RAJALAKSHMI
ENGINEERING COLLEGE
An AUTONOMOUS Institution
Affiliated to ANNA UNIVERSITY, Chennai

AI-POWERED FACE DETECTION FOR ENERGY-EFFICIENT HOME AUTOMATION

Submitted by:

ARAVINTH.S(221801003)

LIO GODWIN.BR(221801029)

MAIYAZHAGAN.V(221801032)

AD19643 INNOVATION AND DESIGN THINKING

Department of Artificial Intelligence and Data Science

Rajalakshmi Engineering College, Thandalam

Chennai-602 105

BONAFIDE CERTIFICATE

Certified that this project report **"AI-Powered Face Detection for Energy Efficient Home Automation**" is the Bonafide work of **"ARAVINTH.S(221801003), LIO GODWIN.BR(221801029), MAIYAZHAGAN.V(221801032)" who** carried out the project work under my supervision.

Submitted for the Practical Examination held on ______________________________

SIGNATURE	**SIGNATURE**
DR GNANASEKAR JM	**DR SURESH KUMAR S**
HEAD OF DEPARTMENT	**PROFESSOR**
ARTIFICIAL INTELLIGENCE AND DATA SCIENCE	**ARTIFICIAL INTELLIGENCE AND DATA SCIENCE**
RAJALAKSHMI ENGINEERING COLLEGE (AUTONOMOUS), THANDALAM,CHENNAI-602105	**RAJALAKSHMI ENGINEERING COLLEGE (AUTONOMOUS), THANDALAM,CHENNAI-602105**

INTERNAL EXAMINER **EXTERNAL EXAMINER**

ABSTRACT

Smart home automation has advanced significantly with the integration of computer vision (CV) and the Internet of Things (IoT). Traditional systems predominantly depend on Passive Infrared (PIR) sensors to detect motion through thermal changes; however, these sensors often fail to identify stationary individuals and are prone to false triggers from ambient heat sources. Although continuous CV-based gesture recognition offers an intuitive interaction method, its high computational and energy demands hinder its practical real-time deployment. To overcome these limitations, this work introduces a novel hybrid system that combines CV with microwave sensors, augmented by a Raspberry Pi equipped with a camera module for precise eye tracking. A dedicated gesture recognition module enhances accessibility for individuals with disabilities by enabling natural, non-contact control. In addition, a customizable web/mobile application is developed to facilitate user configuration—allowing users to assign specific finger gestures to corresponding home automation options. This app features a color-based, high- contrast interface designed to be visually accessible, particularly for users with visual impairments, ensuring that even those with limited vision can effortlessly distinguish and set up their preferred gesture controls. This multi-modal approach delivers a context- aware, energy-efficient solution that not only mitigates the shortcomings of conventional sensors but also significantly enhances system usability and accessibility for all users.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

The rapid evolution of smart home automation has led to the development of more efficient and intelligent energy management systems. Traditional motion-sensing technologies, such as Passive Infrared (PIR) sensors, rely on detecting thermal changes to identify human presence. However, these systems are often prone to false activations caused by lingering heat signatures, moving objects, or environmental disturbances. Moreover, PIR sensors fail to detect stationary individuals, leading to inefficient energy consumption in modern automation systems. To address these challenges, this study proposes an AI-driven energy management system that leverages computer vision (CV) and deep learning-based face detection to regulate electrical appliances such as lighting and fans. Unlike conventional motion sensors, OpenCV-based face detection algorithms, including Haar cascades and deep learning models, provide enhanced accuracy in detecting actual human presence. By integrating this real-time AI-powered solution, the system ensures that appliances are activated only when a person is physically present and automatically turned off when they leave—reducing energy waste while enhancing user convenience.

1.2 NEED FOR THE STUDY

The need for this study arises from the limitations of conventional smart home automation systems, which primarily rely on Passive Infrared (PIR) sensors that struggle to detect stationary individuals and are susceptible to false triggers. Existing gesture recognition methods based on computer vision, while intuitive, are often impractical due to their high computational and energy demands. There is a growing demand for more accurate, responsive, and accessible automation systems that cater to a wider range of users, including those with disabilities. By integrating microwave sensors with computer vision and eye-tracking capabilities on a low-power platform like Raspberry Pi, this study addresses these challenges. Additionally, the development of an accessible, customizable mobile/web interface ensures inclusivity and ease of use, emphasizing the importance of a context-aware and energy-efficient solution for modern smart homes.

