Smart Mailbox Using Piezoelectric Sensors

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Abstract. E-commerce is blooming in Malaysia. Benefited from the blooming of e-commerce, courier industry gained rapid growth in Malaysia as well. One of the challenges in delivery services is failed delivery attempt. Smart mailbox is a potential solution for this challenge. With the rising of Internet of Things and the smart home technologies, the concept of smart mailbox has drawn more attention as the solution for failed delivery attempt in delivery services. In this project, a smart mailbox is built. WeMos board is used to control the smart mailbox system. Piezoelectric sensors are used to detect the delivery of a parcel. Meantime, Blynk app is used to send notification to recipients remotely. This smart mailbox's idea is at initial stage. There is room for improvement in the system such as additional sensors to capture the identity of deliveryman, the condition of delivered parcel and the activities inside the smart mailbox.

Keywords: Parcel Delivery · Smart Mailbox · Piezoelectric Sensors · Arduino · Internet of Things

1 Introduction

Dato' Sri Dr. Mohd Uzir Mahidin, the Chief Statistician Malaysia from Department of Statistics, released that e-commerce had brought in MYR279 billion as income to Malaysia in third quarter of 2021. This established income shows an 17.1% increment compare to third quarter of 2020 [1]. Furthermore, GlobalData's E-Commerce Analytics estimated that e-commerce payments in Malaysia will reach MYR55.7 billion in 2025, growing at a compound annual growth rate (CAGR) of 18.3% compare to 2021 [2]. It has shown that e-commerce is blooming in Malaysia.

Benefited from the blooming of e-commerce, courier industry gained rapid growth in Malaysia as well. For example, 100 million parcels had been delivered by Ninja Van as of July 2021 [3]. Customer satisfaction on the delivery service is an important factor in courier industry. This is agreed by Jane Teh, the Managing Director of Lalamove Malaysia, that customers are expecting better delivery services, delivery time, faster order-matching, more vehicle choices and etc. [4]. In 2006, Huang and Kuo had also reported that customer satisfactions on the delivery services can be improved by enhancing the logistics service quality such as the delivery speed, e-tracking mechanism, delivery flexibility and etc. [5]. To enhance customer satisfaction, DHL Express (M) Sdn Bhd had started digitalisation in delivery services before 2020 [6].

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One of the challenges in delivery services is no recipient at the delivery location. This is because not all people can stay at home for whole day to wait for their parcel to arrive. Furthermore, the recipients may miss the delivery due to toilet break, phone call engagement or a short leave. Once the delivery of parcel is failed, another delivery has to be arranged and another day has to be spent for waiting [7]. One of the innovative delivery services that adopted by the courier industry is automated parcel station (APS). APSs are parcel lockers installed at selected locations that enable delivery companies to place the parcel; while the recipients can pick up their parcel in free time [8]. In Malaysia, Parcel365 and PopBox offer the APS service as the solution to failed delivery attempt [7].

However, there are still some concerns on APS, such as the limited locations, installation costs, and security issues. In this project, a home-based smart mailbox is proposed to provide an alternative solution to failed delivery attempt.

2 Literature Review

In 1999, an electronic mailbox with keypad alarm system was invented by Baggarly [9]. In recent, this concept has been constantly evolving and became the concept of the smart mailbox. Turská and Madleňáková defined the smart mailbox as the system that allow the existence of parcels in the smart mailbox to be determined by recipients remotely from a far location. The smart mailbox is usually consisting of a sensor to detect the existence of parcels, a control unit to communicate with sensors and store information, as well as a remote access system to allow recipients to check the latest status of the smart mailbox. The research of smart mailbox has been continuously invested by foreign courier companies such as United States Postal Service, Australia Post and La Poste to improve the delivery process [10].

Over the years, the concept of smart mailbox had been deployed by researchers in their invention. Yang invented the iBOX device, a home delivery auto receipt system [11]. This system is equipped with video, audio and temperature control device; internet, powerline, wire or wireless communication; as well as the remote programmable keypad. The built-in camera can monitor the presence of parcel. The network system allows the recipients monitor the iBOX remotely, while the keypad allows the iBOx to be controlled on-site.

In 2009, Robert Lee Hanna invented a transmitting device that send signal when the door of a post mount mailbox is opened [12]. The sensor used in this invention is a tilt switch. Once the door of mailbox is opened past a predetermined angle, the tilt switch completes a circuit and send signal to receiver. The audio and visual alarm are activated to indicate the presence of a parcel.

