

Design of Alerting System for Beyond Visual Line of Sight Operational Cargo Delivery UAV

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Abstract

The development of drones is now crucial to many industries, investors, and governments as they are more cost-effective and efficient in various industries, such as filmmaking, consumer, and tourism. They can also be used in various fields, such as agriculture, meteorology, construction, logistics, and conservation. Beyond Visual Line of Sight (BVLOS) technology enables drone operations to perform missions more accurately as it allows them to be operated in a wider angular range. BVLOS includes the use of advanced technologies and systems to monitor drones and ensure they comply with regulations. As such, BVLOS can be used to optimise marine cargo drone operations. In addition, the Ground Control System (GCS) is used by multi-UAV systems to remotely monitor drone performance. This enables advancements in navigation and autonomous technologies that can be utilised in the maritime sector. However, the operation of cargo delivery UAVs, especially those operated as multi-UAVs, requires a surveillance system supported by a qualified warning system. One of them is a warning system that will appear when the UAV approaches the boundary of the area of operation that has been set at the beginning. The warning system aims to improve safety and security because by warning UAVs approaching or entering restricted or sensitive areas, this system can prevent unauthorised access or accidents, ensuring the safety and security of the area and the UAV itself. In addition, it improves efficiency and reduces costs where the warning system can help UAVs avoid entering prohibited or unauthorised locations, improving efficiency, and reducing costs associated with re-routing or returning to home. For this reason, in this research, the design of a warning system for UAVs approaching the boundary of the operating area is performed and shown through simulation. In this research, a two-level alert system was designed and simulated that is triggered when the UAV approaches the boundary of the specified operation area to enable the operation supervisor to perform safety procedures in response to mitigate potential risks.

Keywords: Unmanned Aerial Vehicles (UAV), multi-UAV, Area of Operation, Alerting System, Operation Supervision Module, Cargo Drone

Abstrak

Perancangan Sistem Peringatan untuk Operasi Pengiriman Kargo UAV di Luar Jangkauan Pandang Visual: Pengembangan teknologi drone saat ini menjadi krusial bagi banyak industri, investor, dan pemerintahan karena drone lebih hemat biaya dan efisien dalam berbagai industri, seperti pembuatan film, konsumen, dan pariwisata. Drone juga dapat digunakan dalam berbagai bidang, seperti pertanian, meteorologi, konstruksi, logistik, dan konservasi. Teknologi Beyond Visual Line of Sight (BVLOS) memungkinkan operasi drone untuk melaksanakan misi dengan lebih akurat karena memungkinkannya dioperasikan dalam rentang sudut yang lebih luas. BVLOS mencakup penggunaan teknologi dan sistem canggih untuk memantau drone dan memastikan mereka mematuhi regulasi. Oleh karena itu, BVLOS dapat digunakan untuk mengoptimalkan operasi drone kargo maritim. Selain itu, Ground Control System (GCS) digunakan oleh sistem multi-UAV untuk memantau kinerja drone secara remote. Hal ini memungkinkan kemajuan dalam teknologi navigasi dan otonom yang dapat dimanfaatkan dalam sektor maritim. Namun, operasi UAV pengiriman kargo, khususnya yang dioperasikan sebagai multi-UAV, memerlukan sistem pengawasan yang didukung oleh sistem peringatan yang terqualifikasi. Salah satunya adalah sistem peringatan yang akan muncul ketika UAV mendekati batas area operasi yang telah ditetapkan pada awalnya. Sistem peringatan bertujuan untuk meningkatkan keamanan karena dengan memberi peringatan kepada UAV yang mendekati atau memasuki area terlarang atau sensitif, sistem ini dapat mencegah akses tidak sah atau kecelakaan, memastikan keamanan area, dan UAV itu sendiri. Selain itu, meningkatkan efisiensi dan mengurangi biaya di mana sistem peringatan dapat membantu UAV menghindari memasuki lokasi yang dilarang atau tidak diizinkan, meningkatkan efisiensi, dan mengurangi biaya yang terkait dengan pengalihan atau kembali ke titik awal. Oleh karena itu, dalam penelitian ini, desain sistem peringatan untuk UAV yang mendekati batas area operasi dilakukan dan ditunjukkan melalui simulasi. Dalam penelitian ini, dirancang dan disimulasikan sistem peringatan dua tingkat yang dipicu ketika UAV mendekati batas area operasi yang ditentukan untuk memungkinkan pengawas operasi untuk melakukan prosedur keamanan sebagai respons untuk mengurangi potensi risiko.

