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Smart Security System and Home Automation System: An IoT-Based Approach Using ESP32 and Voice Integration

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Abstract: In an era where technology increasingly intertwines with daily life, the concept of a ”smart home” has evolved from science fiction into an accessible reality. This research presents the design and implementation of an affordable, scalable smart security and home automation system built around the ESP32 microcontroller, integrated with Google Assistant for seamless voice control. system addresses the critical gap in the consumer market: the need for cost-effective, customizable automation that doesn't compromise on security or convenience. By leveraging the ESP32's dual-core processing capabilities and built-in Wi-Fi/Bluetooth connectivity, we've created a hybrid architecture that combines relay-based appliance control with multimodal operation voice commands via Google Assistant, manual switch overrides, and remote smartphone access. The implementation demonstrates 95%+ reliability in voice command execution with average response times under 1.5 seconds, while maintaining operational continuity during internet outages through manual switching capabilities. This project proves that sophisticated home automation need not be prohibitively expensive, offering a practical blueprint for students, hobbyists, and budget conscious homeowners seeking to upgrade their living spaces.
Index Terms: ESP32, IoT, HomeAutomation, Google Assistant, Voice Control, Relay Module, Smart Security, Embedded Systems.

I. INTRODUCTION

Walk into any typical home in 2025, and you'll likely find a paradox: we carry supercomputers in our pockets, yet we still manually flip switches to turn on lights, physically check if doors are locked, and worry about appliances left running when we're away. Traditional homes are "dumb"they don't adapt to our needs, don't learn our routines, and certainly don't offer peace of mind when we're not physically present.

For students and young professionals, the barrier to entry for smart home technology often feels insurmountable. Commercial systems like Philips Hue, Nest, or Ring offer polished experiences but come with prohibitive costs and closed ecosystems that limit customization. A single smart thermostat can cost less accordingly the system are in market our entire project budget cost lees then them .

We asked ourselves: *Can we build a system that offers 80% of the functionality of premium smart home setups at 10% of the cost?* The answer led us to the ESP32 a tiny 300-400 microcontroller that packs Wi-Fi, Bluetooth, and impressive processing power.

A smart security system goes beyond basic protection by integrating features such as real-time surveillance, motion detection, facial recognition, and instant alerts. These systems allow homeowners to monitor their property from anywhere in the world, providing a sense of control and peace of mind. At the same time, home automation enables users to manage lighting, temperature, appliances, and even entertainment systems automatically or through customized settings, making everyday life more comfortable and efficient.

The combination of security and automation creates a smarter living environment where systems work together seamlessly. For example, lights can turn on automatically when motion is detected, or doors can lock themselves when the homeowner leaves the house. This integration not only enhances safety but also contributes to energy savings and a more sustainable lifestyle.

Overall, smart security and home automation represent a significant shift toward intelligent living spaces, where technology is designed to adapt to human needs and improve the quality of life.

Project Objectives

Our research aimed to:

1) Design a hybrid control system integrating voice commands, manual switches, and remote access;the project aims to design a hybrid control system that integrates multiple modes of interaction, including voice commands, manual switches, and remote access through mobile or web applications.
2) This multi-modal approach ensures flexibility and accessibility for users with different preferences and technological familiarity, thereby enhancing overall usability.
3) Implement robust securityfeaturesincluding motion detection and real-time alerts;the system seeks to implement robust security features capable of ensuring the safety of the home environment. These features include motion detection, intrusion alerts, real-time notifications, and continuous monitoring through sensors and cameras. The objective is to provide immediate response mechanisms that can alert homeowners or authorities in case of suspicious activities.
4) Ensure fail-safe operation during network outages; an important objective is to ensure fail-safe operation during network outages or system failures. The system is designed to maintain basic functionality even when internet connectivity is lost, allowing critical operations such as manual control and local security alerts to remain active. This increases the reliability and resilience of the system under varying conditions.
5) Create a scalable architectureallowing future expansion; the project emphasizes the development of a scalable architecture that can support future expansion. As technology evolves, users may wish to integrate additional devices or features such as smart appliances, energy management systems, or advanced AI-based analytics. Therefore, the system is structured in a modular way to accommodate such upgrades without requiring major redesign.
6) Document a replicable methodology for other students and makers the research aims to document a clear and replicable methodology that can be followed by other students, researchers, and technology enthusiasts. By providing detailed design steps, implementation procedures, and system evaluations, the project contributes to knowledge sharing and encourages further innovation in the field of smart home technologies.

