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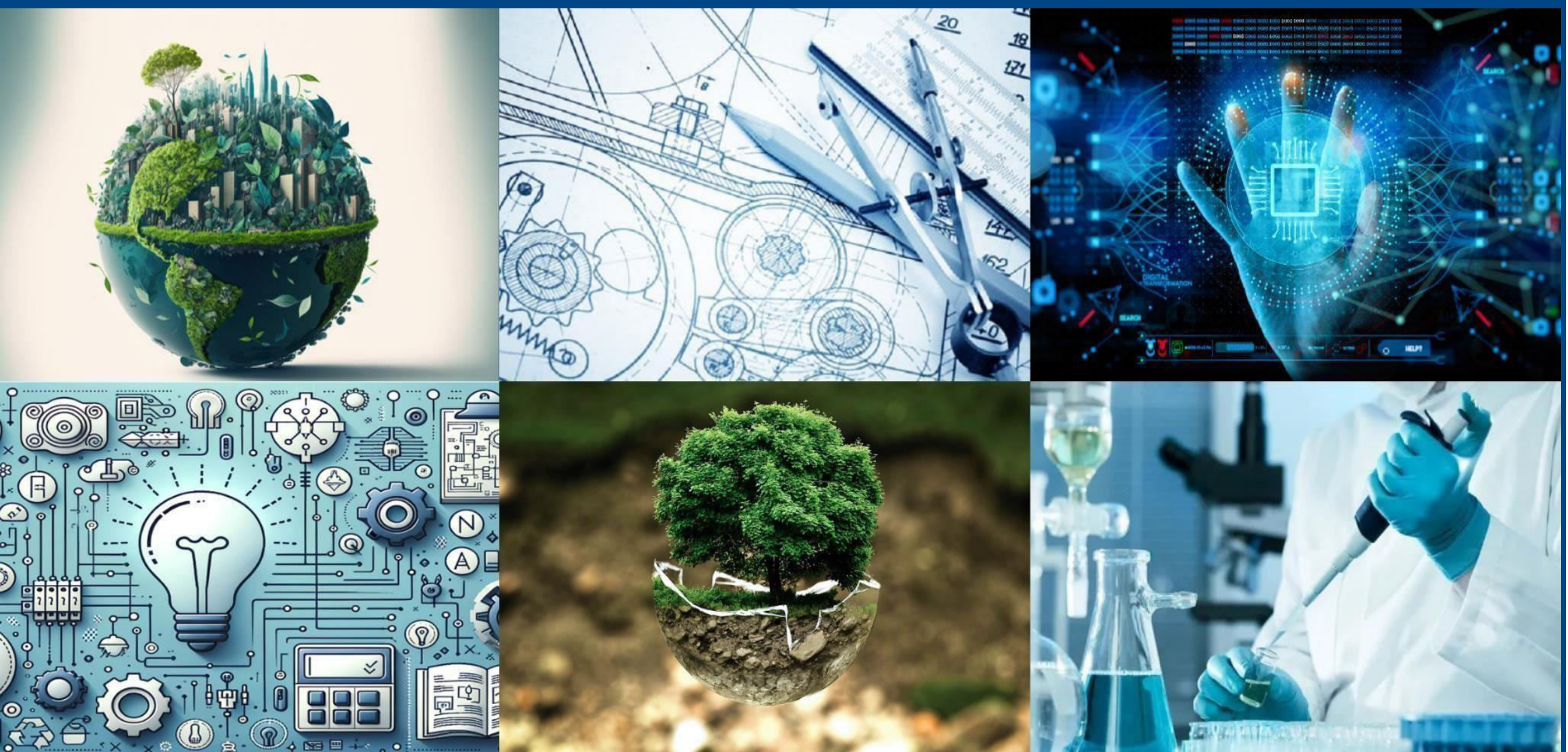

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REAL-TIME BI-DIRECTIONAL CLOUD-SYNCED RELAY CONTROL FOR DOMESTIC AUTOMATION INTERFACES