Kata Kunci: Unmanned Aerial Vehicles (UAV), multi-UAV, Area Operasi, Sistem Peringatan, Modul Pengawasan Operasi, Cargo Drone

1. Introduction

In recent decades, drones have received significant attention from industry players, investors, and governments. Unmanned Aerial Vehicles (UAVs) are currently used to serve a wide range of application areas. In agriculture, for example, drones are used to assess crop needs, such as irrigation and nutrition, as well as in crop spraying and tracking livestock.

One of the current uses of UAVs is as cargo drones to transport goods from warehouses to ships in harbours or near waterways, which can provide additional efficiency and speed in the supply chain. The use of UAVs as cargo drones to transport goods from warehouses to ships has the potential to improve logistics efficiency and performance, especially in scenarios where distances are close and infrastructure to support drone operations is available. However, as with the use of drones in any sector, several obstacles must be overcome to ensure safe, efficient, and compliant operations [1].

One solution to minimize the use of cargo drones at sea is to adopt Beyond Visual Line of Sight (BVLOS) technology. BVLOS allows drones to fly beyond the operator's direct line of sight, which means that drones can perform long-distance flights without the need to physically be in the operator's line of sight. The application of BVLOS in the use of cargo drones at sea has several advantages, including: drones using BVLOS technology can travel long distances, carrying cargo from warehouses to ships in wider waters, without having to be limited to the limited visibility of the operator; drones can fly directly to their destination without having to follow long routes or face obstacles on land; and BVLOS can reduce operational costs because drones can cover more areas in one flight without the need for intermediate landing points [1].

However, the implementation of BVLOS also poses some challenges and considerations, such as require advanced control technologies and systems to ensure the safety of the drones on long-distance journeys and avoid collisions with other objects along the route especially when the drones are operated with multi-UAV systems. Multi-UAV systems require extra attention to security and privacy aspects due to their complex operations involving multiple drones flying in relative proximity.

Therefore, the use of autonomous technology and advanced management systems can help overcome several obstacles and open up new opportunities in the logistics and maritime transport industry, such as the use of a Ground Control System (GCS). The research related to the Development of the DGMIND Operation Supervision Module for Multi UAV Operation at Pen Aviation Company is proposed to study the use of a Ground Control System (GCS) in the operation of multi-UAVs that will be implemented by PEN Aviation Company. One of the challenges in operating a UAV in BVLOS is that the GCS will be located within the truck so that the operations supervisor and safety pilot are unable to directly monitor the UAV being operated. For this reason, PEN Aviation needs an alert system that will notify the operations supervisor if the UAV is approaching the boundary of the operating area.

The research to be carried out aims at Method and Algorithm Development: UAV surveillance operations research aims to develop efficient methods, techniques, and algorithms for UAV operations and surveillance. This involves mathematical modelling, data analysis, and the development of effective surveillance strategies. The first step will be to conduct a literature study in the form of a review of research papers for the operation supervision module to be developed. After the simulation process is carried out, the results obtained will be analysed.

2. Literature Review

An unmanned aircraft system is an unmanned aircraft (an aircraft that is operated without the possibility of direct human intervention from within or on the aircraft) and associated elements (including communication links and the components that control the unmanned aircraft) that are required for the operator to operate safely and efficiently in the airspace system. Over the last five years, unmanned aircraft systems (UAS), or unmanned aerial vehicles (UAVs), often referred to as drones, have been experiencing healthy growth in the United States and worldwide [2].

Accompanying the rapid increase of drone operations over the past few years has been a comparative increase in the regulations governing the industry. The main driver for this has been the safety of societies concerning their populations, property and environment. Generally recognised types of UAS (Unmanned Aircraft Systems) operations include VLOS (Visual Line of Sight), BVLOS (Beyond Visual Line of Sight), and EVLOS (Extended Visual Line of Sight) [3].