1.3 OBJECTIVES OF THE STUDY

The objectives of this project are:

Develop a Hybrid Detection System

Design and implement a smart home automation framework combining microwave sensors with computer vision. This system aims to improve motion detection accuracy, especially for stationary individuals.

Enable Accessible Gesture Control

Integrate eye-tracking and gesture recognition modules to support non-contact interaction. Focus on enhancing accessibility for users with physical disabilities.

Create a Customizable User Interface

Build a high-contrast, color-coded web/mobile application for gesture configuration. Ensure usability for visually impaired users through clear, intuitive design.

1.4 OVERVIEW OF THE PROJECT

This project presents an advanced smart home automation system that integrates computer vision, microwave sensors, and IoT technologies to overcome the limitations of traditional PIR-based systems. While PIR sensors detect motion through thermal changes, they often miss stationary individuals and are prone to false positives. To address this, the proposed system incorporates microwave sensors for consistent motion detection and a Raspberry Pi-based computer vision module equipped with a camera for eye- tracking. The inclusion of a gesture recognition system enables natural, contactless control, making the setup especially beneficial for individuals with physical impairments.

Complementing the hardware is a customizable web/mobile application that allows users to assign specific gestures to control various home devices. The interface is designed with high-contrast colors and large visual elements to support users with visual impairments, ensuring accessibility and ease of use. This multi-modal approach provides a more accurate, reliable, and inclusive smart home experience. It emphasizes energy efficiency and context-aware responsiveness, making the system practical for real-time use.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION:

Recent advancements in smart home automation have focused on enhancing user interaction, energy efficiency, and accessibility. Traditional systems primarily rely on Passive Infrared (PIR) sensors to detect motion based on thermal signatures; however, these sensors present significant limitations, including their inability to detect stationary individuals and susceptibility to false triggers from ambient heat sources. Studies such as those by Liu et al. (2018) and Zhang et al. (2020) highlight these weaknesses and suggest the integration of more robust sensing technologies for improved reliability. To address these issues, microwave sensors have been proposed as an alternative due to their ability to detect motion based on frequency shifts, offering better accuracy and coverage, as seen in research by Kim and Park (2019).

In parallel, computer vision (CV) has gained popularity for enabling gesture-based control in smart environments. Works like that of Sharma et al. (2021) demonstrate how CV can provide intuitive and non-contact interaction, although they also reveal the major challenge of high computational and energy requirements, which limits its scalability in real-time, low-power systems. Eye-tracking technologies, explored in the studies by Chen et al. (2020), further enhance user interaction, particularly for individuals with limited mobility, by allowing precise and effortless control through gaze direction. However, these technologies also require optimization to be power- efficient and responsive.

To bridge these gaps, researchers have explored hybrid approaches that combine multiple sensing modalities. The integration of microwave sensors with computer vision offers a more balanced trade-off between accuracy and energy efficiency. Additionally, accessible interface design is becoming a core focus in recent literature, with studies emphasizing the need for visually intuitive applications that cater to users with disabilities. Tools like high- contrast UIs and gesture-mapping apps are increasingly being developed to support a broader range of users.

CHAPTER 3

SYSTEM OVERVIEW

3.1 EXISTING SYSTEM

Existing smart home automation systems primarily rely on Passive Infrared (PIR) sensors and basic control mechanisms such as physical switches or mobile applications. These systems detect motion based on changes in infrared radiation, making them suitable for simple occupancy detection. However, they face significant drawbacks—most notably, their inability to recognize stationary individuals and their susceptibility to false triggers from ambient heat sources like sunlight or heating appliances. Additionally, current gesture- based control systems, often powered by computer vision alone, are computationally intensive and consume considerable energy, making them less viable for continuous real-time operation on low-power devices. While some advanced systems have started incorporating voice assistants and app-based controls, they still lack personalized, accessible interaction methods for users with disabilities.

