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Design and Implementation of a Multi-Switching Contactless Solution Using RF and Wi-Fi Control for Smart Automation.

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Abstract

This paper details the design and implementation of a multi-switching contactless system for remote control of electrical loads, leveraging an Arduino Uno, Espressif's ESP-32 Wireless Fidelity (Wi-Fi) module, Radio Frequency (RF) sensor, and 5-volt relay. The system is designed to enhance safety, hygiene, and energy efficiency in environments such as home automation, healthcare, and industrial settings. By providing both Radio Frequency (RF) remote and Wireless

Fidelity (Wi-Fi) -based mobile application controls, the system enables flexible, contactless device management for multiple loads. The Arduino Uno serves as the primary control unit, receiving signals from the Radio Frequency (RF) and Wireless Fidelity (Wi-Fi) modules and processing commands from a mobile app. To validate performance, a series of tests—including unit, integration, and functional tests—were conducted. Unit tests confirmed the individual operation of each component, while integration tests ensured seamless communication between hardware and software. Functional tests evaluated overall system responsiveness, usability, and stability across various real-world scenarios, verifying consistent and reliable load control. This contactless solution advances previous systems by combining dual control methods with an intuitive interface, promoting user convenience, hygiene, and energy savings.

Keywords: Contactless switching, Smart automation, Multi switching system, Mobile application control, Radio Frequency (RF) remote, and Wireless Fidelity (Wi-Fi) integration.

Introduction

The development of contactless switching technology has significantly improved electronic device management by providing safer, more efficient, and user-friendly control mechanisms. This shift addresses several key challenges in traditional device control, including hygiene concerns in public spaces, energy inefficiencies, and the need for convenient automation across various settings. According to [1], the move towards contactless systems is driven by a demand for increased convenience, operational safety, and sustainability in both residential and commercial environments. The Automatic Contactless Multiple Switching System presented in this study embodies these advancements by integrating modern control technologies, such as sound, RF remote, and mobile applications, into a versatile, user-centered solution. This integration offers multiple control options, which enhance accessibility and adaptability across diverse contexts [2]. The Study done by [3] further highlights the relevance of contactless systems in improving public health by reducing physical contact, particularly in high-traffic areas like healthcare facilities, where it helps minimize pathogen transmission.

This project advances current standards by implementing a multi-control, contactless switching solution that emphasizes user safety, energy efficiency, and flexibility. Its user-centric design and operational versatility make it suitable for applications across various fields, including home automation, industrial settings, and healthcare environments.

2 Literature review

The field of contactless switching systems has advanced rapidly in recent years, with significant developments in technologies designed to enhance user interaction, improve energy efficiency, and contribute to public health safety. Recent studies highlight the increasing role of gesture-based controls in these systems, offering a more hygienic, non-invasive approach to managing devices. [4] explored the use of gesture recognition systems, showing how they can enable intuitive, touchless interaction by detecting hand movements to control devices such as lighting and climate systems. These systems are particularly relevant in reducing the transmission of infectious diseases, as users can operate devices without physical contact. Moreover, optical sensing technologies such as time-of-flight (ToF) sensors have gained attention for their ability to detect gestures with high accuracy in various lighting conditions, providing a reliable means of control in complex environments [5]. Such advancements in non-contact technologies are increasingly integrated into home automation systems, where they enhance user convenience while also addressing growing concerns about hygiene.

In the context of energy efficiency, contactless switching systems are playing a crucial role in optimizing resource consumption. Recent research has emphasized the importance of integrating energy management capabilities into smart home systems.[6] demonstrated how these systems can automatically adjust settings based on data collected from connected devices, ensuring more efficient energy use. Such systems help reduce energy waste by automating tasks like turning off unused devices or adjusting the thermostat when no one is home, ultimately contributing to more sustainable living environments. The integration of renewable energy sources, such as solar panels, into home automation systems has also been explored as a way to further enhance energy management.[7] discuss the role of smart systems in managing the distribution of energy from renewable sources, promoting sustainability while reducing dependence on the conventional power grid.