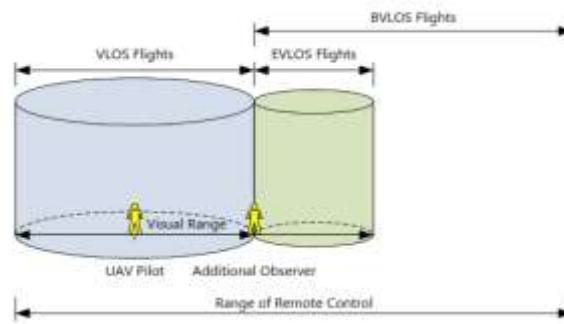


Figure 1 VLOS, EVLOS and BVLOS illustrated

2.1. Multi-UAS

Multi-UAS (Multi Unmanned Aircraft Systems) refers to using more than one UAV (Unmanned Aerial Vehicle) or drone in a single operation or system. In this context, “multi” indicates that multiple drones operate simultaneously or interact with each other to achieve specific objectives [4].

The use of multi-UAS can offer significant benefits, such as broader area coverage, faster response times, and increased efficiency in specific tasks. However, coordinating and controlling multiple drones simultaneously also presents technical and logistical challenges, including effective communication coordination and flight management [5].

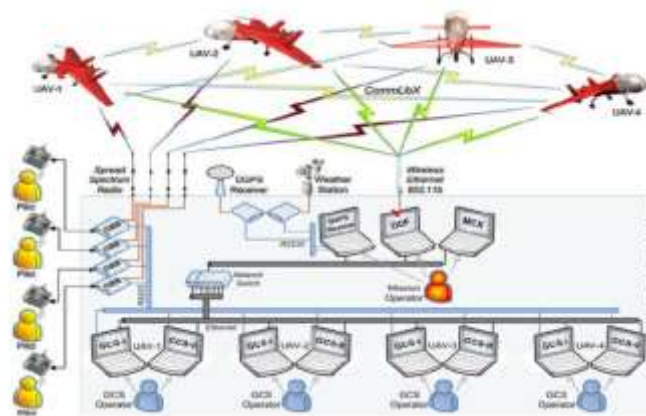


Figure 2 Multi-UAS Operation

2.2. Abnormal Situation

With the rapid development of UAVs (Unmanned Aerial Vehicles), abnormal state detection has become a critical technology to ensure the flight safety of UAVs. The position and orientation system (POS) data, etc., used to evaluate UAV flight status are from different sensors. The traditional abnormal state detection model ignores the difference of POS data in the frequency domain during feature learning, which leads to the loss of key feature information and limits the further improvement of detection performance [6].

UAV anomaly detection method was based on flight data rules; however, the rule-based anomaly detection method has a low detection performance [7]. To better ensure the flight safety of UAVs, ML and deep learning methods have been introduced into the research field of UAV safety. The development of these methods has opened up new ideas for the research of UAV anomaly detection [8]. However, the traditional anomaly detection method ignored the difference between POS data and SS data used to evaluate the flight status of UAVs in the frequency domain, resulting in the loss of some key feature information in-flight data [9].

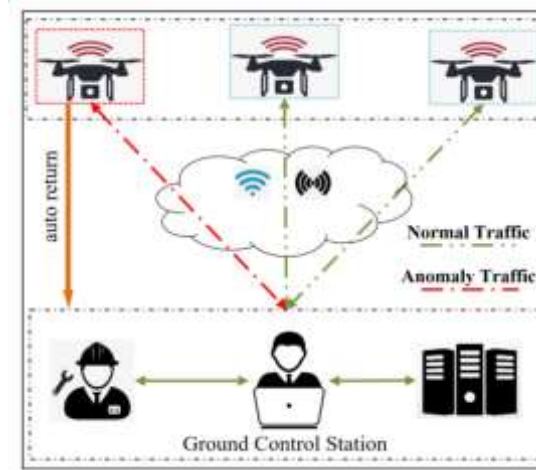


Figure 3 Main components in the UAV anomaly detection system

2.3. UAV Alerting System

The algorithms sense whether the UAV is inside or outside of the geofence and have an alarm to warn the operator [10]. This geofencing concept can be assumed to contain no-fly zones. For research efficiency, our system not only warns against flying into no-fly zones but also detects approaching zones in real-time concerning UAV heading and distance. Moreover, miss-headings and missroutings are detected to trace navigation failures due to strong winds. After the SAS has detected the drifting error during navigation, the error can then be corrected by determining the correct crab angle and saving the heading to a predefined path.

Powerful UAV control systems become crucial when multiple UAVs are operated simultaneously. GCS implementation for multiple UAVs has been carried out in numerous studies. Another study proposed the implementation of a monitoring system for UAVs delivering products. These studies relied on open-source libraries and APIs to receive flight data and control the UAVs. A SAS should be embedded as an additional safety module for all types of GCS for UAV safety [11].

