Intelligent Mailbox

Patrik Ivan, Michal Hodoň, Peter Ševčík

Abstract— This paper presents the development of an intelligent mailbox designed to provide real-time notifications via SMS upon mail delivery. The system employs an ESP32 microcontroller, ultrasonic sensors for detecting mail, and GSM modules for communication. The mailbox offers an innovative solution for enhancing user convenience and ensuring timely awareness of delivered mail. The study covers the hardware and software implementation processes and discusses the results from prototype testing. Initial testing demonstrated the system's accuracy in mail detection and the effectiveness of SMS notifications, highlighting its potential applications in residential and organizational settings.

Keywords— GSM module, ATmega8, Intelligent mailbox.

I. Introduction

Traditional physical mailboxes remain an essential part of communication for receiving important documents, packages, and correspondence. However, the conventional approach of manually checking mailboxes is inefficient, particularly when awaiting time-sensitive or critical deliveries. This inefficiency is further compounded by the inconvenience faced by individuals with limited mobility, unpredictable schedules, or remote mailbox locations. The growing adoption of smart technologies presents an opportunity to modernize and improve this outdated process. By integrating Internet of Things (IoT) technologies, intelligent mailbox systems can provide real-time notifications, enabling users to stay informed about mail delivery without the need for constant physical checks [1][2]. Such systems can significantly enhance user convenience, reduce unnecessary trips to mailboxes, and improve the overall experience of mail handling. The proposed intelligent mailbox system leverages modern microcontrollers and communication protocols to address these challenges. At the heart of the system is the ESP32 microcontroller, a powerful and cost-effective platform widely used in IoT applications due to its WiFi and Bluetooth capabilities and low power consumption [3]. Ultrasonic sensors are employed to detect mail deliveries by measuring changes in distance within the mailbox, while a GSM module ensures reliable notification via SMS to the user's mobile device [4][5]. This design approach prioritizes accessibility and simplicity, ensuring that the system can be easily deployed and used across diverse settings, including residential, commercial, and organizational environments. With the increasing emphasis on automation and connectivity, intelligent mailboxes represent a practical application of IoT that bridges the gap between traditional mail systems and modern technology. Beyond providing basic notifications, such systems can also be extended to integrate additional features, such as cloud-based logging, mobile app connectivity, and energy-efficient power management, enhancing their functionality and sustainability [6][7]. This study focuses on the design, implementation, and testing of a prototype intelligent mailbox, demonstrating its feasibility and identifying areas for future development.

II. Integration

The methodology for designing and implementing the intelligent mailbox system was structured to integrate hardware and software components effectively, ensuring functional reliability and operational efficiency. The system comprises three primary modules: the sensing module, the processing and control module, and the communication module. These modules work together to detect mail delivery, process data, and notify users in real-time through SMS.

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The hardware architecture of the system includes an ESP32 microcontroller, ultrasonic sensors, a GSM module, and a power supply. The ultrasonic sensors are positioned inside the mailbox to measure the distance to the base of the compartment. Changes in this distance indicate the presence of mail. The ESP32 microcontroller serves as the core processing unit, receiving data from the sensors and triggering the communication module when necessary. The GSM module facilitates SMS notifications by interfacing with a cellular network. The power supply consists of a rechargeable Li-Pol battery connected to a TP4056 charging module for safe recharging. An LM2596 step-down converter is used to stabilize the power supply to the microcontroller and sensors.

The mailbox system required a portable and reliable power source due to potential installation locations without direct access to mains electricity. A power bank was selected as the power supply, providing a stable 5 V output suitable for the components used. The power bank connects to the system via a USB micro-B connector mounted on the printed circuit board (PCB). To stabilize the voltage supply and filter out noise, a decoupling capacitor (100 nF ceramic capacitor) was connected across the power lines close to the microcontroller. This capacitor serves as a local energy reservoir, supplying transient currents during sudden changes in load and mitigating voltage spikes that could affect the microcontroller's operation.

The software was developed using the Arduino IDE, employing libraries and code to manage sensor data, control decision-making processes, and handle communication tasks. The ultrasonic sensors were programmed to measure distances at regular intervals and send this data to the ESP32 microcontroller. A predefined threshold distance was set to identify the presence of new mail. If a significant deviation from the baseline distance was detected, the system categorized it as a delivery event. The decision-making algorithm filtered false positives by comparing consecutive sensor readings, ensuring consistent detection.

The software was developed in the C programming language using Atmel Studio 6.2. The program controls sensor readings, processes input data, manages power consumption, and communicates with the GSM module to send notifications.

At startup, the microcontroller performs the following initialization steps:

- ADC Configuration: The ADC is configured to read analog values from the phototransistor. The reference voltage is set to AVCC (connected to 5 V), and the ADC is set to use a prescaler to adjust the conversion speed.
- UART Setup: The UART interface is initialized with a baud rate of 9600 bps, appropriate for communication with the SIM800L module. Frame format is set to 8 data bits, no parity, and 1 stop bit.
- I/O Pin Configuration: The relevant pins are configured as inputs or outputs. The phototransistor input is set as an analog input, while control lines for the GSM module (e.g., reset pin) are set as outputs.

Mail Detection Algorithm:

- The microcontroller continuously monitors the output voltage from the phototransistor to detect changes indicating mail insertion.
- A threshold voltage level is established based on ambient light conditions and the normal signal level when the light beam is uninterrupted.
- The ADC reads the phototransistor's voltage at regular intervals.
- To avoid false triggers due to transient disturbances, multiple consecutive readings indicating an interruption are required before confirming a mail insertion.
- A counter increments each time a mail insertion is confirmed. This counter can be set to trigger an SMS notification after a specified number of insertions or immediately upon detection.