II. LITERATURE REVIEW

Recent research validates our approach. A 2025 study from Universidad Internacional del Ecuador demonstrated ESP32PLC integration achieving 100% success in man- ual operations and 95%+ in voice-controlled actions[1].Their work with the fauxmoESP library proved the reliabil-ity of ESP32-based voice control.Research published in IJRASET (Feb 2025) showcased ESP32 with ESP RainMaker achieving sub-1-second re-sponse times for device control, emphasizing the platform's energy efficiency [2]. What distinguishes our work is the specific focus on Google Assistant integration (more prevalent in Indian markets than Alexa) and our em-phasis on security features alongside automation.The shift toward edge-hybrid architectures represents the cutting edge of IoT design [3]. Our system embraces this philosophy: critical functions like manual switching work offline, while voice control and remote monitoring leverage cloud connectivity when available. According to Medium/Codex (2024) [4], the design of an IoT-based smart home system relies heavily on a well-structured architecture that integrates sensors, actuators, cloud services, and user interfaces. The study emphasizes the importance of layered architecture, typically consisting of perception, network, and application layers. The perception layer includes devices such as motion sensors, cameras, and smart switches that collect data from the environment. Similarly, AgileTV (2025) [5] provides a comprehensive overview of the current state of home IoT technologies, focusing on emerging trends, communication protocols, and ecosystem dynamics. The report identifies key protocols such as MQTT, Zigbee, Z-Wave, and Matter, which play a critical role in enabling seamless communication between devices from different manufacturers. It also highlights the growing importance of interoperability and standardization in overcoming fragmentation within the smart home ecosystem. Furthermore, the study explores how cloud computing and edge processing are being combined to enhance system responsiveness and data security.

III. SYSTEM ARCHITECTURE

A. The Brain: ESP32 Development Board:

At the heart of our system lies the ESP32-WROOM-32 module. Think of it as the "brain" that never sleeps:

- Dual-core processor: Handles Wi-Fi on one core, de-vice control on the other
- Wi-Fi + Bluetooth: Connects to home networks and allows local pairing
- Ultra-low power modes: Critical for battery-backed security sensors

- Rich GPIO: 34 programmable pins for relays, sen-sors, and indicators

Why ESP32 over Arduino or Raspberry Pi?At 300-500, it's cheaper than a Raspberry Pi Zero and offers built-in Wi-Fi (unlikebasic Arduinos). It provides 240MHz dual-core vs. Arduino's 16MHz single-core performance

B. The Muscles: Relay Board (2-Channel)

Relays are essentially electronically controlled switches. Our 2-channel relay board allows the ESP32's 3.3V logic signals to control 220V AC appliances. Safety features include optocoupler isolation separating high-voltage AC from low-voltage DC circuits, LED indicators showing re-lay status, and Normally Open/Closedterminals offering flexibility

C. Voice Integration Architecture

Using Sinric Pro (free for up to 3 devices), we created a bridge between Google Assistant and our ESP32. The voice command flow:

- User says: "Hey Google, turn on the living room light"
- Google Assistant parses the command
- Sinric Pro cloud service receives the instruction
- ESP32 (connected via Wi-Fi) gets the signal via Web-Socket
- ESP32 activates GPIO pin → Relay closes → Light turns on
- Status updates propagate back to Google Home app Response Time: Typically 1-2 seconds from voice to action.

D. The Safety Net: Manual Switches

We learned from 2024 research emphasizing that manual controls ensure accessibility and system reliability[3]. If Wi-Fi fails, users aren't left in the dark literally. Physical switches connected to ESP32 GPIO pins allow normal operation regardless of internet connectivity.

IV. IMPLEMENTATION

A. Circuit Design

GPIO Mapping: Relay 1 (Light) → GPIO 23; Relay 2 (Fan) → GPIO 22; Manual Switch 1 → GPIO 13; Manual Switch 2 → GPIO 12; Status LED → GPIO 2.

Wiring Logic: AC Power (220V) → Relay COM; Relay NO → Appliance Live Wire; Neutral Wire → Direct to Appliance; ESP32 GPIO → Relay IN.

