IJRCS

International Journal of Robotics and Control Systems
Vol. 5, No. 1, 2025, pp. 68-85
ISSN 2775-2658
http://pubs2.ascee.org/index.php/ijrcs

ASCEE

UAV Logistics Pattern Language for Rural Areas

Radyan Rahmananta [a,1], Gregorius Airlangga [a,2,*], Ronald Sukwadi [b,3], Widodo Widjaja Basuki [c,4]
Lai Ferry Sugianto [d,5], Oskar Ika Adi Nugroho [e,6], Yoel Kristian [a,7]

[a] Information System Study Program, Universitas Katolik Indonesia Atma Jaya, Jakarta, Indonesia
[b] Industrial Engineering Study Program, Universitas Katolik Indonesia Atma Jaya, Jakarta, Indonesia
[c] Mechanical Engineering Study Program, Universitas Katolik Indonesia Atma Jaya, Jakarta, Indonesia
[d] Department of Business Administration, Fujen Catholic University, Taiwan
[e] Department of Electrical Engineering, National Chung Cheng University, Taiwan
[1] radyan.202104560016@student.atmajaya.ac.id; [2] gregorius.airlangga@atmajaya.ac.id; [3] ronald.sukwadi@atmajaya.ac.id;
[4] widodo.basuki@atmajaya.ac.id; [5] 158325@mail.fju.edu.tw; [6] oskar@alum.ccu.edu.tw; [7] yoelstudy@gmail.com
* Corresponding Author

ARTICLE INFO

Article history
Received August 06, 2024
Revised September 14, 2024
Accepted December 03, 2024

Keywords
UAV;
Path Planning System;
Pattern Design;
Rural

ABSTRACT

The logistical challenges in rural areas, which often face limited infrastructure, varied terrains, and dispersed populations, often lead to inefficient and costly delivery systems. Recent developments in Unmanned Aerial Vehicle (UAV) technology offer a theoretical framework for overcoming these challenges. This research proposes a comprehensive pattern language specifically designed for multi-UAV logistics operations in rural settings. The proposed system integrates critical components such as LiDAR-based map generation, altitude information storage, partial goal estimation, and collision avoidance into a unified framework. Unlike existing research that typically focuses on isolated aspects like route optimization or payload management, this system features an advanced path planning algorithm capable of real-time environmental assessment and direction-aware navigation. Focus group discussions with logistics experts from Talaud Island, North Sulawesi, Indonesia informed the design and refinement of the proposed patterns, ensuring that they address the practical needs of rural logistics. Our analysis suggests that this system offers a theoretical foundation for significantly improving the efficiency, reliability, and sustainability of delivering essential goods and services to rural areas, thereby supporting equitable development and improving the quality of life in these communities. While no empirical data is presented, the framework serves as a scalable foundation for future implementations of UAV-based rural logistics systems.

1. Introduction

Logistics in rural areas presents unique challenges due to the combination of limited infrastructure, varied terrain, and dispersed populations [1]-[3]. Traditional delivery methods often prove inefficient and costly, leading to delays and limited access to essential goods and services [4], [5]. Although UAV technology offers promising possibilities for overcoming these challenges, there remains a gap in fully leveraging its potential in rural logistics. Addressing logistics in rural areas is of paramount importance [6]. Rural communities frequently suffer from inadequate access to healthcare, education, and economic opportunities due to logistical constraints [7]-[9]. Improving logistics in these regions is crucial for equitable development and the overall enhancement of quality of life [10]. Despite the advances in other areas of UAV technology, rural logistics has not seen substantial improvements, highlighting an urgent need for innovative, tailored solutions [11]. The application of UAV technology in logistics has gained considerable attention in recent years, particularly for its potential to overcome the limitations posed by traditional methods. UAVs can navigate challenging terrains and cover long distances more efficiently than ground vehicles, making them an ideal solution for rural logistics [1]. However, most existing research focused on UAV applications in urban environments, where infrastructure and logistical needs differ significantly from those of rural areas.

UAVs have proven effective in various fields, such as agriculture, disaster management, and surveillance. In agriculture, UAVs are used for crop monitoring, spraying pesticides, and surveying large fields [12]-[14]. In disaster management, UAVs have been used successfully for search and rescue operations, aid delivery, and post-disaster assessments in areas where access is otherwise restricted [15]-[17]. Surveillance applications include border security, wildlife monitoring, and infrastructure inspection [18]. These use cases highlight the versatility and efficiency of UAVs in addressing logistical challenges. Yet, in rural logistics, these individual use cases are often fragmented and not combined into a cohesive system, limited their broader impact.

There is a notable gap in integrating UAVs logistics into a unified system specifically tailored to rural needs. Most studies focus on specific aspects such as route optimization or payload management, without integrating these elements into a comprehensive system that addresses the broader logistical issues unique to rural settings. The urgency of addressing this gap is underscored by the growing demand for timely delivery of essential goods and services to remote rural areas [19]-[21]. Rural communities often face significant delays and high costs associated with traditional logistics methods. This situation underscores the critical need for resilient, adaptable and scalable logistics systems that can ensure the continuous flow of necessary supplies [22]. The lack of sufficient road and electrical infrastructure and varied terrains in rural areas exacerbates these challenges, further reinforcing the need for UAV-based solutions that can dynamically adapt to the environment. Access to essential items such as medical supplies, food, and educational materials is often limited, further highlighting the need for a robust and efficient logistic system that can adapt to the unique challenges of rural areas [23]-[25].

Although many UAV logistics systems have been developed for urban settings, their applicability to rural areas remains limited. Current UAV logistics has primarily focused on urban environments, where infrastructure is more developed, and the challenges differ significantly from those in rural areas [26]. Studies have explored various aspects of UAV logistics, including autonomous navigation, collision avoidance, and efficient delivery algorithms. For example, research on autonomous navigation has led to the development of sophisticated algorithms that enable UAVs to navigate complex urban landscapes autonomously [27]. Collision avoidance systems have been designed to ensure the safe operation of UAVs in crowded airspaces, while delivery algorithms focus on optimizing delivery routes to minimize time and energy consumption [25], [28], [29]. Despite these advancements, there is a notable lack of research addressing the specific needs and challenges of rural logistics. Thus, the application of UAVs in rural logistics remains underexplored and underdeveloped, lacking a comprehensive framework that integrates navigation, environmental assessment, and adaptation to real-time conditions [15], [30], [31].

The research aims to fill these gaps by developing a pattern language that addresses the unique challenges of rural logistics and integrates various aspects of UAV logistics into a cohesive system. The goal of this research is to develop a comprehensive pattern language for a logistic system using multi-UAVs tailored to the specific needs of rural areas. This pattern language will provide a structured framework for addressing the various challenges associated with rural logistics, such as varied terrain, limited infrastructure, and dispersed populations. By integrating different aspects of UAV logistics into a cohesive system, the proposed approach aims to enhance the efficiency, reliability, and sustainability of logistics in rural areas.