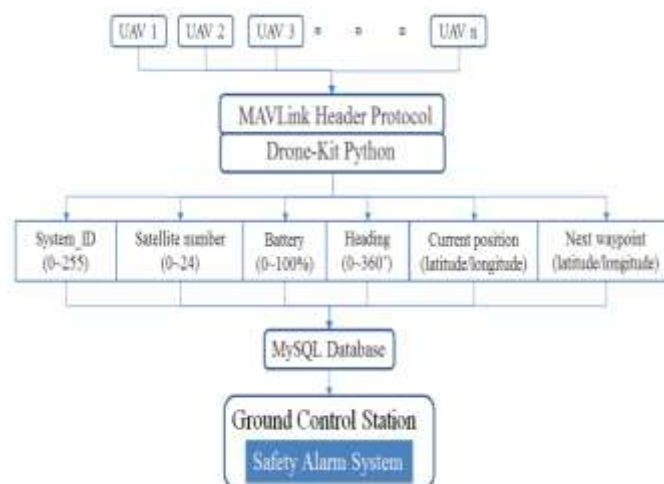


Figure 4 System Interface and Implementation Block Diagram

3. Ground User Interface: DGMIND By PEN AVIATION

The UAV (Unmanned Aerial Vehicle) Ground User Interface (GUI) is the software application or dashboard that allows operators and users to interact with and control the UAV during pre-flight, in-flight, and post-flight operations. It serves as a crucial link between the human operator and the UAV [12].

The UAV ground user interface plays a vital role in enabling operators to plan, control, and monitor UAV missions effectively. Its design and features may vary depending on the UAV's complexity and the specific requirements of the mission.

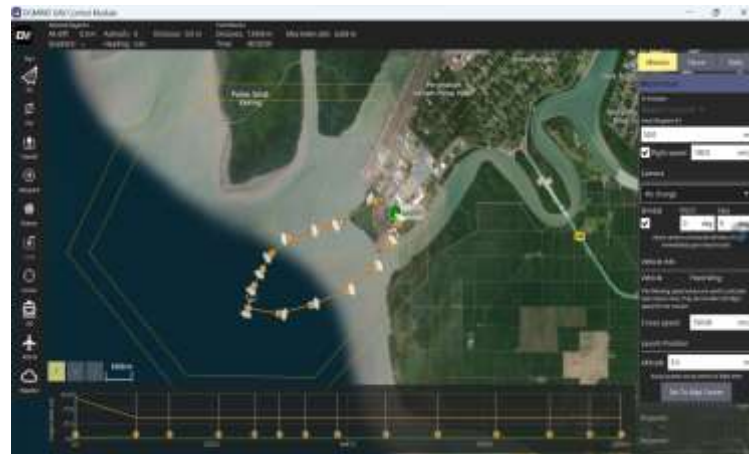


Figure 5 Example of Ground User Interface by PEN AVIATION

Operations Supervision is performed by the Flight Planner or the System Test and Integration Engineer on duty [13]. It consists of monitoring the mission/flight progress via the DGMIND/Ops Supervision Module and checking that:

1. Flight Geography volumes are respected.
2. Detect and coordinate with the System Operator if required in case of collision risks with other flying vehicles.
3. The mission/flight goes as planned for all other aspects, and if not, can activate the ERP, should the System Operator not be able to do so.



Figure 6 Simple Scenario in PEN Aviation

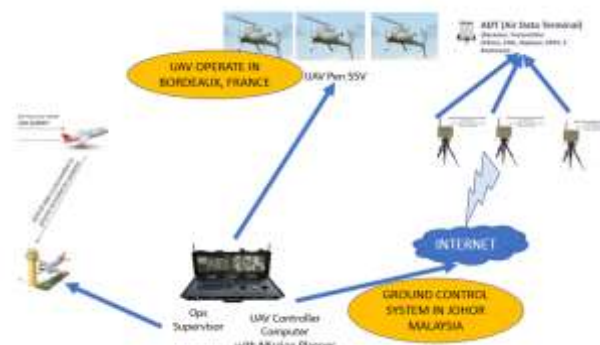


Figure 7 Multiple UAS Scenario

4. Design of Alerting System

In this research report, the scenario for the design of the warning system is that of UAV operations approaching the boundaries of the operational area of the UAV. The area of operation for a UAV is a two-dimensional concept, representing the geographic area or airspace where the drone is authorised or intended to fly. The area of operation is typically defined by geographical coordinates, such as latitude and longitude, and altitude limitations, which determine the boundaries within which the UAV can operate. It is usually represented as a polygon on a map or as a set of coordinates [14].

