THE DEVELOPMENT & INSTRUMENTATION OF A MICROCONTROLLED SMART MAILBOX

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Jeremy is an engineer-in-training with experience in designing military fueling facilities and a graduate student at Kennesaw State University, pursuing an MSEE. Passionate about problem-solving, IoT, and coding, he is driven by curiosity and innovation in technology. Jeremy places a high value on education

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Anthony Ware

Micro-controlled Mailbox

Introduction

This is an ongoing project, spearheaded by a team from Kennesaw State University's Southern Polytechnic College of Engineering and Engineering Technology. The Team aims to develop a micro-controlled mailbox prototype that integrates the ESP32 with core functionalities that include the following: remote unlocking, remote locking status, and mail detection. The team is focused on revolutionizing traditional mailboxes with a prototype that can address the prevalent challenges currently in the industry. This includes security vulnerabilities and the absence of contactless delivery options.

Review of literature

In this cutting-edge project, the Smart Mail Access System, version one (SMA-01), is introduced. SMA-01 is designed for real-time notification of received correspondence. Utilizing Short Message Service (SMS), the system promptly notifies users about incoming mail, providing details on the sender, type of correspondence, and content to enhance security. Unlike existing systems, SMA-01 overcomes limitations such as limited use, low reliability in low light conditions, and lack of recipient identification. The hardware support involves an infrared module, RFID reader, and GSM module powered by a 9V battery. Successful experiments on various mailboxes validate its effectiveness. The software support includes libraries for serial communication, SPI, and RFID. SMA-01 represents a significant leap in secure and efficient mail handling. Future improvements include compact design and support for envelopes. [1]

In the era of widespread internet use, especially post-COVID-19, Thailand has witnessed a surge in mobile banking and e-commerce, emphasizing the need for efficient parcel delivery. To address the issue of missed deliveries and potential losses, this study introduces a solar-powered smart parcel box utilizing IoT technology. The system, combining Node MCU ESP8266, infrared sensors, and a LINE application, ensures timely alerts to recipients via a mobile app. Unlike previous works, this prototype harnesses clean energy, marking a significant research gap. Objective tests demonstrated a remarkable 96% efficiency, with subjective evaluations praising its ease of use. Future iterations aim to enhance functionality and include a broader evaluator base. [2]

This article discusses the Internet of Things (IoT) as a wide range of potential from smart home systems to hospitals or in industry under the title of Industry 4.0. This not only makes our life easier to monitor and manage our tasks but also helps in making a secure and healthy environment around us. This paper describes overall topology and prototype implementation of an intelligent mailbox using concepts of IoT to facilitate monitoring of physical mailbox installed at homes and offices. Successful implementation of prototype also demonstrates how parallel computing power of modern multicore processors and general-purpose graphics processing units (GPGPUs) can be exploited in smart buildings to enhance compute intensive tasks. [3]

ADDSMART is a research project focused on digitizing addresses of locations and building a smart mailbox by combining wireless sensors, cameras, locks, and RFID readers and tags into a system controlled by an Arduino microcontroller board. We explored the idea of address digitization (using RFID tags to store addresses) and incorporated it into a mailbox that can communicate wirelessly with the homeowner to provide mail status updates and home security footage through digital photographs. This paper demonstrates our proposed ideas,

describes the design of a smart mailbox, the technology we have used to build a prototype, and the current results of work along with future research ideas. [4]

Upon receiving new mails or letters in their mailbox, most users do not get notified of this fact. They have to check their mailbox contents speculatively and periodically. In most events, the users are neglectful on checking their mailbox. This at times may lead to the ignorance of important letters and results in various miseries. Most of the multi-story buildings such as apartments, condominiums, office buildings etc. limit the users on limited visits to check or collect their letters due to the centralized mailbox location. Users find it convenient to be on alert for mail they receive to overwrite the conventional method of checking mailbox. Because of the high confidentiality and official letters are increasing as a corresponding tool globally, the users seek for a better solution which enables them to be on their toes each time a mail is delivered. State-of-the-art electronics technology is incorporated into these conventional mailboxes as a solution. The programmable logic controller, interface module and the GSM modem can be incorporated by linking the user's mailbox with short messaging system or email facilities and this enables the users to be notified whenever a new mail is delivered. Mail delivered into the user's mailbox, the system will automatically generate an alert which is sent in the form of a short message system or email that typically details the real time of mail delivery. The system is designed to make human life by sending short messaging system or email to notify the users about important new mails reaching their mailbox. This is likely to be a fast growing and popular application for short messaging systems and email towards mankind. [5]