The importance of smart mailbox has been strengthened with the rising of Internet of Things and the smart home technologies. Thai Post Co Ltd plans to install 22,000 smart mailboxes, that use Internet of Things technology, nationwide [13]. In Internet of Things, Arduino has been widely utilized as microcontroller. Yusro, Guntoro, and Rikawarastuti reported that there are 859 research articles discussing the use of Arduino in the Internet of Things technology between July 2015 and July 2019 [14]. The utilization of Arduino has been extended in prototyping the smart mailbox recently.

Tew and Ray used the Arduino Yun to control the radio-frequency identification reader, camera, motion sensor, locking solenoid, and onboard WiFi module in their smart mailbox prototype [15]. Chandra Prakash Reddy et al. designed a smart system letter box to send notification to recipients on the arrival of letter. This system utilizes Arduino Mega to control the infrared sensors, keyboard and WiFi module [16]. Besides, Fadhlan, Supriyadi and Maulana proposed a smart mailbox prototype using Arduino Uno. This system utilizes NodeMCU to send receipt number that is used to open the door of smart mailbox [17].

WeMos board is a microcontroller with built-in ESP8266 WiFi module that uses Arduino-UNO footprint. In this project, WeMos board is utilized as the microcontroller with the piezoelectric sensors to detect the delivery of parcels in the smart mailbox. Furthermore, Blynk app is used to send notification to the recipients.

3 Research Methodology

In the proposed smart mailbox system, the components used include buzzer, light emitting diode, wires, piezoelectric transducers, ceramic piezoelectric vibration sensor module, spring and WeMos board.

3.1 Piezoelectric Sensors

The front view and back view of the smart mailbox is shown in Fig. 1a and 1b. Inside the smart mailbox, a thin board is placed at the bottom of the box and it is lifted by a spring as shown in Fig. 1c. The purpose of the implementation of spring is to improve the detection of input signal from piezoelectric sensors. 5 piezo elements with leads

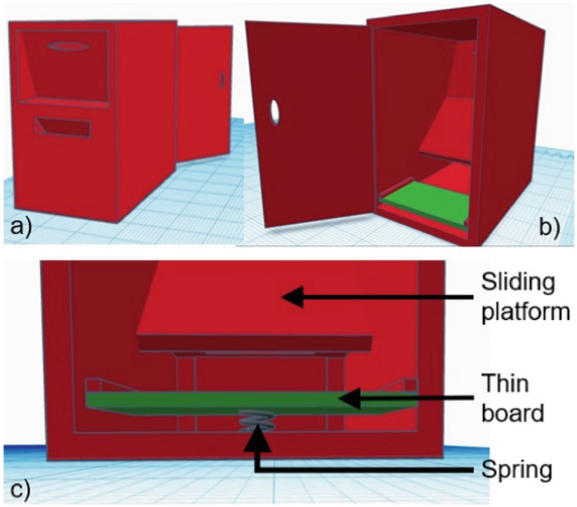

Fig. 1. (a) Front view and (b) back view of the smart mailbox. (c) A thin board is lifted by a spring inside the smart mailbox.

are placed under the thin board to work as the piezoelectric sensors. The piezoelectric sensors are then connected to the ceramic piezoelectric vibration sensor module for further signal enhancement.

3.2 Microcontroller System

Figure 2 shows the operation process flowchart of the smart mailbox. When the smart mailbox is turned on, WeMos board connects the system to WiFi and notifies the recipients that the number of parcels is 0 through Blynk app. At the same time, the light emitting diode is switched on to indicate the system is active. WeMos board reads the