4.1. Functional Objectives

Implementing an alerting system for UAVs (Unmanned Aerial Vehicles) when they are near the boundaries of their designated area of operation is a crucial safety measure. The objective of such a system is to provide timely warnings to the UAV operator or autonomous flight system to avoid unintentional or unauthorised flights outside the permitted airspace.

The primary goal of this alerting system is to enhance safety by preventing the UAV from accidentally leaving its designated area of operation, avoiding potential collisions and unauthorised flights in restricted airspace, and ensuring compliance with local aviation regulations.

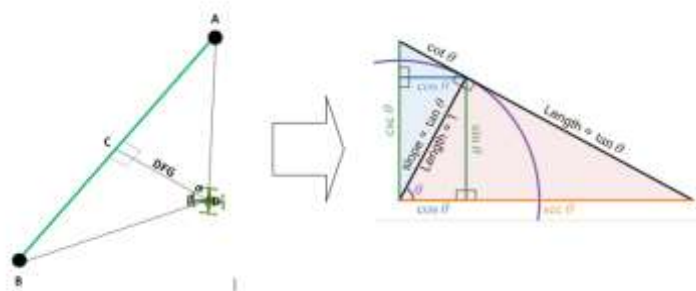
The flight geography of a UAV (Unmanned Aerial Vehicle) refers to the specific geographic area or airspace where the UAV is authorised or intended to fly. It is the designated operational area for the UAV's flight missions. The flight geography is defined by a set of geographic coordinates, such as latitude and longitude, and altitude limitations, which establish the boundaries within which the UAV can operate.

The adjacent area of UAV operation refers to the airspace surrounding the designated flight geography, typically beyond the immediate boundaries. While the adjacent area is not part of the UAV's primary flight geography, it is still relevant and may require consideration for safety and operational purposes.

4.2. Algorithms

The algorithm for designing a warning system for UAVs approaching the boundary of their operating area is described in the next step:

1. Define the waypoints that the drone will fly over as well as restrictions such as Flight Geography (FG) and Adjacent Area (AA). Assuming there are no waypoints that are outside the Flight Geography and the Adjacent Area in this case, the drone flies following the trajectory of the drone.
2. Determine the minimum distance between UAV and flight geography. The DGmin, in this case, is 20 metres.
3. The next step is analysing the distance of the drone to boundaries to determine the parameters. Here are the parameters:



The basic relationship between the sine and cosine is given by the Pythagorean identity:

$$\sin^2 \theta + \cos^2 \theta = 1 \quad (1)$$

4. Determine the direction of the UAV, whether it is flying close to the Geographic Flight line or parallel or opposite to the Geographic Flight line.
5. When the drone is flying in the direction of Flight Geography, it must be measured the time it takes for a drone to travel a certain distance if we know both the distance and the actual velocity (speed) of the drone.

The relationship between distance (d), velocity (v), and time (t) is given by the formula:

$$d = v \cdot t \quad (2)$$

Solving for time (t), you can rearrange the formula as:

$$t = \frac{d}{v} \quad (3)$$

6. In a normal situation, a UAV (Unmanned Aerial Vehicle) is flying parallel to the boundaries of its designated flight geography, and the direction of the drone is opposite to the flight geography line. Before the UAV takes off, the flight plan should be carefully designed to keep the UAV's flight path parallel to the boundaries, maintaining a safe distance from them. This may involve using GPS waypoints or other navigation techniques to guide the UAV along the desired path.

Table 1 Normal Logic Parameter

Illustration	Critical Parameter
	<p>If:</p> <p>DFG > DFGmin, AND UAV track in the opposite direction to FG boundary</p> <p>DFGmin = 20 metres</p>

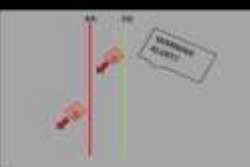
7. Triggering a Flashing caution alert in UAV (Unmanned Aerial Vehicle) operations typically involves setting up certain conditions or parameters that, when met, will automatically generate an alert to the operator. The following is a table that shows the critical parameters along with illustrations of the alarm system from steady caution alert.