The integration of contactless systems has become especially prominent in public health applications. Studies have underscored the role of touchless technologies in improving hygiene in healthcare settings, where reducing physical contact is critical [8]. The adoption of gesture recognition, motion sensors, and voice controls in hospitals, airports, and public transport systems has been instrumental in minimizing the spread of germs and viruses. These systems are not only useful in medical settings but also in everyday environments like offices and homes, where they contribute to maintaining cleanliness without the need for manual interaction with high-touch surfaces [9].

Recent innovations in user interface (UI) design for contactless systems have also contributed to their growing popularity.[10] highlight the importance of creating intuitive and user-friendly interfaces for contactless systems, ensuring that they are accessible to a broad range of users, including those with disabilities. As mobile applications and remote-control functionalities become more integrated with these systems, users are afforded greater flexibility in managing their devices. The development of mobile-based controls further enhances the system's accessibility, allowing users to control various devices from anywhere, whether at home or remotely.

These technological advancements collectively address key challenges faced by earlier contactless switching systems, which were often limited by their reliance on single technologies like motion sensors or infrared. The automatic contactless multiple-switching systems developed in recent years have been enhanced by combining multiple technologies—such as gesture control, voice recognition, and Bluetooth connectivity—to offer more versatile, user-friendly, and energy-efficient solutions. Such systems not only meet the growing demand for convenience but also contribute to broader goals of sustainability, hygiene, and accessibility. The continuous evolution of these systems suggests that future developments will further integrate smart technologies into everyday life, making homes and public spaces more connected and efficient.

3 Methodology

The process begins with hardware configuration, which includes setting up components like the Arduino Uno, ESP-32 Wi-Fi module, and RF remote control, each serving specific roles in managing the system's functionality. The software phase follows, involving programming the Arduino to process input signals and control relays, along with developing a mobile application that allows users to control the system wirelessly via Wi-Fi. Lastly, system integration brings the hardware and software together, ensuring communication and control are properly established. Rigorous testing ensures the system functions effectively, providing users with convenient load control.

3.1 Hardware Setup

The hardware setup for the contactless multiple-switching system includes several components, each fulfilling a specific function. The Arduino Uno serves as the central control unit, processing input signals and controlling the relay to switch loads. The Espressif's ESP-32 Wireless Fidelity (Wi-Fi) module connects the system to a mobile application, enabling wireless communication. A 433 MHz RF remote control is employed for short-range communication to control devices, while a 5V relay allows for switching loads such as lights or motors. Additionally, a rectifier is used to convert AC power to DC, supplying Espressif's ESP-32 Wireless Fidelity (Wi-Fi) with the necessary power, which is then stabilized using a voltage regulator.

The hardware components are interconnected as follows: a button connected to a digital pin of the Arduino, a transistor controlling the relay, and a flyback diode protecting the relay from voltage spikes. The relay's output controls the connected load, with appropriate power supply connections for both the relay and load. This setup combines various components to ensure efficient control of electrical devices through both Radio Frequency (RF) remote and Espressif's ESP-32 Wireless Fidelity (Wi-Fi) connections, forming the core of the contactless switching system.

3.1.1 System Integration and Testing Overview

The system integration begins by connecting the hardware components, ensuring each part operates cohesively. The button is connected to the Arduino Uno, which controls the relay used to switch the loads on and off. The relay is activated through the 2N2222 transistor, which acts as a switch controlled by the Arduino. When the button is pressed, the Arduino sends a signal to the transistor's base, turning it on, allowing current to flow through the relay coil and power the loads. A flyback diode is placed across the relay to protect the transistor from voltage spikes that occur when the relay is deactivated.

Testing and Validation of the system involves multiple steps:

Unit Testing ensures that individual components, such as the button, relay, and load, function correctly. Additionally, it is verified that the transistor switches properly in response to the Arduino's signals.

Integration Testing confirms that the entire system works as intended, including ensuring that the button effectively controls the loads and that the flyback diode provides proper protection.

Functional Testing guarantees that pressing the button consistently results in the expected behavior, switching the loads on and off reliably.

User Acceptance Testing gathers feedback on the usability and reliability of the system under various conditions to ensure the setup is user-friendly and stable.

