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Integration of altimeter and GPS sensors on IoT-based Drone Delivery System (DDS)

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Integration of Altimeter and GPS Sensors on IoT-Based Drone Delivery System (DDS)

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Abstract: As the trend of online shopping increased, the demand for cheaper and quicker delivery became apparent. Hence, the proposed IoT-based DDS is targeted as an alternative to decreasing the price and time taken to perform the delivery operation. This system will extract the current altitude and position of the drone via the MPL3115A2 altimeter sensor and GY-NEO6MV2 GPS module attached to the drone. The ESP32 NodeMCU would collect sensor measurement and transmit this information to the cloud server hosted on AWS EC2 virtual machine wirelessly via Wi-Fi. The recipient and operator can access the dashboard through the cloud server to perform operations such as tracking, registering, confirming, and dropping parcels. The servo motor attached to the drone would automatically facilitate parcel dropping through a simple release mechanism.

1. Introduction

Statistics showed that global sales in e-commerce hit 5.2 trillion U.S. dollars [1]. More importantly, it was expected that international sales would rise to 8.1 trillion dollars by 2026. The forecast growth in sales of 56% indicated that the business growth of online shopping would not cease. Consequently, the logistics sector would be highly loaded from delivering all these orders.

Among all logistics processes, this paper focused on last-mile delivery. Last-mile delivery could be defined as the terminal node in a logistics process, including parcel delivery to the recipient. As the costliest activity, last-mile delivery took up a considerable percentage of the overall cost, ranging from 13% to 73%, depending on several factors [2]. These factors were quality of delivery service, nature of parcel being delivered, location, market share, and vehicles employed.

According to [3], the current status quo for performing last-mile delivery would be using human-driven delivery vans, cargo bikes, and self-service. Subsequently, a human courier driving a delivery van from home to home was the traditional and still largely predominant last-mile delivery concept. It was mentioned in [2], [3] that the development of last-mile delivery should address the following challenges:

- High demand results in high delivery volume.
- High delivery vehicle traffic volume that is not environmentally sustainable.
- Demand on lower cost, and that last-mile delivery is the most expensive.
- Demand on shorter delivery time.
- Challenge in recruiting manpower due to aging workforce.

By considering these facts in mind, an IoT-based DDS was designed and developed to replace the conventional method of couriers driving delivery vans. The DDS included a GPS module to track the latest geographical location of the drone, a quick release mechanism, and a user verification system to ensure that the parcel would be delivered to its legitimate recipient.

1.1. Drones and the IoT

A drone, otherwise known as an unmanned aerial vehicle (UAV), was identified as aircraft flying without a human pilot onboard and instead controlled remotely via radio signal [4]. Aside from its original military applications, drone technology was used commercially in various fields such as journalism, monitoring, agriculture, logistics, and more [5].

Another critical component of the developed DDS is IoT or the Internet of Things [6]. IoT is an extensive network of interconnected things or devices and people via the Internet. All these devices would collect and share information related to their respective environments or functionalities. IoT technology has been a trending topic in the industry and academics alike. Its applications are expanding into various fields: military, healthcare, home automation, waste management, surveillance, asset management, and transportation [7].

Both drones and the IoT played a role in the field of logistics and transportation. Combined, these two technologies transformed a working DDS that can be remotely accessed and controlled.

1.2. Comparative Analysis of Related Works

Two significant features were observed after reviewing past work on employing drones in delivery systems. Firstly, many proposed DDS included the mandatory usage of landing platforms and markers that communicate with the drone. The landing platforms established communications with the drone for accurate landing and for user verification. Secondly, GPS modules were found to be common in most related work to make drone and parcel tracking possible. However, it was suggested that GPS technology alone might not provide sufficient accuracy.

1.3. Motivation

This research aimed to propose an alternative DDS that utilized IoT technology. Compared to previous work, email notifications with generated code would be used for user verification to replace the potentially inconvenient installations of landing platforms and markers. At the same time, the research would investigate the accuracy of GPS module and whether it would be sufficient to track parcels and drones.

2. Methodology

The proposed system process of the IoT-based DDS is shown in Fig. 1. The setting is that a delivery van or truck would depart from a distribution center to a central area where multiple deliveries can be made. The central location could be a neighborhood with numerous houses awaiting deliveries.

Upon arriving at the said central area, delivery drones would be dispatched from the vehicle to respective houses after the operator input the recipients' addresses which would be translated into GPS information. At this point, the recipient would receive a notification regarding the incoming delivery with a tracking number. The tracking number allows the recipient to track the current location of the drone and the attached parcel.