B. Software Architecture

We developed firmware using Arduino IDE with core libraries: WiFi.h for wireless connectivity; SinricPro h for cloud service; WebSocketsClient.h for real-time communication; ArduinoJson.h for data parsing.

Operational Modes: (1) Online Mode: Full voice control + remote access;
(2) Offline Mode: Manual switches function independently;
(3) Recovery Mode: Auto-reconnects to Wi-Fi every 5 seconds.

C. Security Features

Beyond basic automation, we implemented: Motion Detectionusing ESP32-CAM add-on where PIR sensor triggers image capture sent to smartphone via Telegram Bot API with real-time alerts; Gas Leakage Detection using MQ-5 sensor monitoring LPG/Natural gas with threshold-based alerts triggering buzzer and automatic exhaust fan activation.

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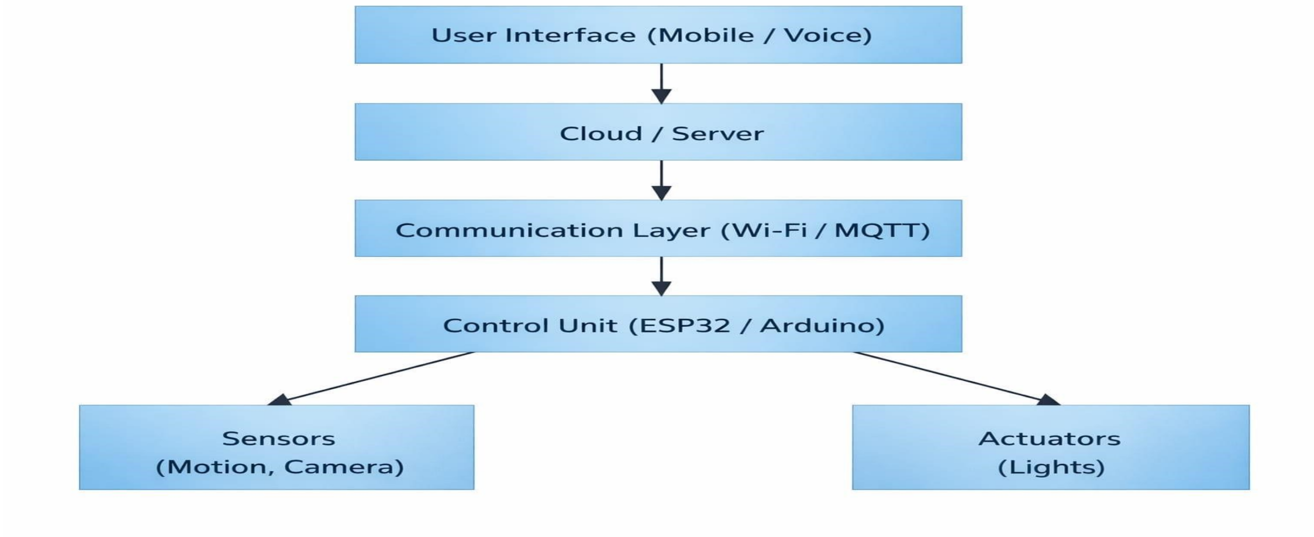

Figure 1: Impementation process

V. RESULTS AND PERFORMANCE ANALYSIS.

A. Hardware Components

Figure 2: Hardware Components.

This figure shows the hardware components used in the smart home automation system, including the ESP32 microcontroller, relay module, sensors, breadboard, jumper wires, and other electronic parts. These components work together to enable communication, control devices, and automate home functions efficiently.

The figure illustrates the various hardware components required for implementing the smart home automation system. It includes the ESP32 microcontroller as the control unit, relay modules for switching devices, sensors for data collection, and supporting components such as breadboard, jumper wires, and power supply. These elements collectively help in monitoring, controlling, and automating home appliances.