The article "Concept of Smart Postal Mailbox" explores the development and application of smart postal mailboxes designed for the delivery of postal items without the recipient's personal presence. The authors introduce a comprehensive solution that encompasses both hardware and software components. The hardware includes the design of the smart postal mailbox and the selection of relevant components, such as sensors and control units. The software part, developed in the Arduino integrated development environment, ensures the proper functioning of the hardware components. The smart postal mailbox aims to address the challenges faced by the postal sector in delivering items efficiently, particularly in the context of the growing popularity of e-commerce. The article discusses the theoretical framework, historical context, and various innovations in the field, presenting a comparison between traditional and smart postal mailboxes. The authors emphasize the potential benefits for both customers and postal operators, including real-time tracking, increased efficiency, and the ability to handle temperature-sensitive deliveries. The article concludes by highlighting the importance of testing and implementing such innovations collaboratively between postal executives, universities, and specialized professionals. [6]

The bachelor's thesis "Smart Mailbox" explores the transformation of a conventional mailbox into a smart one, aiming to notify residents about incoming mail. The project involves examining existing technologies and modules to create a retrofit device capable of detecting different types of mail. Conducting range tests, power consumption measurements, and evaluating RF modules using Arduino, the study maintains a focus on cost-effectiveness for broader home automation use. The need for smart mailboxes is emphasized in Finland, where sparsely populated areas and distant mailboxes pose challenges, especially in adverse weather conditions. The article delves into challenges such as battery performance in cold weather, long-distance communication, and variations in mailbox designs. It evaluates market-available devices like Mail Chime, highlighting the need for a product suitable for diverse markets. The construction and implementation of the device covers aspects like mail detection, wireless

transmission, battery technology, and potential enhancements like detecting different types of mail. The conclusion suggests practical implementations for both mailbox manufacturers and individual consumers, emphasizing the economic and technological viability of smart mailboxes in enhancing convenience and efficiency. [7]

The conference paper “Multi-functional Parvel Delivery locker system” discusses the future of parcel delivery with the growing amount of Ecommerce and delivery companies. The Multi-functional Parcel Delivery Locker or MFPDL for short aims to utilize C51 MCU and GSM/GPRS modules to send customers SMS with passwords, which can then be validated at designated lockers to receive their mail. This system makes mail delivery both safer and more convenient for the user while still offering alternative methods of access like RFID-based keycards or barcode scanning allowing delivery companies to also access the lockers. The planned future of this system is focused on improving performance while minimizing costs and possibly moving to use 32 core ARM-based chips and implementing video monitoring. The paper concludes that MFPDL can help improve efficiency and reduce delivery companies' operating costs while improving security and convenience for the customer and their mail. [8]

The conference paper “Face Recognition Based Multifunction Smart Mailbox” introduces an idea for a smart application that features face recognition by utilizing the Internet of Things, IoT for short. The current mailbox prototype features a fingerprint reader, a camera, a magnetic lock, and an LCD display all connected to an Arduino uno that establishes network connectivity through a GSM module. The system software has two major elements one that runs the main operational algorithm and a second that deals with face recognition related software. The prototype and paper hope to explore and improve logistical operations by using smart applications and face recognition software. The face recognition software performed very well with the tests given in different lighting conditions but had more trouble identifying users when they had drastically different facial features like a beard or a face mask. In the future the team wants to improve the face recognition software's accuracy and reliability as well as improve the mailbox's design. The paper concludes that the mailbox allows safer user interactions and prevents strangers or unauthorized people from accessing the box thanks to facial recognition. [9]