Vol. 5, No. 1, 2025, pp. 68-85

The remaining structure of the journal article is organized as follows. Section 2 provides a detailed literature survey, reviewing the current state of UAV applications in various fields and identifying the gaps in existing research on UAV logistics in rural areas. In Section 3 we detail the research methodology. In Section 4 we provide the contextual analysis of Talaud Island, selected as a case study for rural logistic challenges. In Section 5, we provide an in-depth description of the proposed design pattern, delineating the functionalities of its various components. In Section 6, we provide a plan to evaluate and refine the proposed design and then finally, we conclude the paper by summarizing the key findings and contributions of the research and outline potential future research directions in this area.

2. Literature Survey

UAVs have revolutionized modern agriculture by enhancing efficiency and precision in crop monitoring, pesticide spraying, and field surveying. [32] demonstrated that UAVs equipped with multispectral and thermal sensors provide detailed insights into crop health, enabling precision agriculture practices. These drones capture high-resolution images that help farmers identify stressed plants, assess crop yield, and manage irrigation more efficiently. However, current research often focuses on individual applications without fully integrating these UAV capabilities into a broader agricultural management system. [33]-[35] found that UAVs reduce the labor and time required for crop monitoring, offering a cost-effective solution for large-scale farms. However, the use of UAVs in agriculture has its limitations. While UAVs can cover large areas quickly, they may struggle with data integration and interpretation, especially in varied terrains and unpredictable weather conditions. Additionally, the focus on isolated applications such as crop monitoring and pesticide spraying lacks a cohesive framework that can integrate these operations into a unified agricultural management system. This gap suggests the need for a pattern-based approach to agricultural UAV operations that can provide a more structured and scalable solution.

In disaster management, UAVs have proven invaluable for rapid response capabilities in search and rescue operations, aid delivery, and damage assessment. [36]-[38] highlighted the role of UAVs in locating survivors during natural disasters, where traditional search methods are often hampered by debris and inaccessible terrain. UAVs equipped with thermal imaging cameras can detect body heat, significantly increasing the chances of finding survivors. UAVs are also effective in aid delivery, as demonstrated by [39], who showed that UAVs could transport medical supplies, food, and other essentials to disaster-stricken areas faster than ground vehicles. Despite these advantages, research in disaster management often lacks an integrated framework that combines UAV capabilities such as real-time communication, coordination, and environmental mapping. The current research focuses on specific applications like search and rescue or aid delivery, without a comprehensive approach that integrates these elements into a cohesive disaster management system. By proposing a pattern language, this research aims to offer a structured solution that enhances UAV coordination and efficiency in disaster regions.

UAVs offer cost-effective and efficient means of monitoring large areas in various surveillance applications, including border security, wildlife monitoring, and infrastructure inspection. [40]-[42] emphasized that UAVs equipped with high-resolution cameras and sensors could monitor wildlife populations, track poachers, and assess habitat conditions, contributing to conservation efforts. In border security, UAVs enhance surveillance capabilities by providing persistent aerial coverage of border areas. However, a key challenge in current UAV surveillance research is the lack of unified system that addresses multiple surveillance tasks simultaneously, such as wildlife monitoring and infrastructure inspection. [43], [44] reported the use of UAVs to detect illegal crossings and smuggling activities, thereby strengthening national security. For infrastructure inspection, [39], [45], [46] noted that UAVs could inspect bridges, power lines, and pipelines, identifying structural issues and potential hazards without risking human safety. However, surveillance applications of UAVs face challenges such as privacy concerns, regulatory hurdles, and the need for advanced data processing capabilities. To address these challenges, a standardized framework, such as pattern language, can provide a cohesive system for integrating UAV surveillance tasks, enhancing operational efficiency and ensuring ethical compliance.

In software engineering, design patterns and pattern languages have provided structured solutions to recurring problems, enhancing the efficiency, robustness, and maintainability of software architectures. [47] introduced design patterns to document and reuse solutions to common design problems, promoting best practices in software development. These patterns have been extensively applied in various software domains, offering a systematic approach to design that reduces complexity and improves scalability. While design patterns are well-established in software development, their application in UAV logistics remains underexplored, presenting an opportunity to transfer proven methods from software engineering to UAV systems. [48] expanded on the application of design patterns in complex system architectures, emphasizing their role in scalability and modularity. Design patterns like Model-View-Controller (MVC) and Singleton have become staples in software engineering, helping developers create flexible and scalable applications. Despite their success in software development, the application of design patterns to UAV logistics remains an underexplored area.

The concept of pattern language, introduced by Christopher Alexander in architecture, has been adapted to software engineering to address complex design challenges. A pattern language consists of a collection of interrelated patterns that provide solutions to common problems within a specific context. This concept can be extended to UAV logistics, where a pattern language could offer a structured framework for addressing various logistical challenges, such as route optimization, payload management, and coordination among multiple UAVs. While current research focuses primarily on technical solutions, a pattern language approach can offer a holistic system for managing UAV operations in diverse environments. For example, [49]-[51] focused on optimizing UAV delivery routes in urban settings, where infrastructure is more developed and delivery points are concentrated. These findings, however, may not be directly applicable to rural areas, where delivery points are dispersed, and infrastructure is limited. Similarly, studies on payload management by [52], [53] explored the technical capabilities of UAVs to carry various loads but did not address the logistical challenges specific to rural areas, such as varied terrain and weather conditions.

A notable gap in current research is the lack of integration of these isolated aspects into a comprehensive system tailored for rural logistics. The application of a pattern language could bridge this gap by providing a cohesive framework that integrates various elements of UAV logistics into a unified system. This approach would not only enhance the efficiency and reliability of UAV logistics in rural areas but also ensure that the system is scalable, maintainable, and adaptable to changing conditions. By applying pattern languages, UAV logistics systems can be designed to handle complex, dynamic environments like those found in rural areas. While design patterns and pattern languages are well-established in software development, their application to UAV logistics is still in its infancy. Most current research on UAV logistics focuses on technical and algorithmic solutions without leveraging the structured approach offered by pattern languages. Studies like those by [54] and [55] explore advanced path planning and collision avoidance algorithms for UAVs, emphasizing technical innovation over architectural coherence. These studies, while groundbreaking, often address isolated problems and do not offer a holistic solution framework that can be easily adapted or scaled. By adopting a pattern language approach, UAV logistics systems can benefit from a more structured and reusable framework, ensuring that the solutions developed are both effective and adaptable to various operational contexts, particularly in rural logistics.