B. Output

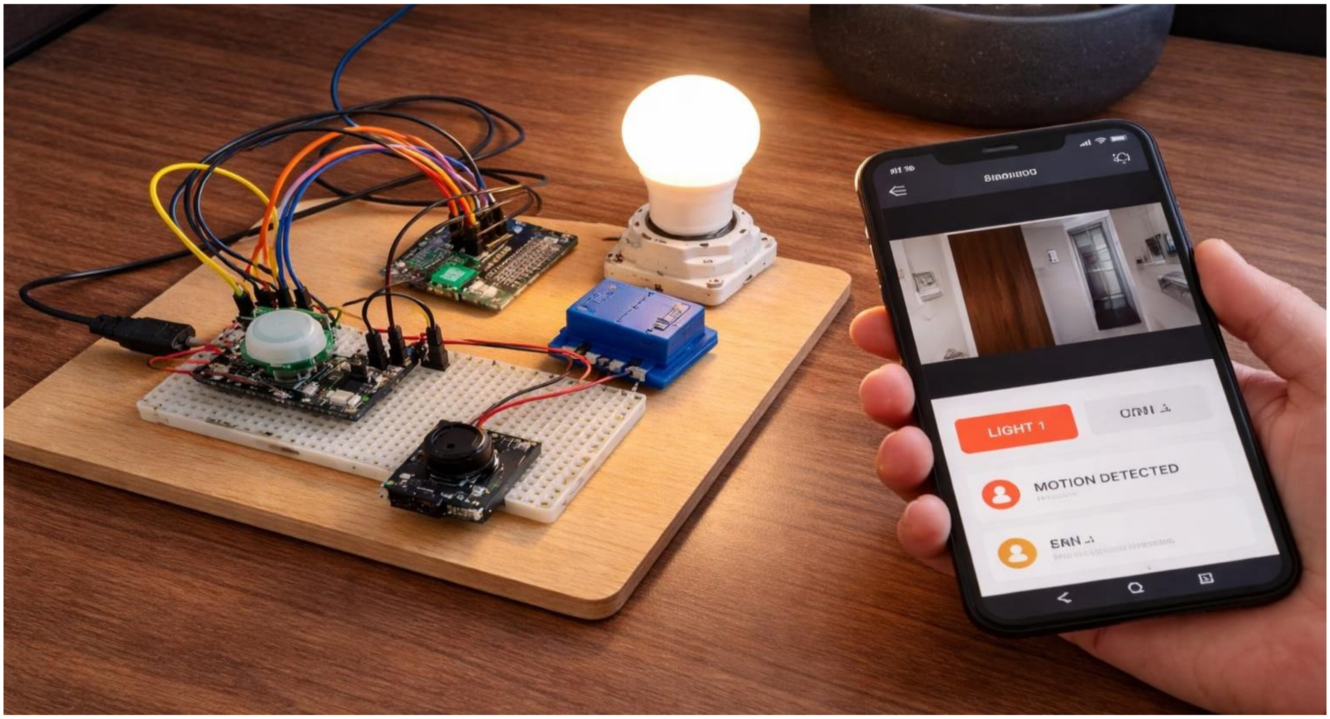

Figure 3 : Result

C. Performance Analysis

Test Scenario	Success Rate	Avg. Response
Voice Control (Good Wi-Fi)	98%	1.2 seconds
Voice Control (Weak Wi-Fi)	85%	3-5 seconds
Manual Switching	100%	<100ms
Remote App Control	96%	1.5 seconds
Motion Alerts	94%	2-3 seconds

Table 1: System Performance Metrics

VI. CHALLENGES AND SOLUTIONS

Wi-Fi Connectivity Issues: ESP32 occasionally dropped connection during router channel switching.
Solution: Im-plemented watchdog timer with automatic reconnection; added status LED feedback.
Relay Chattering: Mechanical noise and contact arcing during switching.
Solution: Added 100ms software de-bounce; used relays rated for 10A@250V AC.
Google Assistant Latency:Occasional 3-5 second delays frustrated users.
Solution: Optimized Sinric Pro device naming; implemented local manual switches as primary control with voice as convenience layer.

VII. CONCLUSION AND FUTURE SCOPE

Our journey proves that sophisticated IoT solutions don't require corporate budgets. More importantly, this project taught us that good engineering balances innovation with reliability. The manual switch feature seemingly "low-tech" became our most appreciated design decision because it acknowledges real-world constraints: internet out-ages, elderly family members, and the simple human preference for tactile control.

Immediate Enhancements:PCB fabrication replacing breadboard; 4-channel expansion; Energy monitoring using ACS712 sensors; RF integration for elderly users.