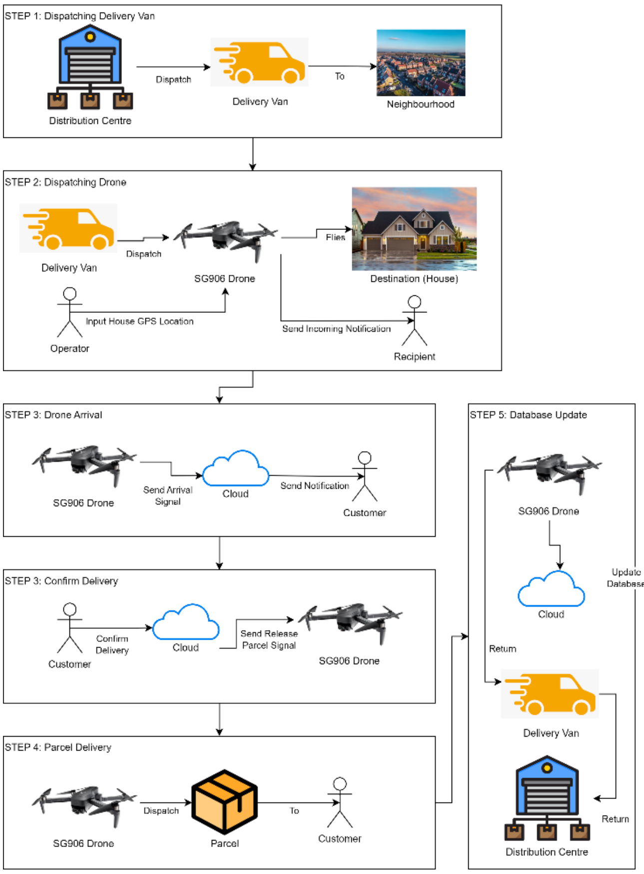

Fig. 1. System process of IoT-based DDS.

Within the proximity of the recipient's address, another notification would be automatically sent to the recipient. This notification would include a confirmation link and a generated code. The recipient could use this to confirm the delivery as a security measure, ensuring that the parcel is intended for the recipient. The person authorizing would be required to enter their contact details as a secondary form of security.

The parcel would be dispatched safely from the delivery drone through a simple release mechanism when the delivery is confirmed. After that, the drone would return to the carrier vehicle before returning to the distribution centre. The database would be updated to indicate the completed delivery.

To achieve the system process, the block diagram of the DDS was designed as in Fig. 2.

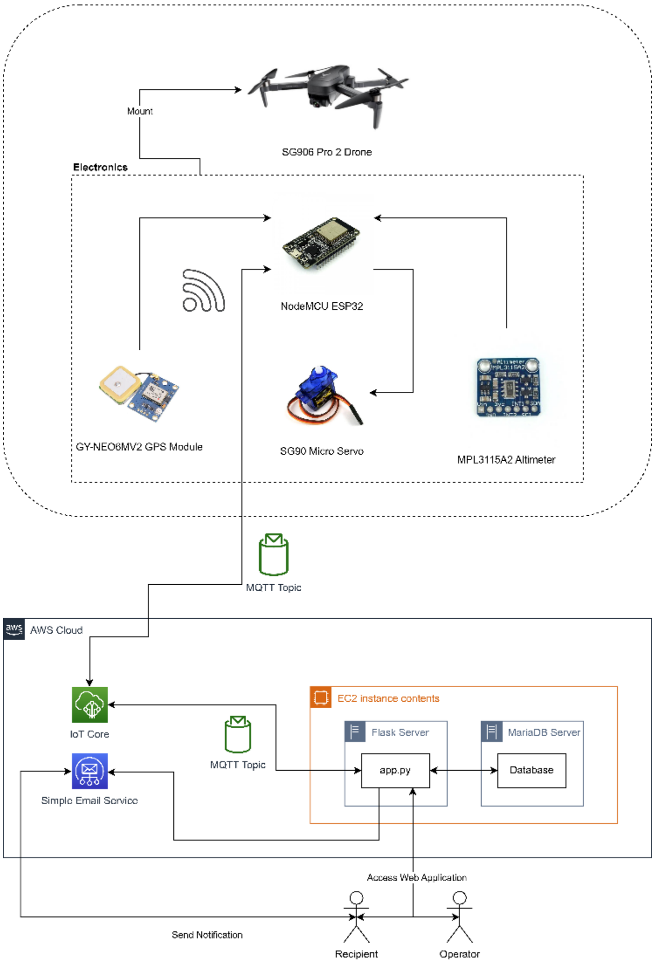

Fig. 2. Block diagram of IoT-based DDS.