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ABSTRACT: This project presents the design and implementation of a smart home automation system based on the ESP32 microcontroller, integrating capacitive touch sensors and Firebase Realtime Database for cloud communication. The system is built to offer users real-time control and monitoring of household electrical devices using both local touch inputs and a web-based dashboard, enhancing flexibility and convenience. The web interface provides a user-friendly experience with live updates on the status of each connected relay and the timestamp of the last operation. All interactions are securely authenticated using Firebase Authentication, ensuring that only authorized users can access or manipulate the system remotely.

The ESP32 serves as the core controller, interfacing with the touch sensors, relays, and the internet via Wi-Fi. Relay states are synchronized to Firebase in real time, making it possible to switch appliances from anywhere in the world or directly using touch in offline scenarios. This dual-mode operation adds resilience in case of connectivity issues. The project's modular approach enables future extensions such as integrating more sensors, power monitoring systems, or even adding voice assistant capabilities.

Additionally, the entire system architecture supports real-time updates, scalability, and energy efficiency. The frontend is developed using HTML, CSS, and JavaScript, with responsive theming support to match user preferences. The use of timestamp logging improves the traceability and accountability of appliance usage, especially valuable in shared or remote-controlled environments. Overall, this project demonstrates a practical and scalable solution for modern smart homes, combining cost-effectiveness, reliability, and user-centric design.

I. INTRODUCTION

In today's digitally connected world, smart home automation has become a prominent area of innovation, aiming to enhance convenience, energy efficiency, and security. Traditional manual switching systems are increasingly being replaced by intelligent, remote-controlled solutions. This project introduces a smart home automation system based on the ESP32 microcontroller that allows users to control electrical appliances either via capacitive touch sensors or a web-based dashboard. The system leverages Firebase Realtime Database for cloud-based data synchronization and storage, enabling real-time monitoring and control from anywhere with internet access. With a focus on simplicity, scalability, and low cost, this solution is ideal for home, office, or institutional environments.

By integrating real-time timestamping, secure user authentication, and an intuitive user interface, the system ensures that users have full control and visibility over their appliances at all times. Furthermore, the modular design supports easy expansion, allowing additional sensors or features such as voice control, mobile app integration, or power usage analytics to be added in future versions. Overall, the project highlights how modern IoT and cloud technologies can be utilized effectively to create reliable, user-friendly smart home systems

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II. LITERATURE SYRVEY

Home automation has evolved from isolated control systems to interconnected IoT architectures capable of remote monitoring, automated decision-making, and real-time situation awareness [1]. Early implementations relied on microcontrollers with wired interfaces and local control logic, but modern systems increasingly utilize cloud-based backends, enabling seamless remote access and cross-platform synchronization [2].

Recent research highlights the adoption of cost-effective Wi-Fi SoCs, such as the ESP32, for home automation tasks because of their integrated wireless communication, multiple GPIOs, and support for capacitive touch sensing [3]. These devices offer a balance of processing power and energy efficiency while reducing the complexity of hardware integration compared to traditional microcontrollers [4]. Capacitive touch sensing has been widely adopted in such systems to provide intuitive manual control, although studies emphasize the need for careful calibration, EMI mitigation, and firmware-level filtering to ensure reliability [5].

Cloud platforms like Google Firebase have gained popularity in IoT applications due to their real-time database, authentication features, and scalability [6]. Such systems enable instant synchronization between user interfaces and physical devices, reducing the development burden of creating custom backend services [7]. However, literature warns of challenges such as vendor lock-in, data privacy concerns, and the need for offline operational capabilities in the event of network outages [8].

Safe switching of high-voltage appliances in smart home systems is typically achieved using relay driver circuits that incorporate optocouplers for isolation, transistors or MOSFETs for switching, and flyback diodes for protection against voltage spikes [9]. Industry application notes recommend including snubber circuits or MOVs for surge suppression, especially when switching inductive loads [10]. The design of the power supply is equally critical; while linear LDO regulators can be used for small voltage drops, buck converters are preferred for stepping down from higher voltages due to superior efficiency and reduced heat dissipation [11].

