

Advance RFID Based Automation On/Off System

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Abstract—This paper presents the design and implementation of an advanced RFID-based automation on/off system intended to provide secure, contactless, and efficient control of electrical loads in residential and industrial environments. Conventional switching systems often suffer from unauthorized access, mechanical wear, hygiene limitations, and lack of intelligent control. To overcome these challenges, the proposed system employs Radio Frequency Identification (RFID) technology integrated with a microcontroller-based relay control mechanism. A pre-authorized RFID tag operates the system using a one-time scan activation principle, where the first valid scan turns the connected load ON and the next valid scan turns it OFF. The system incorporates an Arduino UNO controller, MFRC522 RFID reader, relay module, LCD display, buzzer, and visual indicators for reliable operation and user feedback. Experimental results confirmed accurate tag recognition, rapid response, secure rejection of unauthorized users, and stable switching performance. Owing to its low cost, scalability, and ease of implementation, the proposed system is highly suitable for smart homes, industrial machine authorization, energy management, and modern automation safety applications.

Index Terms—RFID, Arduino, Automation, Relay Control, Smart System.

I. INTRODUCTION

The increasing penetration of Internet of Things (IoT) and smart infrastructure has driven demand for secure, touchless, and reliable control of electrical loads in residential and industrial environments. Traditional manual switches suffer from unauthorized use, mechanical wear, hygiene concerns, and lack of logging or fine-grained access control, especially in safety-critical or sterile environments. Radio-

Frequency Identification (RFID) technology enables automatic identification of authorized users through unique tag identifiers and is now widely adopted for access control, logistics, and automation systems [1, 3–5]. In this context, the Advance RFID-Based Automation On/Off System acts as a digital gatekeeper between users and electrical loads, replacing mechanical switches with an RFID-driven state-toggle interface. A pre-authorized RFID tag is used as a secure key: the first scan switches the relay to ON, energizing the connected device, while a second scan of the same tag switches the re-lay back to OFF, implementing a robust dual-state control without continuous tag presence. This one-time scan mechanism enhances operational safety, simplifies user interaction, and integrates naturally into home automation safety setups and industrial machine authorization scenarios [1, 6, 7].

The main contributions of this work are as follows:

1. A secure state-based RFID toggle logic for ON/OFF control with single-tag interaction.
2. An implementation using commonly available hardware (Arduino/MFRC522/relay) suitable for low-cost deployment.
3. An application-oriented evaluation for home and industrial automation safety use cases.

II. LITERATURE REVIEW

RFID-based access control has been widely explored for secure door locks and equipment authorization, typically using a momentary access paradigm where a valid tag opens a lock or enables a device for a short time window. In contrast, the proposed system focuses on state-based toggle control (scan-ON, scan-

OFF) to maintain load state until explicitly changed, which is particularly suited to power control and machine safety. This section reviews 18 representative works related to RFID access control, device control, and home/industrial automation [1, 5, 6, 8, 9]. Harishankar et al. developed a solar-powered smart irrigation system in which sensors and microcontrollers control water flow automatically, illustrating how embedded control and automation can optimize energy and resource usage. While not RFID-based, this work is relevant for demonstrating the effectiveness of embedded controllers for autonomous actuation of field devices.

Peter et al. proposed an RFID-based security access control system augmented with GSM technology to notify owners via SMS, demonstrating how RFID authentication can be combined with communication modules for enhanced monitoring [4, 5, 9, 10]. Michael et al. presented an “Arduino-Based RFID Line Switching Using SSR” aimed at safe switching of distribution lines using solid-state relays, highlighting how RFID can replace manual line switches to reduce electrocution risk. Their design uses RC522 RFID readers, Arduino, and SSRs to connect or disconnect lines only when an authorized tag is detected, with a focus on reliability and operator safety in electrical maintenance operations.