3. Research Methodology

This paper outlines a comprehensive research methodology for developing a pattern language tailored to UAV logistics path planning systems in rural areas. The methodology is structured into four main phases: problem identification and contextual analysis, pattern identification and formulation, validation and refinement, and documentation and dissemination. Each phase was designed with input from stakeholders and domain experts to ensure practical relevance, adaptability, and scalability of the resulting framework. This structured approach ensures the creation of a robust and adaptable design framework that addresses the unique challenges of rural logistics.

3.1. Problem Identification and Contextual Analysis

The initial phase of this methodology involves understanding the logistical challenges specific to rural areas and identifying the limitations of current UAV technologies. The process begins with an extensive literature review, covering UAV applications, rural logistics, and design patterns in software engineering. This review includes a wide range of sources such as academic journals, conference papers, industry reports, and case studies. Particular attention is given to studies that highlight the complexities of rural environments, such as terrain variability, unpredictable weather conditions, and limited infrastructure. The focus areas include advancements in UAV technology, logistical challenges unique to rural areas, and the application of existing design patterns.

The outcome of this literature review is the identification of gaps in current solutions, particularly concerning UAV path planning and the need for dynamic adaptation. These gaps are corroborated by qualitative input gathered from focus group discussions with logistic experts from Talaud Island, ensuring the research captures the practical difficulties experienced in real-world contexts. Following the literature review, a contextual analysis is conducted to gather qualitative data through field studies and interviews with logistics providers, local authorities, and residents in rural areas. This analysis seeks to understand the logistical constraints such as terrain variability, infrastructure limitations, and population dispersion. The data collected provides a detailed understanding of the practical constraints and requirements for UAV logistics in rural areas, forming a crucial foundation for the subsequent phases. This phase is critical in tailoring the design patterns to the specific requirements of rural logistics, as identified by stakeholders.

3.2. Pattern Identification and Formulation

In the next phase, the research focuses on developing a structured set of design patterns that address the identified logistical challenges. A bottom-up approach is employed, starting with the identification of core challenges from the contextual analysis and then formulating patterns that provide solutions to those specific issues. This involves first identifying the core elements necessary for a UAV logistics system, including navigation systems, obstacle avoidance mechanisms, environmental mapping, and adaptive control systems. These components are defined in terms of their functional requirements and system constraints, derived from the problem analysis conducted in the previous phase.

Each pattern is carefully structured to include its intent, context, problem, and solution, ensuring clarity and ease of implementation. The intent clearly states the purpose of each pattern, while the context describes the conditions under which the pattern is applicable. The problem outlines the specific issues the pattern aims to address, and the solution provides a detailed description of the proposed approach. UML diagrams accompany each pattern to illustrate how the elements interact within a broader system, making the patterns easier to understand and apply in different scenarios.

This systematic approach ensures that each pattern is well-defined and comprehensive. Furthermore, the relationship between these patterns is mapped to form a cohesive pattern language. This interrelation mapping clarifies how different patterns interact and support each other, creating and integrated framework that addresses the various aspects of UAV logistics in rural areas. This phase also involves identifying opportunities for scalability and reuse of patterns across different types of rural settings, ensuring flexibility and adaptability.

3.3. Designing Validation and Refinement

To ensure the relevance, practicality, and effectiveness of the proposed design patterns, the methodology includes a rigorous validation and refinement phase. This phase focuses on iterative testing and validation to ensure that the proposed patterns not only meet theoretical requirements but also address real-world challenges effectively. This feedback loop ensures that the patterns remain relevant to practical applications, particularly in the context of rural logistics, where operational constraints can differ significantly from urban settings.

Following the expert review, scenario-based evaluations are conducted using hypothetical scenarios and case studies to test the patterns. These scenarios are based on real-world logistical challenges identified during the contextual analysis phase, ensuring the tests are grounded in practical needs. These evaluations assess how well the patterns address the identified problems under different conditions, providing practical insights into their effectiveness. Based on the feedback and evaluation results, the patterns undergo iterative refinement, where adjustments are made, and new patterns are introduced if necessary to address any uncovered gaps. This iterative process continues until the patterns are validated for a range of rural logistics scenarios, ensuring robustness and adaptability.

4. Contextual Analysis of Talaud Island

Based on an extensive literature review and comprehensive contextual analysis conducted on Talaud Island, North Sulawesi, Indonesia, several critical logistical challenges specific to this remote rural area have been identified. Talaud Island, one of Indonesia's northernmost regions, faces significant difficulties in terms of infrastructure and accessibility, which have profound implications for the delivery of essential goods and services. The island's topography, compounded by environmental conditions, makes logistics particularly complex. The literature review, which encompassed a broad array of sources including academic journals, conference papers, industry reports, case studies, and direct practical observations, revealed significant gaps in the application of Unmanned Aerial Vehicles (UAVs) for rural logistics. While UAV technology has advanced considerably, existing solutions tend to focus on isolated problems, such as route optimization or collision avoidance, without addressing the integrated challenges of operating in rugged, remote terrains like those found in Talaud. Moreover, most UAV applications have been designed for urban or agricultural settings, leaving a significant research gap in their application for rural logistics in challenging topography.

The contextual analysis conducted on Talaud Island incorporated both qualitative and quantitative data collection methods, including field studies and interviews with local stakeholders such as logistics providers, government officials, and residents. Talaud Island, home to approximately 83,434 residents, covers an area of around 97,312 square kilometers. Its terrain is dominated by steep cliffs and dense forests, with 65% of the land covered by vegetation. The infrastructure on the island is highly underdeveloped, with only 25% of the region accessible via rudimentary road networks, which are mostly unpaved. As a result, traditional logistics that rely on ground vehicles are severely limited in scope and efficiency. One of the most significant findings from the field studies was the inefficiency of current logistics operations on the island. Essential goods, such as medical supplies and educational materials, often take between 10 and 15 days to reach their destinations due to the reliance on infrequent boat services and difficult overland transport. Nearly 70% of the island’s households reported facing frequent delays in receiving critical supplies, particularly in the northern and western regions where road access is practically non-existent. These underserved regions, which account for nearly 40% of the island’s territory, are essentially cut off from regular logistics services, creating serious social and economic disadvantages.

The island’s population is widely dispersed, with many small, isolated communities separated by natural barriers such as steep hills and dense forests. The average distance between households exceeds 500 meters, adding to the logistical challenges. Traditional ground-based logistics methods are inadequate for serving these scattered populations, leading to further delays and inefficiencies. The island’s topography is also marked by significant elevation changes, with 60% of the land experiencing altitude variations greater than 30 meters. Such changes in altitude pose substantial challenges for UAV systems, which must be equipped with advanced navigation and altitude management capabilities to effectively operate in such environments.