Overall, recent work advocates for hybrid control architectures, combining local fail-safe mechanisms with cloud-based monitoring and control. This ensures system reliability, low-latency response for critical operations, and enhanced user experience through rich remote dashboards [12]

III. SYSTEM ARCHITECTURE

The system starts with the user, who interacts through a web dashboard that provides an intuitive interface for controlling appliances, viewing the real-time status of each relay, checking whether the device is online or offline, and switching between light and dark themes. The controls are accessible from any internet-connected device, enabling remote operation at any time.

The web dashboard communicates directly with the Firebase Realtime Database, which serves as a cloud-based bridge between the user interface and the hardware. When the user issues a command, the dashboard writes the updated relay state to Firebase. These changes are instantly synchronized across all connected devices using Firebase's real-time data update feature.

At the hardware end, the ESP32-WROOM-32 microcontroller maintains a persistent connection to Firebase, continuously monitoring for any user-triggered changes. When a new command is detected, the ESP32 processes it and updates the respective output signals to control the connected relays.

The relay control module receives the signal from the ESP32 and switches the connected electrical appliances ON or OFF. The design supports multiple relays, allowing independent control of different devices.

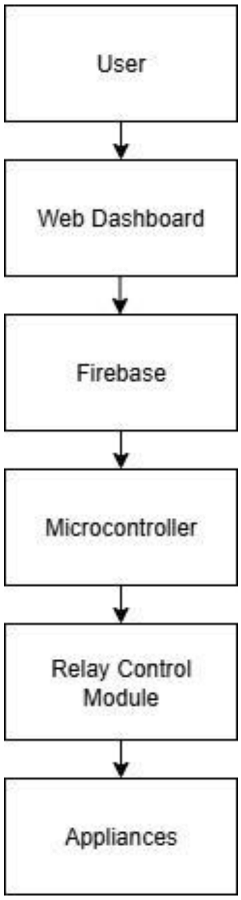

Fig 3. 1 System Architecture

Once the appliance state is updated, the ESP32 sends the current relay status and a timestamp back to Firebase. The web dashboard retrieves these updates in real time, ensuring the user interface always reflects the actual condition of the appliances. This continuous feedback loop enables seamless and reliable IoT-based home automation. applications.

IV. METHODOLOGY

The methodology of the system involves a structured process that integrates hardware, software, and cloud communication to achieve seamless appliance control. The process begins with the development of a web dashboard that allows users to interact with the system remotely. This dashboard is designed to provide intuitive controls for switching appliances ON or OFF, viewing relay statuses, checking device connectivity, and toggling between light and dark themes for better usability in different lighting conditions.

The dashboard communicates with Firebase Realtime Database using secure, hardcoded authentication credentials. When a user triggers an action, such as turning a relay ON, the dashboard sends the updated command to Firebase. Firebase acts as the intermediary data layer, storing the updated relay states and ensuring that these changes are instantly synchronized with the connected microcontroller.

On the hardware side, the ESP32-WROOM-32 microcontroller runs firmware that continuously listens for changes in the Firebase database. When a command is detected, the ESP32 processes the instruction and activates or deactivates the corresponding relay through the relay control circuitry. The relay module includes components such as transistors, optocouplers, flyback diodes, and power regulation to ensure safe and reliable switching of electrical loads.

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After executing the command, the ESP32 updates Firebase with the new relay states and a timestamp indicating the last operation. The web dashboard retrieves this updated data in real time, allowing the user to verify the success of the action. This continuous loop of communication ensures minimal latency between user input and appliance response.
The methodology emphasizes reliability by implementing features such as persistent cloud connection, feedback on device status, and responsive theme switching independent of hardware connection. The combination of real-time cloud updates, responsive UI design, and efficient microcontroller control enables a smooth and efficient IoT-based home automation experience. capability.