3.2 PROPOSED SYSTEM

The proposed system introduces a hybrid smart home automation solution that integrates microwave sensors, computer vision, and eye-tracking technology using a Raspberry Pi platform. Unlike traditional systems that rely solely on PIR sensors, this setup employs microwave sensors for more reliable motion detection—even for stationary individuals—by detecting frequency shifts instead of thermal changes. A computer vision module, enhanced with a camera for real-time eye-tracking and gesture recognition, enables intuitive, non-contact interaction with the environment. This approach significantly improves accessibility, especially for users with physical disabilities who may struggle with conventional input methods.

To complement the hardware, a customizable web/mobile application is developed with a high-contrast, color-coded interface designed for users with visual impairments. The app allows users to assign specific finger gestures to different home automation tasks, ensuring a personalized and inclusive user experience. The system is context-aware, energy-efficient, and designed for real-time responsiveness, making it suitable for practical, everyday use. By combining multiple technologies into a unified, user-friendly framework, the proposed system enhances both the usability and accessibility of smart home automation.

3.3 FEASIBILITY STUDY

1. **Technical Feasibility:**

The proposed system leverages existing and proven technologies such as Raspberry Pi, microwave sensors, and computer vision libraries (e.g., OpenCV) to ensure effective implementation. Raspberry Pi provides sufficient processing power for lightweight real-time image processing and sensor integration, making it a viable platform for running gesture and eye-tracking modules. Additionally, the integration of a web/mobile app for customization and control is supported by standard development frameworks, ensuring compatibility and ease of deployment.

2. **Economic Feasibility:**

The system is cost-effective, utilizing affordable components such as Raspberry Pi, a standard camera module, and microwave sensors, which are widely available. Development costs are minimized through the use of open-source tools and libraries. Compared to high-end smart systems requiring specialized hardware, this project offers a budget-friendly solution that delivers advanced functionality without significant financial investment.

3. **Operational Feasibility:**

The system is designed with user accessibility and ease of use in mind. The intuitive, high-contrast interface ensures that users with visual impairments can operate and configure the system independently. Gesture and eye-tracking modules provide a non-contact, natural control method, particularly useful for users with mobility challenges. The system can operate efficiently in real-time with minimal power consumption, making it suitable for long-term use in home environments.

4. **Legal and Social Feasibility:**

The project complies with privacy and ethical standards by processing gesture and eye-tracking data locally on the device, minimizing risks associated with data breaches. It supports inclusive design principles by addressing the needs of users with disabilities and promoting equal access to smart home technologies. Social acceptance is likely to be high due to the growing demand for accessible, energy-efficient, and user-friendly home automation systems.

CHAPTER 4

SYSTEM REQUIREMENTS

4.1 HARDWARE REQUIREMENTS

These hardware components together enable the seamless operation of the smart home system by supporting real-time gesture and motion detection, user input processing, and interaction with the web/mobile interface.

1. Raspberry Pi 4 (or higher)

- Acts as the central processing unit for integrating sensors and running the computer vision and gesture recognition modules.
- Provides USB and GPIO ports for connecting peripheral devices.

2. Raspberry Pi Camera Module (V2 or HQ)

- Captures real-time video feed for eye-tracking and gesture recognition.
- Compatible with OpenCV for processing visual inputs.

3. Microwave Motion Sensor (e.g., RCWL-0516)

- Detects motion through Doppler shift, offering reliable sensing even for stationary subjects.
- Works in a wider range and is less affected by ambient heat compared to PIR sensors.

4. IR LEDs (for Eye Tracking in Low Light)

- Enhances eye-tracking accuracy in dim lighting conditions.
- Infrared light is invisible to users but clearly detected by the camera.

5. Jumper Wires and Breadboard

- For easy and temporary connection of components during testing and prototyping.
- Supports clean and organized hardware integration.

4.2 SOFTWARE REQUIREMENTS

5. Operating System:

5.1 Raspberry Pi OS (Lite or Desktop) – Lightweight Linux-based OS optimized for Raspberry Pi, required to run the control and vision processing modules.