The paper “Smart Intimation of Mailbox using IoT” discusses methods of storing and alerting users their mail has arrived without them having to physically access the mail. This is possible by utilizing IoT and transferring the information from the outdoor mail unit to the indoor unit which then alerts the user via SMS allowing users to know their mail has been safely received without having to physically interact with the mailbox or mail itself. The mailbox can detect mail through use of IR sensors which sense the differentiation in the mailbox. And then transfers the data to the indoor unit using an ESP826. These concepts are implemented in the system using the GSM method. The proposed benefits of the system are time convenience, reduced human effort, and improved security. The paper concludes that the system is mainly designed for a single person who cannot be at home often, allowing them to safely collect and store their mail. The future for the system involves expanding the scope of the system so it can service larger populated places like apartment buildings or neighborhoods. [10]

A reliable outdoor binocular camera calibration method for a multi-GPS (Global Positioning System) apparatus and multi-cameras-based surveillance system is introduced in this paper. Different to other systems, the user needs this system to track the motion and estimate the shape of the selected vehicle in real time with binocular cameras. So, we implement our system by these steps below: 1) fixing a GPS apparatus in each vehicle to collect the location

information. 2) Calibrating the interior and exterior parameters of the binocular cameras. 3) Computing the coordinate transform matrix between the GPS coordinate system and the camera coordinate system. 4) Using GPS information to guide the binocular cameras to track the moving vehicle. To calibrate the binocular camera in an outdoor environment, we use the Scale Invariant Feature Transform (SIFT) descriptor to compute the features. The RANSAC matching technique is used to eliminate mismatch point pairs. After that, we use an essential matrix based self-calibration technique to compute the camera parameter. Finally, we analyze the relationship between the blur affection level of the calibration image and our proposed method. Many experiment results have shown the robustness of our method. [11]

Today, digital images are commonly used to preserve and present analogue media. To minimize the need for digital storage space, it is important that the object covers as large a part of the image as possible. This paper presents a robust methodology, based on common edge and line detection techniques, to automatically identify rectangular objects in digital images. The methodology is tailored to identify posters, photographs and books digitized at the National Library of Sweden (the KB). The methodology has been implemented as a part of DocCrop, a computer program written in Java to automatically identify and crop documents in digital images. With the aid of the developed tool, KB hopes to decrease the time and manual labor required to crop their digital images. [12]

The Internet of Things (IoT) has a wide range of applications, and it has potential to make things easier to monitor and manage in our day-to-day life. This research has developed a prototypic implementation of an intelligent mailbox using the concepts of internet of things to facilitate monitoring of physical mailbox installed at homes or workplaces. The successful demonstration of prototypes suggests that low-cost embedded platforms such as Raspberry Pi 2 can be used to develop economical, smart and easy to manage IoT applications. This project can be scaled up to commercial level for offering services to masses with further modifications. [13]

The article “A Smart IoT Security System for Smart-Home Using Motion Detection and Facial Recognition” presents a comprehensive approach to developing a smart IoT security system for smart homes, emphasizing motion detection and facial recognition. The system utilizes a Raspberry Pi, No Infrared (NoIR) Pi Camera Module, and Passive Infrared (PIR) Motion Sensor to detect unauthenticated access in a smart-home environment. The proposed approach involves machine learning, specifically the Local Binary Patterns Histogram (LBPH) algorithm, for facial recognition. The system aims to notify users of security threats through a smartphone application, achieving a motion detection accuracy of 99%. The facial recognition feature demonstrates an accuracy of 92%. The article emphasizes the limitations of existing IoT security systems, particularly those lacking machine learning capabilities. The proposed system aims to address these limitations and enhance security through real-time alerts and authentication mechanisms. The research contributes to the development of reliable and efficient smart-home security systems, with potential future enhancements discussed. [14]