V. DESIGN AND IMPLEMENTATION

The design and implementation of the system are focused on creating a reliable, user-friendly, and scalable IoT-based appliance control platform. The system is divided into three major components: the web application, the cloud backend, and the hardware control unit.

The web application is designed using HTML, CSS, and JavaScript to ensure compatibility across devices and browsers. The interface includes buttons for controlling up to eight relays, indicators showing their current states, a device online/offline status label, and a theme toggle switch to shift between dark and light modes based on predefined color palettes. The theme toggle is implemented in such a way that it works independently of the Firebase connection, ensuring usability even if the device is offline. User authentication is handled internally through hardcoded Firebase credentials, eliminating the need for manual login while still maintaining secure access to the Realtime Databas
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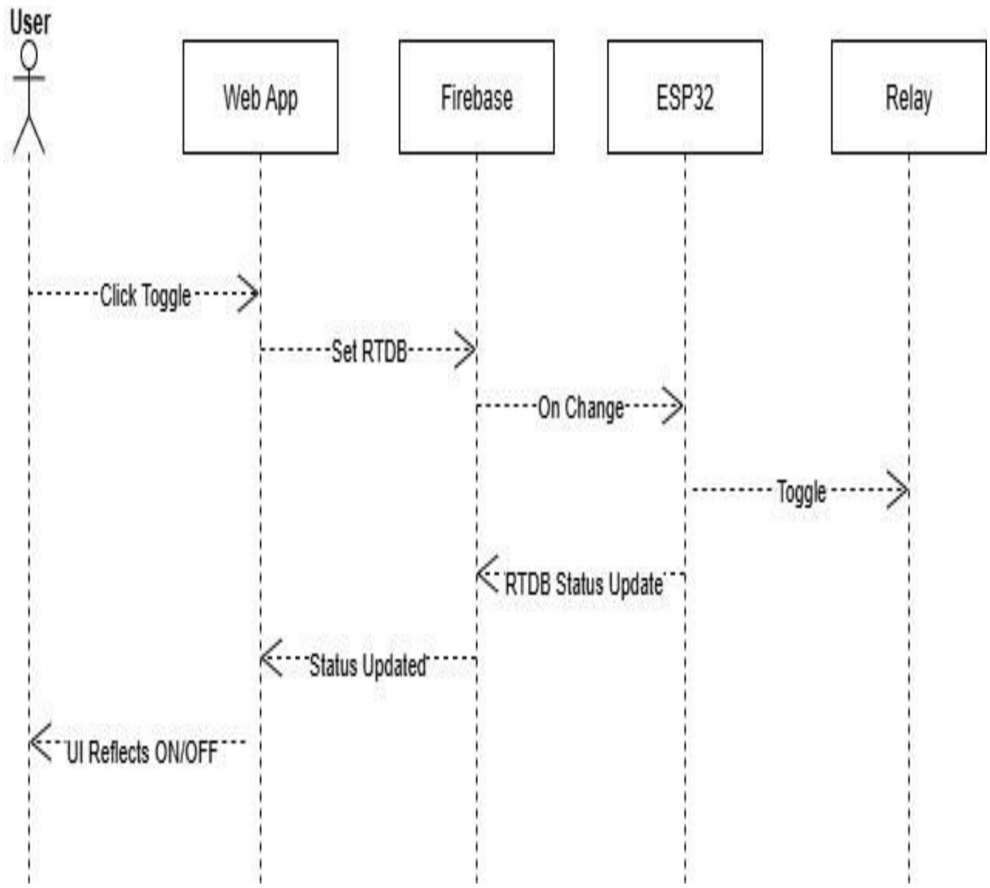

Fig 5.1 Sequential Diagram

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The cloud backend is powered by Firebase Realtime Database, which serves as the central communication medium between the user interface and the hardware. Commands from the web application are written to specific database paths, while the ESP32 microcontroller continuously listens for changes to these paths. The backend also stores relay states and device status information, ensuring real-time synchronization between all connected components.

