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AUTONOMOUS MEDICAL AND DISASTER LOGISTICS PLATFORM

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APPROVAL FORM

The undersigned certify that they have supervised the student **RUSSEL T MUZANENHAMO** dissertation entitled **Autonomous Medical And Disaster Logistics Platform** submitted in partial fulfilment of the requirements for the Bachelor of **Software Engineering** at Bindura University of Science Education.

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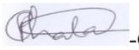

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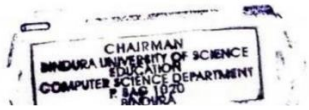

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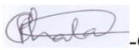

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DEDICATION

This project is dedicated to emergency and disaster response personnel who risk their lives to protect and assist others during times of crisis. Their dedication and willingness to serve communities under difficult circumstances provided the inspiration behind the development of this autonomous drone system.

It is also dedicated to healthcare professionals whose hard work and commitment play a vital role in saving lives and improving the well-being of individuals and communities. Their efforts highlight the importance of reliable and innovative solutions that can support healthcare delivery, especially in areas where access to medical services is limited.

I would also like to dedicate this work to my family for their continuous support, encouragement, and understanding throughout my studies. Their sacrifices, patience, and confidence in my abilities gave me the determination to complete this project.

Finally, this project is dedicated to future innovators, engineers, and researchers who are committed to using technology to solve practical problems and create positive change in society. May this work encourage further exploration and development of solutions that improve the lives of people and communities.

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ABSTRACT

This study successfully designed, developed, and tested an autonomous medical drone platform integrated with a web-based management system for monitoring and controlling delivery operations. The results demonstrated that the drone was capable of transporting medical supplies efficiently while providing real-time mission tracking and data management through the web portal. The prototype proved that drone technology can play a significant role in improving access to healthcare services, particularly in remote, rural, and hard-to-reach areas where conventional transportation methods are often slow and unreliable.

The findings also highlighted the practical benefits of integrating unmanned aerial vehicles with digital technologies to enhance the speed, efficiency, and reliability of medical supply distribution. While limitations such as payload capacity, battery endurance, and weather conditions affected performance during some test missions, the overall system achieved its intended objectives. Therefore, the study concludes that autonomous medical drones have strong potential to support healthcare delivery and emergency response services, contributing to improved patient care and reduced delivery times.

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CHAPTER 1

PROBLEM IDENTIFICATION

1.1 Introduction

Technology has reshaped how essential services are organised and delivered across almost every sector. Among the more consequential developments of the past decade is the rise of Unmanned Aerial Vehicles (UAVs) or drones which began as military tools but have since found roles in disaster response, logistics, surveillance, agriculture, and healthcare.

Getting medicines, vaccines, blood products, and emergency supplies to remote communities has long been one of the harder problems in healthcare delivery, particularly in developing countries. Poor roads, long distances, and thin emergency infrastructure mean that delays are common and the consequences for patients can be serious (Sharma and Sharma, 2024).

Zimbabwe serves as an example of such pressures. Across much of the country roads are unstable, the terrain is difficult to traverse and communities in rural areas are periodically isolated by flooding or other natural hazards. Local clinics are often under-resourced and links to transport services too unstable to ensure reliable supply chains. Where deliveries fall short – whether medicine, samples for testing or emergency supplies – the human toll can be immediate.

This project presents a practical solution using drones. These unmanned vehicles can be dispatched carrying medical supplies directly to inaccessible locations that road networks simply cannot serve efficiently, reducing delivery times and enhancing access (Stierlin, Risch and Risch, 2024).

An Autonomous Medical Logistics Platform, hereinafter referred to as AMLP, is being developed to support healthcare delivery to rural and disaster affected areas, combining autonomous drone operations, a web based management application and data analytics. Its proposed applications include transporting medical supplies, transporting samples for

laboratory testing and transporting emergency equipment, and its use for aerial surveillance in times of crisis.

Other evidence from elsewhere in Africa has proven instructive. Drone delivery schemes across Rwanda and Ghana have already confirmed that it is feasible to deploy the technology in developing country environments, bringing services to those locations that road infrastructure consistently fails to serve (Olatunji et al., 2023). However, it does not only reduce journey times: it can fundamentally change the entire logic of supply chains, allowing clinics to request supplies on an "as needed" basis rather than having to maintain large stocks. The AMLP is being designed for use in Zimbabwe's Eastern Highlands, the specific region of study being Chimanimani, whose prone nature to flash floods provides a reasonable test scenario as it is one of the locations in which road transport systems frequently fail. Improving the healthcare supply chain here, and enhancing its capabilities in the face of emergency, can be readily extrapolated to numerous other similarly situated locations across the region (Campbell et al., 2024).

A key component of the technical architecture of the AMLP, based upon GPS navigation and IoT connectivity and supported by web-based surveillance has been conceived for robust and manageable operation across the region's tough topography (Habibi, Ivaki and Barata, 2025), filling in the critical gaps that its terrestrial equivalent leaves unattended.

1.2 Background to the Study

Access to healthcare facilities is an enormous problem in most rural parts of Zimbabwe. In areas in or around mountainous or very isolated terrains, communities would rely on limited and poor road systems to gain access to either a clinic or a hospital. During periods of extremely bad weather or a natural disaster such as a flood or landslide, it would be impossible to get access to clinics and hospitals leaving communities completely cut off and without much needed medical care.

In Chimanimani district, Eastern Highlands of Zimbabwe several disasters have been experienced revealing how vulnerable the existing transport and logistics system of the country is. The Cyclone Idai Disaster, in 2019, was one of the most devastating natural disasters to hit the country, destroying roads, bridges and communications leaving communities completely

cut off from any help for days. The transportation system would not be able to cope. Medical aid and supplies couldn't reach the needy communities at the time when it was most essential.
Today healthcare logistics heavily rely on road transport, supplying blood samples, vaccines and laboratory samples between various healthcare centers. In rural communities where it is mountainous and a difficult terrain, the system would be very slow and it would not be efficient especially when there's a disaster and also sometimes inefficient and ineffective. Patients from remote areas would have to walk great distances just to reach a hospital while healthcare professionals struggle to deliver supplies.
Drones offer a solution to conventional transport systems. Unlike ground vehicles drones will travel in direct point to point transmission without relying on the road infrastructure. This would make the service very fast and efficient for the delivery of various things especially blood samples, vaccines, emergency medical kits and laboratory specimens.
Other than delivering these necessary items, drones would be used to assess damage during and after disaster struck, and also monitor the state of the infrastructure. Drones can also be equipped with cameras to provide an aerial view of the damaged areas and locate specific locations that require medical help.
The concept of an Autonomous Medical and Disaster Logistics Platform (AMLP) aims to combine these factors in one integrated system. The platform would include autonomous drone systems, a Laravel web-based logistics platform and a central data analysis base for collecting statistics and data, and a system designed for advanced emergency resource mobilisation.

1.3 Statement of the Problem

The accessibility of healthcare services in remote areas in Zimbabwe continues to be a great challenge owing to poor road infrastructure, rugged terrains and extreme proneness to natural hazards. For example, regions like Chimanimani in the Eastern Highlands are prone to flash floods and landslides that cause damage to roads and bridges hence it becomes extremely challenging for health care providers and emergency services to access these affected regions.

During a disaster like Cyclone Idai, communities were completely cut off since major roads have been completely washed away and health care workers found it extremely challenging to deliver urgently required health services, laboratory samples and emergency equipment to these communities hence significantly affecting the efficiency of the disaster response efforts and putting affected communities in great danger. Even under normal circumstances, blood

samples and laboratory samples from rural areas often find it difficult to reach the provincial hospitals for testing and processing as much of the health system relies on the road networks.

Disaster responders are often unaware of the condition of roads and damaged facilities; hence it makes coordination efforts and the response system difficult to operate efficiently. Although drone technology has already proved to be extremely beneficial in health care logistics and emergency response in other parts of the world it is yet to be widely embraced by Zimbabwe. In this regard, this paper seeks to examine how autonomous drone technology coupled with digital logistics systems can enhance health care accessibility and disaster response in the remote areas of Zimbabwe.

1.4 Research Objectives

General Objective

To design and develop an Autonomous Medical And Disaster Logistics Platform (AMLP) that utilizes drone technology to improve healthcare logistics, disaster monitoring, and emergency response in remote areas of Zimbabwe.

Specific Objectives

1. To design a drone-based system capable of delivering medical supplies to isolated communities.
2. To develop a web-based logistics management platform using Laravel for scheduling and monitoring drone deliveries.
3. To assess the effectiveness of using drone-based systems in the delivery medical supplies to isolated communities
4. To integrate camera-based aerial monitoring for disaster assessment and infrastructure monitoring.
5. To develop a centralized database and analytics system for managing and analysing medical logistics data.
6. To design a system that supports advanced emergency resource mobilisation during disaster situations.

1.5 Research Questions

1. How can drone technology improve healthcare logistics in remote areas of Zimbabwe?
2. How can an autonomous drone system assist in delivering medical supplies to isolated communities during disasters?
3. How can a web-based platform improve the management and monitoring of drone-based medical logistics?
4. How can drone technology be used to transport laboratory samples between rural clinics and hospitals?
5. How can aerial imaging from drones assist in disaster assessment and infrastructure monitoring?

1.6 Research Propositions / Hypotheses

H1: Drone-based medical logistics systems can significantly improve the speed of medical supply delivery in remote areas.

H2: Autonomous drone systems can improve healthcare accessibility in communities affected by poor road infrastructure and natural disasters.

H3: Integrating drone logistics with a web-based management platform improves the efficiency of healthcare service delivery.

1.7 Significance of the Study

This study is important because it proposes a technology-based solution to some of the challenges affecting healthcare delivery in remote regions of Zimbabwe. By integrating drone technology with intelligent logistics management systems, the Autonomous Medical And Disaster Logistics Platform (AMLP) has the potential to improve the transportation of medical supplies, laboratory samples, and emergency equipment.

The system can enhance disaster response capabilities by making it possible for the necessary supplies to be delivered to remote regions when an emergency occurs, so as to reduce the waiting time. Furthermore, cameras carried by the drones are also useful in providing overhead view images to the authorities so that they may evaluate the situation during a disaster, the damaged conditions, the locations of communities needed to be saved.

This project also supports the National Development Strategy 2 of Zimbabwe (2026-2030) in modernizing the health system via the utilization of science, technology, and innovation to enhance its capacity to provide adequate health care services with enhanced infrastructure and equal accessibility throughout the rural and remote areas.

Furthermore, the AMLP project is supporting Zimbabwe's Vision 2030, aiming to transform Zimbabwe into an upper middle-income country through technological innovation, digital transformation and efficient public services delivery. By providing a drone-based medical delivery system, this study demonstrates how the advanced technology can bring about sustainable development of the country.

1.8 Assumptions

Based on several assumptions, this study has developed and evaluated the presented system.

1. It is assumed that drone technology is permitted to be used for research and development in a study region after taking proper aviation and related permissions.
2. It is assumed that the relevant institutions of healthcare and organizations can share their respective information that relates to medical logistics (especially laboratory samples and medical items transport) in medical logistic processes.
3. It is assumed that the required hardware and software resources can be available during the process of prototype system development (hardware components for drones, computing devices, internet, software development environment etc.).
4. It is assumed that the internet speed is acceptable to support the web-based logistics platform that allows medical people and system administrators monitoring and managing logistic tasks.

1.9 Limitations / Challenges

Despite the advantages of the proposed system, there are a number of challenges and constraints that may influence the successful implementation and evaluation of the project:

1. One of the main constraints is the regulations concerning the operation of drones. Aviation authorities might impose flight restrictions and operational boundaries which could compromise testing and deployment of the system.

2. Another constraint is the weather. In a region like Chimanimani with mountainous terrains, weather might pose an issue as strong winds, heavy rain and storms could cause operational unreliability and destabilize the drone.
3. The technical issues expected are experience with the upkeep of the drones and system integration. This impacts the lifespan and long-term viability of the drone application.
4. The financial issues may pose problems in large scale deployment due to the cost of purchasing and servicing drones, sensors, and communication equipment.
5. These issues notwithstanding, the research hopes to prove the feasibility and viability of using drones for health logistics and disaster relief.