The article "Smart Mailbox with Security System" presents a smart mailbox system aimed at addressing the limitations of traditional mailboxes. The conventional mailboxes often result in inconveniences as recipients may not be available to receive parcels, leading to undelivered consignments stored at post offices. The proposed Smart Mailbox (SMIX) incorporates Smart IoT Technology, a camera, and a servomotor to provide a secure and efficient parcel receiving system. Users can control the smart mailbox through a Blynk application on their mobile phones, using the servomotor to lock or open the mailbox door. The camera serves as a monitoring system accessible to users, and a push button allows courier service personnel to

notify the recipient for secure parcel delivery. The article emphasizes the importance of improving current mailbox functions to enhance security and efficiency for both users and courier services. [15]

In this groundbreaking research, the mechanical and manufacturing engineering team has unveiled a prototype Smart Mailbox designed to revolutionize parcel delivery in the age of booming e-commerce. Focused on tackling issues like parcel mishandling and theft, the system utilizes an Arduino Uno microcontroller and combines aluminum and acrylic for fabrication. By instantly notifying users via email upon barcode scanning, the Smart Mailbox enhances delivery efficiency, eliminating the need for customers to be present during deliveries. With its IoT integration, this innovation signals a potential shift in Malaysia's courier landscape, offering a glimpse into the future of connected delivery systems. [17]

The upward growth trend of e-commerce is expected to persist, driven by varied delivery methods: home shipping, in-store click and collect, in-store reserve and collect, parcel store, and smart lockers. This study explores the diverse applications of smart lockers. Noteworthy is their role in the pandemic, ensuring secure, contactless parcel deliveries. The paper delves into authentication methods, challenges, and opportunities, offering a comprehensive overview of smart locker technologies. [18]

In this age of electronic communication, checking the physical mailbox is still part of our daily life. Mailboxes are placed several meters away from the house, and sometimes across the opposite side of a street. It is annoying to walk to the mailbox each day and realize that the mailbox is empty. In this paper, an Internet of Things (IoT)-connected smart mailbox is developed that automatically sends a notification to the smartphone whenever new mail arrives. This notification removes the frustration of an unnecessary trip to the mailbox. The proposed mailbox contains a low power device comprising of sensors, a system-on-chip microcontroller with Bluetooth Low Energy (BLE), and a rechargeable battery that charges with a solar panel. Whenever the mailbox door is closed, it checks the presence of mail and then sends the data to a hub using BLE. The hub is placed inside the house and sends a push notification to the smartphone using the home Wi-Fi. A smart speaker, Google Home, is also interfaced with the system, which can verbally say the status of the mailbox when asked a customized question. A prototype of the smart mailbox, the hub, and the smartphone app is developed and tested successfully. [21]

The BeagleBone Black (BBB) is the freshest addition to the Beagle family, boasting a potent TI Sitara™ ARM Cortex™-A8 processor clocked at 1 GHz. With 2 GB flash memory, it serves as the board's "hard drive," running Linux through the user-friendly Bonescript in Cloud9. From simple scripting to complex C/C++ functions, the BBB adapts as user skills grow. The Beagle community adds depth with projects, forums, and documentation. The paper explores BBB's evolution, emphasizing its low-cost, ARM Cortex-A8 prowess, and diverse interfaces. Also, unfolding the BeagleBone's role in engineering projects, highlighting a robot car venture, showcasing its potential in education. [25]

The surge in Internet of Things (IoT) devices, from wearables to smart homes and cars, highlights the need for robust security. Smart locks, a crucial aspect of this landscape, face vulnerabilities, particularly in password-based systems. This paper proposes an innovative, secure, and cost-effective platform for smart locks, utilizing peer-to-peer communication between smartphones. The system employs a combination of Host Card Emulator (HCE) and Secure Element (SE) for enhanced security. The architecture involves BeagleBone Blue, NFC modules, and a unique encryption algorithm. By leveraging a linked-list data structure and

advanced cryptographic methods, the proposed solution aims to transform smart locks into a safer and more accessible technology. The paper concludes with a comprehensive cost analysis, demonstrating the affordability of the proposed system. [26]

The paper "Real-Time Monitoring Security System integrated with Raspberry Pi and e-mail communication link" discusses a system designed to help monitor and assist in catching thieves. The system features motion activated security cameras that can record and even live stream videos to users through their email. This system utilizes a Raspberry Pi 3 to control the different applications. The system does have limitations like needing a constant connection to the internet to be able to stream recordings and email users. The paper concludes that the system worked during testing and successfully recorded and alerted users to the detected motion and that the system could help increase efficiency of security recording systems by only using power while active when it senses motion. [29]