2.1. Hardware

The hardware components used for the developed IoT-based DDS are presented below.

Table 1 Hardware Components Involved

Components	Purpose
NodeMCU ESP32 [8]	The small form factor microcontroller provides Wi-Fi connectivity and controls the other sensors and actuators.
SG906 Pro 2 Drone [9]	The relatively inexpensive drone has a range of up to 1200m and a maximum flight altitude of 800m.
GY-NEO6MV2 Flight Control GPS Module [10]	The GPS module updates the system's database of the drone's current location in the form of longitude and latitude.

Components	Purpose
MPL3115A2 I2C Altitude Sensor [11]	The sensor updates the current altitude of the flying drone to ensure that it is at the appropriate operating and parcel release height.
SG90 Micro Servo [12]	The servo motor actuates the quick-release mechanism via the push rod attached.
3D Printed Quick Release Mechanism [13]	A simple, quick-release mechanism that holds the parcel in the air and releases it when the altitude is appropriate and when the customer confirms the delivery.

The circuit diagram of the sensors, actuator, and the NodeMCU ESP32 on the drone is as presented in Fig. 3. The GY-NEO6MV2 GPS module (in green) is connected to the second serial pins (RX2, TX2) and the MPL3115A2 (in red) is connected to the I2C pins (SDA, SCL).

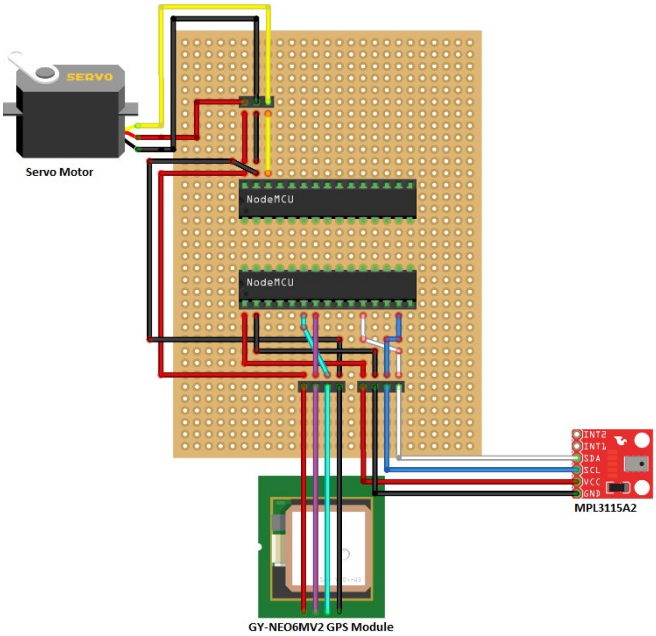

Fig. 3. Circuit diagram

The 3D printed and assembled quick release mechanism can be seen in Fig. 4. A stainless-steel wire acts as the lock. The motion of the SG90 servo motor would pull or push the wire, resulting in the gap opening or closing.

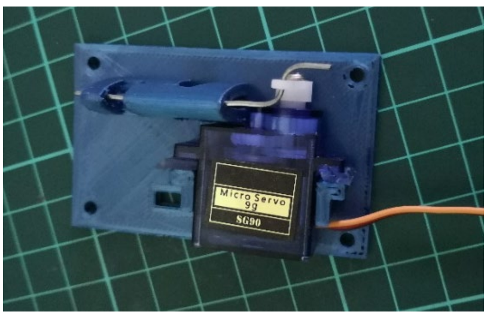

Fig. 4. Assembled quick release mechanism

The quick release mechanism is attached to the side of the drone with the servo motor facing downwards. This is the appropriate location for the mechanism to be attached to the SG906 Pro 2 drone because the supporting legs are shorter than the overall mechanism. Placing the mechanism directly below would damage the mechanism when the drone is placed on the ground. Subsequently, the final build of the prototype drone is shown as in Fig. 5.