1.10 Scope / Delimitation of the Research

The design and development of a prototype Autonomous Medical And Disaster Logistics Platform (AMLP) to help healthcare logistics in remote areas and disaster regions will be examined in this research work, the main aspect which will be studied is:

- The use of drones for delivery of medical supplies to isolated communities.
- Transfer of blood samples and lab specimens from the remote clinics to the hospitals.
- The use of drone-mounted cameras for disaster monitoring and aerial assessment.
- The assessment of road infrastructure and disaster-affected areas through aerial imaging.
- The development of a web-based logistics platform using Laravel to manage and monitor drone operations.
- The integration of a database and analytics system to support logistics management and decision making.
- The support of advanced emergency resource mobilisation during disaster situations.

The study will draw upon experiences in the Eastern Highlands province of Zimbabwe, especially in the Chimanimani district which is susceptible to flash floods and natural disasters.

The project scope would include the design and testing of a proof-of-concept prototype, not a national level deployment.

1.11 Definition of Terms

- **Drone (Unmanned Aerial Vehicle – UAV):** A machine, designed to operate without any person inside; can also be piloted remotely for various tasks, such as surveilling, mapping, or delivering cargo.
- **Autonomous System:** A set of integrated technologies able to carry out an operation with minimal or zero human supervision, driven by sensors, software, algorithms, control logic.
- **Medical Logistics:** It defines the process of planning, implementation and control of the movement of medical supplies, medical materials, and laboratory specimens from the origin to the destination.
- **Disaster Monitoring:** This includes the identification of needs for the observation and assessment of disasters and the analysis of disasters impact to communities and infrastructure.
- **Web-Based Platform:** This includes any application that you access via a Web browser.

CHAPTER 2:

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Advances in information and communication technologies have greatly revolutionized the ways organizations carry out services, management of logistics, and responses to emergencies. Among the emerging technologies, Unmanned Aerial Vehicle (UAV) often called drones, have become one of the effective approaches to tackle the problem of transportation and access problems in different fields such as agriculture, environment monitoring, disaster management, surveillance, health and logistics. Integration of autonomous navigation systems, Internet of Things (IoT) techniques, cloud computing, and real-time communication networks have increased the capabilities of modern UAV systems beyond that of conventional military drones.

The problem of healthcare logistics has become a critical issue in a lot of developing countries, especially in rural and remote areas that lack well developed infrastructure. This is due to the long distance, lack of good roads, time limitations as well as poor transportation networks which are critical to the transportation of medical products such as blood, vaccines, medicines and others, and laboratory samples, emergency equipment, among other needs. This scenario often affects timely transportation of these products, thereby impacting negatively on the health and care delivery services offered in such communities.

In recent time, drones have been recognized as a key technological solution to this problem by significantly reducing travel times and overcoming accessibility barriers. According to Nyaaba and Ayamga (2021), drone technology has become indispensable to the healthcare delivery system in recent times because of its potential in overcoming challenges related to geographical barriers and long traveling distances. Similarly, Adu-Gyamfi, Gyasi and Darkwa (2021) pointed out that drone-based healthcare delivery systems has addressed the access to the remote areas and it has proven its effectiveness in providing delivery of medical products such as vaccines, medicines and others in rural Africa.

The capability of UAV systems in managing the monitoring and emergency response actions is also a major point of interest for modern transportation and logistics management systems. Natural disasters such as floods, cyclones, landslides, earthquake, etc, can paralyze

transportation systems and make it difficult for people to access the disaster-tricken areas. The problem is more acute when delivering relief to the affected areas. However, UAVs can provide real time information, analyse damage assessment, monitor the disaster zones, and deliver emergency supplies effectively. Research conducted by Ishiwatari (2024) highlighted the effectiveness of UAVs in disaster monitoring due to the improved situational awareness by providing timely aerial surveillance and data collection in critical situations.

Modern autonomous drone systems are well suited with various sensors to enhance navigation, obstacle avoidance, and mission management. The use of GPS, IMU, LiDAR sensors, barometric sensors and telemetry communication modules are all enabling technologies that makes modern UAVs operation well-efficient and autonomous to carry out various complex mission operations with limited or zero intervention from the human operators.

The integration of IoT based systems provides enhanced capacity for drone based medical logistics management. The integration of the system with the internet will improve the operational transparency, decision making, real-time communication and data logging of all activities carried out by the drone. Gubbi et al. (2013) indicated that Internet of Things enhances the operations with a continuous data generation, information collection and exchange across networked systems.

Currently many integrated systems focus on one operation such as transportation, navigation, or monitoring in separation, while there is also a great need for affordable systems that can be easily deployed and implemented in developing countries where there are insufficient financial resources to deploy complex and expensive systems. There is thus a great need for autonomous drones with an integrated system of obstacle avoidance, autonomous navigation, real-time monitoring and the use of IoT for effective medical supply delivery system and disaster management response system.

This study aims at providing a contribution towards achieving these requirements by developing an Autonomous Medical Supply Delivery Drone with integrated Real-Time Monitoring Web Portal system. The developed system consists of autonomous GPS navigation with the integrated obstacle detection, telemetry communication and an IoT based real time monitoring web portal. This system utilizes both hardware and software technologies and its main objective is to provide efficient transportation of medical supplies.

2.2 Relevant Theory of the Subject Matter

There are numerous theories that demonstrate and illustrate development and utilization of autonomous drone technology in healthcare logistics, including theories related to technology acceptance, logistics optimization, intelligent communication systems, and autonomous decision-making processes. These theories build the foundation of the research to study how these drone technologies could enhance the quality of health services delivery, especially in remote and underdeveloped regions. This study is based on: Technology Innovation Theory, Logistics Management Theory, Internet of Things (IoT) Theory and Autonomous Systems Theory.

2.2.1 Technology Innovation Theory

The core of Technology Innovation Theory centers around the innovation of technology in order to combat specific issues within an organization or the broader community. Technology innovations are said to arise due to the need for a more efficient, effective, and productive solution in place of a conventional practice (Campbell et al., 2024). Innovations offer organizations an avenue through which to improve services, decrease expenditures, and increase efficiency. Healthcare has been taking advantage of technological innovation to help ease issues such as access to care, transport, and emergency response. In a field such as healthcare, which traditionally relies on traditional transportation such as cars or trucks to deliver medicines, blood products, or vaccines, the roads are often congested, impassable, or too far of a distance to travel in a reasonable time. A solution such as drones have proven that the issue of transporting goods quickly via the air can be circumvented and overcome these physical obstacles.

Technology Innovation Theory also claims that the adoption of a new technology rests upon what perceived advantages the users are likely to derive from it. In the field of health care logistics, drones offer increased speed, better access to care, and overall greater efficiency in terms of delivering goods, which are just some of the reasons the drones are beginning to be adopted throughout countries like Ghana and Rwanda.

The autonomous medical supply delivery drone follows the concepts presented within the Technology Innovation Theory as a more advanced approach to providing these services in both emergency situations as well as the overall delivery system. Thedrone employs automatic navigability and a remote monitoring system in order to implement the increase of effective delivery for healthcare purposes in remote locations.

2.2.2 Logistics Management Theory

Logistics Management Theory, to me, is the concept and application of designing, implementing, and controlling the movement of goods, services, and information from a point of origin to a point of consumption in the supply chain. In other words, it’s making sure the right resource is being shipped to the right location, at the right time and in the correct state. In the healthcare system, efficient and effective logistics management is critically important because a delay in the shipping of medical supplies may lead to poor results for patients.

Healthcare logistics is primarily defined as movement of medicines, vaccines, blood, blood products, laboratory samples, and emergency medical equipment through the various healthcare supply chain networks. There is high interdependence of the performance of healthcare logistics networks with the logistics networks themselves in terms of the efficiency of the transportation modes, communication channels, inventories management and the co-ordination between the parties involved in the network. The current logistic systems used in the majority of developing countries' health sector systems face challenges such as poor transportation networks and geographic barriers that lead to the transportation of critical materials late, thus negatively impacting the health sector performance. UAV provides an alternative way that can tackle poor transportation networks and geographical barriers with its independent capability of using transport infrastructure. Stierlin, Risch and Risch (2024) revealed that an improved medical logistics service using drones provides an advancement in both healthcare access and logistics networks resilience.

Logistics Management Theory's importance to the scope of this project arises from the theory's core concept of the efficient utilization of transportation systems. In this regard, a successful drone system can help to optimize the medical logistics systems by minimizing the transportation delay.

2.2.3 Internet of Things (IoT) Theory

Internet of Things (IoT) theory explains the interconnected communication and information exchange between devices over communication networks. The components of an IoT system, as stated by Gubbi et al. (2013), are sensors, communication, data processing and users and all these components interact to develop a smart monitoring and decision system.

Internet of Things technology revolutionised the recent automation by facilitating real-time communication between devices. In drone system, IoT enables data (operational data) collection, transmission, processing and visualization. Sensors on drones continuously gather information about the position, altitude, speed, battery capacity, status and environmental factors, and forward the data over communication network for processing and visualization in central monitoring system.

IoT technologies improve the overall operation performance by facilitating constant monitoring and decision making as suggested by Al-Fuqaha et al. (2015). Collecting and processing real-time data plays an important role in the healthcare logistics, since real-time information access will make impact on system operation.

In the system, IoT theory is used by having GPS sensor, LiDAR sensor, telemetry communication module, and a web application for monitoring system.

2.2.4 Autonomous Systems Theory

Autonomous Systems Theory is the branch of study that involves machines undertaking activities autonomously based on their awareness of their environment by processing incoming information and making decisions through an automated decision-making process. An autonomous system can undertake operation through the use of sensors, an embedded processor and automated decision making algorithms.

According to Austin (2010), an autonomous system is one which continually collects information about the environment it is in, processes the collected information, and reacts accordingly by executing a pre-defined action in response. For UAV operations, Autonomous systems depend upon GPS, IMUs, LiDAR sensors, flight controllers and navigation algorithms for executing autonomous flights.

Using Autonomous systems in a drone system provides a multitude of benefits that are not experienced with manually operated drone systems, such as better consistency, fewer human

errors, safer flight operation and higher operational efficiency. According to Beard & McLain (2012), "autonomous navigation systems can facilitate a drone to autonomously complete its mission with the minimized work load for a pilot."

The application of Autonomous Systems Theory to the proposed autonomous medical delivery drone is facilitated by the provision of an autonomous navigation system, a capability that will enable it to automatically detect objects, plan routes and then execute its mission. The reduction of reliance upon continuous human operation has been implemented in order to increase the efficiency of healthcare logistics operations in a safer and reliable manner.

As a body, the theories of Technology Innovation theory, Logistics Management theory, Internet of Things theory and Autonomous Systems Theory form the theoretical framework upon which this research is conducted. Each of these theories contributes a component explanation to the overall argument on drone implementation for healthcare logistics.

2.3 Empirical and Theoretical Literature Review

2.3.1 Evolution of Unmanned Aerial Vehicle Technology

Unmanned Aerial Vehicles (UAVs), often referred to as drones, have undergone remarkable advancements since their conception as exclusively military systems. Originally employed in the armed forces for surveillance, intelligence and reconnaissance (ISR) operations, today, advancements in the field of computing technologies, communication systems, navigation algorithms and sensor integration have opened new avenues and extended their capabilities into civil domains, such as agriculture, environmental monitoring, disaster management, inspection of infrastructure, delivery logistics, and medicine delivery.

As reported by Austin (2010), present-day UAV systems are equipped with advanced flight controllers, navigation systems, communication capabilities, and processing powers allowing them to fly autonomously. Modern UAVs demonstrate higher levels of flight stability and reliability, while at the same time permitting a higher degree of operational accuracy. Similar arguments were made by Beard and McLain (2012) regarding enhancement of the intelligence capacity of drones; their research focuses on embedded systems and sensor technologies enabling autonomous and complex task execution with minimal human interaction.

Valavanis and Vachtsevanos (2015) also indicate that the evolution of artificial intelligence and machine learning technologies has increased the autonomy of the systems. Modern UAVs have the ability to perceive their environment, detect and avoid obstacles, optimize their routes and consequently autonomously navigate without any human assistance. These characteristics make UAVs a feasible candidate for demanding services such as delivery logistics in the health care sector. The dramatic reduction in costs associated with UAV hardware have also made drone technology more feasible for developing regions with insufficient transportation infrastructure. The autonomous delivery drone for medical supplies outlined below builds upon these factors and utilizes an autonomous control system.