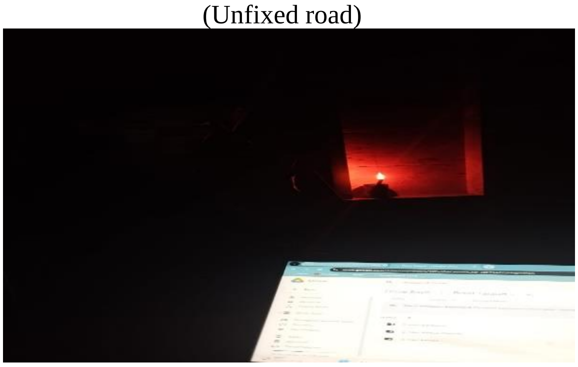
Additionally, the island faces a range of environmental challenges that further complicate logistics. Talaud experiences an average of 200 rainy days per year, with total annual rainfall exceeding 2,000 millimeters. This constant precipitation often results in landslides and road washouts, which disrupt the already fragile transportation network. High winds, particularly during the monsoon season, can reach speeds of up to 15 m/s, posing a significant challenge for UAV stability and flight accuracy. These weather conditions necessitate UAV systems that can dynamically adjust their flight paths in response to real-time environmental changes. Beyond these physical and environmental barriers, Talaud Island also experiences frequent electricity blackouts, particularly at night. This unreliable power supply not only disrupts daily life but also hampers the operations of UAVs and other technology-based logistics systems, which require consistent energy to function effectively. Additionally, the island suffers from poor telecommunications infrastructure, leading to regular network signal losses. This lack of stable communication further complicates logistics planning, and the coordination of UAV operations, as real-time communication and monitoring are essential for the success of UAV-based logistics systems.

These findings underscore the critical need for an adaptive and reliable UAV logistics system tailored to the unique challenges of Talaud Island. The island's complex terrain, coupled with environmental factors and infrastructural limitations, calls for advanced UAV systems equipped with dynamic path-planning capabilities, real-time environmental assessment tools, and robust obstacle-avoidance mechanisms. These systems must be capable of adjusting their flight paths in response to real-time changes in weather and terrain, while also overcoming the challenges posed by power outages and communication blackouts. By addressing these issues, an effective UAV logistics system can significantly enhance the delivery of essential goods and services, improving the quality of life for the residents of Talaud Island and promoting equitable development in this remote region. Field observation shown in Fig. 1.

(Interview with local government)

(Unfixed road)

(Interview with the local health center)



(Blackout)

Fig. 1. Field observation

5. Proposed Pattern Language

5.1. Intent

The primary intent of the proposed UAV logistics path planning system pattern is to enhance the efficiency, accuracy, and adaptability of UAVs operating in rural areas with challenging terrains and limited infrastructure. This pattern introduces an online, real-time approach to environmental assessment and path planning, allowing UAVs to dynamically adapt to changing conditions without relying on predetermined paths or prior map knowledge. By doing so, this pattern aims to improve the delivery of essential goods and services in rural areas, aligning with broader goals of sustainable infrastructure development and policy innovation.

5.2. Example

Consider a scenario where a UAV is deployed to deliver medical supplies to a remote village on Talaud Island. The area features steep slopes, dense forests, and unpredictable weather conditions. Traditional navigation methods, dependent on fixed routes and pre-existing maps, are inadequate in such a dynamic environment. Here, the online path planning system pattern proves invaluable. As the UAV embarks on its mission, it continuously assesses the environment and adjusts its path in real-time, navigating around obstacles, adjusting for weather conditions, and ensuring timely delivery of critical supplies. Another scenario involves a UAV used for agricultural monitoring in a rural area with varied terrain. The UAV must navigate fields, hills, and water bodies, encountering unexpected obstacles like livestock or newly erected structures. Utilizing the online path planning system pattern, the UAV can dynamically adapt its path, ensuring efficient and comprehensive coverage of the area. This pattern empowers the UAV to handle unforeseen changes, enhancing its effectiveness in complex rural environments.

5.3. Context

The UAV logistics path planning system pattern is applicable in various contexts where autonomous UAVs must operate in dynamic and unpredictable rural environments. These environments are characterized by frequent or unexpected changes that can significantly impact the UAV's navigation and mission success. In the context of UAV operations in changing rural landscapes, the pattern is ideal for areas with diverse and challenging terrains such as mountains, forests, and rivers. These environments are prone to sudden changes due to natural events or human activities, necessitating a navigation system that can adapt in real-time. The UAV must consider its current speed, direction, and orientation to navigate efficiently and safely through these dynamic landscapes. Additionally, in agricultural settings, this pattern is applicable where UAVs are used for monitoring crops, spraying pesticides, or surveying large fields. Agricultural environments are dynamic, with changing crop patterns, varying altitudes, and the presence of movable obstacles like livestock. The UAV requires an online path planning system that can adjust its path based on real-time data, ensuring efficient and effective operations.

5.4. Problem

Traditional path planning algorithms have significant limitations when dealing with dynamic and unpredictable rural environments. These algorithms typically rely on static maps or predetermined paths, assuming the environment remains constant during the UAV's operation. However, rural environments are inherently dynamic, with variables such as weather changes, moving obstacles, and terrain alterations. Additionally, traditional algorithms often fail to account for the UAV's orientation and direction, which are crucial for efficient navigation in complex environments. Ignoring these factors can lead to inefficient routes, potential collisions, and failure to complete missions. For instance, a UAV delivering medical supplies in a mountainous area might encounter unexpected obstacles or weather changes. Without the ability to adapt dynamically, the UAV could crash or fail to deliver the supplies on time. Traditional motion systems typically employ reactive approaches, addressing immediate obstacles rather than proactively planning for efficient navigation. They may also overlook the UAV's current speed, inertia, and orientation, leading to suboptimal path following or collisions. The problem extends beyond improving the path planning algorithm; it requires enhancements in the UAV's motion system to respond effectively to dynamic path planning in real-time, ensuring safe, efficient, and adaptive navigation in rural areas. Therefore, both the path planning process and the UAV's motion system need significant improvements to meet the challenges posed by dynamic rural environments.