Description of Approach

The approach of the Team to this design was to first research the already available technology that is on the market today for prototyping. After careful consideration, the team opted to utilize the ESP32 as its development board due to its extensive array of features and versatile Input/output (I/O) ports. A standout feature of this board, Figures 1 & 2, is its capability to communicate over 2.4 GHz broadband, facilitating seamless over-the-air communication via Wi-Fi. Central to the communication between the user and the mailbox is a web browser interface, providing a graphical user interface (GUI) for user interaction. Drawing inspiration from established IoT projects, the team tailored its design to suit its specific requirements.

Throughout the development process, the team underwent multiple rounds of ideation and iterative design to refine its prototype. However, due to constraints within the semester timeframe, certain functionalities had to be foregone. Notably, the integration of a webcam alongside the web server button and status GUI. Below we will take a look at some of the features currently listed in the team's design.

1) Graphical User Interface

The graphical user interface (GUI) can be seen in Figure 3. The implementation of this GUI provided remote access and control to the locking mechanism located inside our mailbox. The Teams' GUI is designed with visual elements such as icons, buttons, and text that give the user a visual representation of the accessibility available to them all in one place. GUIs have become the standard interface for most consumer and enterprise software, leading to widespread familiarity among users. This ubiquity simplifies the onboarding process for new users and promotes interoperability between different software systems like Android or iPhone devices.

2) Power Distribution

The power distribution approach for the micro-controlled mailbox focuses on effectively managing energy from the Goal Zero Nomad 10 solar panel and the 3.7V lithium-ion battery pack, Figure 4. The Adafruit solar charge controller was chosen to oversee this process, effectively regulating the battery's charging from the solar panel while concurrently supplying power to the ESP32 microcontroller. This controller serves as a pivotal component, ensuring seamless integration of the available energy sources. Both the solar panel and the battery pack are directly connected to the solar charge controller, enabling continuous battery charging while simultaneously powering the ESP32 microcontroller. Furthermore, the Adafruit solar charge

controller acts as an effective battery management system within the micro-controlled mailbox. It monitors various parameters such as battery voltage and current to ensure optimal charging performance and prevent overcharging or over-discharging of the battery. Additionally, it has the capability to monitor battery temperature with the addition of a thermistor, which can be soldered onto the charge controller. However, the team opted not to include this feature for the project, although it could easily be added by someone wishing to deploy the mailbox. By intelligently managing the flow of energy between the solar panel, battery, and load, the solar charge controller extends the lifespan of the battery and enhances the overall reliability and efficiency of the system. This approach not only maximizes the operational uptime of the mailbox but also ensures its autonomy by harnessing renewable energy sources.