2.3.2 UAV Healthcare Logistics Frameworks

Logistics in healthcare refers to the supply, movement and management of pharmaceuticals, vaccines, laboratory samples, blood and emergency supplies within healthcare systems. Reliable healthcare logistics are needed to ensure adequate stocks are available within healthcare settings and can be efficiently supplied to affected areas in emergency situations.

Problems with transport delays, poor road conditions, geographical barriers and lack of resources often challenge healthcare logistics. This can have particularly drastic implications for healthcare facilities within remote or geographically isolated locations in developing nations.

Stierlin, Risch and Risch (2024) reported how drone-based logistics greatly increased transport efficiency reducing the delivery times and increasing access to remote areas. In their study, they were able to show that UAVs are reliable in transporting medical supplies regardless of conventional transport infrastructure.

Campbell et al. (2024) provided a systematic review on drone applications in healthcare and determined that drones improve resilience, efficiency and responsiveness of healthcare supply chains. The authors confirmed that drones are useful when it comes to quick transportation of urgently needed medical supplies such as blood products, vaccines and emergency medicines.

Amukele et al. (2017) used experimental testing on the transporting of medical samples with UAVs to show how samples transported using the UAV technology were clinically comparable

to those transported by conventional methods for journeys over 250 kilometers. This provides strong empirical evidence that drone technology is an alternative form of transport when considering laboratory samples in healthcare logistics.

Eichleay et al. (2019) created a decision-support framework for assessing when drone systems are appropriate in healthcare supply chains and concluded that UAVs are a potential effective solution to last-mile transportation challenges in rural and under-resourced settings.

Despite many advantages of using UAVs, there are other issues in the use of healthcare drones, such as limited battery life, limited weight capability of drones, bad weather conditions affecting flights, regulations within the transportation networks and an inability to integrate with existing healthcare infrastructures. These issues indicate further research needs to be carried out regarding the most beneficial combination of different logistic systems when considering healthcare systems.

The reviewed literature strongly supports the usefulness of UAVs for health care logistics. To implement them successfully, adequate integration of navigation systems, communications technology, monitoring systems and healthcare supply chain processes must be achieved.

2.3.3 Medical Drone Delivery Systems in Africa

Africa has emerged as one of the leading regions in the adoption of drone technology for healthcare logistics. The continent faces significant healthcare delivery challenges including poor transportation infrastructure, limited healthcare resources, and geographical barriers that affect access to medical services. These challenges have encouraged governments and healthcare organizations to explore innovative solutions capable of improving healthcare accessibility.

Medical Drone Delivery in Rwanda

Rwanda is considered one of the best examples of successful application of drones in delivery of healthcare services. The use of autonomous drones to transport blood products, vaccines and other urgent medical materials to health centers across the country is being undertaken through partnership between the government and Zipline.

According to Nyaaba and Ayamga (2021), the Rwandan drone delivery program has reduced transportation time and increased access to medical facilities and that it provides a service that is currently in place whereby health centers are now getting necessary materials from hours to minutes allowing better and rapid emergency response and treatment of patients.

Nyaaba and Ayamga also add that drones in Rwanda have also been shown to have reduced waste of blood in blood transfusion stations through improved logistics and management of blood and health centers are now requesting on demand to reduce the storage space needed to maintain a sufficient amount of blood, hence also reduces waste due to expiry.

Olatunji et al. (2023) further observes that the drone delivery program in Rwanda is one that has achieved international recognition in Africa as a role model for application of innovation in health delivery which has been established as having been shown that autonomous drone system can effectively be operational in developing economies providing tangible improvements in logistics in health.

Notwithstanding, there are certain limitations in drone delivery which include operating costs, regulatory requirements, required maintenance and weather disruptions and that these may also have a bearing on the long-term feasibility and scalability of the operation in Rwanda.

Medical Drone Delivery in Ghana

Similarly, Ghana has invested in the application of drone technology to overcome its healthcare logistics problems. The country has started utilizing drone delivery systems to tackle challenges involved in delivering vaccines, blood products, laboratory samples and emergency medicines to distant healthcare facilities.

Adu-Gyamfi, Gyasi and Darkwa (2021) concluded that the drone delivery system has improved healthcare accessibility in remote locations through shortening delivery time and enhancing the reliability of medical supply chain. According to their study, healthcare facilities in remote locations saw an increased access to emergency medical supplies after drone delivery service had been introduced.

Moreover, Olatunji et al. (2023) found that healthcare providers generally hold positive attitudes toward drone technology and recognize the role of drones in overcoming poor medical emergency response and medical care services. The rapid delivery speed was a factor which

was stated to be critical to patient well-being where delays may compromise the result of the medical treatment.

Although Ghana is one of the developing countries where drone delivery system in healthcare has proven useful, authors also listed many of the obstacles such as high operating cost, necessity of infrastructure, efficient communication network and regulation compliances.

Lessons from African Healthcare Drone Systems

The case studies from Rwanda and Ghana are beneficial to the planning of healthcare drone delivery systems in developing countries, both of which indicate the positive effects UAV systems have on healthcare access, delivery time, and emergency response in developing countries. However, the literature also indicates the importance of supporting systems, which include communication networks, monitoring systems, navigation platforms, and system operation management models. UAV assisted delivery system is more than simply delivering items; a reliable system must also be capable of monitoring its operations, managing missions and ensuring reliability of the system. The finding is relevant to the study since it establishes the possibility of drone delivery in healthcare logistics. The development of autonomous navigation, obstacle detection, telemetry communication and real-time monitoring capabilities of the proposed system aim at improving some of the identified shortcomings of existing healthcare drone delivery systems.

2.3.4 Internet of Things and Autonomous Drone Systems

IoT has emerged as a backbone for the construction of intelligent autonomous systems. IoT is the interconnectivity of all devices which collects, exchanges and processes the data using the communication networks. Incorporating IoT system into the UAV system enhanced many of the operating efficiency, monitoring, and decision-making characteristics.

Gubbi et al. (2013) described an IoT system comprises sensing devices, communication infrastructure, a data processing platform and the user interface which works together in performing intelligent operation. IoT system allows for real time monitoring and control by transmitting the gathered information from interconnected devices.

Sensors onboard the drone are interconnected with on-board sensors, flight controllers, telemetry system, cloud platforms and monitoring application. The information is gathered

through the sensors onboard the drone, where the information such as location, altitude, battery status, speed, weather and operating condition are gathered continuously. These data are sent to monitoring application where it is further processed and can be viewed by users.

Al-Fuqaha et al. (2015) stated that IoT architectures could enhance a system's reliability and efficiency in operation by ensuring continuous data flow, and supporting intelligent decision-making by empowering users with precise information on system performance.

As part of healthcare logistics, IoT is particularly important due to its role in real-time monitoring of delivery operations. It facilitates effective communication within the supply chain, allowing healthcare organizations to obtain information on current deliveries and operational status.

The system here proposed uses IoT in sensing, telemetry communication modules and also through the use of a web application for monitoring of the operation.

2.3.5 GPS Navigation Systems

One of the most crucial capabilities within current UAV systems is autonomous navigation. These navigation systems allow drones to achieve awareness of their position, execute predetermined paths, and fly to predetermined destination points without direct human input.

The global positioning system (GPS) is very important in the autonomous functioning of a drone, because it offers a highly precise way to obtain positional information. It has made autonomous navigation through providing drones with a great degree of accuracy for location determination Austin (2010). GPS systems work by communicating with the satellites which orbit the earth, in order to determine location coordinates. Using these coordinates, drones can navigate to certain coordinates that have been plotted into their flight plan, and keep along a given route. Beard and McLain (2012) point out that GPS systems can be used for route planning, mission execution, and location keeping, all important when delivering items. Despite the strengths, it has been noted by researchers that signal jamming and atmospheric interference could reduce accuracy as well as low satellite access in highly populated urban areas, however GPS has been one of the most reliable and consistently used systems to-date. This drone uses GPS to facilitate route planning and also to enable mission tracking and location reporting on the web interface.

2.3.6 LiDAR Technology and Obstacle Detection

Obstacle avoidance is a critical requirement for autonomous drone systems because collisions can result in mission failure, equipment damage, and safety risks. To address this challenge, modern UAV systems increasingly utilize advanced sensing technologies capable of detecting obstacles and supporting autonomous navigation.

Obstacle detection is one of the most useful solutions for obstacle detection by an autonomous system using Light Detection and Ranging (LiDAR) which, as stated by Shan and Toth (2018), emits laser beams at the environment and measures the time the reflection returns, thus estimating distance. A 3D map of the surroundings is obtained from the LiDAR technology.

In a study made by Fotouhi et al. (2019), an autonomous navigation system that uses better sensing technology decreased risks of collisions and improves flight security. According to the authors, an obstacle detection system is a crucial component for an autonomous UAV system.

In a study by Habibi, Ivaki and Barata (2025), it is observed that obstacle avoidance system based on LiDAR greatly enhances autonomous navigation performance by decreasing the risk of collisions and improving flight safety. The systematic review indicates that obstacle detection technologies are essential components in autonomous UAV systems.

For healthcare logistics operation, the function of obstacle avoidance is especially useful in the environment that involves buildings, trees and other uneven land surface. The ability to detect and avoid obstacles directly ensures success of mission and security of operation.

This system employs LiDAR technology which assist in autonomous obstacle detection and avoidances thus improving navigation security and safety in drone delivery.

2.3.7 Telemetry Communication Systems

In terms of effective operation of UAVs it is very important that they have reliable communication system. The telemetry communication system is used to transmit the information between the UAV and the ground control system to monitor the mission progress and to check how the systems are working on a real time basis. According to Gupta, Jain and Vaszkun (2016) reliability is among the most significant factors influencing UAV mission success. The telemetry systems are designed to stream information such as the location of the

UAV (GPS co-ordinates), its altitude and the level of battery charge, speed, flight modes and the overall progress of the mission at all times. According to Meier et al. (2012) the MAVLink has emerged to be among the best communication protocols for autonomous drone systems; the communication between the flight controller, ground control system and other monitoring application using this protocol has an extremely low communication overhead. The situational awareness is enhanced by use of the telemetry system that provides continuous stream of operational information; in this way failure of any system as well as problems occurring due to communication or mission threats can easily be noticed in real time. Using the telemetry communication, the developed drone would transmit the flight data from the UAV to the monitoring portal where the users would be able to view the progress of the mission and monitor the operation performance on a real time basis.

2.3.8 Web-Based Monitoring Systems

Increased complexity of autonomous UAV operation brings the need for a powerful monitoring and control platform. Web-based monitoring platforms offer unified interfaces where users can monitor drones operations, analyze the performance of the system and manage mission. As Khan & Salah describe, the operation efficiency is increased through greater operational visibility and improved decision making provided by a web-based monitoring system that provide real time data such as flight path, coordinates, battery status, altitude and mission state. Campbell et al report that adding monitoring abilities to drones platform improves mission visibility and operational control as well as enables management at early stages to solve future potential problems. Monitoring platforms can add analytics and allow performance analysis, route optimization and predictive maintenance to further increase efficiency and reliability in the long term. The portal developed in this paper follows this concept to enable monitoring of drones operations, visualization of telemetry, monitoring of battery state, as well as management of the delivery mission.

2.3.9 Relationship Between IoT and the Proposed System

The presented Autonomous Medical Supply Delivery Drone is a practical implementation of how IoT technology and autonomous UAV operation could coexist. This autonomous UAV is made up of connected sensors, communications devices, processing units and a web interface which work together to ensure that medical logistics are optimized. The GPS module ensures that accurate location data is fed to the flight system for autonomous flight, while the IMU

gives feedback about the drones' orientation and position for stabilisation. The LiDaR technology allows for collision avoidance in the air and at the landing site. Sensors that report battery power and remaining battery are also included, as are telemetry communication devices for linking the drone to the web server.

Information from the sensors on the autonomous drone are relayed through telemetry communication to the web portal where data is analysed, stored and displayed to users of the system. The operator of the system is then able to monitor the position of the drone, the status of its mission, its flight performance, and how to optimize its performance.

2.3.10 Research Gap

As identified by previous studies, advancements are being made in the integration of UAV technology in logistics of healthcare, disaster monitoring and disaster response. Previous work has revealed that drone technology can enhance the transportation efficiency, accessibility of health and promote awareness of the current situation.