Table 2 Flashing Caution Alert Logic Parameter

Illustration	Critical Parameter
	<p>If:</p> <p>DFG ≤ DFGmin, AND UAV trajectory towards or approaching the FG boundary</p> <p>DFGmin = 20 metres</p>

8. Triggering a warning alert in a UAV (Unmanned Aerial Vehicle) when reaching boundaries involves implementing a geofencing system. Geofencing uses GPS or other location-based technologies to create virtual boundaries in which the UAV is allowed to operate. When the UAV crosses these boundaries, a warning alert is triggered, as shown in the following table

Table 3 Warning Alert Logic Parameter

Illustration	WARNING Logic
	<p>If UAV between AA and FG, or UAV outside AA</p>

5. Design of Procedures

When a UAV (Unmanned Aerial Vehicle) approaches the boundaries of its designated flight geography and triggers the alerting system, it is crucial to follow specific procedures to ensure safety, compliance with regulations, and responsible UAV operation. Below are the procedures that the UAV operator or the autonomous flight system should follow when alerted according to the alerting system.

5.1. Flashing Caution Alert Procedures

The safety procedures designed when a flashing caution alert occurs are the operator supervisor or operator system ensures the position of the UAV, the global navigation satellite system shows a green

indication, there is a minimum of 4 GNSS measurements, the main Data Transfer System is in the green position, and the back up stand by. The procedure that must be done by the safety pilot is to control the UAV to loiter and to make the next decision whether to return to the last waypoint or continue to the next waypoint. The procedure can be summarised as shown in detail below:

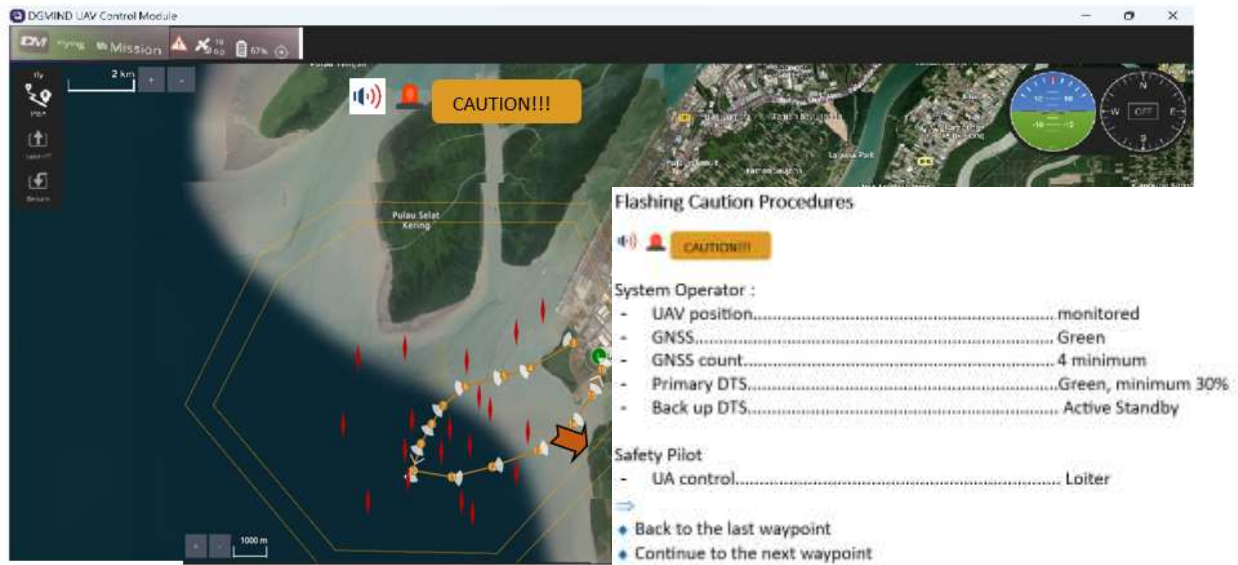


Figure 8 Ground User Interface and Safety Procedures of Flashing Caution Alert

5.2. Warning Alert Procedures

For safety procedures designed when there is a warning alert system, some of the procedures are the same, but there are differences in supervisor operations, such as ensuring that the UAV battery is still sufficient if it has to return home and activating the Flight Termination System. The procedure conducted by the safety pilot is to control the UAV for hold and guided posts so that later a final decision will be made between returning home or making an emergency landing in a safety area as in the following details:



Figure 9 Ground User Interface and Safety Procedures of Warning Alert

6. Simulation

The initial step taken in testing the previously designed warning system design is to create waypoints and boundaries of the UAV operating area, as shown in Figure 7.

