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RF-Enabled Smart Doorbell with Video Surveillance and Remote Door Lock Control

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Abstract - This paper presents the design and implementation of a smart doorbell system that integrates Radio Frequency (RF) technology with video surveillance and remote door lock control. The idea of informing the hosts about a visitor at the door started much before the invention of the electrical doorbell. In these modern times bells are based on smart technologies that made easy human life. Many intruder alert systems with motion detection and other complex systems have been developed and they are working perfectly well. This smart doorbell system circuit integrates knowledge of these other previous models and uses more readily available components. The introduction of video for real-time monitoring and motion sensors has increased the sensitivity of the whole system. The door lock was introduced to help mostly people with disabilities to easily give access to visitors. Major components used in the project are the motion sensors, the RF module transmitter and the receiver, the camera, the Android module, etc. The motion sensor connected to the RF transmitter picks up movement and activates the camera to start videoing, then sends a signal to the receiver which triggers the speaker. The output from the camera will then allow the homeowner to decide whether to open or not the door lock. The system was tested and found to offer enhanced sensitivity, increased security, and greater affordability compared to existing alternatives. The system's modular design ensures ease of maintenance and reduces the risk of cybersecurity vulnerabilities.

Keywords: Radio Frequency (RF), Smart Systems, Microcontroller, Home Security, Video Surveillance

1. Introduction

As technology continues to advance, the integration of smart devices into residential settings has become increasingly common, with homeowners seeking to enhance convenience, security, and energy efficiency. The development of a smart doorbell system with video surveillance and Radio Frequency (RF) door lock technology represents a significant advancement in this domain. One of the biggest problems with traditional security systems is not having real-time access to events happening around them. The advent of video doorbells has begun to address some of these limitations, offering homeowners the ability to see and communicate with visitors through a camera and speaker system. However, many of these systems are standalone devices that do not integrate with other security features, such as door locks. RF door locks offer a convenient way to control access to a home without the need for physical keys. These systems can be operated remotely, allowing homeowners to lock or unlock their doors from a distance. However, like video doorbells, RF door locks are often implemented as separate systems, if this is not done it can create complexity and reduce overall security when multiple devices are used dependably. Creating a separate standalone system also makes it not susceptible to hacking. The ability to control smart home devices through an Android application offers unparalleled convenience and accessibility (Shrivastava, A. K. et al. 2020). The study focuses on the development of a smart doorbell system that combines these technologies to provide a comprehensive security solution.

2.1 Theoretical Framework

2.1.1 Wireless Communication: Wireless communication is fundamental to the operation of both the video doorbell and the RF door lock. The video doorbell relies on a stable Wi-Fi connection to transmit video data to the Android application.

2.1.2 Video Processing

Video processing involves capturing, encoding, transmitting, and decoding video streams. The camera installed as part of the smart doorbell captures video in real time, which is then encoded using video compression to reduce bandwidth usage while maintaining video quality.

2.1.3 Mobile Application Development

The Android application serves as the user interface for the smart doorbell system. The application must be designed to provide a seamless user experience, allowing homeowners to easily access the video feed and control the RF door lock.

2.1.4 Encryption and Security

Security is a critical aspect of the theoretical framework, particularly in ensuring that the video feed and RF signals are protected from unauthorized access.

2.1 Review of The Related Works

The development of smart doorbell systems with integrated video surveillance and RF door locks has been the subject of various research studies and commercial products over the past few years. This section reviews related works, highlighting key developments and identifying areas where this project can contribute to the field.

Smart Home Integration (Smith, 2018): Smith's study delved into the integration of automatic doorbell systems with smart home technology. It highlighted how these systems can be synchronized with home automation platforms, allowing users to remotely monitor and control their doorbell from mobile devices. However, this integration often overlooked the importance of centralized control of both video and door-locking mechanisms, a gap this paper seeks to address.