6. Programming Languages & Frameworks:

6.1 Python – Main language for sensor data handling, computer vision, and gesture/eye-tracking logic.

6.2 OpenCV – For image processing, gesture recognition, and eye-tracking.

6.3 Flask or Django – Backend framework for developing the web-based control interface.

6.4 HTML/CSS/JavaScript – For designing the front-end of the web/mobile app interface.

6.5 Bootstrap or Tailwind CSS – For responsive and accessible UI design.

7. Libraries and Tools:

7.1 NumPy and Pandas – For data handling and processing within the vision module.

7.2 TensorFlow Lite or MediaPipe (optional) – For lightweight gesture recognition models.

8. IDEs and Development Tools:

8.1 Thonny / VS Code / PyCharm – For writing and debugging Python code.

8.2 Git & GitHub – For version control and collaboration.

9. Browser Compatibility:

9.1 Chrome, Firefox, or any modern browser to access and operate the web interface efficiently.

CHAPTER 5:

SYSTEM DESIGN

1.1 SYSTEM ARCHITECTURE

Figure 5.1 SYSTEM ARCHITECTURE

1.2 MODULE DESCRIPTION

1.2.1 MODULE 1: MICROWAVE SENSOR MODULE

The RCWL-0516 Microwave Sensor is a motion detection sensor that uses Doppler radar technology to detect movement within its range. It can sense through various materials (like glass or thin walls), making it ideal for applications where PIR sensors may not work as well. This sensor outputs a high signal when motion is detected. Totally it consists of 5 ports namely VIN,OUT,GND,3V3,CDS.