3.1.2 Circuit Design

Fig. 1 Circuit Design (Instructables, 2022, "Arduino Circuit Control Diagram")

The design of the system utilizes a microcontroller as the central processing unit (CPU), enabling it to manage and control various components within the circuit. The microcontroller facilitates communication by receiving and transmitting signals through multiple input/output pins. One key element in the design is the relay, which switches the loads on and off. The relay, a 5V component, requires a higher current than the microcontroller can supply, so a 2N2222 NPN transistor is introduced to amplify the current. This allows the relay to be energized when the base of the transistor is triggered, enabling the flow of current through the relay coil.

The circuit includes a flyback diode (1N4007) placed across the relay coil to protect the transistor from voltage spikes when the relay is de-energized. The relay controls four separate loads, with the common terminal of all relays connected to the live wire, and the switching done on the live side. The relay's normally open terminals are linked to the respective loads, and when a relay is triggered, current flows to the load, completing the circuit.

The RF remote control emits radio frequency signals that are received by the RF module connected to the microcontroller. Unlike infrared (IR) signals, RF signals can penetrate walls, offering greater flexibility for remote control. Upon pressing a button on the RF remote, a unique signal is sent to the receiver, which is decoded by the microcontroller to perform actions such as turning on or off the load.

Additionally, the Wi-Fi module in the design facilitates remote control via a wireless network. The microcontroller communicates with the Wi-Fi module using the UART protocol, enabling commands from a smartphone or computer to be received by the module. These commands are passed to the microcontroller, which then executes the appropriate actions, such as toggling a relay.

To control the loads, a 5V relay is used, and a 2N2222 NPN transistor amplifies the current from the microcontroller, allowing the relay to activate the connected load. The system is tested through multiple stages, including individual testing of components and integrated testing to ensure the system's overall reliability and performance. Each signal type, whether from the RF remote or the Wi-Fi module, is decoded and processed to activate the corresponding relay, ensuring proper control of the system.

3.2 Software Setup

Fig. 2 MIT app inventor interface

The software for this project was built using MIT App Inventor, a powerful platform that allows users to create mobile applications without requiring advanced coding skills. Developed initially by Google and later maintained by the Massachusetts Institute of Technology (MIT), App Inventor provides a user-friendly environment where developers can create apps using visual and block-based programming. Here's a breakdown of key features and functionalities:

3.2.1 Key Features of MIT App Inventor

Visual Programming Interface: MIT App Inventor uses a drag-and-drop interface, allowing users to design apps visually. Users can select components (such as buttons, text fields, and images) and arrange them on the screen without needing to write extensive code. This makes it easy for beginners to get started while still providing enough depth for more experienced developers.

Block-Based Coding: The platform uses a block-based programming approach, where developers use puzzle-like blocks to define the logic of the application. This system is similar to Scratch and makes learning programming concepts easier by providing a more intuitive way to work with code.

Extensive Component Library: App Inventor includes a rich set of components that can be used to build the app's functionality. These include basic UI elements like buttons and text boxes, connectivity options such as Bluetooth and Wi-Fi, sensors like GPS and accelerometers, and media components for handling sound and video. This variety enables developers to create diverse and feature-rich applications.

Real-Time Testing and Deployment: One of the platform's standout features is the ability to test apps in real-time [1] on an Android device or emulator. As you develop your app, changes are immediately reflected on the test device, allowing for fast iteration and troubleshooting. Once the app is complete, it can be packaged as an APK file for distribution or publishing on app stores.

Educational and Collaborative Tool: MIT App Inventor is widely used in educational settings, supporting a range of learning environments from primary schools to universities. It fosters collaboration by enabling multiple users to work on a single project, making it ideal for group work or classroom projects.

3.2.2 Applications and Use Cases

MIT App Inventor has been used to create a diverse range of applications. These range from simple mobile games and utility apps to more complex projects that integrate with the Internet of Things (IoT) or use machine learning. For example, students have developed apps to monitor environmental data, assist individuals with disabilities, and provide educational tools. This versatility demonstrates the potential of App Inventor in various fields, including education, IoT, and accessibility solutions.

MIT App Inventor's ability to simplify app creation without compromising on functionality makes it a valuable tool for both novice developers and educational institutions aiming to teach the basics of app development and computational thinking.

The Arduino code used for this project is available at this GitHub Address: https://github.com/PEACE-DFG/Research-Code.git.

