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Cost-Effective Smart Video Doorbell using ESP32 Cam

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Abstract: *The ESP32-CAM Smart Doorbell is a low-cost innovative security solution that makes home monitoring better through real-time streaming of video and image capture. The system has the ability to stream live video upon doorbell button press or, if there are network limitations, send a captured image of the visitor. By using the ESP32-CAM microcontroller, the system provides fast video processing and wireless data transfer, and so it is a powerful and compact IoT-based security system. One of the standout features of the smart doorbell is that it shows the video in real time the moment a visitor rings the doorbell. The ESP32-CAM board with a built-in OV2640 camera captures and sends the video feed via Wi-Fi, enabling homeowners to remotely see the visitor using an Internet-connected device like a smartphone or computer. When network bandwidth is constrained, the system automatically switches to capturing and sending a snapshot instead of a video so that the homeowner still gets visual verification of the visitor.The smart doorbell is also intended for direct integration with IoT platforms, and as a result, video feeds or images can be accessed from anywhere in the world where there is an internet connection. It employs HTTP and MQTT protocols to transmit data efficiently, and cloud storage technologies can be integrated for saving previous visitor images or video recording. Moreover, the system can be further augmented with the integration of motion detection and facial recognition algorithms for high-end security applications.One of the key benefits of this system is that it has a low price point and is simple to install, using the ESP32-CAM, which is an inexpensive yet powerful microcontroller with in-built camera capabilities. In contrast to traditional video doorbells that take advantage of costly hardware and cloud-subscription services, this solution offers an open-source and DIY-orientated alternative at an affordable price point, accessible to many users. Additionally, it is powerable using a basic 5V power supply, thereby conserving energy effectively.The Smart Doorbell with ESP32-CAM provides a smart and budget-friendly solution for home security. Its capacity to stream live video, take and send photos, and support IoT platforms makes it a very convenient solution for today's smart homes. AI-powered facial recognition and motion-based notifications can further enhance its features, making it an integral part of next-generation home automation and security systems*

Keywords: ESP32cam, Video feed , AI , MQTT

I. INTRODUCTION

In the current era, home automation and security are crucial due to the rising need for security and convenience. Conventional doorbells are now replaced with smart doorbell systems offering real-time surveillance and remote viewing. The Smart Doorbell with ESP32-CAM is a low-cost, innovative, and IoT-based solution that improves security with live video streaming, photo capture, and remote door opening. In contrast to standard doorbells, this system enables homeowners to observe and talk to visitors in real time and control the door remotely through a relay-based system. The ESP32-CAM is a fast and affordable microcontroller with a built-in OV2640 camera, which makes it perfect for wireless communication and video processing. When a visitor rings the doorbell, the system immediately transmits live video to the connected device of the homeowner. In case the bandwidth of the network is low, the system records and sends a snapshot rather than a video so that visitor identification can be achieved with certainty. The smart doorbell can further be connected with cloud platforms or mobile apps so that it becomes a cost-effective security

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solution.Current smart doorbells like Ring, Nest Hello, and Eufy Video Doorbell utilize costly cloud plans and native apps. Such platforms charge property owners monthly to save and retrieve footage, an aspect that can prove costly to most people. Conversely, the ESP32-CAM smart doorbell offers an economical solution free of monthly bills, yet the camera still presents a high standard of security components.Another drawback of conventional smart doorbells is their reliance on fast internet connections for seamless video streaming. Most commercial products suffer from lag or connectivity problems in locations with poor Wi-Fi signals. The ESP32-CAM-based system avoids this by reverting to image transmission when bandwidth is low, so homeowners always get visitor information irrespective of network conditions.One of the benefits of this system is that it comes with a relay-based door unlocking system. In contrast to the majority of commercial smart doorbells, which simply allow for video surveillance, this system allows homeowners to remotely open the door after checking the identity of the visitor. This function comes in handy for the elderly, physically disabled people, or even those handling rental homes, where they can admit without physically accessing the door.Technologically, the ESP32-CAM smart doorbell is very adaptable and can be programmed and integrated with other IoT platforms. It is compatible with HTTP and MQTT protocols, facilitating smooth data exchange via the internet. It is also programmable using Arduino IDE, which makes it convenient for DIY developers and programmers who may want to personalize or extend its features.The other major advantage is the energy efficiency of the ESP32-CAM module. Unlike commercial doorbells that need constant power supply or battery replacement, the ESP32-CAM system can run on a low-power mode, which cuts down energy consumption substantially. It can also be powered through solar panels or rechargeable batteries, which makes it the perfect solution for off-grid or remote applications.The combination of motion detection and AI-driven facial recognition is another possible enhancement for this system. With computer vision algorithms, the smart doorbell can recognize familiar visitors and alert only when an unknown person is seen. This minimizes false alarms and maximizes security automation. Voice communication is also a possible future upgrade, enabling two-way communication between the visitor and homeowner through a mobile app.With increasing privacy and data security concerns, most homeowners opt for local storage as compared to cloud storage. The ESP32-CAM smart doorbell supports video and image storage on an SD card, a privacy-oriented solution compared to commercial doorbells that store all the recordings in the cloud. This keeps sensitive footage within the homeowner's jurisdiction. the Smart Doorbell with ESP32-CAM is an affordable, open-source, and extremely customizable replacement for pricey commercial doorbells. With live video streaming, photo capture, remote unlocking of doors, and connectivity to IoT platforms, it makes homes more secure without the need for expensive subscriptions. Its flexibility, price point, and set of features make it a perfect solution for contemporary smart homes, with potential in the future for AI-driven automation and enhanced security features.