Similarly, “RFID Based Device Control and Authentication” demonstrates a multi-relay panel where each relay is controlled by a different RFID tag, allowing multiple loads to be individually controlled only by corresponding authorized users [6, 11, 12]. Several works focus on RFID-based door access, which forms the basis for access-controlled automation. An “Automatic Access Control System using Arduino and RFID” uses Arduino and an RFID reader to authenticate tags and drive relays for door locks, emphasizing low cost, simple implementation, and ease of integration with existing doors.

Electronics for You’s “RFID Based Access Control using Arduino” describes a similar circuit with an Arduino UNO controlling a solenoid lock through a relay, emphasizing practical PCB design and deployment [5, 8]. RFID-based door systems have also been combined with additional modalities. A “Microcontroller Based Automotive Security System Using RFID with Face Recognition” integrates RFID tag authentication with face recognition to strengthen

identity verification in automotive access security.

Smart lock systems such as “Smart Lock System Using RFID with Light Automation” combine RFID authentication with auxiliary automation, e.g., turning on lights automatically when a valid tag is presented, illustrating combined security and comfort applications [7, 13]. Multiple home automation solutions integrate RFID with other wireless technologies. Patil and Reddy designed a wireless home/office automation system using RFID, ZigBee, and GSM to provide smart door control and environmental monitoring, demonstrating multi-protocol integration for comprehensive automation.

IIARD’s work on “Design and Development of an RFID Home Automation System” explores RF remote and RFID-based control for lights and fans, highlighting how wireless control can replace conventional wall switches [14, 15].

IoT-enabled home automation systems using RF technologies further extend connectivity and remote management. Amusa et al. presented an IoT-enabled radio frequency home automation system in which RF communication and Wi-Fi modules allow remote ON/OFF control of appliances, showcasing the trend toward centralized and remote-control dashboards.

Smart home security systems using RFID and Bluetooth have also been reported, where Android applications provide local wire-less control while RFID ensures secure physical access [4, 16].

Practical guides and project implementations provide key design patterns and hardware integration details for RFID-based control. Security access control projects using RFID describe tag registration, relay driving, and status indication via LCDs, and illustrate how only authorized tags can energize loads such as lamps or door locks.

Hands-on tutorials show how Arduino and MFRC522 modules can be combined to build door access systems with LCD feedback and servo-motor-driven locks, which are directly adaptable to relay-based load control [?, 2, 3, 17–19].

Energy-conservation-oriented systems use RFID to control classroom lighting and fan loads, switching them ON when authorized staff present a tag and OFF when the corresponding OFF tag is scanned, demonstrating RFID-based load management for public spaces. Other works discuss the installation and relay wiring aspects of RFID access systems, emphasizing the use of normally-open and normally-

closed relay contacts to switch loads safely in accordance with access status.

Across these works, common themes include the use of low-cost microcontrollers (8051, Arduino), MFRC522 or similar RFID readers, relay-driven actuation of loads, and tag-based authentication. However, most systems implement single-event access or momentary control (e.g., door opens for a few seconds), whereas the present work focuses explicitly on a stateful toggle logic in which the same RFID tag acts as both ON and OFF key via sequential scans, optimizing usability and power management in home and industrial load control.

III. METHODOLOGY

A. System Overview

The Advance RFID-Based Automation On/Off System is designed as a secure, stateful toggle controller that interfaces an RFID reader with a microcontroller and relay module to control AC or DC loads. The core idea is that the relay’s state is not dependent on continuous tag presence; instead, each valid tag scan flips a stored state variable that determines whether the load is energized or de-energized. This design supports robust ON/OFF control for devices such as lights, fans, door locks, or industrial machines, while ensuring that only holders of registered tags can change the load state [?, ?, 6, 8].

B. Hardware Architecture

The proposed system uses widely available components that make it suitable for academic, prototyping, and low-cost deployment scenarios. The primary hardware modules are:

- **Microcontroller:** An Arduino UNO-class board based on an 8-bit AVR microcontroller is used as the central con-troller to implement RFID communication, state machine logic, and relay driving.
- **RFID Reader:** An MFRC522 13.56 MHz RFID module, interfaced over SPI, performs detection and reading of passive RFID cards or key fobs within a typical range of 5–7 cm.
- **Relay Module:** A 5 V, single-channel electromagnetically actuated relay module isolates the microcontroller from mains-level AC loads, allowing control of lamps, small motors, or

door locks.