Some gaps that are present in current body of literature include: (1) Most studies focused on just the delivery operations of drones, not the total monitoring and management systems that are required. (2) Little attention has been paid to the integration of LiDAR based obstacle detection system on medical delivery drone. (3) Proprietary solutions seem to be preferred for actual implementation, this is not beneficial in low-resource environments.

There is little or no research conducted on the autonomous delivery system in developing country context like Zimbabwe. Current work has been limited to huge delivery project in Rwanda and Ghana. It is crucial to design for local conditions and constraints.

This research proposes an Autonomous Medical Supply Delivery Drone System incorporating the components of GPS, LiDAR based obstacle detection, telemetry communication system and a web based real time monitoring system. This proposed system combines the transport, monitoring and autonomous navigation into one platform.

2.4 Chapter Summary

This chapter presented a thorough review of the existing theoretical and empirical literatures in the areas of UAV, logistics in healthcare sector, automated navigation system, Internet of

things (IoT), communication system, and web-based monitoring systems. The literatures discussed the main theories relevant for this study which includes; The Theory of Technological Innovation, Logistics Management Theory, Internet of things Theory, and The Theory of Autonomous Systems.

The literature further indicated that drone technology has a great potential for improving the logistics of health sector by enabling fast and easy transport of medical supplies thereby bridging the gaps of medical delivery and also helping emergency response services. Examples from Rwanda and Ghana indicate that autonomous drone system is able to facilitate healthcare services in developing countries.

The literature also emphasise on the needs of integration of IoT, GPS, LiDAR, telemetry and web-based monitoring system to enable the autonomous drone system to operate smoothly. It concluded by showing the loopholes in the existing studies that make this study imperative. Chapter two deals with the methodology of research adopted.

CHAPTER 3:

RESEARCH METHODOLOGY

3.1 Research Design and Data Collection Approaches

3.1.1 Research Design

The study used a Design and Development Research (DDR) paradigm. DDR is most often used within the domains of engineering and computer science where the intent is to design, build, test, and analyse a technical product, system, or process to meet a problem or need in the real world.

This DDR paradigm was identified as the most appropriate approach since the intended design of this study was a workable autonomous drone delivery system capable of transporting medical supplies, and providing continuous real-time operational monitoring via the utilization of IoT devices. Unlike the traditional surveys that collect respondents' opinion, this study would aim to create and analyse a prototype.

The study was conducted in several planned steps:

1. Requirements Analysis
2. System Design
3. Prototype Development
4. System Integration
5. System Testing
6. Evaluation and Analysis

Requirements analysis - The literature on autonomous drones, IoT, medical logistics, and web-based monitoring system were used to collect the necessary information for defining the functional and non-functional requirements of the proposed system.

Design - The system architecture, database scheme, communication infrastructure, and hardware interfaces were designed.

Prototyping - The drone hardware components were assembled, flight controller was setup, sensors were interfaced, and the web portal was developed in Laravel framework.

System integration - To establish effective communication among the drone, onboard computer, sensors, telemetry and the web portal.

Testing & Evaluation - To analyze whether the designed system fulfills the functional and performance requirements and objectives.

The Design and Development Research approach enabled iterative testing of the prototype in order to improve the system until it was successfully able to achieve the desired functions.

3.1.2 Data Collection Approaches

To collect data, the system developed, the autonomous drone delivery system, was physically tested and assessed. The research, in the sense that it is technological based and aimed to develop a technology, generates its data directly from system execution, software testing, flights and sensor readings.

Various testing methods have been adopted:

Black Box Testing

Black Box Testing was conducted to evaluate the functionality of the system without examining its internal source code. The purpose of this testing approach was to determine whether the developed system produced the expected outputs when users interacted with different modules.

The testing focused on the following functionalities:

- User authentication and login
- Mission creation and scheduling
- Real-time drone monitoring
- GPS tracking
- Flight log generation
- User management

For each test case, expected outputs were defined and compared with actual system outputs. Successful execution indicated that the system met the specified functional requirements.

White Box Testing

To determine the functionality of internal logic and source code of the web portal White Box Testing was applied. This kind of testing looks at execution paths, conditions, loops, data communication with databases and error processing.
The tests were performed in order to achieve the reliable performance of the components of the application in various conditions. Main parts considered while performing this test type were authentication components, mission control module, interfaces and databases.

Integration Testing

Integration Testing was performed to verify communication and interoperability among various hardware and software components.

The testing evaluated interactions between:

- Pixhawk Flight Controller and Raspberry Pi
- Raspberry Pi and GPS Module
- Raspberry Pi and LiDAR Sensor
- Raspberry Pi and Ultrasonic Sensor
- Raspberry Pi and Telemetry Module
- Telemetry Module and Laravel Web Portal
- Laravel Application and MySQL Database

The objective was to identify and resolve communication failures, synchronization issues, and compatibility challenges before system deployment.

Flight Testing

Flight Testing was conducted under controlled outdoor conditions to evaluate the practical performance of the autonomous drone.

The tests assessed:

- Take-off capability
- Flight stability
- Autonomous navigation
- Obstacle detection and avoidance
- Payload transportation
- Landing accuracy
- Mission completion success rate

Data generated during flight missions provided valuable information regarding the operational effectiveness of the proposed system.

Performance Testing

Performance Testing was used to assess the responsiveness and efficiency of the system during operation.

The following parameters were evaluated:

- Web portal response time
- Sensor update frequency
- GPS refresh rate
- Telemetry communication reliability
- Data transmission speed
- System responsiveness

The results obtained from these tests were used to evaluate whether the system was capable of supporting real-time medical delivery operations.

3.2 Population and Sample

3.2.1 Population

The population for this study consisted of all operational processes, hardware components, software modules, communication systems, and generated data associated with the autonomous drone delivery system.

Unlike social science research where populations consist of human participants, this technology-based study defined the population in terms of system activities and operational events.

The population included:

- Autonomous flight operations
- Sensor-generated data
- Mission execution records
- Telemetry communication logs
- Web portal transactions
- Database records
- Drone monitoring activities

The population also included all functional modules developed within the system, such as user management, mission management, drone tracking, and flight logging components.

3.2.2 Sample

A purposive sampling technique was employed in selecting representative system operations for testing and evaluation.

Purposive sampling was considered appropriate because specific tests and missions were deliberately selected based on their relevance to the objectives of the study.

The sample consisted of:

- Three autonomous flight missions
- Black Box Testing scenarios
- White Box Testing cases
- Integration Testing procedures
- Performance Testing measurements
- Sensor data generated during flight operations

The selected sample provided sufficient information for evaluating the functionality, reliability, efficiency, and effectiveness of the developed system.

3.3 Research Instruments

Research instruments refer to the tools and equipment used to collect data throughout the study. In this project, both hardware and software instruments were utilized to develop, monitor, test, and evaluate the autonomous drone delivery system.

3.3.1 Hardware Instruments

F450 Drone Frame

The F450 frame served as the structural foundation of the drone. It provided mounting points for all hardware components and ensured stability during flight operations.

Pixhawk Flight Controller

The Pixhawk Flight Controller was the central part of the system managing the flight. Its role was to ensure the flight stability and the automatic navigation along the waypoints.

Raspberry Pi 4

The Raspberry Pi served as the onboard computer and the IoT gateway. It was responsible for gathering information from sensors, processing data and transferring operational data through communication links to the web portal.

GPS Module

The GPS module provided real-time geographical positioning information used for navigation, route planning, and location tracking.

LiDAR Sensor

The LiDAR sensor was used for obstacle detection and distance measurement. The sensor utilized laser technology to identify obstacles and improve flight safety.

Ultrasonic Sensor

The Ultrasonic sensor provided short-range obstacle detection and assisted in landing operations by measuring distances between the drone and surrounding objects.

Telemetry Module

The telemetry module enabled wireless communication between the drone and the monitoring portal. It facilitated real-time transmission of flight information.

Lithium Polymer (LiPo) Battery

The LiPo battery supplied electrical power to all drone components during flight operations.

Brushless Motors and ESCs

Brushless motors generated the thrust required for flight, while Electronic Speed Controllers (ESCs) regulated motor speed according to commands from the flight controller.

Medical Payload Compartment

The payload compartment was designed to securely hold and transport medical supplies during delivery missions.

Component	**Purpose**
F450 Frame	Structural support
Pixhawk Flight Controller	Flight control and navigation
Raspberry Pi 4	IoT processing and communication
GPS Module	Position tracking
LiDAR Sensor	Obstacle detection
Ultrasonic Sensor	Short-range distance measurement
Telemetry Module	Data communication
LiPo Battery	Power supply
Brushless Motors	Flight propulsion
ESCs	Motor control
Payload Compartment	Medical supply transportation

Table 1:Hardware Components Used in the Study

3.3.2 Software Instruments

Several software tools were used during system development and testing.

Laravel Framework

Laravel was used to develop the web portal responsible for mission management, user management, and drone monitoring.

PHP

PHP was used to implement backend functionalities and communication processes within the portal.

MySQL Database

MySQL was used to store mission records, user information, telemetry data, and flight logs.

Mission Planner

Mission Planner was used for drone configuration, waypoint planning, and flight monitoring.

MAVLink Protocol

MAVLink was used as the communication protocol between the drone systems and the monitoring platform.

Visual Studio Code

Visual Studio Code served as the primary development environment for software implementation.

Git

Git was used for source code management and version control throughout the development process.

Software	Purpose
Laravel	Web portal development
PHP	Backend programming
MySQL	Database management
Mission Planner	Flight configuration
MAVLink	Communication protocol
Visual Studio Code	Software development
Git	Version control

Table 2:Software Components Used in the Study

3.3.3 Testing Instruments

The following testing techniques served as instruments for collecting evaluation data:

- Black Box Testing
- White Box Testing
- Integration Testing
- Performance Testing
- Flight Testing

These testing instruments enabled the collection of quantitative and qualitative data relating to system functionality, performance, reliability, and operational effectiveness.

3.3.4 Implementation

System Prototype and Interface Presentation

The system prototype that was developed was also a tool for the research. The system prototype was comprised of:

- A web application built on Laravel
- Drone hardware platform
- Pixhawk flight controller
- Raspberry Pi companion computer

- GPS modules
- Telemetry communication systems

By using the system prototype, hands-on experiments could be performed and real time operational data could be collected.

The developed system interfaces were also used while conducting the usability test and the system evaluation.