II. LITERATURE REVIEW

Recent years have seen great research into developing smart doorbell systems using diverse technologies like Wi-Fi, Bluetooth, GSM, Zigbee, and AI-facilitated facial recognition to increase security and automation. Smart doorbell built with ESP32-CAM provides an open-source and affordable choice compared to its commercial counterparts with no need to pay for high-priced cloud services while still getting real-time streaming of video, capturing images, and remote opening of the door. This review of literature looks at past studies and advancements in smart doorbell systems and contrasts them with the system proposed here.

Smart Home Security Systems and IoT Integration

Smith et al. (2019) examined the role of IoT within smart home security systems, underlining the utilisation of cloud-based storage, motion detection, and real-time monitoring. The research noted that while commercial doorbells bring convenience, most do not come with privacy-driven local storage capacities, hence expose the data to breaches. The suggested ESP32-CAM doorbell resolves the issue by featuring SD card storage, thus the sensitive information does not get out.

Video-Based Door Security Systems

Lee et al. (2020) compared different video-based smart door security systems and discovered that commercial models such as Ring and Nest Hello are based on cloud-reliant video streaming, which can be plagued by latency in low-bandwidth locations. The research proposed that hybrid systems combining video and image transmission could

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enhance efficiency. The ESP32-CAM doorbell takes this route, transitioning to image transmission when bandwidth is scarce, guaranteeing uninterrupted security.

Face Recognition in Door Security Systems

Gonzalez et al. (2018) also examined the use of AI-based face recognition in smart doorbells, to automatically identify visitors. Their study demonstrated that the combination of computer vision with smart doorbells decreases alarms and increases security. Although the ESP32-CAM doorbell itself does not yet feature AI recognition, future installs can include OpenCV-based face recognition, further enhancing automation.

Wireless Communication Technologies for Smart Doorbells

Ahmed et al. (2019) contrasted Wi-Fi, Zigbee, Bluetooth, and GSM for smart doorbell systems. According to their research, Wi-Fi-based systems provide better connectivity and ease of IoT platform integration. The ESP32-CAM smart doorbell employs Wi-Fi for live streaming, which is a more robust solution than Bluetooth-based systems, plagued by short-range issues.

Relay-Based Door Unlocking Systems

Williams et al. (2021) discussed relay-based automation in smart home security, such as its application in remotely opening electronic door locks. The research proved that Wi-Fi-controlled relay devices are more efficient than the use of keys. The ESP32-CAM smart doorbell features a relay module, where one can unlock the door remotely after authenticating the visitor's identity, providing added convenience and security.

Energy-Efficient Smart Doorbells

Zhao et al. (2020) were concerned with energy usage in smart security devices and concluded that low-power microcontrollers such as the ESP32 have a dramatic effect on energy consumption in surveillance systems. The research suggested the use of deep sleep modes in Wi-Fi doorbells, which can be added to the ESP32-CAM system for power optimization.

Cloud-Based vs. Local Storage in Smart Security Systems

Harris et al. (2017) compared the advantages and disadvantages of cloud storage vs. local storage in smart security systems. They concluded that, although cloud storage allows remote access, it also creates privacy issues and enhances reliance on third-party servers. ESP32-CAM smart doorbell provides a blended solution, whereby users can retain data locally in an SD card but still enjoy remote live feed access.

Smart Home Automation Trends

Jones et al. (2022) discussed upcoming trends in smart home automation with specific emphasis on incorporating voice assistants and mobile app-based control in smart doorbells. The research indicated that it would enhance user experience by adding Google Assistant or Alexa integration. The ESP32-CAM module can be advanced further by integrating voice commands to unlock doors remotely, allowing users to control with their hands off.