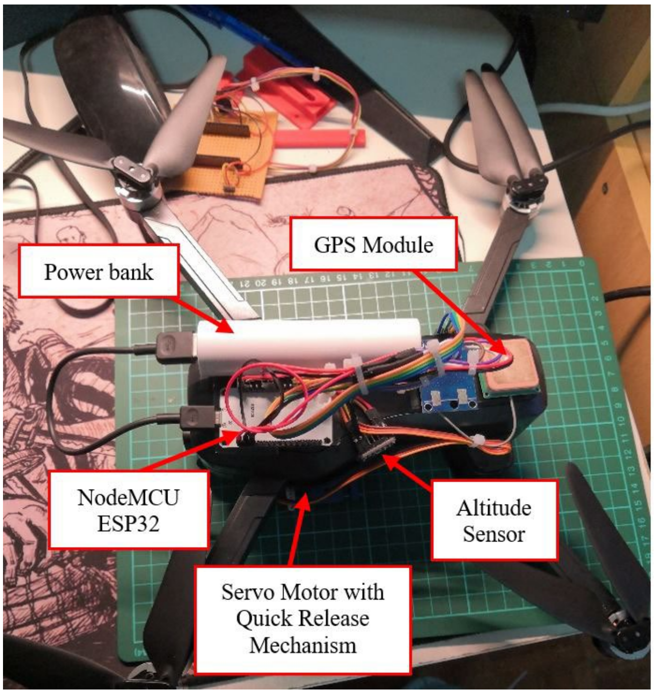

Fig. 5. Final build of drone prototype

2.2. Software

The software components used for the developed IoT-based DDS are presented below.

Table 2 Software Components Involved

Components	Purpose
Amazon Elastic Compute Cloud (Amazon EC2)	The virtual machine within the AWS cloud platform hosts both the flask and MariaDB servers.
Flask Server	The Python-based web framework server is the dashboard.
MariaDB Server	The database stores information on deliveries and drones.
AWS IoT Core	It is the facilitator for MQTT messages between the ESP32 NodeMCU on the drone and the EC2 instance in the cloud.
Amazon Simple Email Service (SES)	Provides the functionality to send out email notifications from the EC2 instance to the customers.

The system flowchart for a typical delivery process using the IoT-based DDS was developed as shown in Fig. 6.

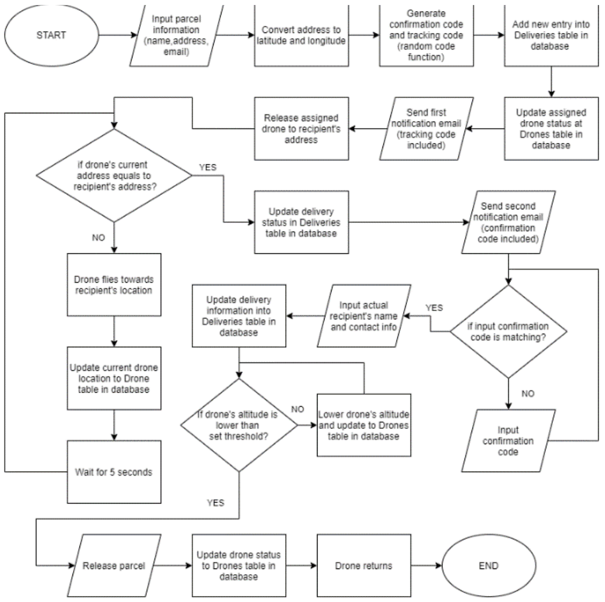

Fig. 6. Flowchart of the IoT-based DDS

The system flowchart for a typical delivery process using the IoT-based DDS was developed as shown in Fig. 6. As the GPS module returns current location in terms of latitude and longitude values, the semantic address is converted to latitude and longitude using Google Maps Geocoding API. Another important feature of the DDS is its two notification emails that includes the tracking number and confirmation code respectively. The two codes made up of random upper-case letters and digits are randomly generated within Python. The input information is stored inside the database. The database's schema used in the prototype is depicted in the entity relationship diagram as seen in Fig. 7.