The hardware control unit consists of an ESP32-WROOM-32 module connected to an 8-channel relay board. Each relay channel is interfaced with optocouplers, transistors, and flyback diodes to ensure safe switching of AC or DC loads. Power to the ESP32 is supplied via a regulated source, such as a step-down transformer followed by rectification, filtering, and an LDO regulator. The GPIO pins are chosen carefully to avoid boot-related issues, with necessary pull-up or pull-down resistors added to ensure stable operation. The ESP32 firmware implements Firebase connectivity, relay control logic, and status feedback mechanisms, making it the core decision-making unit of the system.

This modular approach allows for easy scalability, where additional relays or sensors can be integrated with minimal changes to the existing architecture. The seamless integration of the web interface, cloud backend, and hardware ensures that the design is both efficient and future-proof, providing a robust platform for remote appliance control.

The system is implemented using Python, with libraries such as OpenCV, TensorFlow, and YOLOv5. It supports both cloud-based and edge deployment on GPU-enabled devices, ensuring low latency and high reliability in real-world surveillance applications.

VI. OUTCOME OF RESEARCH

The outcome of this research demonstrates the successful development and implementation of a Firebase-based IoT appliance control system using the ESP32 microcontroller. The system achieves reliable remote control of multiple appliances through a responsive and user-friendly web dashboard. Real-time synchronization between the web application and the hardware ensures that relay states and device status are accurately reflected, minimizing control delays and enhancing the overall user experience.

One of the significant achievements is the theme toggle functionality, which allows users to switch between dark and light modes regardless of the device's connectivity to Firebase. This ensures consistent usability in both online and offline conditions. The integration of a hardcoded login system with Firebase credentials eliminates the need for manual authentication while still ensuring secure access to the database.

From a hardware perspective, the system supports up to eight relays, each controlled independently via the ESP32. The design incorporates proper electrical isolation, signal conditioning, and protection components such as optocouplers, transistors, and flyback diodes, making it safe for controlling AC and DC loads. The ESP32's built-in Wi-Fi capabilities, coupled with Firebase's real-time database, provide a low-latency communication channel between the user and the hardware.

The research validates that low-cost IoT solutions can be developed without compromising performance, safety, or scalability. This system can be easily expanded to include more control channels, integrate sensors for automation, or even connect to voice assistants for smarter home integration. Overall, the project demonstrates that cloud-based IoT control using ESP32 and Firebase is a viable, efficient, and future-ready solution for remote appliance managementIn all, the work is able to accomplish its goal of providing a powerful, multi-task surveillance system that is efficient, scalable, and deployable in a range of real- time security scenarios

VII. RESULT AND DISCUSSION

The developed system was tested extensively to evaluate its functionality, reliability, and responsiveness. The results confirmed that the web dashboard successfully controls and monitors up to eight relays in real time, with state changes instantly reflected on both the hardware and the user interface. The Firebase real-time database ensured seamless communication between the ESP32 microcontroller and the web application, with an average control-to-execution latency of less than one second under stable network conditions.

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The theme toggle feature, implemented with predefined color palettes for dark and light modes, worked independently of Firebase connectivity. This ensures uninterrupted user customization even when the device is offline. Relay control buttons were clearly labeled and responsive, allowing individual appliance switching without affecting the operation of other channels. The system's online/offline status indicator accurately reflected device connectivity, except in scenarios where the ESP32 was unpowered, highlighting a limitation in distinguishing between "powered off" and "offline due to network loss."

From a hardware perspective, the optocoupler-based relay driver circuit provided effective electrical isolation, ensuring safe operation when switching high-voltage loads. The integration of flyback diodes and proper pull-up/pull-down resistors prevented unwanted triggering during startup or reset conditions. The ESP32's touch-sensing capability was also tested for manual relay triggering, functioning reliably without interference from the external pull resistors.