5.5. Solution

As presented in Fig. 2, the pattern proposes a solution that integrates an advanced path planning algorithm with a sophisticated UAV motion system. The main components of this solution include

Vol. 5, No. 1, 2025, pp. 68-85

the modified A* algorithm, Lidar-based map generator, altitude information storage, partial goal estimator, adaptive module manager, direction pattern generator, automatic speed and altitude configuration, and collision avoidance module. The proposed system includes a modified A* algorithm, referred to as the Direction-Aware Algorithm, which incorporates the UAV's current orientation into its calculations. This modification enables the algorithm to select the next move based on both distance and alignment with the UAV's orientation, reducing unnecessary turns and detours. This enhancement is particularly beneficial in complex environments, where it improves navigation efficiency. The algorithm operates in real-time, which is crucial for dynamic environments where obstacles may suddenly appear. Its output integrates with the direction pattern generator and adaptive module manager, facilitating swift re-planning in response to new obstacles or potential collision risks.

The system also features a Map Generator that utilizes Lidar technology to create a detailed 2D map of the UAV's environment in real-time. Lidar works by emitting pulsed laser light to measure distances to surrounding objects, thus generating an accurate representation of the environment. This map is continuously updated to reflect real-time changes, enabling the UAV to detect and avoid obstacles effectively. The real-time mapping capability is vital for the collision avoidance module and feeds data into both the modified A* algorithm and the direction pattern generator. Altitude information is efficiently managed using a hash map data structure, which allows for rapid access to altitude data. This information is essential for navigating environments with significant altitude variations, such as hilly terrains. The altitude data supports several other modules, including automatic speed and altitude configuration, the modified A* algorithm, and the collision avoidance system.

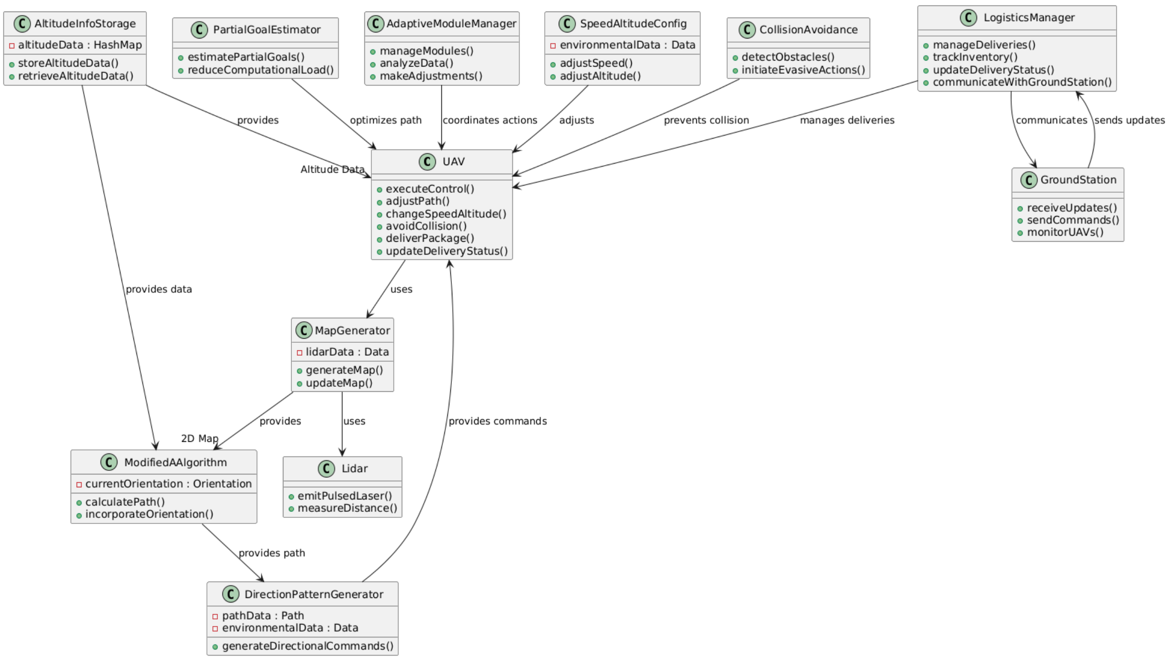


Fig. 2. Class diagram of UAV system

To optimize the UAV's journey, the Partial Goal Estimator module divides the journey into smaller, manageable segments known as 'partial goals.' This approach reduces the computational load and facilitates real-time processing, allowing the UAV to adapt its path dynamically based on the most current environmental information. This segmentation enhances both navigation safety and efficiency. The Adaptive Module Manager acts as the central coordinating system, ensuring seamless communication and cooperation between all modules. It continuously receives data, analyzes it, makes decisions on necessary adjustments, and sends signals to execute these actions. This dynamic adaptation capability significantly improves the UAV's real-time responsiveness and operational efficiency. The Direction Pattern Generator is responsible for translating the planned path into a series of step-by-step directional commands for the UAV. It receives input from the modified A* algorithm and generates instructions that account for the UAV's orientation and immediate environmental factors. These instructions are then relayed to the UAV control system, ensuring precise and accurate navigation. The system includes an Automatic Speed and Altitude Configuration module, which manages the UAV's speed and altitude in real-time based on environmental characteristics such as obstacles, terrain elevation, and weather conditions. This module collects data, analyzes the situation, decides on the optimal speed and altitude, and implements these adjustments dynamically throughout the flight. Finally, the Collision Avoidance module serves as a critical safety feature, functioning as a real-time mechanism to prevent collisions. It gathers environmental data from sensors, assesses potential risks, and makes decisions on necessary evasive actions. These actions are implemented by adjusting the UAV's path, speed, or altitude. This module works in conjunction with other modules to ensure the overall safety and efficiency of the UAV's operation.

5.6. Structure

The structure of the proposed system is visually represented through diagrams as presented in the Fig. 3, Fig. 4, Fig. 5, making it easier to comprehend and conceptualize. The structure typically illustrates the key elements of the pattern and their interactions, highlighting roles, relationships, and collaborations among these elements. A class diagram represents the dynamic path planning system for UAVs, including components such as LiDAR, SensorManager, UAV, MapGenerator, PathPlannerManager, PathPlanner, PathOptimizer, and ControlSystem. A sequence diagram illustrates the sequence of operations, including data collection, processing, map generation, path planning, optimization, and control signal execution, showing the UAV's interaction with the environment and its response to dynamic changes. A deployment diagram demonstrates the implementation process, highlighting sensor selection, integration, algorithm development, testing, and deployment, ensuring the UAV can handle computational loads and perform well under real-world conditions.

5.7. Dynamics

Dynamics describe the behavior of a pattern or system as it evolves over time, influenced by various internal and external factors. It elucidates how a pattern behaves, adapts, and reacts to different scenarios, which is crucial for effective use and adaptation. Interaction represents the relationships and interdependencies among different components within the pattern, helping anticipate systemic responses to changes. Flow encapsulates the sequence and interaction of information, resources, or actions within the system, providing a blueprint for effective implementation. Behavior under different conditions describes how the pattern performs under various conditions, optimizing its effectiveness across different scenarios.