Calculations/Logic Diagrams/Schematics

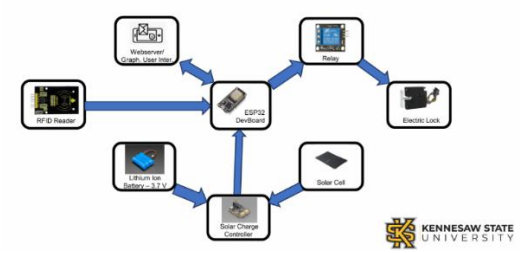

Figure 1: Micro-controlled Mailbox Relationship Diagram

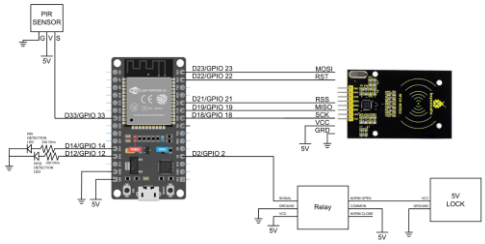

Figure 2: ESP32 Wiring Schematic

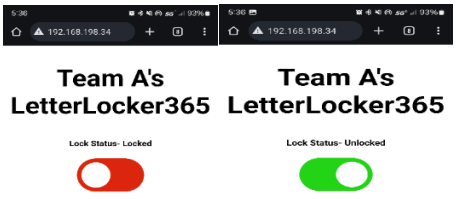

Figure 3: ESP32 Web Server GUI

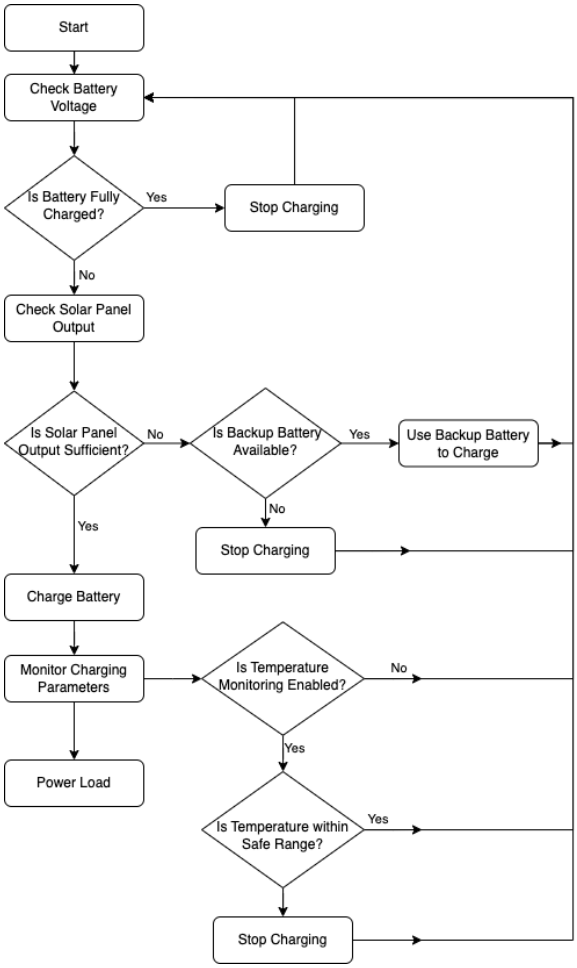

Figure 4: Battery Management System – Solar Charge Controller Flowchart

Figure 5: Oasis® Classic Locking Post Mount Mailbox

Experimental Results and Discussion

The micro-controlled mailbox prototype, Figure 5, successfully demonstrated the key functionalities envisioned at the outset of the project. The integration of the ESP32 microcontroller with the solar power system, comprising the Goal Zero Nomad 10 solar panel, 3.7V lithium-ion battery pack, and the Adafruit solar charge controller, performed exceptionally well. This setup ensured a reliable and consistent power source for the ESP32, enabling it to function seamlessly throughout the project's operation.

The remote unlocking functionality, facilitated by the electric lock, operated as intended, allowing for secure access to the mailbox Figure 5.

The RC522 RFID module played a vital role in providing an additional layer of security and convenience for mailbox access. By integrating this module with the ESP32, users could easily unlock the mailbox by simply presenting their registered RFID card or fob to the reader. This feature not only enhanced security by preventing unauthorized access but also offered a contactless and hassle-free method for retrieving mail.

The graphical user interface (GUI), developed using HTML, CSS, and JavaScript, provided an intuitive and user-friendly platform for monitoring the mailbox status and controlling its functions. Users could easily check the mailbox's lock status and receive notifications when mail was detected, enhancing the overall user experience.

Discussion

The successful implementation of the micro-controlled mailbox prototype demonstrates the potential for integrating Internet of Things (IoT) technology into traditional mailbox systems. By leveraging the capabilities of microcontrollers, sensors, and wireless communication, the project addressed several challenges faced by traditional mailboxes, such as security vulnerabilities and the lack of contactless delivery options.

The solar power system, consisting of the solar panel, battery pack, and charge controller, played a crucial role in ensuring the mailbox's autonomous operation. By harnessing renewable energy, the system eliminated the need for frequent battery replacements or external power sources, promoting sustainability and reducing maintenance requirements.