The GSM module was configured to send SMS notifications when a delivery event was confirmed. The microcontroller communicated with the GSM module using AT commands, which controlled text message composition and transmission. A queue system was implemented to manage multiple notifications, ensuring that SMS transmission was completed before new events were processed.

The components were integrated to form a cohesive system. The sensors continuously monitored the mailbox interior, sending distance measurements to the microcontroller. The microcontroller analyzed the data, compared it with the threshold value, and identified events. When a delivery was detected, the GSM module transmitted a preformatted SMS containing information about the delivery time to a predefined recipient's number. The entire process was designed to operate autonomously without user intervention.

Power efficiency was an important consideration in the design. The Li-Pol battery provided the necessary power for all components, while the TP4056 charging module enabled safe recharging when connected to an external power source. The step-down converter ensured consistent voltage delivery to the ESP32 and the sensors. Sleep modes were incorporated into the microcontroller’s firmware to reduce power consumption during idle periods, extending the battery’s operational lifespan.

The system underwent iterative testing to ensure functional reliability. Calibration of the ultrasonic sensors was performed by measuring distances under controlled conditions and comparing them to the expected values. Environmental factors such as temperature and humidity were considered to account for potential variations in sensor performance. The GSM module's connectivity was tested under various network conditions to verify message transmission reliability. The complete system was tested for operational consistency by simulating mail deliveries of different sizes and frequencies.

The system design accounted for potential challenges such as environmental interference, signal strength variability, and power limitations. Protective enclosures for the electronic components were considered to shield them from environmental factors such as moisture and dust. The communication module's reliance on cellular networks was identified as a limitation in areas with poor signal coverage. Future iterations of the system could address these challenges by incorporating alternative communication protocols or enhanced power management solutions.

Fig. 1 Developed PCB

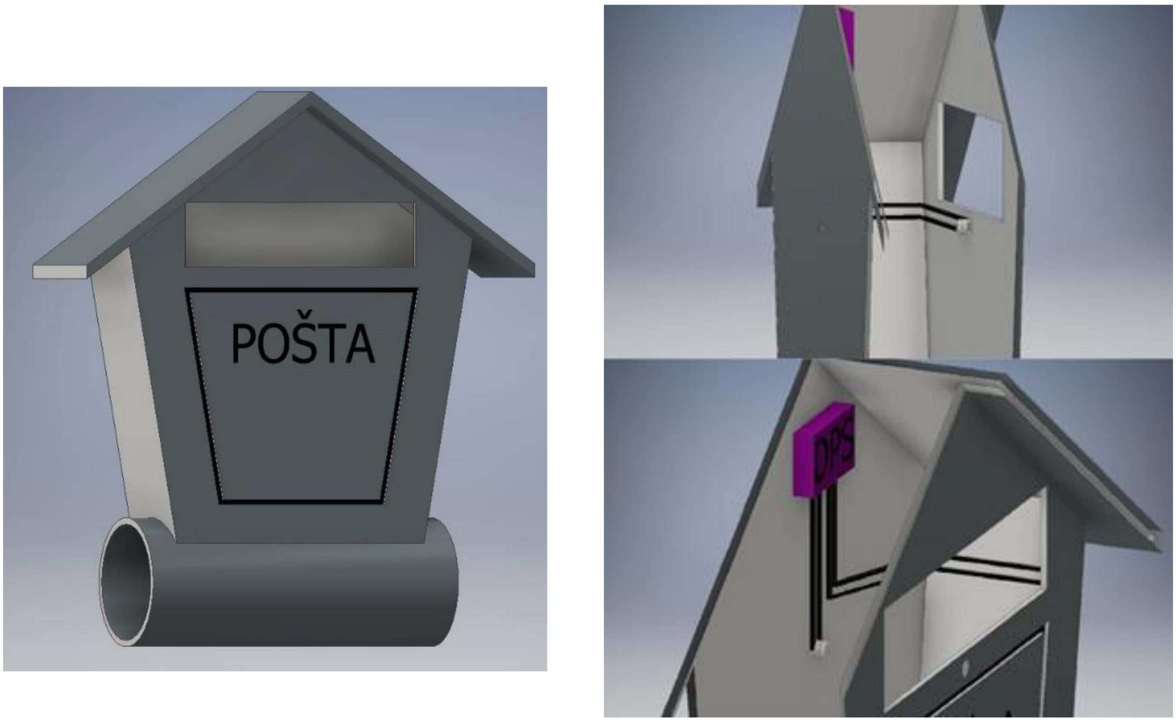

Fig. 2 Placement in the mailbox

III. Conclusion

Prototype testing demonstrated the system's ability to accurately detect mail delivery using ultrasonic sensors. The SMS notification system reliably sent messages to the user's mobile phone within seconds of detection. Power consumption tests showed the system could operate for extended periods on a single battery charge, making it practical for daily use. Some challenges, such as sensor sensitivity to environmental changes and GSM module signal interference, were identified and mitigated during testing. The intelligent mailbox system offers significant improvements over traditional methods by providing users with timely and convenient notifications. Its reliance on commonly available components ensures affordability and ease of deployment. However, environmental factors such as extreme weather conditions may impact the durability and reliability of the system, suggesting the need for protective enclosures or sensor optimization. Additionally, integrating alternative notification methods, such as email or app-based alerts, could enhance its versatility. Future research could explore energy harvesting methods, such as solar panels, to further extend the system's operational autonomy. This study successfully designed and implemented an intelligent mailbox system capable of providing real-time SMS notifications. The system demonstrated high accuracy in mail detection and reliable communication performance during testing. By addressing common challenges in traditional mailbox usage, the intelligent mailbox has the potential to improve convenience for residential and organizational users alike. Future developments could focus on enhancing robustness and expanding notification capabilities to increase its applicability.

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