System Flowchart

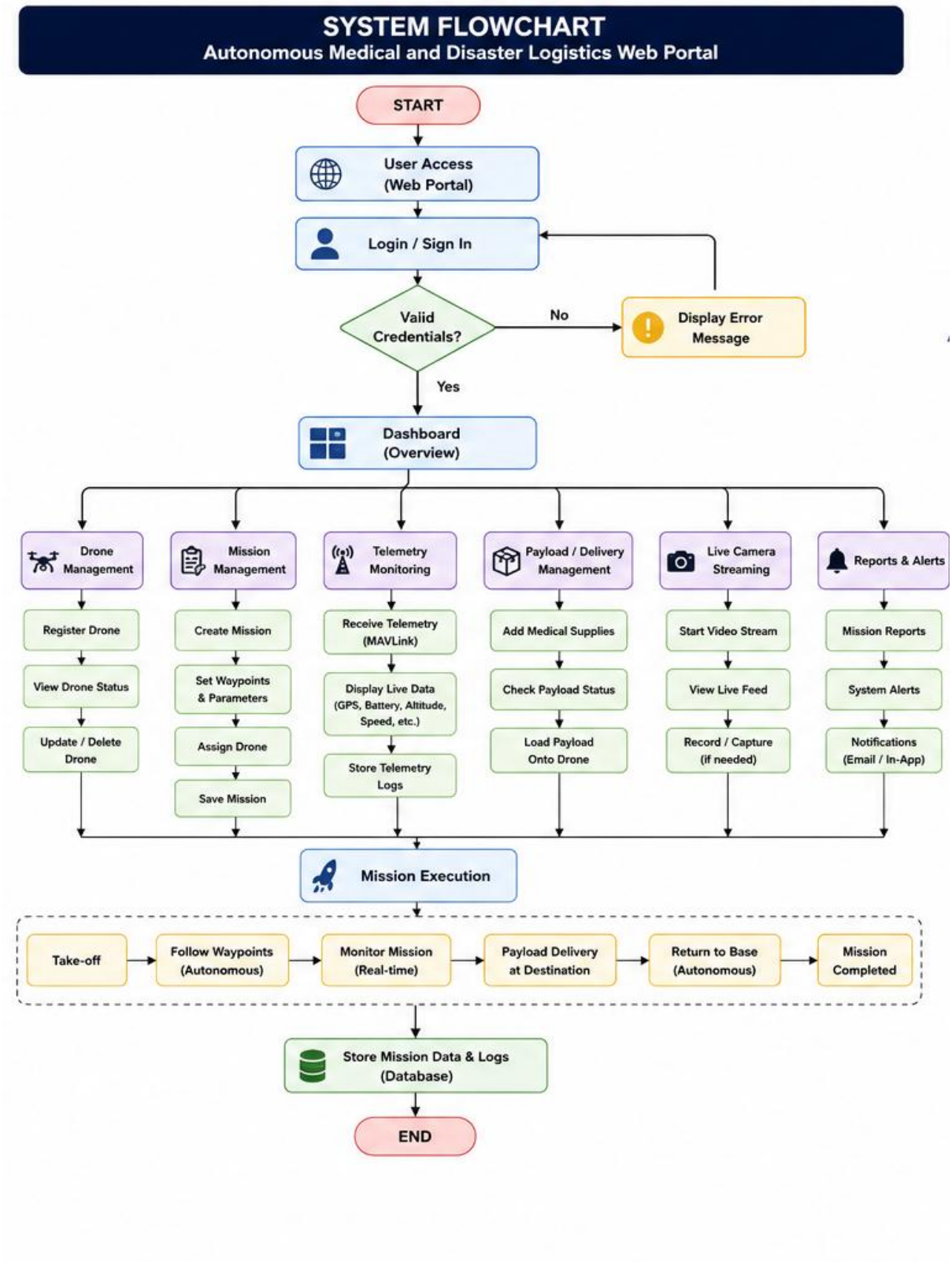

Figure 1:System flowchart

System Use Case Diagram

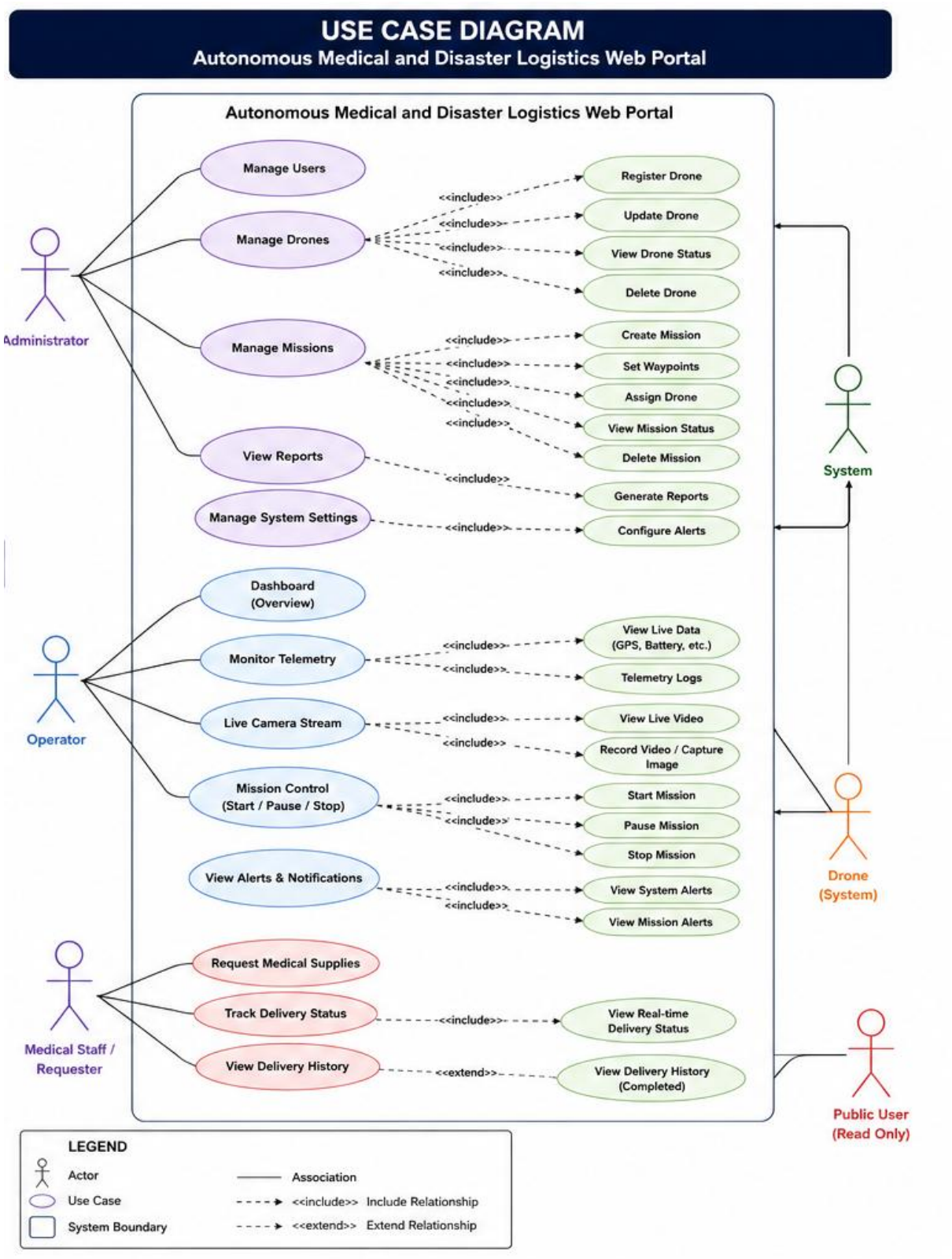

Figure 2:System Use-Case Diagram

Login Interface

Login interface ensures a secure login procedure to the permitted users for using the platform. The user must enter proper credentials to access the dashboard and mission management parts.

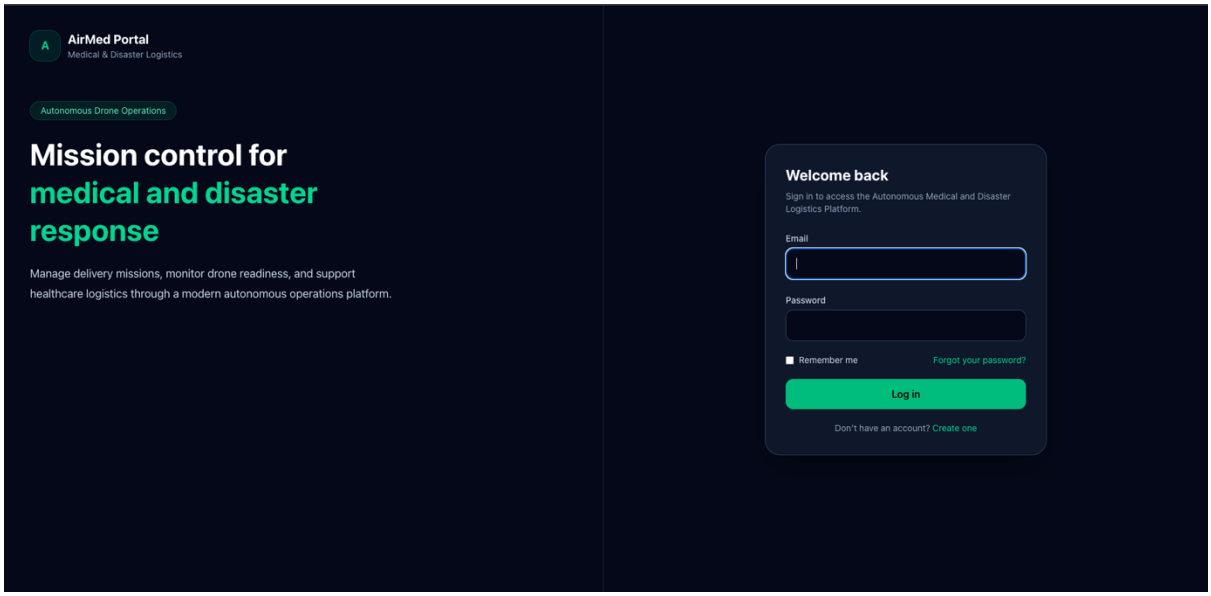

Figure 3Login interface of the Autonomous Medical and Disaster Logistics Platform

Dashboard Interface

The dashboard is very easy and provides an overview of the following:

- Drone missions
- Telemetry statistics
- Mission status
- System alerts

The dashboard therefore, enables administrators and operators to monitor system activities in real time.

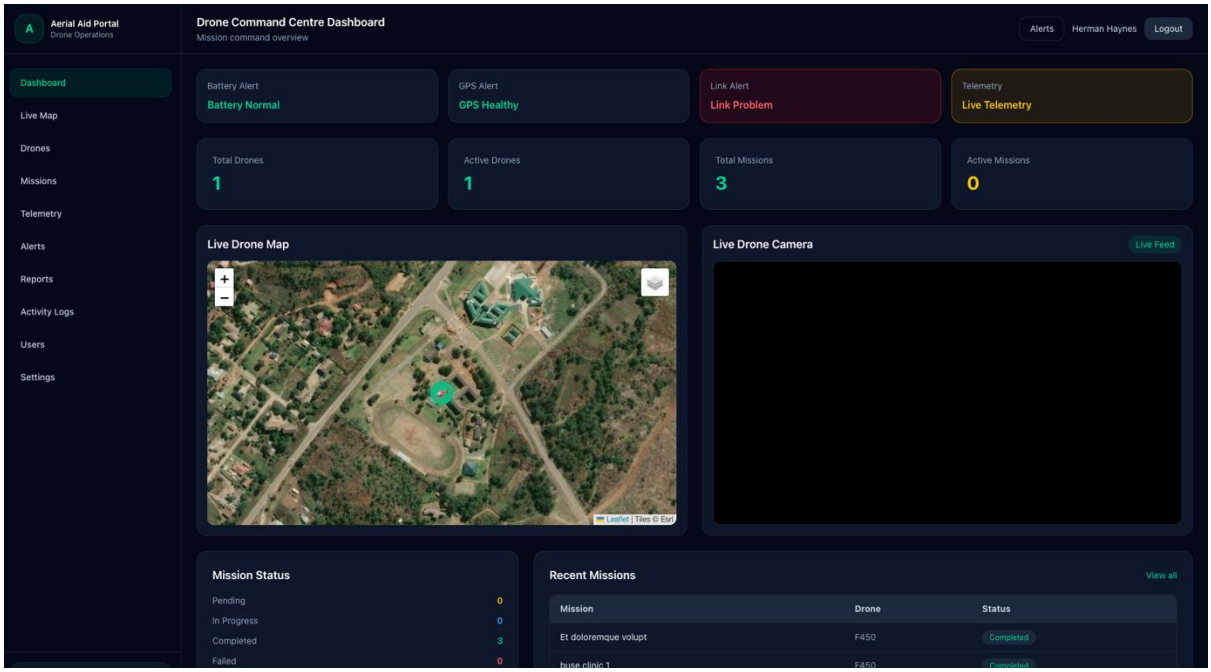

Figure 4:Main dashboard interface showing mission overview and telemetry statistics.

Mission Planning Interface

The mission planning module allows administrators to:

- Create missions
- Configure GPS coordinates
- Set mission altitude
- Assign drones to missions

This module supports automated mission execution and route planning.