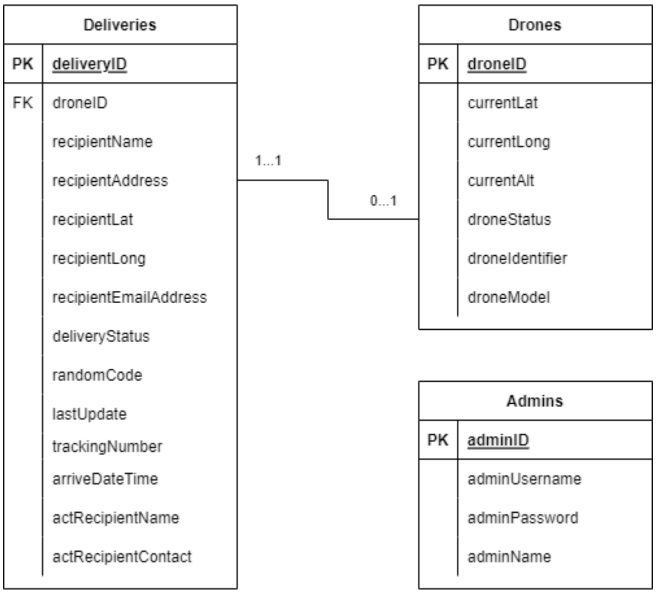

Fig. 7. Flowchart of the IoT-based DDS System

Within the database structure, the focus should be on the Deliveries and Drones tables. Each delivery is recorded as a row under the Deliveries along with the information and the drone used for that delivery.

3. System Performance

As the SG906 Pro 2 drone is a commercial drone designed for photography and videography and the quick release mechanism uses a servo motor to drive a thin wire, heavy parcel could not be carried. Instead, the drone is only capable to carry thin letters that is light. Even then, the circuit mounted on the drone would drain the drone's battery faster from the rotors spinning faster to compensate the weight. Besides, the flight of the drone would be affected to be less stable as the result of adding weight onto the drone.

With the circuit mounted on the drone, the prototype could not travel in the air. The current prototype of the drone would require the operator to manually fly the drone via a remote controller as autonomous flying was not implemented. On the other hand, the other aspects of the prototype, including the parcel tracking and user verification features were verified.

The circuit itself was switched on without the drone flying. Instead, the travelling was done by car. The NodeMCU ESP32 was connected to the Internet through the usage of mobile hotspot so that the information can be transmitted to the cloud and back. The dashboard can be accessed on mobile phone's browser as it was a web application. In addition, the prototype was not loaded as the 3D printed release mechanism showed signs of breaking apart during initial testing as a result of lower quality of material ad print. However, the actuation of the release mechanism was observed to find out whether the prototype could automatically release the parcel when receiving user confirmation.

3.1. Parcel Tracking

Upon registering a parcel via the operator dashboard as in Fig. 8, the recipient received a notification email as shown in Fig. 9. The recipient could track the parcel's current location by either inputting the tracking number provided into the tracking web form or clicking on the provided link.

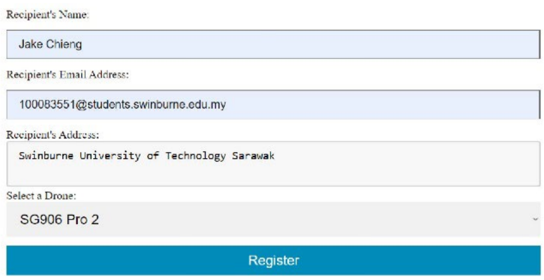

Fig. 8. Delivery registration dashboard.

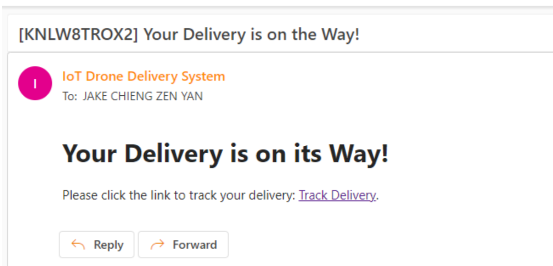

Fig. 9. Example of the first notification email to provide tracking number and link.

When clicking on the link, the customer will be redirected to the tracking page where the current location of the drone and the destination will be shown as in Fig. 10. With this, recipients could find out the current location of the drone carrying the parcel graphically on the map.

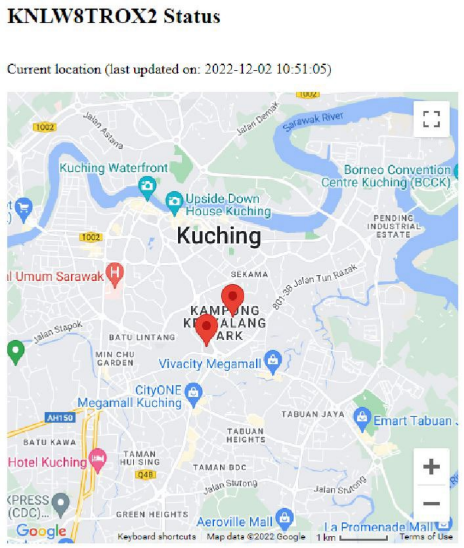

Fig. 10. Example of the tracking page for recipient to view.