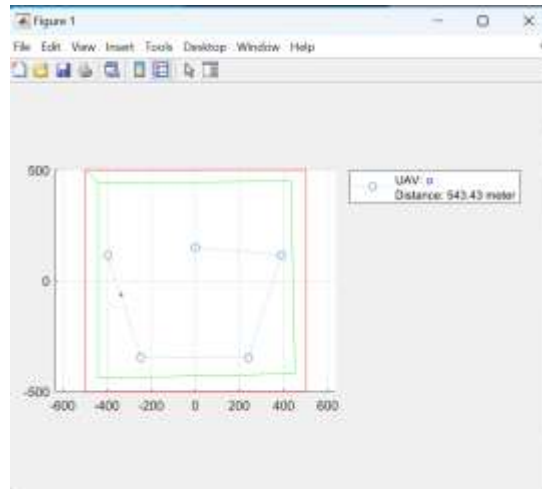


Figure 10 Waypoint and Boundary

Based on the design concept of the warning system carried out previously, Simulations were carried out using MATLAB. From the simulation results, it is found that the warning system will appear when the UAV approaches the boundary of the operating area, as shown in Figure 8.

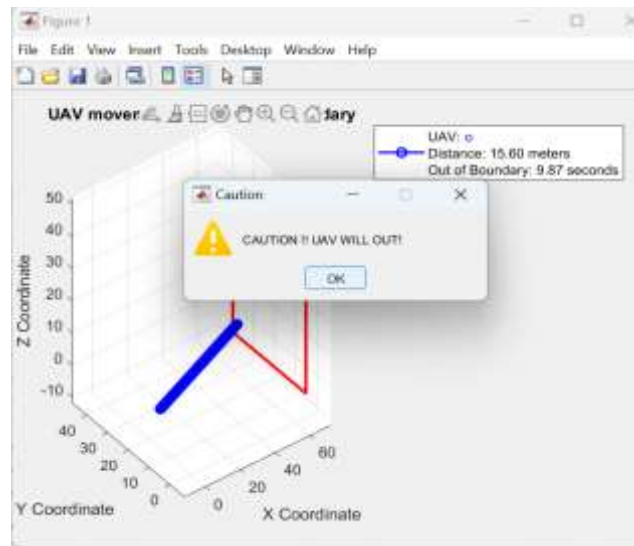


Figure 11 Flashing Caution Alert

Figure 8 shows a simulation of a flashing caution alert triggered when the UAV is less than 20 metres from the boundary with the UAV moving towards the boundary.

If the UAV continues to move towards the boundary and eventually crosses the boundary, it will cause a warning alert to appear stating that the UAV has left the boundary, as illustrated in the simulation Figure 9.