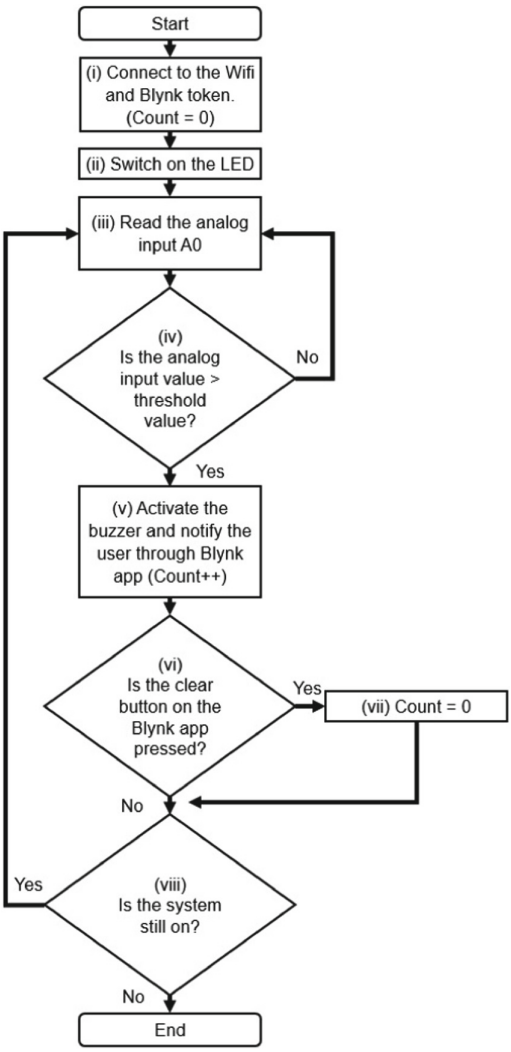

Fig. 2. The operation process flowchart of the smart mailbox.

analog input from piezoelectric sensors continuously. In this project, a 25-gram solid sample is used as a parcel. When the parcel is dropped onto the thin board at the bottom of the smart mailbox, the hitting of the parcel causes the generation of electric signal from piezoelectric sensors. This signal is compared with a predefined threshold value in WeMos board. If the signal is larger than the predefined threshold value, the buzzer is triggered. This is a notification to deliveryman that the parcel is counted. At the same time, the recipients are notified that the number of parcels has been increased to 1 through Blynk app. The counting of parcels is continued until the "Clear" button in the Blynk app is pressed to reset the counting.

4 Results and Discussions

In this project, piezoelectric sensors determine the appearance of a parcel by detecting the vibration that is caused by the dropping of the parcel onto the thin board. However, the piezoelectric sensors are also sensitive to the vibration sources from the environment in a building such as air conditioning system, lift, piping system and human activities [18]. These vibration sources contribute to the noise in Figs. 3 and 4. Figures 3 and 4 show the input signal from piezoelectric sensors plotted with Arduino serial plotter before and after the implementation of spring and ceramic piezoelectric vibration sensor module. By comparing Figs. 3 and 4, the signal-to-noise ratio is found increased after the spring and ceramic piezoelectric vibration sensor module are implemented in the smart mailbox.

As shown in Table 1, a set of data is retrieved from the Arduino serial plotter to calculate the signal-to-noise ratio. It is showed that the signal-to-noise ratio after the implementation is almost double of the signal-to-noise ratio before the implementation of the spring and ceramic piezoelectric vibration sensor module. The spring can amplify the vibration when a parcel drops onto the thin board in the smart mailbox. At the same time, the spring isolates the thin board from the vibration source in a building when no parcel is dropped into the smart mailbox.

When the smart mailbox is turned on, WeMos board connects the system to WiFi and Blynk app. Figure 5 shows the output from the Arduino serial monitor if the connection of WeMos board to WiFi and Blynk app are successful.

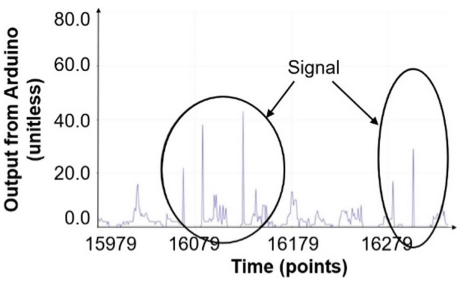

Fig. 3. Input signal from piezoelectric sensors plotted with Arduino serial plotter before the implementation of spring and ceramic piezoelectric vibration sensor module.

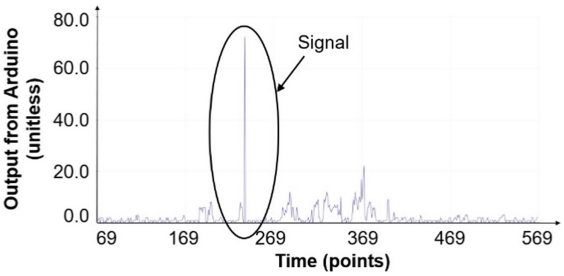

Fig. 4. Input signal from piezoelectric sensors plotted with Arduino serial plotter after the implementation of spring and ceramic piezoelectric vibration sensor module.

Table 1. Signal-to-noise ratio before and after the implementation of the spring and ceramic piezoelectric vibration sensor module

	Peak Signal	Peak Noise	Signal-to-noise, $\left(\frac{s}{n}\right)$
Before	42	23	1.83
After	75	21	3.57

Fig. 5. Output from the Arduino serial monitor when WeMos board is connected to WiFi and Blynk app.

If the signal generated by piezoelectric sensors is larger than the predefined threshold values in WeMos board, notification message is sent to recipients that a parcel is received. The notification message can appear at Bylnk app as well as at home screen as shown in Fig. 6.