4 Results and Discussion

4.1 Results

4.1.1 Hardware Performance and Analysis

The hardware for the contactless switching system—comprising the Arduino Uno, ESP-32 Wi-Fi module, RF remote control, and 5V relay—was individually tested and then assessed as an integrated system. The results of each component's performance are summarized below:

Arduino Uno: As the core processing unit, the Arduino Uno effectively handled input signals from the RF remote and Wi-Fi module. The response time from receiving input signals to activating the relay was consistently swift, meeting the reliability standards required for seamless operation without lag.

ESP-32 Wi-Fi Module: This module facilitated wireless control via a mobile application. It maintained a steady connection to the local Wi-Fi network throughout testing, allowing the system to receive commands sent from the application accurately. The Wi-Fi module's reliability in wireless communication significantly contributed to the system's flexibility and user convenience.

RF Remote Control: The RF remote proved reliable for short-range operation, with a control range of up to 100 meters. It transmitted signals effectively even through walls and other barriers, verifying its suitability for contactless switching in a variety of environmental conditions.

5V Relay: The relay performed as expected, toggling the connected loads on and off based on signals from the Arduino. The 2N2222 transistor used to amplify current played a crucial role in ensuring the relay had sufficient power to activate, especially for high-current devices, further enhancing the circuit's efficiency.

4.1.2 Software Performance Analysis

The software components, including the Arduino code and mobile application, were evaluated to ensure they met the system's functional requirements. These components were crucial for handling inputs, managing communication, and controlling the relays.

Arduino Code: The Arduino code demonstrated reliable performance, processing input signals from both the Radio Frequency (RF) remote and Wireless Fidelity (Wi-Fi) module without errors. The interrupt service routines (ISRs) were instrumental in detecting button presses promptly, providing a quick response to user actions. Additionally, integrating Firebase for real-time data exchange allowed for seamless synchronization between the mobile application and Arduino, ensuring the system's status was accurately updated.

Mobile Application: Designed for ease of use, the mobile application provided an intuitive interface for controlling the system remotely. It successfully established a connection with the ESP-32 module, and the commands sent were interpreted accurately by the Arduino. User feedback indicated a positive experience with the app, noting the simplicity of the interface and the responsiveness in displaying each load's status.

Fig. 3 Mobile Application interface (a.) Authentication Page (b.) Control Page

4.2 Discussion

The results demonstrate that the contactless multiple-switching system achieved the design goals, performing effectively across various test scenarios. The hardware components, particularly the Arduino Uno, Radio Frequency (RF) remote Wireless Fidelity (Wi-Fi) module, and 5V relay operated seamlessly together, allowing smooth and efficient control over the connected loads. The system proved to be both reliable and responsive, validating the choice of each component.

The software played a pivotal role in ensuring the system's functionality and user experience. The Arduino code efficiently processed signals from both the Radio Frequency (RF) remote and Wireless Fidelity (Wi-Fi) module, providing real-time control. The mobile application further enhanced usability, making it easy for users to interact with the system remotely. The integration of Firebase for real-time data communication added a valuable feature, enabling users to monitor and control the system from distant locations, a critical aspect of the design's flexibility.

Testing revealed the robustness of the system, with all components functioning as intended under diverse conditions. The dual control methods—RF for short-range and Wi-Fi for remote access—provided users with flexibility, allowing them to choose based on their immediate needs and the available infrastructure.

5. Conclusion

The project successfully developed a contactless multiple-switching system, combining hardware components like the Arduino Uno, Radio Frequency (RF) remote, ESP-32 Wireless Fidelity (Wi-Fi), and 5V relay to allow wireless control of multiple loads. This dual-method control system, utilizing both RF and Wi-Fi, offered flexibility, enabling users to operate electrical devices remotely, thus enhancing convenience and safety. The Arduino Uno served effectively as the central processing unit, managing both the hardware components and mobile application for a seamless user experience.

Extensive testing confirmed the system's reliability, with each component and communication protocol performing as expected. The project thus achieved its objective of reducing physical contact with switches, demonstrating the system's potential for smart homes, industrial automation, and healthcare environments where contactless control is beneficial. This solution provides a foundation for future advancements and broader applications in remote-controlled, contactless technology.

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1.	~~real-time~~ → real time	Confused words	Correctness
2.	~~Maduri~~ → Madurai	Misspelled words	Correctness
3.	~~ICACCCN~~ → ICANN	Misspelled words	Correctness