The RFID access control system, facilitated by the RC522 module, added an extra layer of security and convenience to the mailbox. Users could easily gain access to their mail without the need for physical keys or combination locks, eliminating the risk of losing or forgetting access credentials. Additionally, the contactless nature of RFID technology aligns with the growing demand for touchless interactions, particularly in the wake of the COVID-19 pandemic.

While the prototype achieved the core objectives, there is room for further improvement and expansion of its functionalities. Future iterations could incorporate additional features, such as mail detection capability with a PIR (passive infrared) motion sensor, a webcam for visual mail monitoring, enhanced security measures like facial recognition or fingerprint authentication, and the ability to support multiple users or households.

Additionally, the integration of cellular networks and technology could enable remote access and control of the mailbox outside of WIFI coverage, further enhancing its convenience and versatility.

Furthermore, the project could benefit from more extensive testing and user feedback to identify potential areas for improvement and ensure that the design meets the specific needs and preferences of various user groups.

Overall, the micro-controlled mailbox project demonstrated the feasibility and potential benefits of applying IoT technology to traditional mailbox systems, paving the way for future advancements in this field.

Conclusions

The focus of this project was to develop a micro-controlled mailbox prototype that addresses the problems faced with the evolving landscape of parcel deliveries, particularly in the context of the

increasing demand for secure and contactless solutions. Through the integration of technologies such as the ESP32 microcontroller, RFID access control, and solar power systems, the project has successfully tackled various challenges faced by traditional mailboxes.

The implementation of remote unlocking functionalities, alongside the incorporation of RFID technology, not only enhances security but also offers users a convenient and hassle-free experience. The graphical user interface provides an intuitive platform for monitoring mailbox status and controlling its functions, further elevating user experience. Moreover, the utilization of renewable energy sources ensures the autonomy and sustainability of the system, mitigating the need for frequent battery replacements and reducing maintenance requirements. This aligns with the growing emphasis on environmental sustainability in technological advancements. It also fits into the ASEE-Instrumentation Division focusing on our duty as educators to teach our students modern techniques of instrumentation. Accordingly, this will provide a professional vehicle for the exchange and propagation of new ideas related to the field of instrumentation in engineering education.

Future Work/Legacy

The development of a micro-controlled mailbox prototype presents several potential benefits for our partners, Florence Corporation and Architectural Mailboxes, particularly in addressing the increasing demand for secure and contactless solutions for mail delivery. These companies can capitalize on the advanced security features demonstrated in the prototype, such as RFID access control and remote unlocking functionalities. By incorporating these features into their products, they can offer customers a higher level of security for their mail and packages, thus increasing customer satisfaction and trust in their brand. The utilization of renewable energy sources, such as solar power, ensures the autonomy and sustainability of the system. This can appeal to environmentally conscious consumers and position themselves as a sustainable choice in the market.

An ongoing partnership with Kennesaw State University's Electrical and Computer Engineering department will allow for continued collaboration and innovation. As the industry pivots towards cluster mailbox solutions per USPS direction, Florence Corporation and Architectural Mailboxes can work with KSU researchers and students to develop secure, sustainable cluster mailbox prototypes incorporating the latest technologies.

There is also potential to expand this industry partnership to include other engineering disciplines at KSU, such as computer science, mechanical engineering, and industrial design. This interdisciplinary approach could lead to even more advanced mailbox solutions with additional features like mail detection through passive infrared sensors, visual monitoring via webcams, advanced security measures like facial recognition or fingerprint authentication, integration of cellular networks for enhanced accessibility beyond Wi-Fi coverage, more robust electronic locks, and increased structure and physical security.

Overall, by incorporating the findings and innovations from the prototype into their product development process, while continuing to foster research collaborations with universities, Florence Corporation and Architectural Mailboxes can maintain their position as leaders in the industry. They can offer innovative, secure, and sustainable solutions for mail and package deliveries that meet evolving consumer needs and regulatory requirements in the modern era. In conclusion, the report highlights the success and versatility of the prototype, along with the immense potential for further enhancement and expansion by embracing emerging technologies through strategic partnerships.