The use case diagram in Fig. 6 illustrates the interactions between various actors and the UAV logistics path planning system, detailing the key functionalities and processes involved in managing and executing unmanned aerial vehicle missions, particularly for delivery operations in rural and challenging environments. The main actors in the system include the operator, the logistics coordinator, the ground station, and the unmanned aerial vehicle itself. The operator is responsible for initiating and overseeing missions, ensuring that the UAV is set up, the mission parameters are configured, and the UAV is launched for its designated task. The logistics coordinator manages the logistics operations, including the execution of deliveries and updating the status of these operations, ensuring that goods are delivered as planned and communicating any issues or updates.

The ground station serves as the interface through which the operator and logistics coordinator monitor and communicate with the UAV. It acts as a central hub for mission control, receiving data from the UAV and relaying commands as necessary. The UAV, equipped with various sensors and systems for navigation, control, and delivery execution, performs the physical tasks required for the mission. This includes collecting data, generating maps, planning and optimizing paths, and delivering goods. The use case for initiating a mission involves the operator starting the mission, setting up the UAV, and launching it. During the mission, the operator and the ground station continuously monitor the UAV's progress, tracking its status, position, and any environmental data it collects. The UAV gathers data from onboard sensors, including Lidar, which is crucial for real-time environmental assessment and navigation. Using this sensor data, the UAV generates a detailed, real-time map of its surroundings, which is essential for understanding the environment and planning safe and efficient paths.

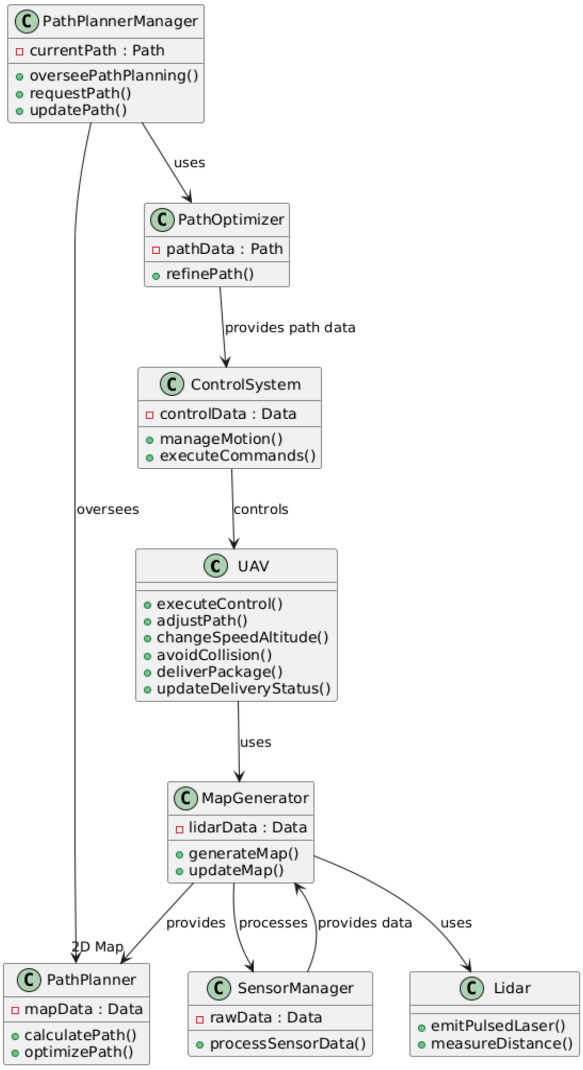


Fig. 3. Class diagram of UAV path planning system

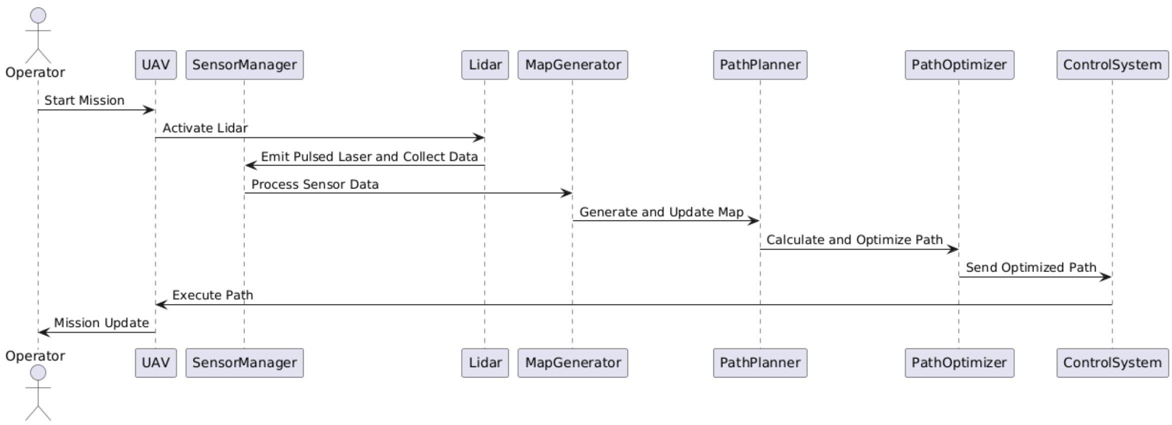


Fig. 4. Sequence diagram of UAV path planning system

Based on the generated map, the UAV calculates an optimal path to reach its destination, considering obstacles, terrain, and other relevant factors. This initial path plan is then refined to improve efficiency, safety, and reliability, potentially involving adjustments to avoid obstacles, reduce energy consumption, or adapt to changing conditions. The control system within the UAV executes the planned and optimized path, making real-time adjustments to speed, altitude, and direction to follow the determined route accurately. During the execution of the delivery, the logistics coordinator oversees the UAV's actions to ensure the goods are delivered correctly, whether by dropping off a package or providing a specific service. After completing the delivery, the UAV updates the delivery status, which is then communicated back to the logistics coordinator. This status update includes confirmation of successful delivery, or any issues encountered during the mission. The diagram also shows the relationships between the different processes, highlighting how each step in the operation depends on the completion of previous steps. For instance, the generation of a map depends on the collection of sensor data, and path planning requires an up-to-date map. The optimization of the path is based on the initially planned route, and the UAV's control actions are informed by the optimized path.

5.8. Implementation

Implementing the pattern involves a multi-step process that requires careful attention to various technical details, including sensor data integration, real-time adjustments, and direction awareness. The first step is understanding the environment, which involves comprehending potential obstacles, dynamic elements, and terrain variations that the UAVs may encounter. Next, sensor selection and integration are crucial; it is essential to choose appropriate sensors for real-time environmental perception and develop efficient sensor fusion algorithms to combine data from multiple sources accurately. Following this, the development and optimization of the path planning algorithm are necessary. This involves modifying traditional algorithms to work with real-time data and account for direction-awareness, ensuring the UAVs can navigate efficiently. Integration of Lidar data and altitude information is also vital. Ensuring accurate and efficient data processing enhances environmental awareness, allowing the UAVs to navigate more effectively.

