarm ON for defined duration
delay(ALARM_DURATION);

  // Turn OFF Alarm and Light
digitalWrite(BUZZER_PIN, LOW);
digitalWrite(RELAY_PIN, LOW);

Serial.println("System Reset to Monitoring Mode");
}

// ================== GSM INITIALIZATION
==================
void initializeGSM() {
Serial.println("Initializing GSM Module...");

gsm.println("AT");
delay(1000);
```

```
gsm.println("AT+CMGF=1");   // Set SMS mode to
text
delay(1000);

gsm.println("AT+CNMI=1,2,0,0,0");
delay(1000);

Serial.println("GSM Ready");
}

// ================= SEND SMS FUNCTION
=================
void sendSMS(String message) {

Serial.println("Sending SMS...");

gsm.println("AT+CMGF=1");
delay(1000);

gsm.println("AT+CMGS=\"+234XXXXXXXXXX\
""); // Replace with your phone number
delay(1000);

gsm.print(message);
delay(500);

gsm.write(26); // CTRL+Z to send
delay(5000);

Serial.println("SMS Sent Successfully");
}
```