Security and Access Control (Jones et al., 2020): Jones and colleagues investigated the role of automatic doorbell systems in bolstering security and access control. The review discussed how features such as facial recognition and motion detection contribute to enhanced safety measures in residential and commercial spaces. These systems lacked accessibility for people with disabilities, which is addressed in our design through remote door control.

Energy Efficiency (Wang et al., 2017): Wang and co-authors investigated the energy efficiency of automatic doorbell systems. The study assessed power consumption patterns and proposed strategies for optimizing energy usage, addressing concerns related to sustainability and environmental impact. Our system builds on this research by incorporating a low-power RF module and efficient video compression techniques to reduce overall energy usage.

User Experience and Design (Brown, 2019): Brown's research focused on user experience and design aspects of automatic doorbell systems. The study emphasized the importance of user-friendly interfaces, considering factors such as accessibility and customization options for seamless interaction with the technology.

Wireless Communication Protocols (Garcia & Patel, 2021): Garcia and Patel explored the various wireless communication protocols employed in automatic doorbell systems.

Johnson et al. (2018): This study focused on the development of a smart doorbell system that utilized Wi-Fi to transmit video to a Smartphone application. The system was designed to provide real-time monitoring and communication with visitors. However, the study identified issues with latency and reliability, particularly in areas with poor Wi-Fi coverage.

The literature review indicates increasing interest in smart doorbell systems that combine video and RF technologies, enhancing security and convenience for homeowners. Significant progress has been made in video transmission, RF communication, and mobile app development, but challenges persist in areas like interoperability, security, and user experience. Research emphasizes the importance of optimizing communication protocols, strengthening encryption, and designing intuitive interfaces. This project builds upon previous findings by integrating video surveillance and RF door locks technology into a unified system, offering real-time monitoring, remote access control, and improved security, addressing the limitations noted in earlier studies.

3. Materials and Methods

3.1. Materials

- Resistors and Capacitors
- RF Modules
- PIR Motion Sensors
- Camera Module
- Microcontroller (ESP32)
- Power Supply
- Relay and Door Lock
- Wi-Fi Module
- Android Application remotely.
- Door Lock (Electric Strike/Solenoid Lock)
- Push Button (Doorbell)

Software required

- Raspbian Jessie OS
- Proteus
- HTTP protocols
- Open CV: For video capture, face recognition, motion detection

3.2. Methods

Circuit Flow

The Smart Doorbell System with Video and RF Door Lock works by integrating several key components to enhance home security. When the PIR sensor detects motion near the door, it signals the microcontroller to activate the camera module, which begins recording video. This video is then processed by the microcontroller and transmitted via the Wi-Fi module to the homeowner's Android app. Simultaneously, the microcontroller uses the RF transmitter to send a signal to the RF receiver connected to the door lock, allowing the user to remotely lock or unlock the door through the RF transmitter. The power supply ensures that all components receive the necessary voltage for smooth operation, linking the entire system into a cohesive and responsive security solution. In summary, each component's function is interconnected, with the PIR sensor triggering the camera, the microcontroller coordinating data processing and communication, and the RF and Wi-Fi modules enabling remote interaction with the system through the smartphone application.