The counting of received parcels continues until the "Clear" button in Blynk app is pressed. As shown in Fig. 7a, the number of received parcels is 6. When the "Clear" button is pressed, the button is highlighted as shown in Fig. 7b. The number of parcels returns to 0 after the button is pressed as shown in Fig. 7c.

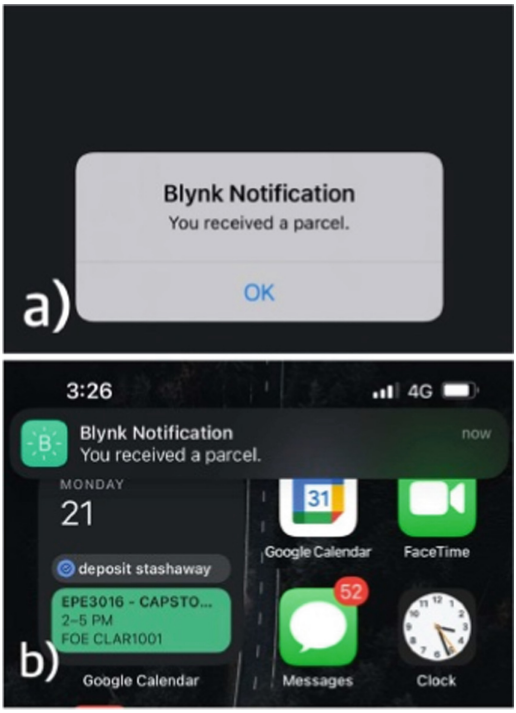

Fig. 6. Notification message at a) Blynk app and b) home screen that send to recipients when a parcel is received.

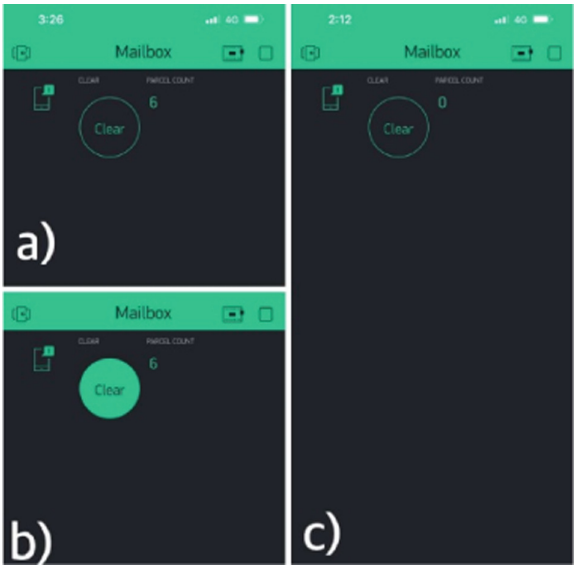

Fig. 7. The appearance of Blynk app a) before, b) when and c) after the "Clear" button is pressed.

5 Conclusion

Refer to the concept proposed by Turská and Madleňáková, a smart mailbox has been successfully demonstrated. In this project, the smart mailbox is controlled by WeMos board, a microcontroller with built-in WiFi module that uses Arduino-UNO footprint. Piezoelectric sensors are used to detect the delivery of parcels and Blynk app is used to notify the recipients remotely. Through experiments, the implementation of spring and ceramic piezoelectric vibration sensor module in our smart mailbox system demonstrated an enhancement in signal-to-noise ratio of the input signal from piezoelectric sensors.

Compare to existing smart mailbox system, our smart mailbox design has higher security level. It is because the parcel can only be dropped into the smart mailbox by the deliverymen, but they cannot take out the parcels from the smart box. Compare to APS, our users are not required to travel for parcels collection because they can install at their home. However, our home-based smart mailbox has challenge in collecting the large parcel and parcel with fragile item.

Our idea in building a smart mailbox using piezoelectric sensors is still in the initial stage. From user experience survey, we found that there is room for improvement in our smart mailbox. Additional sensors are suggested to capture more information, such as, the identity of deliveryman, the condition of delivered parcel and the activities inside the smart mailbox.

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Authors' Contributions. Yew-Keong Sin, Joe-Win Ng and Zhe-Kang Lim conceived and planned the experiments to build a smart mailbox using piezoelectric sensors. Yew-Keong Sin wrote the manuscript with support from Joe-Win Ng and Zhe-Kang Lim. Zhe-Kang Lim built the body for smart mailbox, while Joe-Win Ng set up the microcontroller system for smart mailbox.

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