Upgrading the UAV's motion system is another critical step. This involves adjusting control surfaces and propulsion systems to achieve responsive behavior. Testing and iteration come next; conducting rigorous testing in various environments, along with regular monitoring and system adjustments, helps refine the system's performance. Addressing potential inhibitors, such as computational limitations, sensor inaccuracies, or rapidly changing environments, is also crucial to ensure the system's robustness. The final stages involve the physical installation of hardware and the integration of software on the UAV, ensuring real-world performance meets expectations. Additionally, considerations for multi-UAV operations must be addressed, including formation structure, cooperative sensing, task allocation, and intra-collision avoidance. These steps collectively ensure that the UAV logistics system is efficient, reliable, and adaptable to the dynamic challenges of rural environments.

5.9. Known Uses

The pattern has broad applications in enhancing the adaptability and efficiency of path planning and motion control for autonomous systems navigating in complex and dynamic rural environments. In search and rescue operations, the pattern significantly improves efficiency and safety by enabling UAVs to operate effectively in dynamic and unpredictable environments. This capability is crucial for locating and assisting individuals in distress, especially in areas with difficult terrain or rapidly changing conditions. For surveillance and monitoring, the pattern allows UAVs to navigate complex rural landscapes efficiently and accurately. This is particularly useful for tasks such as wildlife monitoring, agricultural surveillance, and border security, where precise and reliable data collection is essential. Autonomous vehicles also benefit from this pattern, as it enhances their path planning and motion control capabilities in dynamic rural environments. This improvement allows these vehicles to navigate more effectively, ensuring timely and safe transportation of goods and services. Lastly, the pattern is beneficial for indoor robots, improving their path planning and motion control in cluttered indoor spaces like rural warehouses or barns. This enhancement allows robots to perform tasks such as inventory management, material handling, and maintenance with greater efficiency and accuracy, contributing to improved operational productivity in rural settings.