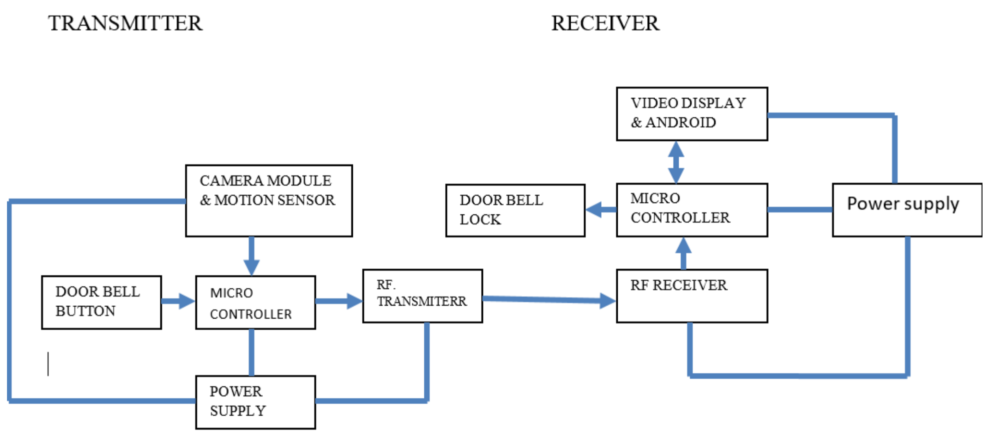

Figure 1. Block Diagram of the smart doorbell system

3.2.1 Circuit Description

The Smart Doorbell System with Video and RF Door Lock is designed to enhance home security by integrating video monitoring and remote door access control. The system's circuit involves several key components, including a camera module, microcontroller, RF transmitter/receiver, power supply, and other peripheral devices. Each component is interconnected to ensure seamless operation, providing video streaming, doorbell functionality, and remote locking/unlocking of the door.

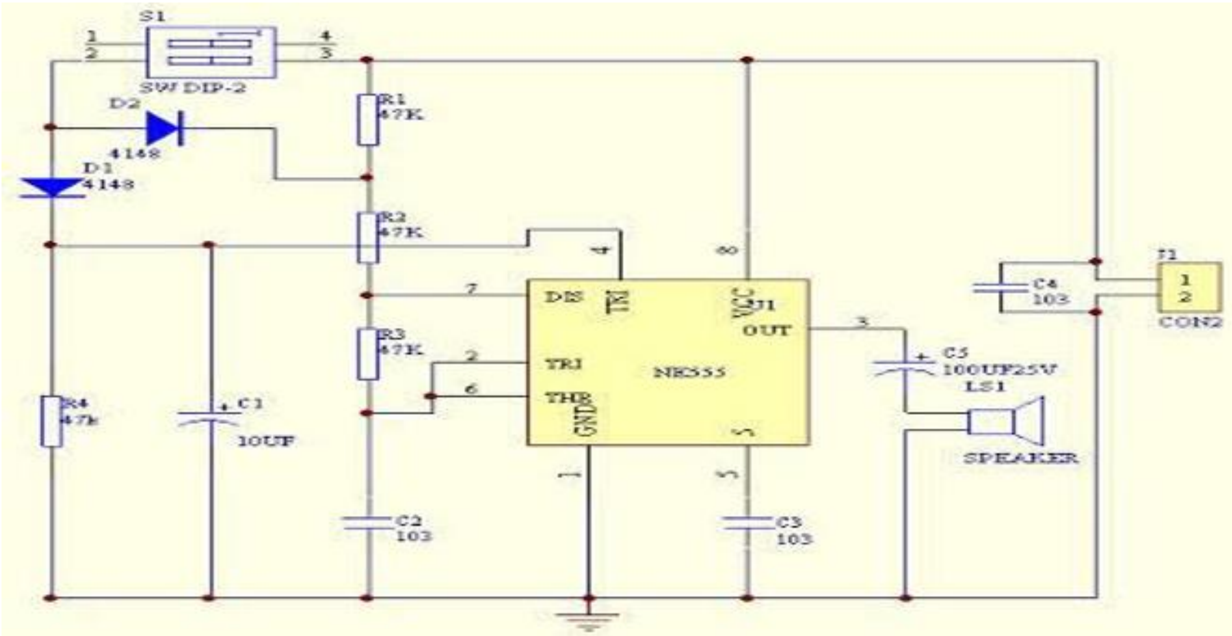

Figure 2. Circuit Diagram of smart doorbell system

Camera Module: The camera module is the core of the video monitoring feature. It captures live video feed and transmits it to the Android application via Wi-Fi. The sensor captures light and converts it into electrical signals, which are then processed by the onboard electronics to produce video output.