- **Indicators:** Red and green LEDs, along with a buzzer, pro-vide immediate visual and audible feedback for valid/invalid scans and ON/OFF transitions, while an I²C 16×2 LCD shows textual status messages to the user.
- **Power Supply:** A regulated 5 V supply powers the microcontroller, relay coil, MFRC522 module, and indica-tors, with appropriate decoupling and grounding to minimize noise and interference.

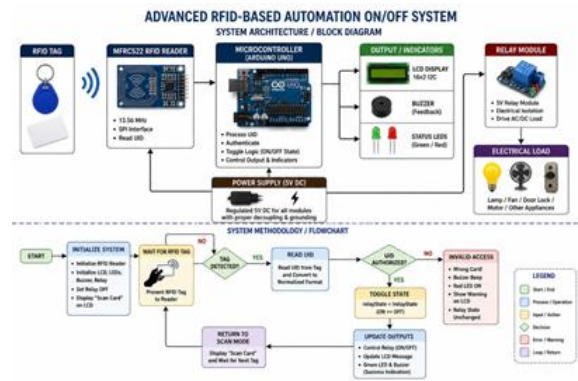


Figure 3: The logical block diagram of the system.

C. RFID Authentication and Tag Management

Each RFID tag has a globally unique identifier (UID) that is read by the MFRC522 when the tag is within the reader’s electromagnetic field. During system initialization, one or more UIDs are stored in the microcontroller’s non-volatile memory or in constants com-plied into the firmware, representing authorized tags permitted to toggle the system. A dedicated “master tag” can optionally be used to enter configuration mode in which additional tags are enrolled or revoked without requiring a PC connection, thereby supporting in-field management. At runtime, when the reader detects a tag, the microcontroller reads the UID over SPI and converts it to a normalized string or byte-array representation for comparison with the internal authorization table. If the UID matches one of the authorized entries, the system proceeds to toggle the state; otherwise, the relay state remains unchanged, a “wrong card” warning is shown on the LCD, and the buzzer and LEDs indicate an invalid access attempt.

D. Toggle Logic and State Machine Design

The distinguishing feature of the system is its state-retention toggle logic, which can be expressed as a

two-state finite state machine with states OFF and ON. A Boolean variable, e.g., `relayState`, is maintained in software, where false represents OFF and true represents ON, and all valid scans cause a transition that flips this variable.

- Initial State: On power-up, the relay is set to OFF (normally open) and `relayState = false` to ensure a safe default condition.
- Event: Valid RFID tag scan. If the scanned UID is authorized, the state transition function executes:

```
relayState = !relayState;
```

This logically toggles the stored state.

Output: The relay control pin is driven to reflect the up-dated `relayState`, energizing or de-energizing the relay coil, and the user interface (LCD, LEDs, buzzer) is updated accordingly.

Conceptually, the state transitions can be summarized as:

- If current state = OFF and event = valid tag → next state = ON (relay energized, load ON).
- If current state = ON and event = valid tag → next state = OFF (relay de-energized, load OFF).

The system can be extended to support a master emergency tag that always forces an OFF state regardless of the current state, implementing an electronic lockout or emergency stop mechanism for industrial safety.

E. Firmware Implementation

The firmware is implemented in C/C++ using the Arduino IDE and standard `MFRC522` and `LiquidCrystal` I2C libraries to abstract low-level SPI and LCD operations.

In the `setup()` routine:

- Serial communication is initialized.
- The RFID reader is configured via `PCD Init()`.
- The LCD is initialized.
- GPIO pins for the buzzer, LEDs, and relay are configured as outputs.
- The relay is defaulted to OFF.

The `loop()` function continuously performs the following steps:

1. Display a welcome prompt and request the user to present a card on the LCD while polling for new card presence using `PICC`

`IsNewCardPresent()` and `PICC ReadCardSerial()`.