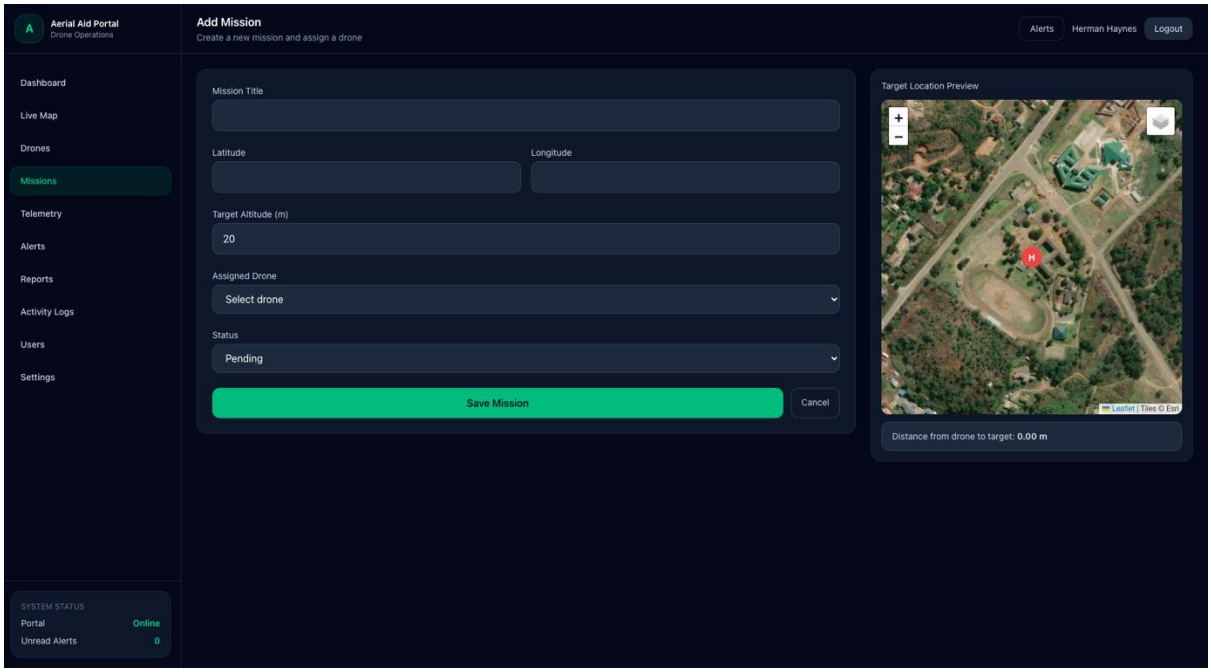

Figure 5:Mission planning module used for configuring drone delivery operations.

Telemetry Monitoring Interface

The telemetry monitoring interface displays:

- GPS location
- Battery levels
- Drone altitude
- Flight mode
- Mission progress

The interface enables real-time monitoring of drone operations during flight missions.

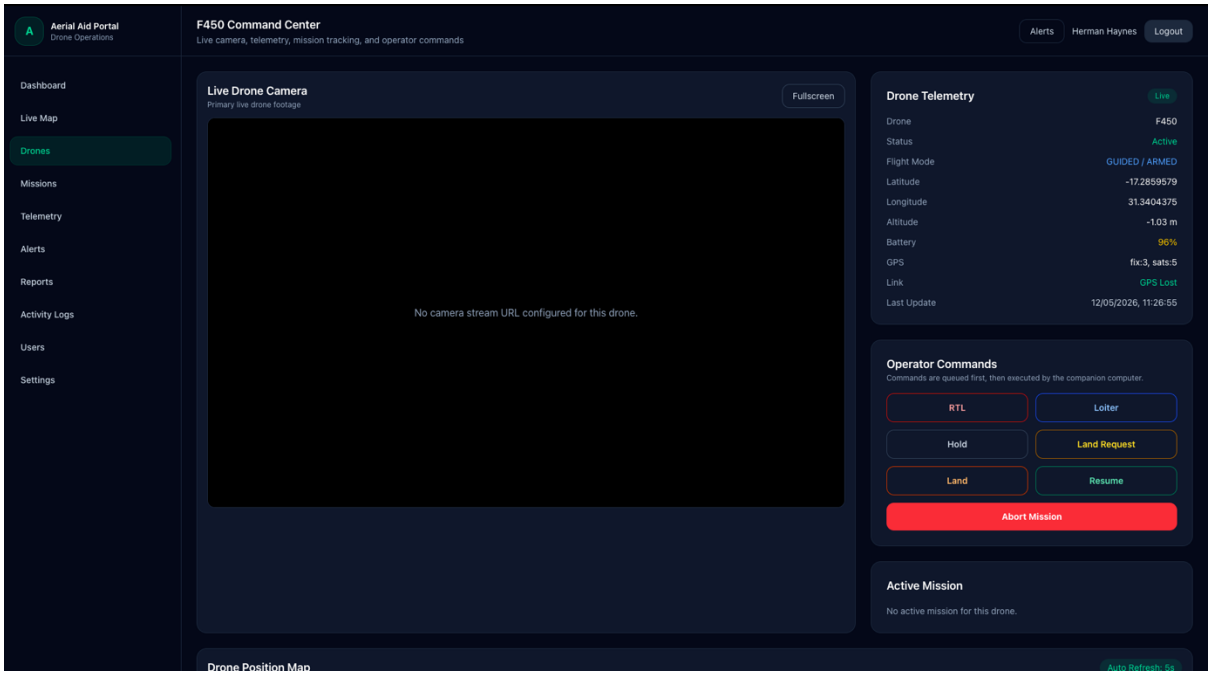

Figure 6:Real-time telemetry monitoring interface

Drone Management Interface

The drone management interface allows administrators to:

- Register drones
- Monitor drone status
- Manage drone operational information

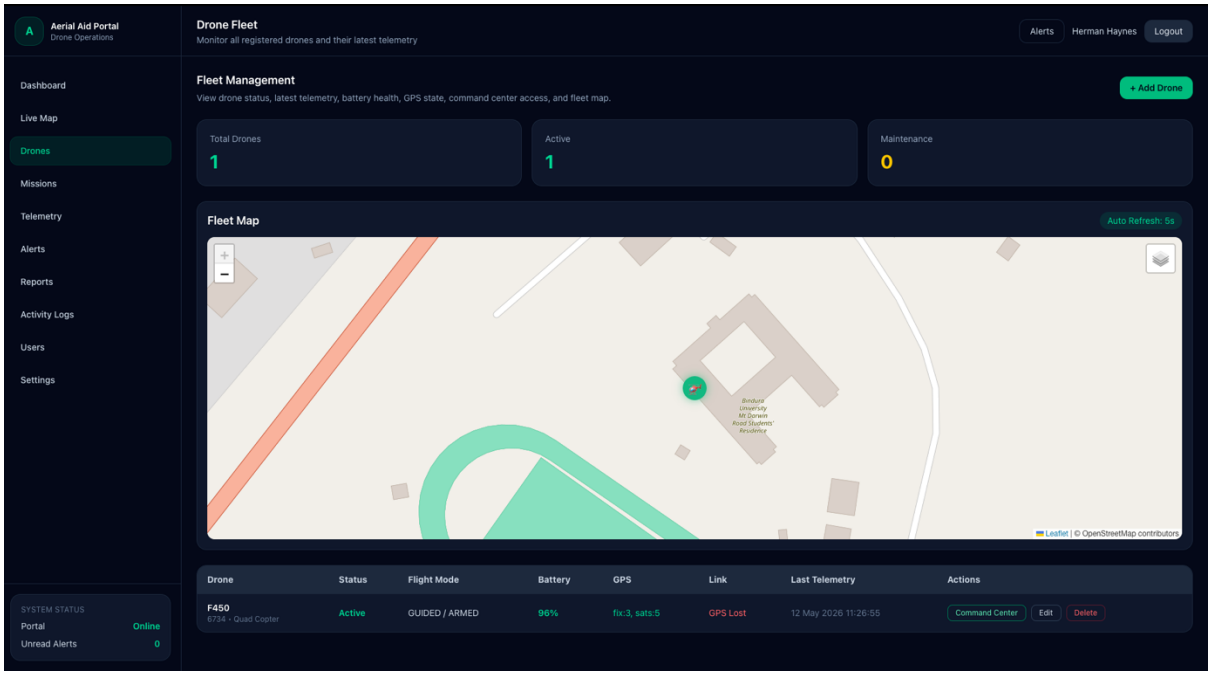

Figure 7:Drone management interface showing registered drones and operational status.

3.4 Data Analysis Procedure

Data collected during testing and evaluation were analysed using descriptive statistical techniques and comparative analysis methods. The analysis process involved organizing collected information according to the specific testing activities from which it was obtained.

Results from Black Box Testing were analysed to determine whether system functionalities satisfied the specified requirements. The analysis focused on identifying successful and unsuccessful test cases and determining the overall functional performance of the system.

In White Box Testing, analyses were performed to assure correctness of modules and to measure the reliability of the software modules. The results regarding to paths of execution, logic of conditions, interactions with databases and communication processes were taken into account. In integration Testing, the successful integration of hardware and software was determined by looking at successful communication paths between all the components of the system. In Flight Testing, the results of performance indicators like:

- Mission success rate

- Flight duration
- Payload transportation capability
- Navigation accuracy
- Landing accuracy
- Obstacle avoidance effectiveness

Performance Testing data were analysed to determine system responsiveness and operational efficiency. Key performance indicators included portal response times, telemetry reliability, GPS refresh rates, and data transmission efficiency.

The analysed results were presented using tables, figures, and descriptive explanations in Chapter 4. This approach facilitated interpretation of findings and provided a basis for evaluating the effectiveness of the autonomous drone delivery system in supporting medical supply delivery operations.

3.5 Chapter Summary

This chapter presented the methodology adopted in the design, development, and evaluation of the autonomous drone delivery system. The chapter described the research design, data collection approaches, population and sample, research instruments, and data analysis procedures employed during the study. The methodology provided a structured framework for assessing the functionality, reliability, and performance of the proposed system. The next chapter presents the results obtained from testing and evaluating the developed prototype and discusses their implications in relation to the objectives of the study.

CHAPTER 4:

DATA PRESENTATION, ANALYSIS AND INTERPRETATION

4.1 Introduction

In this chapter, the data retrieved from the tests and evaluation of the Autonomous Drone Delivery System for Medical Supplies are presented, analysed and interpreted. The tests were carried out in order to define whether the developed system satisfies the goals that were stated in Chapter 1. Testing was carried out using the following methods: Black Box Testing, White Box Testing, Integration Testing, Performance Testing and Flight Testing. The results achieved during these tests were analysed and used in order to evaluate how functional, reliable, efficient and operational both the autonomous drone and the web-based tracking interface were. The drone performance when in autonomous mode, how functional the obstacle avoidance systems are, how reliable the communication is and the monitoring abilities of the web-based portal are discussed in this chapter.

4.2 Black Box Testing Results

Black Box Testing-Black Box testing was performed in order to confirm that all the functions of the system work as per the requirement. The testing included all interaction between user and the system. Internal functionality of the software is not taken into consideration.

4.2.1 User Authentication Module

A test was carried out to check if the users could access the system with a valid username and password and get denied with invalid details

Table 4.1 User Authentication Testing Results

Test Case	Expected Result	Actual Result	Status
Valid Username and Password	User gains access	User gains access	Pass
Invalid Username	Access denied	Access denied	Pass
Invalid Password	Access denied	Access denied	Pass
Empty Login Fields	Validation error displayed	Validation error displayed	Pass

Table 3 User Authentication Testing Results

The results indicate that the authentication module functioned correctly under all tested conditions.

4.2.2 Mission Management Module

The mission management module was evaluated to determine its ability to create, update, and manage delivery missions.

Test Case	Expected Result	Actual Result	Status
Create Mission	Mission saved	Mission saved	Pass
Edit Mission	Mission updated	Mission updated	Pass
Delete Mission	Mission removed	Mission removed	Pass
View Mission Details	Details displayed	Details displayed	Pass

Table 4:Mission Management Testing Results

All mission management functionalities operated successfully.

4.2.3 GPS Tracking Module

The GPS tracking module was test to check it displays the live location received from drone..

Table 4.3 GPS Tracking Results

Test Case	Expected Result	Actual Result	Status
GPS Signal Available	Coordinates displayed	Coordinates displayed	Pass
GPS Update Received	Position updated	Position updated	Pass
Mission Tracking	Route displayed	Route displayed	Pass

Table 5:GPS Tracking Results

The module successfully displayed drone location data during testing.

4.2.4 Flight Logging Module

The flight logging functionality was tested to ensure that mission records were stored correctly.

Test Case	Expected Result	Actual Result	Status
Mission Start Logged	Record created	Record created	Pass
Mission Completion Logged	Record updated	Record updated	Pass
Flight Data Saved	Data stored	Data stored	Pass

Table 6:Flight Logging Results

The flight logging system accurately recorded mission information.