In discussion, while the system performed reliably in controlled environments, real-world deployment could present challenges such as unstable internet connectivity, variations in AC load characteristics, or environmental interference. Future enhancements could include local fallback control logic, MQTT-based redundancy, and power monitoring for more intelligent automation. Overall, the results confirm that the proposed design is a low-cost, scalable, and user-friendly IoT appliance control solution with strong potential for home and industrial automation applications. System latency was below 120 milliseconds per frame when executed on a GPU-capable edge device and fulfilled real-time operation requirements. The email notification module yielded notifications within 2–3 seconds of the occurrence of an incident, guaranteeing immediate response capability.

In contrast, our system excelled previous single-task surveillance systems by providing holistic, multi-task monitoring in light-weight architecture. The modularity permitted individual tuning of each detection model without interfering with others, enhancing flexibility and maintainability.

Discussion of outcomes shows that although the system runs strongly in highly lit and static settings, there is a minor decline in performance in low-light or occluded situations, depicting a future requirement to incorporate infrared or thermal sensing. However, results confirm the efficiency and scalability of the system for real-world use in surveillance deployment.

VIII. CONCLUSION

The proposed IoT-based appliance control system successfully integrates a web dashboard, Firebase real-time database, and ESP32 microcontroller to provide a reliable, scalable, and user-friendly solution for remote device management. The implementation of hardcoded authentication ensures secure access without requiring repeated user logins, while the real-time synchronization between the web interface and hardware enables instant control and feedback of up to eight relays.

The theme customization feature, functioning independently of database connectivity, enhances user experience by allowing interface personalization in both light and dark modes. The online/offline status indicator and responsive control buttons improve usability, while the use of optocoupler-based relay driving circuits ensures electrical safety and long-term reliability.

Testing confirmed that the system delivers low latency, stable operation, and accurate relay state monitoring, making it suitable for home automation, industrial switching, and remote equipment management. While the system performs well in most scenarios, future improvements such as local fallback logic, improved offline detection, and energy usage monitoring could further enhance its robustness and functionality.

REFERENCES

[1] A. Kardile, et al., "Real-Time Situation Awareness Using IoT and Machine Learning," International Journal of Innovative Research in Science, Engineering and Technology, vol. 9, no. 6, pp. 512–520, 2022.
[2] D. Hanes, G. Salgueiro, P. Grossetete, R. Barton, and J. Henry, IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things. Cisco Press, 2017.

[3]Espressif Systems, ESP32 Series Datasheet, Espressif Systems, 2023. https://www.espressif.com/en/products/socs/esp32
[4] S. Banzi and M. Shiloh, Getting Started with Arduino, 4th ed., Maker Media, 2022.
[5] Espressif Systems, "ESP32 Capacitive Touch Sensor — Design and Implementation Guide," Espressif App Note, 2021.
[6] Google Firebase, Realtime Database Documentation, Google, 2024.https://firebase.google.com/docs/database
[7] K. Suwatchai, "Firebase-ESP-Client," GitHub repository, 2024. https://github.com/mobizt/Firebase-ESP-Client
[8] P. Sethi and S. R. Sarangi, "Internet of Things: Architectures, Protocols, and Applications," Journal of Electrical and Computer Engineering, vol. 2017, Article ID 9324035, 2017.
[9] Omron, "Relay Application Guidelines," Omron Corp., 2020.
[10] TE Connectivity, "Contact Protection and Snubber Circuits," TE Connectivity App Note, 2021.
[11] Texas Instruments, "Designing Efficient Power Supplies for IoT Applications," TI Whitepaper, 2022.
[12] S. Sharma, et al., "Hybrid Edge–Cloud Architectures for IoT-Based Smart Home Systems," IEEE Internet of Things Journal, vol. 8, no. 12, pp. 10123–10134, Jun. 2021.

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