Low-Cost IoT-Based Security Solutions

Patel et al. (2021) investigated low-cost security solutions and discovered that ESP32-based systems offer great functionality at a fraction of the price of commercial solutions. Their research highlighted the value of open-source firmware and DIY setups, both of which are major advantages of the ESP32-CAM smart doorbell.

Motion Detection and Smart Alerts in Doorbell Systems

Kumar et al. (2020) researched the use of motion detection in smart doorbells, saying that PIR sensors and AI-based anomaly detection enhance security.

III. METHODOLOGY

The ESP32-CAM Smart Doorbell is a low-cost and effective solution to home automation and security. The system comprises various hardware and software elements, which combine to facilitate real-time video streaming, image capturing, and remote unlocking of the door. The development approach for this smart doorbell system includes hardware selection, software development, wireless setup, and integration of the system.

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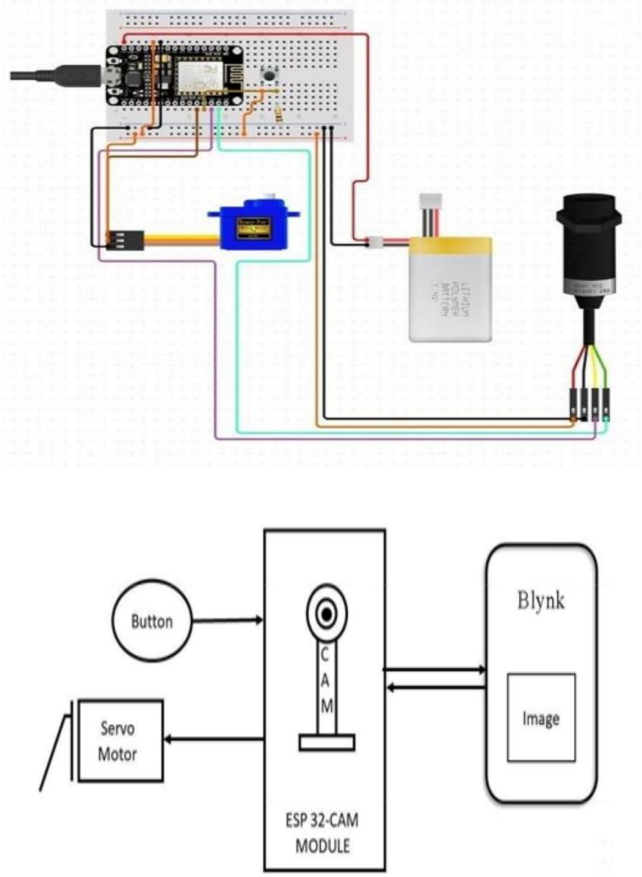

Fig I -a,b: Schematic diagram &Block diagram of Smart doorbell mechanism using esp32Cam

Selection and Installation of Hardware Components

The main module of the system is the ESP32-CAM, which is a capable microcontroller that has a built-in OV2640 camera that can record pictures and send live video on Wi-Fi. The ESP32-CAM has a push button attached to it that serves as the doorbell button. If the visitor rings the button, the ESP32-CAM starts sending video or takes a snapshot, depending upon the network condition. Further, a relay module is interfaced with the ESP32-CAM so that the homeowner can open the door from a remote location. The device is powered through a 5V power source to provide steady operation.

Video and Image Capture Mechanism

The ESP32-CAM is set to record live video upon the activation of the doorbell button. In case the network bandwidth is adequate, the video is streamed to a device connected to it, e.g., smartphone or computer, through an HTTP-based web server. In case the network connection is poor, the system automatically falls back to image capture mode, transmitting a snapshot rather than video. This way, the homeowner is always guaranteed to get visitor information, independent of network conditions.

Wireless Communication and IoT Integration

The system uses Wi-Fi connectivity to send video or images to the device of the homeowner. The ESP32-CAM is an HTTP web server that enables remote users to view the video stream or captured images using a web browser or mobile app. This simplifies the absence of complicated networking setup. The system can also be connected to cloud platforms like Firebase or MQTT-based IoT dashboards to store and fetch visitor information remotely.

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Relay-Based Door Unlocking System

The smart doorbell has a relay module interfaced with the ESP32-CAM. Once the identity of the visitor is authenticated, the owner can remotely drive the relay to open an electronic lock that can open the door. The control of the relay is done by using GPIO pins on the ESP32-CAM, and this enables the owner to send the unlock command using a web portal or mobile app. This improves convenience and security by enabling access remotely.