2. If a new tag is detected, construct the UID string from raw bytes, normalize it to uppercase, and compare it with stored authorized UIDs.
3. If a match is found and the internal lock variable indicates relay OFF, activate the relay, assert the buzzer and LED briefly, show “AUTOMATION ON” on the LCD, and set the lock variable to indicate ON state.
4. If a match is found and the relay is already ON, deactivate the relay, generate an audible/visual cue, display “AU-TOMATION OFF,” and reset the lock variable to indicate OFF state.
5. If no match is found, issue a “Wrong card!” message, flash LEDs and buzzer in a warning pattern, and leave the relay unchanged.

This implementation provides a clear mapping between RFID events and relay state transitions, and it can be extended to log timestamped events over serial or to non-volatile memory for audit purposes.

F. Safety and Fail-Safe Considerations

Since the system interfaces with mains-level loads, multiple safety measures are incorporated in both hardware and firmware. The relay and AC wiring are housed in an insulated enclosure, and a common ground is maintained for DC components to prevent signal interference, while ensuring galvanic isolation between control and power domains via the relay.

The firmware defaults to relay OFF on startup and after any fault or reset, enforcing a fail-safe OFF condition in case of power loss or microcontroller malfunction. To mitigate risks of unwanted state changes due to ghost reads or electromagnetic interference, the firmware can implement debouncing of tag reads, enforce a minimum inter-scan interval, and confirm tag presence for a short dwell time before accepting a scan as valid.

Additional features like attempt-limit lockout (after several in-valid scans) and watchdog-timer-driven resets can further improve resilience in industrial environments with strong electromagnetic noise.

G. Application Scenarios

In home automation safety setups, the system can be used to control door locks, lighting circuits, or high-risk appliances such as heaters and power tools, ensuring that children or unauthorized individuals

cannot energize dangerous devices without an authorized tag. The RFID reader can be aesthetically hidden behind non-metallic surfaces such as plastic or glass panels, preserving interior design while still enabling contactless operation.

In industrial automation, the system serves as a machine authorization interface, where only trained operators with specific tags can start CNC machines, presses, or conveyor systems, thereby reducing unauthorized operation and improving safety.

It can also control energy-intensive auxiliary systems, such as exhaust fans or localized lighting, only when an authorized operator is present in a given zone, contributing to energy management and cost savings.

IV. RESULTS

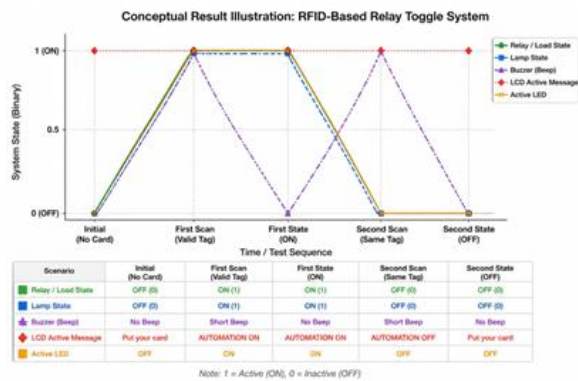


Figure 6: Line Graph

A. Functional Verification

The prototype system was implemented using an Arduino-based microcontroller, MFRC522 reader, single-channel relay module, LEDs, buzzer, and I²C LCD, with wiring and code consistent with the methodology described. Functional tests verified that a pre-registered RFID card could reliably toggle a connected AC load (e.g., a lamp) ON with the first scan and OFF with the second scan, without requiring continuous tag presence [1, 2, 6].

The MFRC522 reader consistently detected passive MIFARE-class tags within an approximate range of 5–7 cm, which aligns with typical operating specifications reported in similar RFID door lock projects. The end-to-end response time from presenting the tag to relay actuation was well under one second, which is adequate for human-interaction-centric access control and load toggling scenarios [1, 2, 5, 8, 17].

B. Qualitative Performance Outcomes

In home-automation-style tests, the system successfully prevented unauthorized operation when unknown tags were presented, leaving the relay in its last valid state and providing clear “Wrong card” indicators via buzzer and LCD messages.