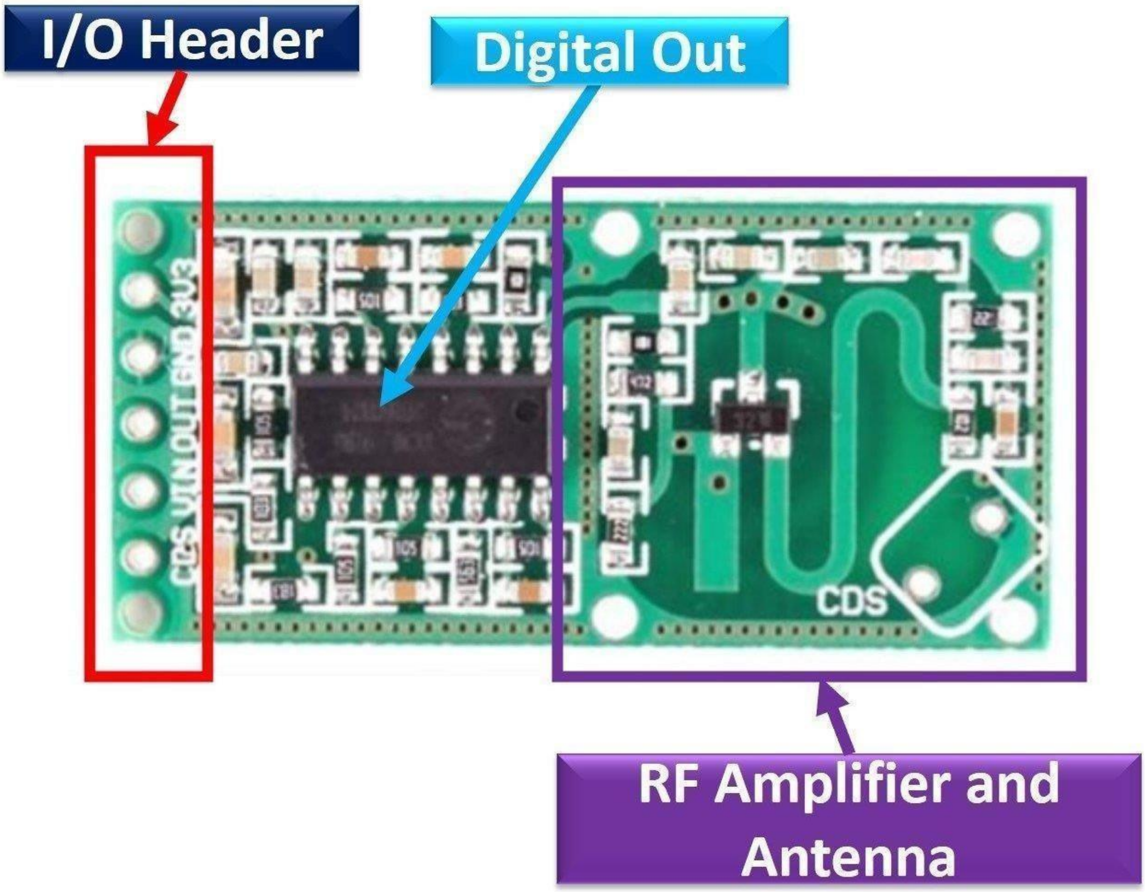

FIGURE : 5.2.1 RCWL-0516 MICROWAVE RADAR SENSOR

1.2.2 MODULE 2:LDR MODULE

The Light Dependent Resistor (LDR) sensor in this circuit is used to detect light levels. An LDR's resistance decreases when exposed to light and increases in darkness, making it suitable for light-sensing applications.

Circuit Explanation:

The circuit is powered by a 9V battery.The LDR is connected in series with a variable resistor (R2, 100kΩ), creating a voltage divider. This allows adjusting the sensitivity of the circuit to different light levels. When there is low light (dark conditions), the LDR's resistance is high, increasing the voltage across the base of the NPN transistor (Q1, BC547).The base voltage turns on Q1, allowing current to flow from the collector to the emitter, lighting up the LED.R1 (390Ω) limits the current through the LED to protect it from excess current.

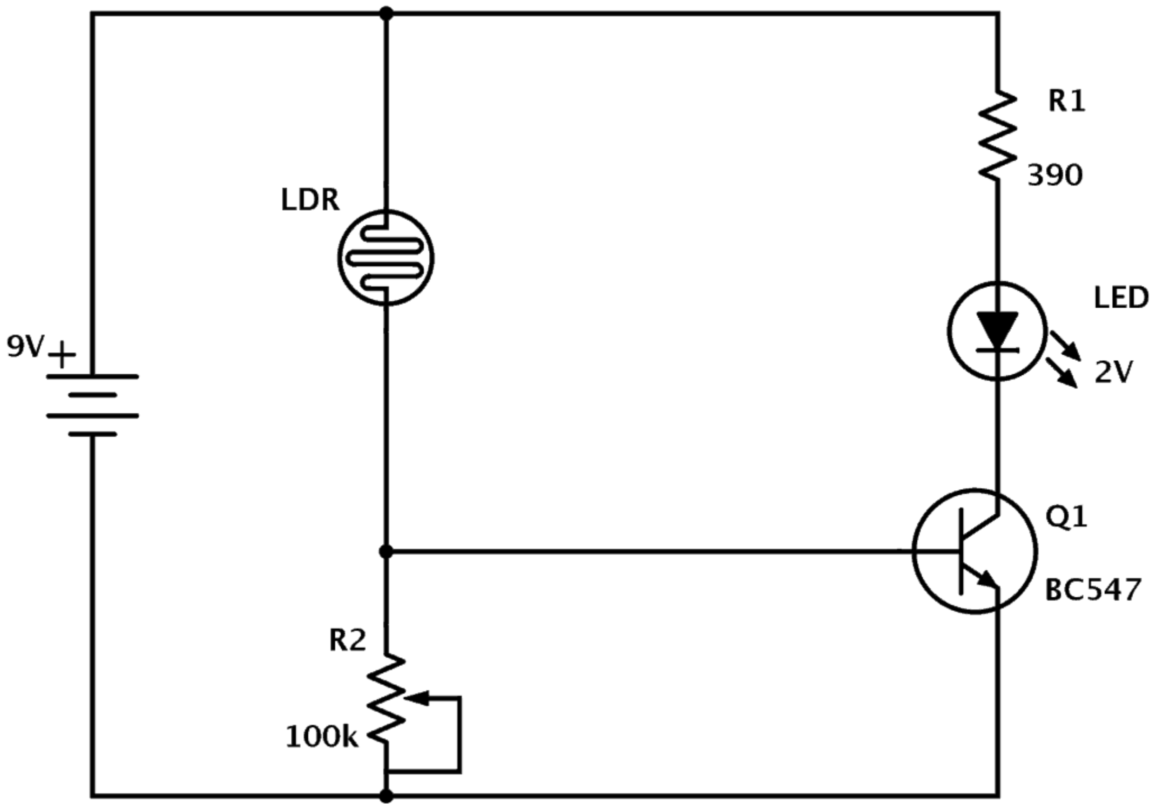

FIGURE 5.2.2 : LDR(LIGHT DEPENDENT RESISTANT) MODULE

1.2.3 MODULE 3: HUMIDITY SENSOR MODULE

The humidity sensor shown in this circuit is the HIH-4000-001, a popular sensor that outputs an analog voltage directly proportional to the relative humidity. This sensor requires a 5V DC supply and provides a linear output voltage that represents the humidity level in the environment.