4.2.5 Analysis of Black Box Testing Results

All tested modules successfully met their functional requirements. No critical failures were encountered during testing. The overall Black Box Testing success rate was 100%, indicating that the developed system provided the intended functionalities to users.

4.3 White Box Testing Results

White Box Testing was conducted to evaluate the internal structure of the Laravel-based web portal.

The testing focused on:

- Authentication logic
- Database connectivity
- Mission management controllers
- API communication modules
- Error handling procedures

Module	Execution Paths Tested	Successful Paths	Result
Authentication Module	8	8	Pass

Mission Controller	12	12	Pass
Flight Logging Module	6	6	Pass
GPS Tracking Module	7	7	Pass
API Communication Module	10	10	Pass

Table 7:White Box Testing Results

The results indicate that all critical execution paths functioned correctly.

Analysis of White Box Testing Results

The test performed showed that the internal logic of the application is correct and is able to work with the multiple operating modes of the application. The database communications, condition statements and communications all worked without breaking down the application.

4.4 Integration Testing Results

Integration Testing was conducted to verify communication among the various hardware and software components.

Components Integrated	**Result**
Pixhawk ↔ Raspberry Pi	Successful
Raspberry Pi ↔ GPS Module	Successful
Raspberry Pi ↔ LiDAR Sensor	Successful
Raspberry Pi ↔ Ultrasonic Sensor	Successful
Raspberry Pi ↔ Telemetry Module	Successful
Telemetry Module ↔ Web Portal	Successful
Web Portal ↔ MySQL Database	Successful

Table 8:Integration Testing Results

The results indicate that all integrated components communicated effectively.

Analysis of Integration Testing Results

Successful integration of subsystems made sure that data flows smoothly between sensors and on-board processor, as well as the monitoring portal. Real-time broadcast of flight parameters was made without any significant communication dropouts.

4.5 Performance Testing Results

Performance testing was conducted to evaluate the responsiveness and efficiency of the developed system.

Performance Metric	**Result**
Average Portal Response Time	1.3 seconds
GPS Refresh Rate	1 second
Telemetry Communication Range	unlimited
Average Data Transmission Delay	0.8 seconds
Flight Log Update Time	1.2 seconds

Table 9 System Performance Results

Analysis of Performance Results

This shows that the system was capable of providing near real time monitoring and communications. The portal provided a good response time and telemetry was stable within its range.

4.6 Flight Testing Results

Flight testing was conducted to evaluate the operational performance of the autonomous drone under practical conditions.

Three autonomous delivery missions were performed.

4.6.1 Mission 1 Results

Parameter	Value
Flight Distance	500metres
Payload Weight	200 g
Flight Time	6 minutes
Mission Status	Successful

Table 10 Mission 1 Results

The drone successfully completed the mission and delivered the payload without incident.

4.6.2 Mission 2 Results

Parameter	Value
Flight Distance	800metres
Payload Weight	300 g
Flight Time	8 minutes
Mission Status	Successful

Table 11 Mission 2 Results Table

The drone completed the mission successfully while maintaining stable flight characteristics.

4.6.3 Mission 3 Results

Parameter	Value
Flight Distance	1500metres
Payload Weight	500 g
Flight Time	10 minutes

Table 12 Mission 3 Results

The drone failed to complete the mission successfully.

4.6.4 Analysis of Mission 3 Failure

The failure of Mission 3 was attributed to several operational limitations.

Battery Limitations

The increased payload caused the motors to consume more power, resulting in faster battery depletion. The available battery capacity was insufficient to support the mission for its full duration.

Payload Limitations

The payload weight approached the practical carrying capacity of the F450 drone platform. The additional load negatively affected manoeuvrability, stability, and overall flight efficiency.

Weather Conditions

Moderate wind conditions were experienced during testing. The heavier payload combined with wind resistance increased power consumption and reduced flight stability.

Flight Efficiency

The increased energy requirements associated with carrying a heavier payload reduced overall flight endurance and contributed to mission failure.

These findings indicate that future improvements should focus on optimizing payload capacity, battery performance, and environmental adaptation.

4.7 Obstacle Detection and Avoidance Evaluation

The LiDAR and Ultrasonic sensors were tested to evaluate their effectiveness in detecting obstacles during flight.

Sensor	Function	Result
LiDAR Sensor	Long-range obstacle detection	Successful
Ultrasonic Sensor	Short-range obstacle detection	Successful
Combined Operation	Obstacle awareness	Successful

Table 13 Obstacle Detection Results

Analysis

The LiDAR sensor effectively detected obstacles at greater distances, while the ultrasonic sensor provided accurate short-range measurements. The combination of both sensors enhanced situational awareness and improved operational safety during flight.

4.8 Discussion of Findings

The test results prove that most of the stated aims for the Autonomous Drone Delivery System have been achieved. Both the Black Box and White Box testing results verified the correct and effective functioning of the web portal. The Integration Testing provided positive proof that all parts of the system, from Raspberry Pi through the Pixhawk to the sensors, telemetry module and web portal, all communicate successfully. The performance test proved that the web portal could be used to enable approximately real time flight monitoring and mission management and the flight test confirmed that autonomous drones could be used effectively over short ranges to transport small medical payloads. Mission 1 and 2 show that the developed prototype has achieved fully autonomous delivery, however, Mission 3 identifies areas for improvement regarding payload, battery life and weather dependence. The obstacle detection proved highly effective and indicates that the combination of LiDAR and ultrasonic sensors offers a robust solution to a critical aspect of drone flight and mission management. Overall, the results show a good system that can provide a practical solution for the autonomous transport of medical supplies where access is limited.

4.9 Chapter Summary

This chapter presented and analysed the results obtained from testing and evaluating the developed Autonomous Drone Delivery System for Medical Supplies. The findings demonstrated that the system successfully performed autonomous flight operations, real-time monitoring, and mission management functions. While certain limitations relating to payload capacity and battery endurance were identified, the overall results confirm the feasibility of integrating drone technology, IoT communication, and web-based monitoring to support medical supply delivery operations. The next chapter presents the conclusions and recommendations derived from the study.

CHAPTER 5:

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The final chapter of the research paper concludes with a summary of findings and discusses the degree to which the objectives of the study were achieved. In this study the design and development of an Autonomous Medical Logistics Platform using drones and a web-based application is considered, to enhance, efficient and reliability of delivery of medical supplies. This can be in remote, rural areas and disasters. Medical supplies delivery is faced by delays which could be attributed to infrastructure problems, long distances and inadequate access to emergency transportation system, all of which this system aims to provide as a solution. The chapter explains the conclusions obtained from the design, implementation and test of the system and also gives recommendations in respect of future considerations.

5.2 Major Conclusions Drawn

5.2.1 System Design and Architectural Development

The main objective which is to design the fully integrated autonomous medical logistics system has been accomplished in this study. It has been formulated the appropriate architecture combining both drone hardware control and a web-based central control interface.

This structure illustrates the concept of a medical logistics system being automated and digitalized by various components such as mission planning, drone launching, tracking and delivery reports. It also indicates that autonomous systems for medical applications can be constructed with not very complex systems.

In this design phase, the feasibility and scalability to the multi-drones, multi-health centres and the larger area have also proved to be attainable.

5.2.2 Development of Web-Based Control and Monitoring Platform

A completely web-based operational system was constructed to control drone operations and logistics. Through the platform, administrators could define and schedule drone delivery missions, assign drones to delivery mission, check mission progress and review mission history.

By providing the centralized functions of controlling system that would otherwise need complicated coordination, the platform effectively increased operational efficiency. With the transparency the platform provides, administrators are able to look at drone activities in real time.
It can be shown that integration of drones with web based application does increase logistic efficiency of health system effectively.

5.2.3 Integration of Drone Hardware with Software System

One of the important contributions of the study is the seamless integration of the drone hardware with the digital logistics platform. Communication between the drone system and the web application helped update the execution of mission, behaviour of the drone, and the delivery progress.

This integrates physical world with digital management system which is essential for managing autonomous deliveries in coordination and verifies the feasibility of using IoT-based communication between drones and the system in the domain of healthcare logistics.

5.2.4 Improvement in Medical Delivery Efficiency

The investigation showed that medical logistic system can be increased efficiently through the use of the drone-based transportation method rather than current transportation system. Generally, medical transportation using conventional ways is always impeded by the road conditions, traffic jam, long distance.

However, the travel time is reduced with using the drone-based transportation and for some important medical delivery such as blood transfusion, vaccines, emergency medicines the response for time is significantly improved. The response for time is very important for critical medical situation which delays of delivery might lead to great losses.

5.2.5 Enhanced Accessibility to Remote and Underserved Areas

The potential use of the system to enhance the availability of medical care in rural, remote and inaccessible regions was outstanding. Since drones are not restricted by physical barriers like rivers, mountains or road conditions they can be employed for last-mile delivery of medical

commodities to the remotest of the regions. This overcomes health inequity, bringing indispensable medical services to isolated regions quickly.

5.2.6 Real-Time Monitoring, Tracking, and Control

A real-time monitoring system that keeps track of drone operations is established. Through the web interface, users are able to monitor mission progress, delivery status and system operations in real-time. Such feature allows greater traceability and reliability of the operations ensuring that the medical deliveries can be traced and accounted for. This also enables for a more efficient management by providing system administrators with real-time operational information.

5.2.7 Technical Feasibility and System Validation

The study verified the technical feasibility of the presented system by using available technologies: GPS module, flight controllers, communication systems and web technologies.

The tests made in the prototype and system stages have showed that the medical logistic by drone could be applied on the small-to-medium level. The system, for the large scale, need optimization especially in energy efficiency, range of communication, payload and resistance to environment factors.

5.2.8 Role in Emergency and Disaster Response

It has been shown that autonomously operating drones are very crucial for disaster response, as well as emergency healthcare. In situations such as flooding, epidemics, or failure of existing structures, the drones are capable of reaching locations that are otherwise difficult to reach and supplying necessary emergency resources. Such application makes the system a very useful system for disaster preparation and emergency aid.

5.2.9 Challenges and Limitations Encountered

Although the system was built and tested successfully, there were a number of limitations in the research conducted:

- Hardware purchases: budget limitations severely restricted the purchasing of certain hardware for the system. Certain higher-end drone parts were not possible to purchase with budget restrictions.
- Part availability: certain high-end drone parts and sensors were unavailable to purchase due to budget constraints.
- Validation: validation of the system was achieved partially, via prototyping rather than actual deployment.
- Environmental and regulatory factors: these constrained testing, making outdoor testing of the system difficult.

Although limitations such as these were observed during the research process, the main objective could still be attained.

5.2.10 Development of a 90% Functional Drone Prototype

As part of the research an actual physical prototype of a drone was manufactured and tested. This prototype was around 90% functional and provided a stable flight performance through take-off, landing, hovering and manoeuvring control. The prototype acted as a functional implementation of the proposed system as it proved that autonomous delivery of medicine is indeed feasible and acted as a connection between the theory of system design and the actual system itself. Not all of the proposed components could be implemented however. The custom-built payload delivery box was not manufactured as a plastic container was used for testing. While this would suffice for basic demonstration it was limited in its design due to aerodynamic efficiency limitations and its light weight which would allow for less than ideal weight optimization for medical deliveries. A thermal imaging camera was also not installed onto the drone, which would have allowed for more complex search and rescue operations

5.3 Overall Conclusion

From the study it has been found that Autonomous Medical Logistics platform is a feasible and useful solution to the issues encountered in the healthcare delivery system in remote and underdeveloped areas. The incorporation of drone technology in the centrally located digital platform provides solutions to quick, efficient and accessible delivery of medical service.

Despite lack of financial resources not being able to acquire the full hardware for the platform, the aim was successfully accomplished by successfully designing, developing and prototyping

it. The functioning drone prototype at 90% shows it is an attainable possibility rather than just an imaginary concept.

In a nut shell, the research reveals that drone operated medical logistics has a high prospect to revolutionize the healthcare delivery system especially with suitable funding, legislations and infra structure.

5.4 Recommendations

5.4.1 Healthcare Institutions

It is also important for health services to embrace the use of drones for logistics, especially in emergencies, but also to bring supplies and deliver samples in rural areas. Health facilities need a computerized ordering system to make requests. Personnel will need to be trained to use the drones effectively.