3.2. User Verification

A second email would be sent to the recipient, such as in Fig. 11, when the drone is within 100m of the recipient's address. The confirmation code that is randomly generated is included in the email notification. When the link is clicked, or the tracking number and confirmation code are inputted into the form, the recipient would be requested to input their name and contact number as in Fig. 12. This information collection acts as a second layer of security to ensure that the parcel is indeed sent to the correct personnel. Only after this is completed will the server issue the MQTT message to command the drone to release the package after lowering it to a safe altitude of 1m.

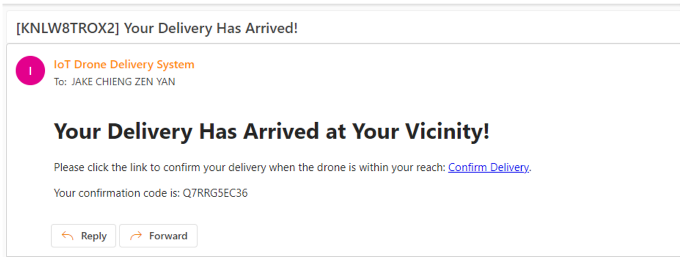

Fig. 11. Example of the second notification email to provide tracking number, confirmation code, and link.

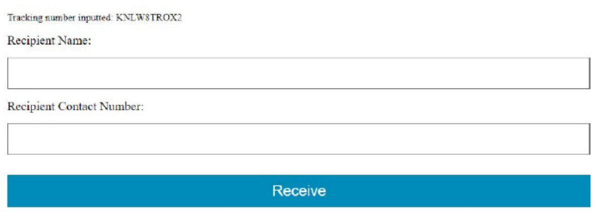

Fig. 12. Form to input actual recipient's name and contact number.

4. Limitations

The limitations identified by the developed IoT-based DDS are listed in the table below.

Table 3 Limitations of Prototype

Limitations	Description
Drone's Capabilities	The SG906 Pro 2 is a commercial drone for photography and videography with only a range of 1200m and a maximum flight height of 800m. These range limits are impractical in a DDS. Furthermore, it must be manually controlled through its remote controller. The drone can only carry around 200g of load, including the circuit and the release mechanism on board [9], [14].
Range of Wi-Fi	The communication channel drones in this system use to communicate with the cloud server is Wi-Fi. According to [15], Wi-Fi is limited to 10m and a sensing range of 6m to 8m. Again, this is impractical for drones that are expected to fly a few kilometres from the router.
Aviation Law	In Malaysia, any unmanned aircraft system (UAS) flying over commercial, residential, industrial, and recreational areas requires a permit from the Civil Aviation Authority of Malaysia (CAAM). Depending on the location, additional documents might be needed before applying for the license. In addition, commercial drone operations would require an aerial work certificate to be applied for and renewed yearly. Additional authorization will also be needed if the drone weighs over 20 kg [16].
Parcel Release Accuracy	As the decision to release the parcel solely relied on the distance between the drone and inputted recipient's address, the release accuracy would be pretty low compared to those systems with additional sensors or communication protocols, such as in [17]–[20].
Reliability of Release Mechanism	The quick-release mechanism used was 3D printed, and it was brittle. It was suspected that the mechanism might be deformed or destroyed under heavier weight.
AWS Free Tier	As the free tier was used, there was a limitation with the amount of MQTT messages that could be transmitted, the verified email address that could be sent through, and the change in IP addresses every time the EC2 instance was restarted.

5. Conclusion

An IoT-based DDS that utilized AWS as the cloud platform was developed. The design provided a method for user verification via the implementation of the email notification with a tracking number and randomly generated confirmation code. In addition, the DDS incorporates a GPS module and altimeter to inform the customers where the drones are carrying their packages. The cloud dashboard that can be accessed anywhere with an Internet connection also adds to the convenience of using this system. With these features, it is evident that drone delivery would become a practical alternative to the traditional method of last-mile delivery.

6. Future Scope

This research and development project is meant to be a starting point for the research field of DDS that incorporates IoT technology. Considering the limitations presented in the previous segment, the following areas should be explored further in future research:

- Research on alternative communication protocols that has a more extended range and higher reliability that can be used to implement the DDS.
- Research on optimizing the mechanical design of delivery drones to carry the appropriate load without interfering with flight performance.
- Research on alternative release mechanisms that can reliably and securely hold a parcel of the appropriate weight.
- Research on optimization of user verification method to add an additional layer of security.

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