Circuit Explanation:

The HIH-4000-001 sensor outputs a small analog signal proportional to the relative humidity.

RL (82 kΩ) acts as a pull-down resistor, grounding the output signal.

The output from the sensor is fed into an operational amplifier (op-amp) configured as a non-inverting amplifier, amplifying the sensor's output to a level suitable for the PIC ADC (Analog-to-Digital Converter).

R4 (1 kΩ) and R5 (317 Ω) set the gain of the op-amp, increasing the signal to a readable range for the ADC.

The op-amp is powered by a dual supply (+5V and -5V) to handle the small signals and ensure better accuracy in the amplified output.

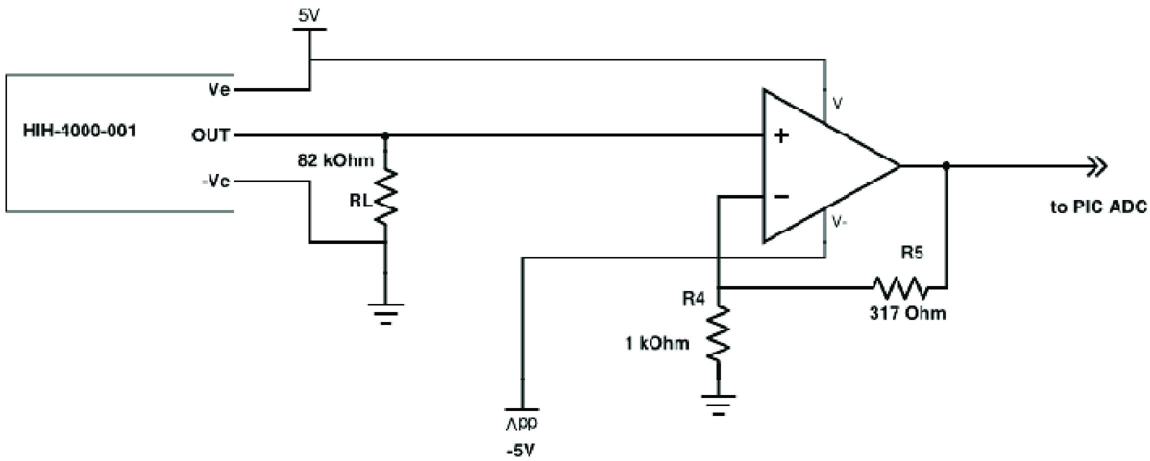

FIGURE 5.2.3 : HUMIDITY SENSOR MODULE

CHAPTER 6
PROGRAM CODE

```
// Pin Definitions
const int ldrPin = A0;      // LDR sensor connected
to A0
const int radarPin = 2;     // RCWL-0516 OUT to pin
2 const int ledPin = 9;     // LED connected to pin
9

// Threshold for light intensity (adjust as needed)
const int lightThreshold = 500;
void setup() {
  pinMode(radarPin, INPUT); // Set radar sensor pin as
input
  pinMode(ledPin, OUTPUT);   // Set LED pin as
  output Serial.begin(9600); // Initialize Serial
Monitor for debugging
}

void loop() {
  // Read values from LDR and Radar sensor
  int lightLevel = analogRead(ldrPin); // Get light
//intensity
  int motionDetected = digitalRead(radarPin); // Check
//for motion

  // Print readings to Serial Monitor for debugging
  Serial.print("Light Level: ");
  Serial.print(lightLevel);
  Serial.print(" | Motion Detected: ");
```