5.4.2 Government and Policy Makers

Government should establish clear regulations regarding medical drone operations. Innovation in the healthcare supply chain should be funded and designated drone flight corridors should be put in place to allow medical drones to operate safely. Public-private sector cooperation should also be encouraged to expedite deployment.

5.4.3 Disaster Management Agencies

Drone systems must be incorporated into the existing disaster response plans. Authorities need to use drones to quickly survey a disaster area and to deliver urgent medical supplies. Drills and simulations must be held frequently to maintain preparedness.

5.4.4 Communities

Sensitivity building programs on how the delivery of health-care via drones benefits communities must be implemented. A wide public awareness and information campaigns for understanding and acceptance of the technology need to be organized. Community

involvement for designating safe landing zones and supporting demonstration projects are crucial.

5.4.5 System Developers

For the future system, efforts should be made to increase the accuracy of the real-time tracking and integrate AI for route planning, enhance the security and enable the management of multiple drones' fleet. Develop mobile applications to facilitate field access.

5.4.6 Future Research

Future research should consider the development of long range delivery drones, advancements in battery technology and the autonomous navigation by AI, the cost-benefit analysis of using drones for logistic needs in healthcare should be addressed as well as public perception and the regulatory framework in developing countries.

5.4.7 Funding and Resource Recommendation

Adequate funds are a must for the hardware-based research projects. The future projects should raise fund prior to purchasing the components. Likewise, universities and institutes should provide adequate funds for the innovation-based student projects with possible industry collaboration.

5.5 Chapter Summary

This chapter effectively brought an end to the study. It assesses whether the system performs to the objective defined in the early parts of the research. The results showed that the Autonomous Medical Logistics platform fulfilled its purpose, to provide enhanced medical supply through automated systems utilizing drones. Although not having a manufactured payload box and lack of a thermal camera due to the cost and hardware limitations, the system prototype operated about 90% functionally and is applicable for real-world usage. The research concludes that autonomous drone-based medical logistics is a promising innovation capable of transforming healthcare delivery systems when supported by adequate resources, regulatory approval, and technological development.

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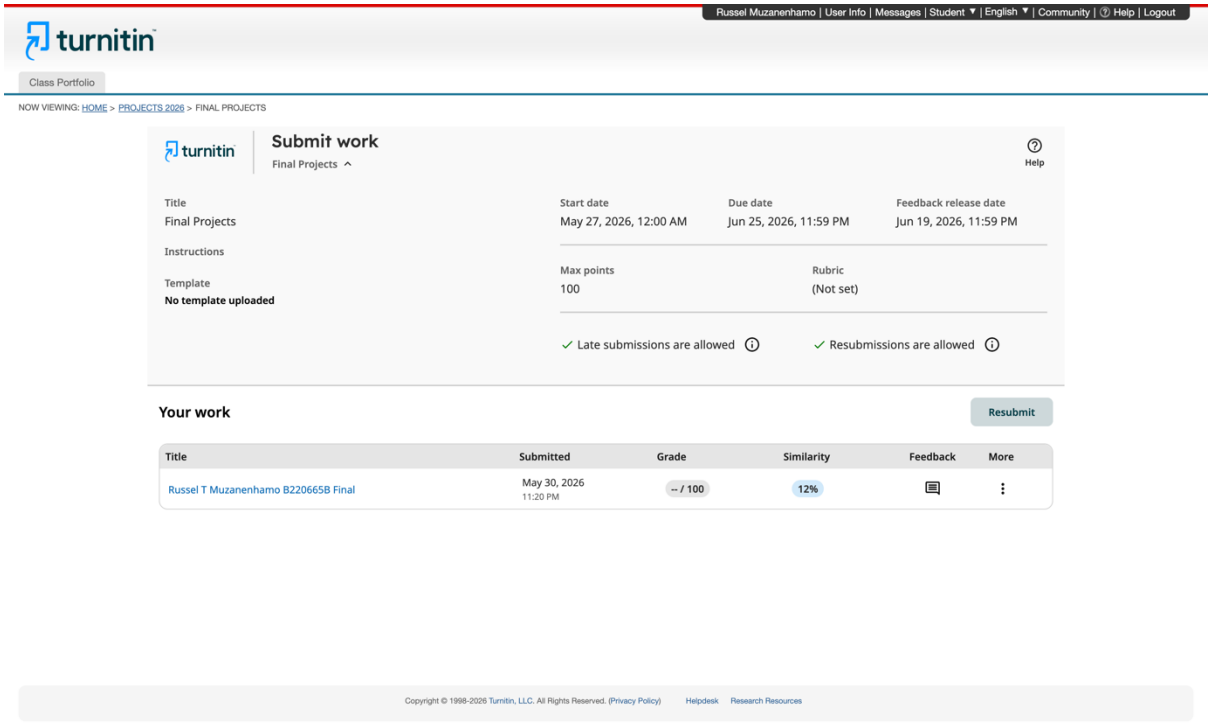
APPENDIX

Turnitin Proof



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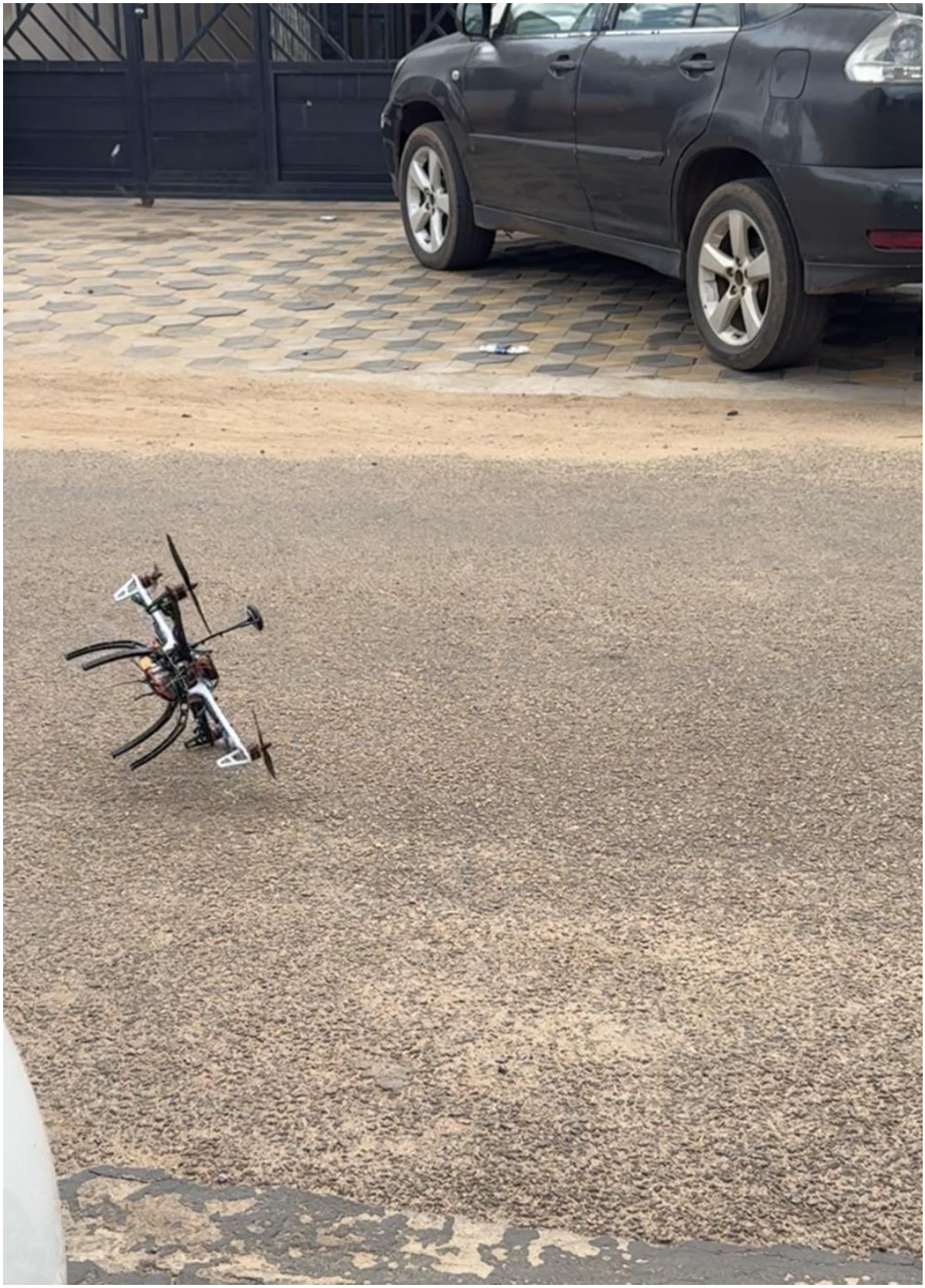


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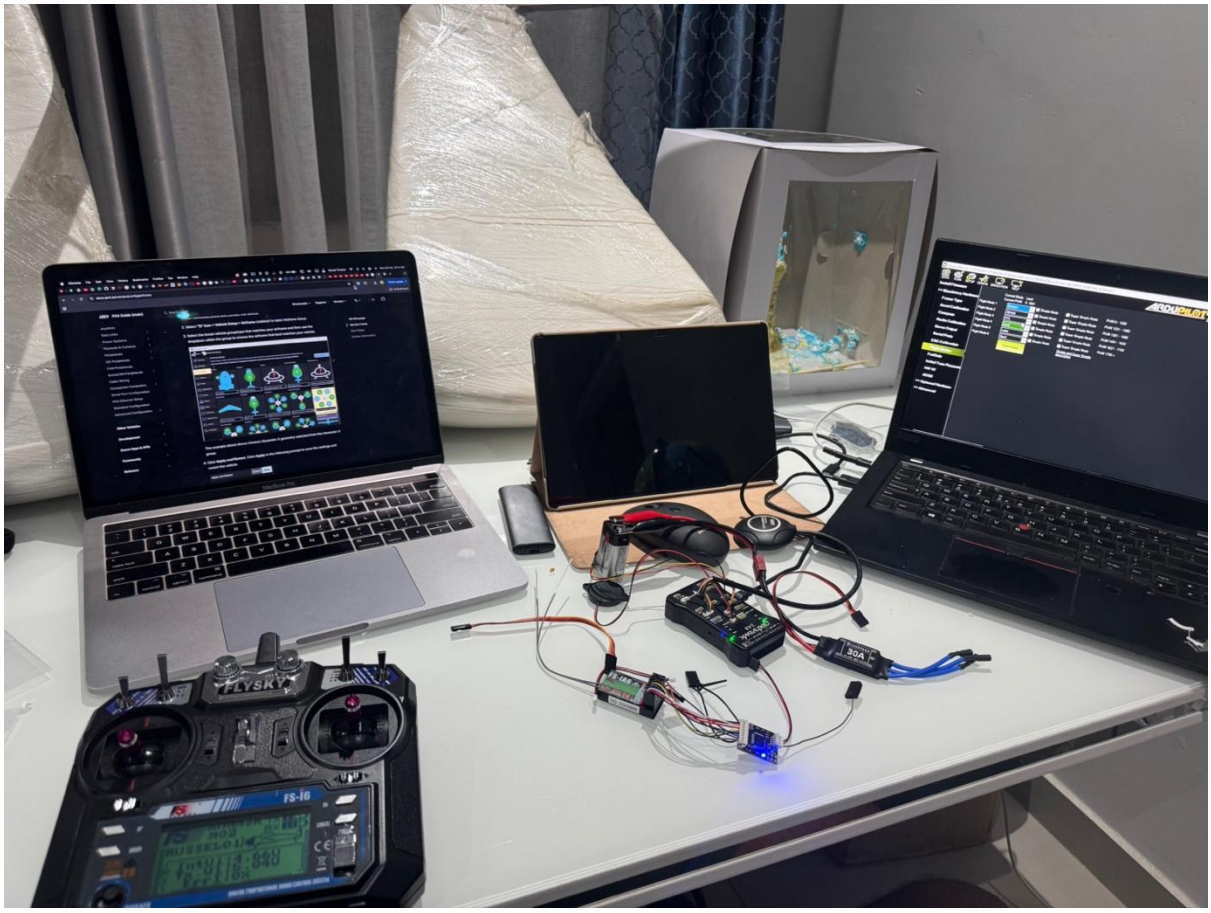
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