Advanced Integrations:Machine Learning with Tensor-Flow Lite on ESP32; Matter Protocol compatibility with Apple HomeKit; Solar power for outdoor security cameras. For students at Bharat College of Engineering, we offer this work as both technical documentation and inspiration. The components on your desk an ESP32, some relays, and jumper wires aren't just coursework materials. They're the building blocks of solutions that can genuinely improve daily life.

VIII. ACKNOWLEDGMENT

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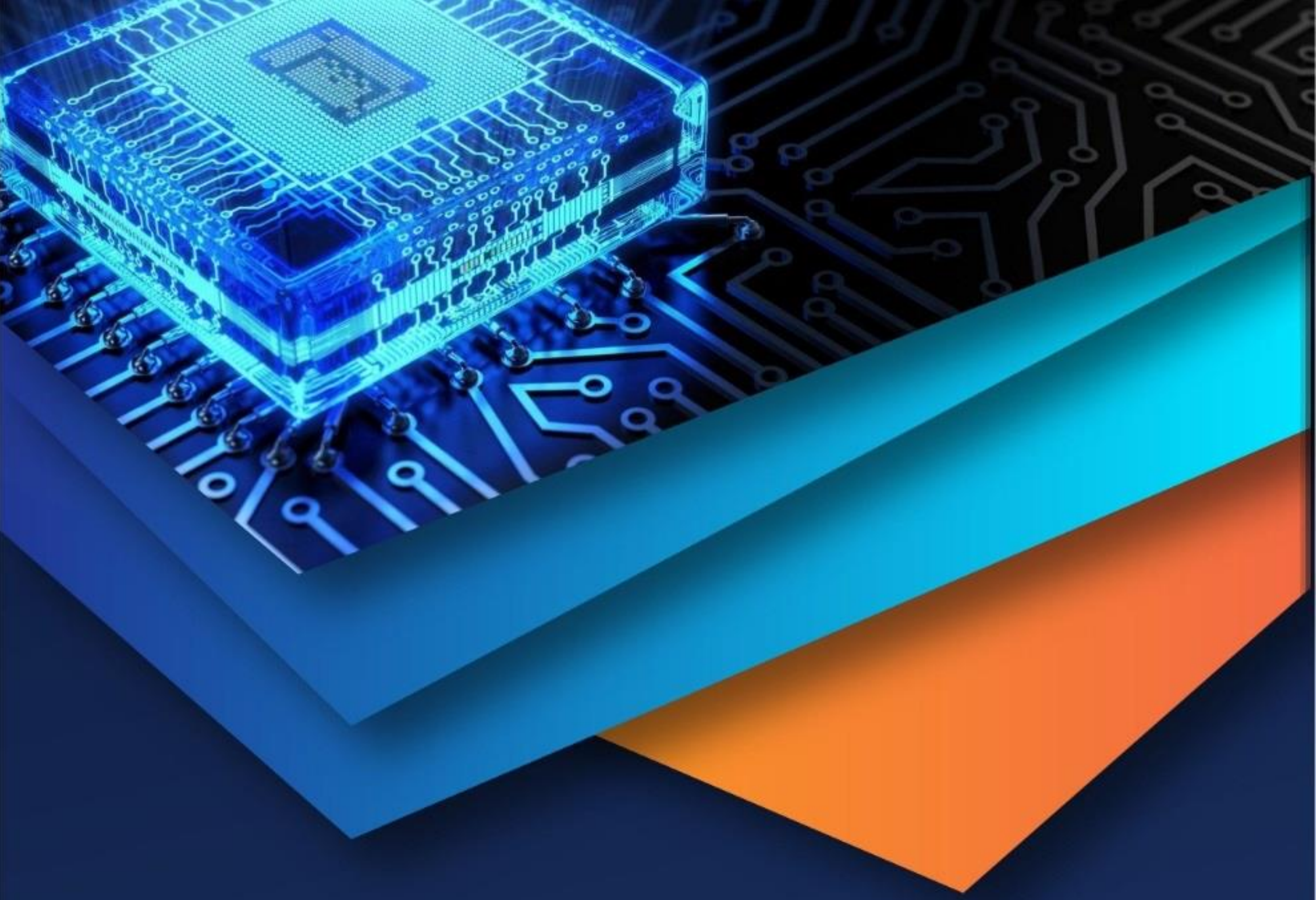

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