Microcontroller Unit (MCU): The MCU is responsible for processing the video signal, managing the RF communication, and controlling the door lock mechanism. It also handles input from the doorbell button and sends alerts to the connected Android device.

RF Transmitter and Receiver: The RF (Radio Frequency) transmitter and receiver pair is used for wireless communication between the microcontroller and the door lock mechanism. The transmitter, located near the doorbell, sends control signals to the receiver, which is integrated into the door lock.

Power Supply: The power supply unit provides the necessary electrical power to all the components. The system typically operates on a DC power supply, which could be sourced from a battery or a mains adapter. A 12 V DC power supply was used for this system, with voltage regulators (LM7805) used to step down the voltage to 9 V for components like the microcontroller and RF modules.

Door Lock Mechanism: The door lock mechanism is controlled by the RF receiver, which operates an electric strike or a solenoid lock. The lock is powered by the same power supply that runs the rest of the system, with the microcontroller sending signals via the RF receiver to lock or unlock the door. The system is designed to be fail-safe, meaning the door remains locked in case of a power failure unless explicitly programmed otherwise.

Wi-Fi Module: The Wi-Fi module enables communication between the microcontroller and the Android application. It allows the video feed captured by the camera to be transmitted to the user's smartphone, enabling real-time monitoring. The ESP32 microcontroller, for example, has built-in Wi-Fi capabilities, making it a popular choice for this type of project.

3.3 System's Design Specifications

These calculations were done to select the proper ratings for each component, ensuring the system operates efficiently without overloading any parts

Camera Module

- **Power requirement:** camera's operating voltage and current rating (3.3 V to 5 V with current ratings around 200 mA to 500 mA).

Considering 5 V with current ratings around 300 mA

Power consumption= Voltage × Current (1)

The camera operates at 5 V and draws 300 mA,

Power = 5 V × 0.3 A = 1.5 W.

- **Resistors and Capacitors**

Resistor selection: Using Ohm's Law:

R = V/I (2)

where V is the voltage across the resistor, and I is the current.

- **Capacitor selection**

Capacitors are chosen based on the voltage rating

(1.5x the operating voltage) (3)

The required capacitance to filter power supply noise or stabilize signals. For decoupling, common values are 10µF or 100nF.

- **RF Modules**

Operating voltage: 3.3 V to 5 V. The power requirement was calculated based on the module's current draw (50 mA to 100 mA).

Power consumption = Voltage × Current

For a 3.3 V RF module with 80 mA current,

Power = 3.3 V × 0.08 A = 0.264 W.

- **PIR Motion Sensors**

Power consumption: PIR sensors typically operate at 3.3 V or 5 V with a current draw of about 15 mA.

Power consumption = Voltage × Current

For a 5 V PIR sensor drawing 15 mA,

Power = 5 V × 0.015 A = 0.075 W.

- **Microcontroller (ESP32)**

Power requirement: ESP32 operates at 3.3 V and consumes approximately 240 mA when Wi-Fi is active.

Power consumption = Voltage × Current

Power = 3.3 V × 0.24 A = 0.792 W.

- **Power Supply**

System voltage: 12 V or 9 V DC power supply was used depending on the components.

- **The total current drawn:**

The current requirements of all the components were summed to determine the necessary power supply capacity.

For the system's total current draw of 1 A,

A 9 V or 12 V adapter was needed with at least 1 A output.

- **Relay and Door Lock**

Voltage: 12 V for the door lock system.

Current: Based on the door lock's specification (1 A).

Power consumption = Voltage × Current

Since the lock operates at 12 V and draws 1 A,

Power = 12 V × 1 A = 12 W.

- **Wi-Fi Module (ESP32)**

Power consumption: Integrated within the ESP32 microcontroller. The Wi-Fi module is separate. It operates at 3.3 V to 5 V with a current draw of around 170 mA.