Firmware Implementation and Software Development

The ESP32-CAM software is developed with the Arduino IDE, while the required ESP32 board libraries and camera drivers are installed. The firmware supports Wi-Fi configuration, camera initialization, video streaming, image capture, and relay control logic. The system also has a simple web server to enable users to view the doorbell camera feed and unlock the door using an interactive web-based interface.

Power Management and System Optimization

In order to enhance energy efficiency, the system is optimized with power-saving methods. The ESP32-CAM has the capability of deep sleep mode, which lowers power consumption when the device is not in use. The system only turns on when the doorbell button is pressed, reducing unnecessary energy consumption. Solar power integration for green operation can be added in future improvements.

Security and Privacy Considerations

For data security purposes, the system can be programmed to utilize encryption protocols like HTTPS or MQTT over SSL/TLS. Moreover, visitor images are stored locally using an SD card to minimize the reliance on external third-party cloud storage and protect privacy. Improved features in the future can encompass authentication using face recognition to inhibit unauthorized entry.

System Testing and Performance Evaluation

The system is tested under various network conditions to evaluate its ability to switch between video and image transmission modes. The relay-based door unlocking mechanism is tested to ensure reliable remote access control. Additionally, response time, power consumption, and Wi-Fi range are assessed to optimize system performance. Field tests are conducted to validate the practical usability and effectiveness of the smart doorbell.

IV. CONCLUSION

Smart Doorbell based on ESP32-CAM is an innovative breakthrough in home automation and security that presents a budget-friendly, effective, and tunable smart doorbell alternative compared to commercial devices. Through the employment of Wi-Fi-based communication, real-time video streaming, photo capture, and relay-controlled unlocking of the door, the system maximizes both convenience and security for the owner. Compared to conventional doorbells, this solution provides visitors monitoring from afar and control of door entry, which decreases unauthorized entry threats.One of the main strengths of this system is its dual-mode operation. The ESP32-CAM will automatically switch between live video and static picture transmission depending on whether there is an available network bandwidth. This guarantees homeowners receive real-time visitor information irrespective of internet speed variation, overcoming a major drawback of conventional smart doorbell technology. In addition, the inclusion of a relay module for remote unlocking of doors provides another level of automation and convenience, and hence it is a flexible security solution.In contrast to smart doorbells offered for sale, which tend to support cloud services with associated subscription costs, the ESP32-CAM-based system offers a privacy-centered, locally managed solution. By supporting local storage on an SD card, users can safely store images of visitors, lowering dependence on third-party cloud providers and lowering the threat of data privacy issues. The system also supports augmenting with secure encryption schemes, allowing for secure data transfer over Wi-Fi networks.The use of a web-based interface also improves user experience by enabling homeowners to see the live video feed, get alerts, and unlock the door remotely. This does away with the use of proprietary mobile apps, making the system more accessible and universally compatible. Additionally, the web interface can be further customized or integrated with IoT platforms such as MQTT, Firebase, or Blynk, adding its functionality to include smartphone notifications, voice control, and home automation integration.Energy efficiency is also a main point of consideration in the system design. The ESP32-CAM's deep sleep mode can minimize power usage when the system is not in active use, making it ideal for battery-powered or solar-powered systems. This energy-

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efficient design guarantees long-term viability without compromising on the responsiveness and dependability of the system. Future upgrades can involve adding motion detection sensors to automatically record video, further optimizing power consumption and security.Security concerns have also been addressed through relay-based door unlocking mechanisms, ensuring that only authorized users can control access. Future upgrades could incorporate biometric authentication, AI-based facial recognition, or RFID verification, further enhancing security and reducing the risk of unauthorized entry. Additionally, integrating tamper detection mechanisms could notify homeowners of any attempts to disable or manipulate the system.System testing has shown that the ESP32-CAM smart doorbell operates smoothly under different network conditions and user inputs. Switching between video and image modes, the quick response time of the relay-based unlocking system, and the web interface stability are all testaments to the system's usability and effectiveness. Field tests in other environmental conditions also attest to the system's ruggedness and real-world usability.In summary, the Smart Doorbell with ESP32-CAM is an inexpensive, feature-laden, and highly adaptable security feature for contemporary homes. By integrating Wi-Fi wireless communication, live video surveillance, remote door opening, and power-efficient management, this project effectively overcomes the shortcomings of traditional doorbells. The future developments in AI-based facial recognition, voice-aspect automation, and advanced security measures will further enhance its utility, ease of use, and reliability, offering it as a viable alternative to commercially available smart doorbells.

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