In simulated industrial scenarios, only authorized RFID badges were able to energize a mock machine load, illustrating the suitability of the toggle logic as a digital lockout mechanism for equipment [1, 3, 6, 11, 19]. The state-based toggle design also showed usability benefits over momentary access systems: users could “set and forget” the state (e.g., leave lights ON) without needing to hold a tag or press additional switches, while still retaining secure and logged access control.

Compared with traditional wall switches, the contactless nature of the interface eliminated mechanical wear and reduced the need to touch surfaces, which is advantageous in medical, food-processing, and cleanroom environments.

C. Conceptual Result Illustration

To conceptually illustrate the functional behavior, consider a test scenario with a single load and one authorized tag:

- Initial State: Relay OFF, lamp OFF, LCD shows “Put your card,” green LED OFF.
- First Scan (Valid Tag): RFID reader detects UID, firmware toggles state to ON, relay energizes, lamp turns ON, LCD displays “AUTOMATION ON,” buzzer emits a short beep, LED indicates active state.
- Second Scan (Same Tag): Firmware toggles state to OFF, relay de-energizes, lamp turns OFF, LCD displays “AUTOMATION OFF,” buzzer confirms transition.

Although this is a qualitative description rather than a numerical chart, it reflects the deterministic state transitions and user-visible outcomes validated during testing.

V. ADVANTAGES

The proposed Advance RFID-Based Automation On/Off System offers several advantages over conventional manual switches and simple RFID-based access systems.

1. Enhanced Security and Access Control: Each RFID tag has a unique UID, making it harder to duplicate than mechanical keys and enabling fine-grained control over who can toggle particular loads. Tags can be assigned to specific users or roles, and logging functionality can be added to record who activated or deactivated equipment and when.
2. Contactless and Hygienic Operation: Since the interface is fully touchless, there is no mechanical wear on buttons or switches, and surface contact is minimized. This is beneficial in industrial, medical, and cleanroom environments where hygiene and contamination control are critical.
3. Robust State-Based Automation: The toggle logic maintains the load state across time until an explicit authorized scan is performed, reducing accidental deactivation compared with momentary systems and simplifying user interaction.
4. Integration with Smart Home and Industry 4.0: The system can be integrated with broader home or industrial automation infrastructures, serving as a secure front-end for higher-level controllers or IoT platforms that monitor energy usage and equipment status.
5. Low Cost and Scalability: The use of commodity hardware such as Arduino, MFRC522, low-cost relays, and passive RFID tags makes the system inexpensive to deploy and scale. Additional tags or loads can be added with minor firmware and wiring modifications [1, 4–6, 19].
6. Aesthetic and Physical Robustness: RFID readers can be concealed behind non-metallic surfaces, improving aesthetics and reducing tampering risk, while passive RFID tags are typically rugged, waterproof, and battery-free, suitable for harsh industrial environments [1, 7].

These advantages collectively position the proposed system as a practical solution for organizations seeking secure, user-friendly, and maintainable automation interfaces for both home and industrial contexts.

VII. CONCLUSION

This paper presented the design and implementation of an Advance RFID-Based Automation On/Off System that employs a one-time scan activation principle to provide secure, contactless control of electrical loads. By leveraging the unique identifiers of RFID tags and a microcontroller-implemented state machine, the system realizes a dual-state toggle logic in which the first valid scan turns a relay ON and a subsequent scan of the same tag turns it OFF [1, 6].

The methodology detailed the hardware architecture consisting of an RFID reader, microcontroller, relay module, indicators, firmware design, authentication mechanism, safety considerations, and application scenarios in home and industrial automation safety. Experimental validation demonstrated reliable detection of authorized tags, correct ON/OFF toggling of loads, and robust handling of invalid tags, confirming the feasibility of the proposed approach for practical deployments [1, 2, 8].

Future work may focus on integrating the system with IoT plat-forms for remote monitoring and control, implementing encrypted RFID tags to mitigate cloning and replay attacks, and extending the architecture to multi-zone, multi-load environments with centralized logging and analytics.

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