Power consumption= Voltage × Current

For a 3.3 V Wi-Fi module drawing 170 mA,

Power = 3.3 V × 0.17 A = 0.561 W.

- **Battery Rating**

Total power consumption: The power consumption of all components added to get the total system power consumption.

Battery capacity: To calculate the required battery capacity, use the formula:

Battery Capacity (Ah) =

Total Power Consumption (W) x Operational Time (hours)/ Battery Voltage (V) (4)

Given the total power = 3 W

Time for the system to run in a day = 10 hours, using a 12 V battery,

$$\text{Battery Capacity} = \frac{3\text{W x }10\text{h}}{12\text{V}} = 2.5 \text{ Ah}$$

System Efficiency

Assuming an overall system efficiency of 85 % (= 0.85 η), the actual power required, accounting for efficiency losses, is:

$$P^{actual} = \frac{P^{total}}{\eta} = \frac{3\text{W}}{0.85} = 3.53 \text{ W} \quad (5)$$

Updated Battery Capacity Calculation

Using the actual power consumption:

$$\text{Battery Capacity (Ah)} = \frac{P^{actual} \times \text{Time (hours)}}{\text{Battery Voltage(V)}} \quad (6)$$

$$\text{Battery Capacity (Ah)} = \frac{3.53\text{W} \times 10\text{h}12\text{V}}{12(\text{V})} = 2.94 \text{ Ah}$$

With an 85% system efficiency, the required battery capacity increases to approximately 2.94 Ah**,** accounting for efficiency losses.

Software Implementation

The project design and simulation were carried out using Proteus, an electronic simulation software that allows for easy visualization of the system's performance. The system utilizes an ultrasonic sensor to detect obstacles and measure distances. To generate the ultrasound, the Trig pin was set to a high state for 10 µs, which triggers the ultrasonic signal. The reflection time of the signal is used to calculate the distance between the sensor and the detected object. The distance in centimeters is calculated by multiplying the received travel time from the Echo pin by 0.034 and dividing it by 2.

$$\text{Distance (cm)} = \frac{\text{Travel Time} \times 0.034}{2} \quad (7)$$

Where **Travel Time** = The time recorded by the Echo pin.

0.034 = The speed of sound in air (343 m/s), converted to cm/µs.

Once a figure is detected, the calculated distance is displayed on the Liquid Crystal Display (LCD) screen. The LCD prints the measured distance, indicating the presence of an obstacle. This software design ensures precise detection and calculation, contributing to the efficiency of the smart doorbell system. The system was optimized for stability, speed, and accessibility using minimal hardware components, including an ultrasonic sensor.

3.4 Interfacing Smart Doorbell System Components with ESP32 Microcontroller

3.4.1 Component Setup

1. Resistors were connected in series, and capacitors were placed across the power supply for noise filtering.
2. The data pins of the 433 MHz RF module transmitter and receiver were connected to ESP32 GPIO16 (receiver) and GPIO17 (transmitter). The module was powered using the 5V pin, with connections made as follows:
   - VCC → 5V
   - GND → Ground.
3. The OUT pin of the PIR motion sensor was connected to ESP32 GPIO5, and the sensor's VCC and GND were connected to the 5V and Ground pins, respectively.
4. The ESP32-CAM module was connected, and its onboard camera was integrated with the ESP32 microcontroller.
5. A push button was connected with one terminal to ESP32 GPIO18 and the other terminal to Ground. A 10 kΩ pull-up resistor was added to stabilize the signal when the button was not pressed.