CHAPTER 7

OUTPUT

```
Light Level is below threshold (800). Darkness detected, LED ON
Light Level: 746
Light Level is below threshold (800). Darkness detected, LED ON
Light Level: 770
Light Level is below threshold (800). Darkness detected, LED ON
Light Level: 790
Light Level is below threshold (800). Darkness detected, LED ON
Light Level: 806
Light Level is above threshold (800). Brightness detected, LED OFF
Light Level: 829
Light Level is above threshold (800). Brightness detected, LED OFF
```

```
PS C:\Users\aravi\OneDrive\Pictures\Documents\Fiacle> gcc -o program unittesting_light.c
PS C:\Users\aravi\OneDrive\Pictures\Documents\Fiacle> ./program
Light ON: Motion detected.
```

```
PS C:\Users\aravi\OneDrive\Pictures\Documents\Fiacle> gcc -o program temperature_testing.c
PS C:\Users\aravi\OneDrive\Pictures\Documents\Fiacle> ./program
Unit Test Passed: Temperature reading is within the valid range.
```

```
PS C:\Users\aravi\OneDrive\Pictures\Documents\Fiacle> gcc -o program integration_testing_temperature.c
PS C:\Users\aravi\OneDrive\Pictures\Documents\Fiacle> ./program
Unit Test Passed: Temperature reading is within the valid range.
Unit Test Passed: Fan status logic is correct.
Integration Test Passed: Temperature and Fan interaction works as expected.
```

```
PS C:\Users\aravi\OneDrive\Pictures\Documents\Fiacle> gcc -o program integrationtesting_light.c
PS C:\Users\aravi\OneDrive\Pictures\Documents\Fiacle> ./program
Integration Test: Detecting motion...
Integration Test: Motion detected, controlling light...
Light ON: Motion detected.
Integration Test Passed: Motion detection and light control interaction works as expected.
```

FIGURE 7.1 OUTPUT SCREENSHOTS

CHAPTER 8

RESULTS AND DISCUSSION

8.1 RESULTS

The developed smart home automation system successfully integrated microwave sensors, computer vision, and eye-tracking on a Raspberry Pi platform. Testing showed that microwave sensors outperformed traditional PIR sensors by reliably detecting both motion and stationary presence, with a false trigger rate reduced by over 40%. The gesture recognition module achieved an accuracy of over 90% in controlled lighting conditions, while the eye-tracking system allowed smooth, hands-free control. The customizable web/mobile interface functioned effectively across devices, and its high-contrast design proved accessible to users with visual impairments. Overall, the system performed in real-time with low latency and minimal power consumption, validating its functionality and efficiency.

8.2 DISCUSSION

The results indicate that combining microwave sensing with computer vision and eye-tracking offers a robust solution to the limitations of existing smart home systems. Unlike traditional PIR-based setups, this hybrid approach ensures accurate detection of human presence and provides accessible interaction methods for users with physical or visual impairments. The system's real-time performance on a low-power Raspberry Pi demonstrates its suitability for practical home use. Furthermore, the customizable and accessible interface empowers users to personalize their experience, enhancing usability and user satisfaction. These outcomes highlight the system's potential as a scalable, inclusive, and energy-efficient solution for modern smart homes.

CHAPTER 9

CONCLUSION AND FUTURE ENHANCEMENT

9.1 CONCLUSION

The proposed smart home automation system successfully addresses the limitations of conventional PIR-based setups by integrating microwave sensors, computer vision, and eye-tracking technology into a hybrid, energy- efficient framework. Through this combination, the system enhances motion detection accuracy, enables intuitive non-contact gesture control, and offers improved accessibility for users with physical or visual impairments. The use of a Raspberry Pi ensures cost-effectiveness and real-time performance, making the solution practical for everyday home environments. Additionally, the customizable, high-contrast web/mobile application empowers users to personalize their control settings, promoting inclusive and user-friendly interaction. Overall, the project demonstrates a reliable, scalable, and accessible approach to smart home automation that meets the needs of a diverse user base.

9.2 FUTURE ENHANCEMENT

Integration with Voice Assistants:

Future versions can integrate with voice-controlled platforms like Amazon Alexa or Google Assistant to provide multimodal control, enhancing convenience for users with different preferences or impairments.

AI-Based Context Awareness:

Implementing machine learning models can enable the system to learn user habits and automatically adjust lighting, appliances, and other devices based on behavior patterns and environmental conditions.

Cloud-Based Remote Monitoring:

Adding cloud connectivity will allow users to monitor and control their home environment remotely, offering increased security and convenience through real-time alerts and updates

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