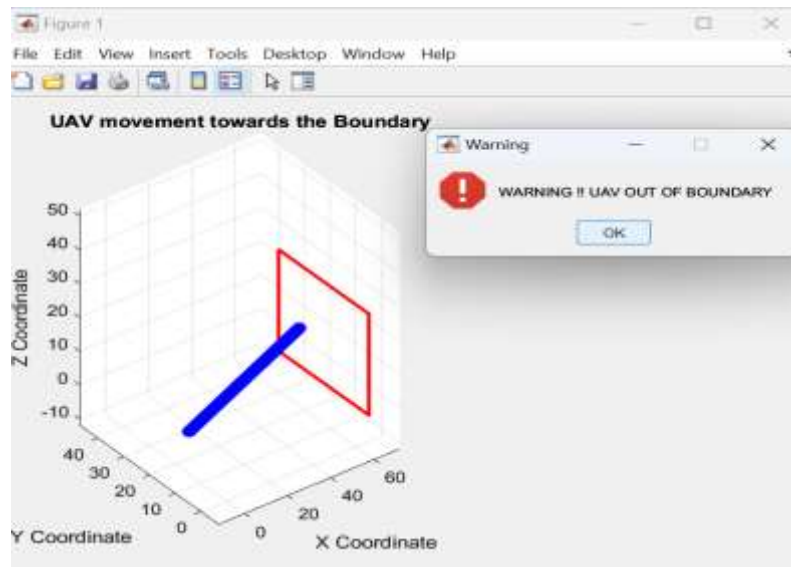


Figure 12 Warning Alert

7. Discussion

In the supervision module design concept proposed to the PEN Aviation company, if an alert appears, the Supervisor Operator will warn the safety pilot to perform the safety procedure as designed. If the safety pilot is performing other tasks, the operator supervisor will take over control of the UAV manually by loitering. From the simulation results, it is determined that the algorithm of the UAV alert system when approaching the boundary of the operating area is applicable. However, in this case, the simulation performed has not taken into consideration the wind speed and direction so it is not included in the mathematical calculations of the warning system.

According to the author, loiter is a solution that can be made automatically so that when the UAV is approaching the boundary, and a flashing caution alert has appeared, the UAV will loiter automatically to wait for the next step to be taken by the safety pilot. In addition to increasing safety, it can also increase time efficiency.

The automatic loiter system can be simulated and seen in Figure 10, where the UAV loiters automatically before reaching and crossing the boundary.

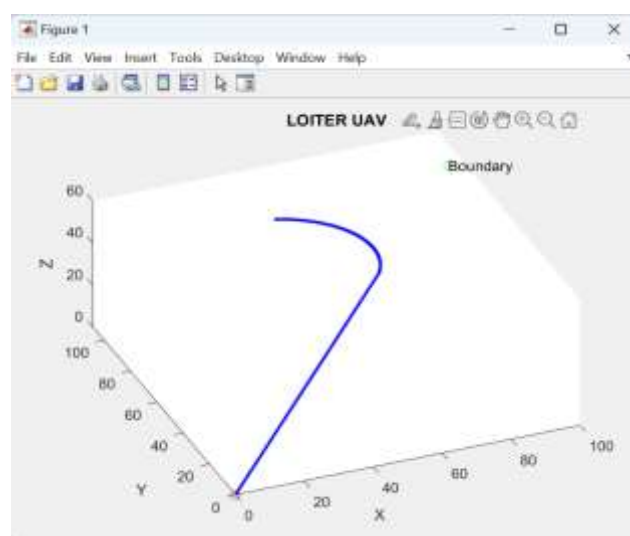


Figure 13 Loiter System Simulation

The second procedure proposed by the author is an automatic hold post system that can be applied to the UAV if it has triggered a warning system, as in Figure 11, accompanied by a message box that is

easily read by the operations supervisor to facilitate and speed up decision making to increase safety in the operation of the UAV.

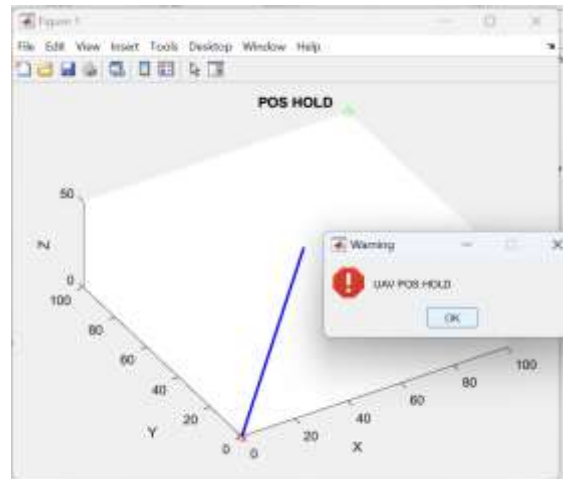


Figure 14 Pos Hold Simulation

8. Conclusions

It can be concluded that:

1. This paper presents the design of a two-level alert system, which includes a flashing caution and a warning alert that notifies the operation supervisor when the UAV is approaching the boundary of the operation area which are the objectives of this research.
2. For each triggered alarm system, the authors drafted a safety procedure that can be implemented by the operations supervisor and safety pilot, which should mitigate and reduce the risk to the safety of the UAV.
3. Two proposals from the author can be used as material for further testing, namely to carry out loiter procedures when flashing caution alerts arise automatically and post-hold procedures when warning alerts are also triggered automatically. Both procedures are still proposed in simulation, which may, in the future, be implemented in flight tests.
4. The design of alert systems and procedures is only conceptual and simulations, so further flight tests with sufficient equipment are recommended to achieve more accurate and specific real test results.

Acknowledgement

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