3.4.2 Integration of Sensors and Modules

1. All sensors and modules were integrated using:
   - GPIO pins for digital inputs and outputs (e.g., RF module, PIR sensor, relay).
   - I2C, SPI, or UART protocols for communication with external modules such as the Wi-Fi module and ESP32-CAM.
2. A 9V DC battery provides power. The voltage was stepped down to 5V using an LM7805 voltage regulator.
3. Separate power lines were provided for high-current components like the relay to ensure stable operation.
4. A relay module was connected for door lock control:
   - The signal pin of the relay was connected to ESP32 GPIO14.
   - The relay's NO (Normally Open) and COM pins were linked to the door lock terminals.
   - VCC and GND were connected to power the relay coil.

3.4.3 Wi-Fi Configuration and App Development

1. The ESP32's built-in Wi-Fi module was configured in Station Mode to connect to a router for video streaming.
2. An Android app was developed to communicate with the ESP32 over HTTP protocols. The app was designed to Stream live video from the ESP32-CA and send commands to lock or unlock the door via the relay.
3. The door lock was connected to the relay, enabling it to act as a switch to power the lock based on commands from the ESP32.

3.4.4 Hardware Implementation

After completing the software design, the hardware components were assembled and connected to ensure proper system functionality. Key components included the ultrasonic sensor, motion sensor, microcontroller (Arduino), RF modules, a power source (battery), and a speaker. The ultrasonic sensor was configured to have a detection range of up to four meters, although the detection range was manually adjusted to 50 centimeters using the Arduino microcontroller. When the ultrasonic sensor does not detect an object (that is no reflected signal is received), the microcontroller remains idle. However, when an obstacle is detected (that is an echo is received), the microcontroller processes the signal and calculates the distance to the object using the speed of sound (340 m/s).

3.5 Casing and Packaging

The whole project has two sections or parts, namely the transmitting parts and the receiving parts. The transmitting parts of the circuit were packaged in a 3-by3-inch plastic box, and the other was packaged in a 3-by-6 plastic box. The project has both the motion sensor and the switch with an indicator in the 3by3 plastic box. Both casings of the project parts were painted with blue paint and allowed to dry properly. After that, the respective circuits were placed in, and packaged The diagram of the transmitter and receiver setup is seen in Figures 3 and 4.

Figure 3: Transmitter setup

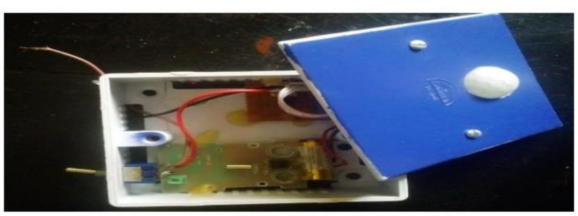

Figure 4: Receiver setup

3.6 Testing and Optimization

1. The system was simulated in Proteus to verify functionality before connecting high-current components.
2. Calibration was performed to adjust the motion sensitivity of the PIR sensor and the timing threshold levels for various signals.
3. The Android application was tested to ensure reliable communication with the ESP32. This included verifying consistent video streaming and the accurate execution of lock/unlock commands.

Conclusion

In this study, a microcontroller-based smart doorbell system with wireless connectivity was successfully designed, fabricated, and tested. The system, powered by a DC voltage source (battery), eliminates the need for traditional manual doorbell systems by automatically detecting the presence of visitors using a motion sensor. Upon detection, a signal is sent to a receiver inside the house, triggering a speaker to emit a tone. The project effectively met its design goals, providing reliable motion detection, distance calculation, and remote control functionality. The integration of both hardware and software components resulted in a functional and responsive security system, enhancing home security through innovative technology.

Recommendation:

Based on the design and results obtained, it is recommended that future designs incorporate a battery charger circuit and a rechargeable battery to minimize costs associated with non-rechargeable batteries. Additionally, a battery with higher ampere-hours should be used to extend the system's operational hours. While the transmission and reception range of signals between the transmitter and receiver was effective, further improvements can be made to enhance performance. Specifically, the design of the blade should be optimized for better cutting angles. Lastly, a switch should be added to the receiver section, allowing the device to be powered on only when in use.

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