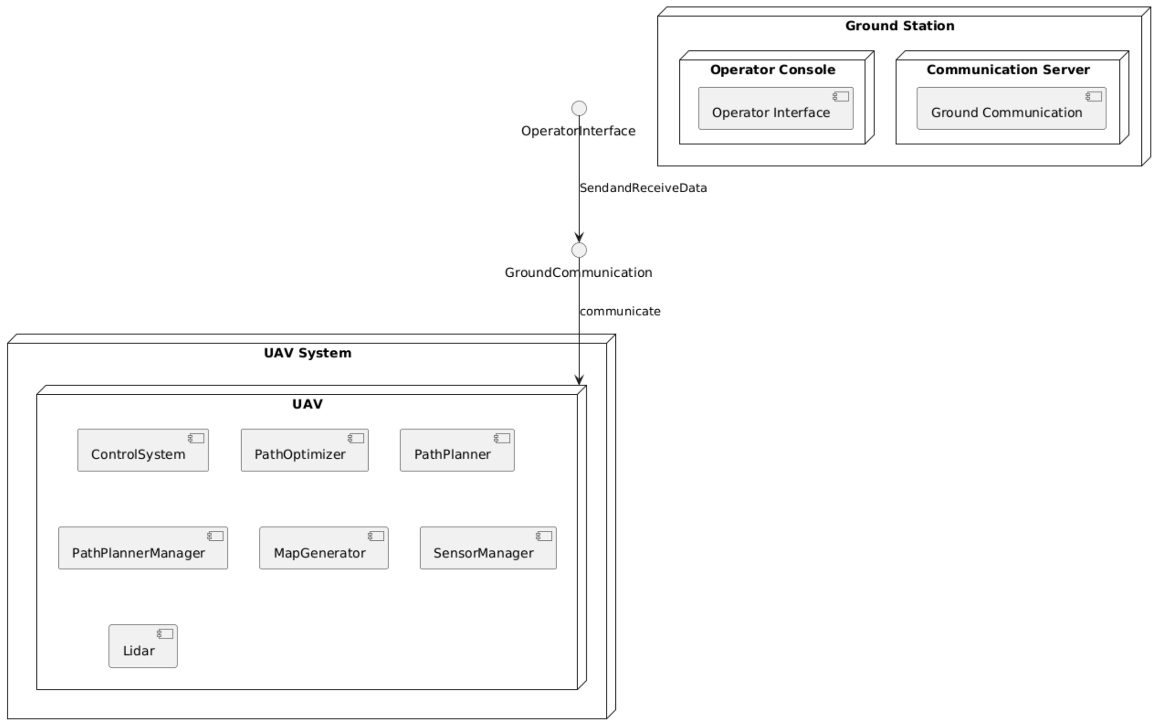


Fig. 5. Deployment diagram of UAV path planning system

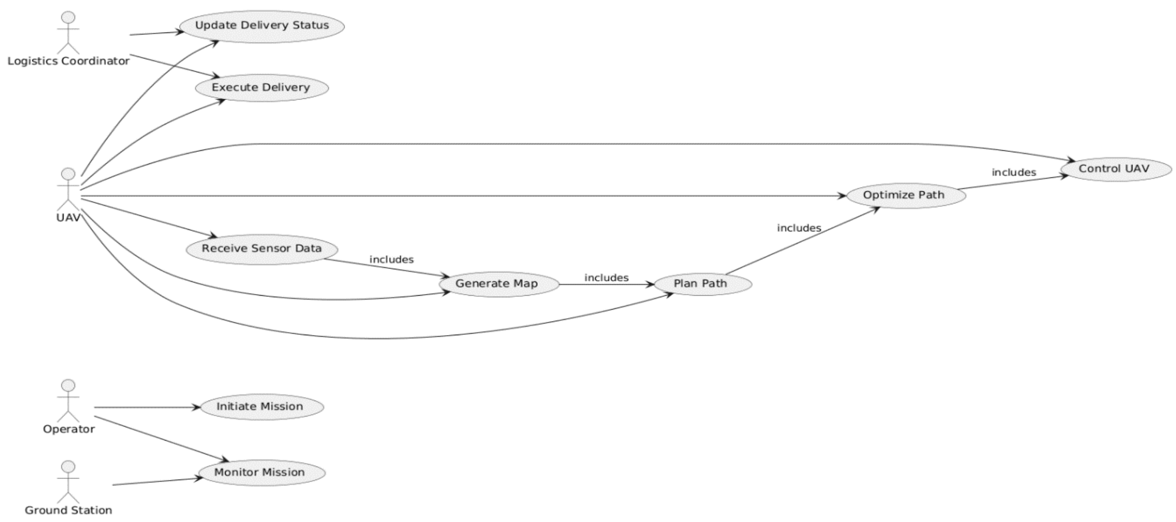


Fig. 6. Use case diagram of UAV path planning system

5.10. Consequences

The implementation of the pattern carries several significant consequences, both positive and negative. On the positive side, it results in improved efficiency, accuracy, and adaptability in path planning. This improvement leads to reduced unnecessary movements, enhanced environmental awareness, and real-time adjustments, making UAVs more effective in rural areas. These benefits are crucial for optimizing logistics and ensuring the timely delivery of essential goods and services in challenging environments. However, there are also negative consequences to consider. The sophisticated algorithms and additional sensor data integration required for the pattern lead to increased computational resource requirements. This increase could result in higher costs, greater energy consumption, and additional weight from the onboard computer. Managing these factors during implementation is critical to ensure the system remains viable and efficient without compromising the UAV's performance and operational capacity.

5.11. Related Patterns

The pattern relates to several other patterns dealing with navigation, control, and coordination of autonomous systems. Traditional path planning algorithms serve as the basis for many navigation systems. These algorithms are extended by incorporating real-time data and adjusting for UAV orientation and direction, enhancing their applicability in dynamic environments. SLAM (Simultaneous Localization and Mapping) is another related pattern, providing real-time updates about the environment, which are crucial for informed path planning. Additionally, sensor fusion algorithms play a significant role by enhancing input data for the pattern, offering a more accurate picture of the dynamic environment. This integration of diverse sensor data improves the overall reliability and precision of the system. Control theory applications further enhance the pattern by improving the motion system's response to the path planning algorithm's output, ensuring smooth and efficient navigation. Finally, swarm intelligence is a related pattern that coordinates multiple UAVs to complete tasks more efficiently. This complements the pattern by enabling effective multi-UAV coordination, which is essential for complex operations that require simultaneous actions from multiple autonomous systems.

6. Validation and Refinement Design

To ensure the relevance, practicality, and effectiveness of the proposed UAV logistics path planning system pattern, we conducted a comprehensive validation and refinement process. This process included field observations, interviews with local stakeholders, and focus group discussions involving residents, logistics providers, and local authorities from Talaud Island, North Sulawesi. These activities allowed us to test the design patterns in real-world scenarios and gather invaluable feedback from those directly affected by the logistical challenges in rural environments. The focus group discussions with experts in UAV technology, logistics, and software engineering provided critical insights into the clarity, completeness, and applicability of the design patterns. This expert review phase helped refine the system's conceptual framework, ensuring it aligns with both technical standards and practical needs. The stakeholders also emphasized the importance of the UAV's adaptability in dynamic, unpredictable environments, which was central to our system's design.

We then conducted scenario-based evaluations to test the system under real-world conditions. The first scenario involved deploying a UAV to deliver medical supplies to a remote village on Talaud Island. The village, characterized by steep slopes, dense forests, and unpredictable weather conditions, presented numerous logistical challenges. The UAV was tasked with navigating through rugged terrain, dynamically adjusting its path in real-time to avoid obstacles and respond to changes in weather conditions. This scenario tested the system's ability to handle real-time environmental assessments and ensure timely delivery of critical supplies, such as medical items, to isolated communities. The second scenario focused on agricultural monitoring in a rural area with varied terrain. In this case, the UAV had to navigate fields, hills, and water bodies, encountering obstacles such as livestock and newly erected structures. This scenario demonstrated the system's capacity for real-time path planning and adaptability in a rapidly changing agricultural environment. Both scenarios were designed to push the UAV system to its operational limits, examining how well it could adjust to unexpected obstacles and environmental changes.

Based on the results of these scenario-based evaluations, we refined the design patterns through an iterative process. For example, feedback indicated that the system's obstacle detection needed improvement in densely vegetated areas. As a result, we enhanced the UAV's sensor accuracy and adjusted its real-time path planning algorithms to improve navigation through such terrain. This refinement process was guided by quantitative metrics collected during the evaluations, including delivery time, path efficiency, energy consumption, obstacle avoidance success rate, and overall system reliability. Additionally, we integrated feedback from local stakeholders into the validation process, which provided practical insights into the system's real-world applicability. The residents and logistics providers highlighted the importance of reliable delivery times for critical supplies, particularly in regions where transportation infrastructure is lacking. This input informed further enhancements to the system's adaptability, ensuring it can meet the specific logistical demands of remote communities like those on Talaud Island.

7. Conclusion

This study proposes a comprehensive UAV logistics path planning system specifically designed to address the unique challenges associated with rural areas, where complex terrains and limited infrastructure often hinder efficient logistical operations. The system's primary goal is to enhance UAV operational efficiency, accuracy, and adaptability, enabling reliable delivery of essential goods and services in remote regions. By incorporating a real-time, online environmental assessment and dynamic path planning approach, the system overcomes the limitations of traditional methods reliant on static maps and predetermined routes. The research outlines an iterative validation and refinement process, which includes an expert review to assess the system's conceptual framework and scenario-based evaluations to test practical applications. These planned scenarios, such as medical supply delivery to remote villages and agricultural monitoring in challenging terrains, will provide critical insights into the system's performance under real-world conditions. Moreover, the inclusion of local stakeholder feedback ensures that the system is not only technically robust but also practically relevant to the needs of the communities it serves.

The anticipated outcomes of these evaluations include improvements in UAV operational efficiency, delivery accuracy, and the system's ability to adapt to dynamic environments. The integration of advanced technologies, such as the modified A algorithm, LiDAR-based map generation*, and adaptive control systems, positions this UAV system as a versatile solution for rural logistics. Quantitative metrics and feedback from stakeholders will guide the refinement process, ensuring that any identified gaps are addressed. In conclusion, this study lays the foundation for developing a scalable and adaptable UAV logistics system, tailored to the specific logistical complexities of rural environments. The proposed validation and refinement phases will be crucial in ensuring the system meets the high standards required for such challenging applications. Through this research, we aim to contribute significantly to the field of UAV technology, particularly in enhancing logistical operations in underserved rural areas, thereby improving access to essential goods and services and fostering sustainable development.

Author Contribution: All authors contributed equally to the main contributor to this paper. All authors read and approved the final paper.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

[1] M. Azmat and S. Kummer, "Potential applications of unmanned ground and aerial vehicles to mitigate challenges of transport and logistics-related critical success factors in the humanitarian supply chain," *Asian Journal of Sustainability and Social Responsibility*, vol. 5, no. 1, p. 3, 2020, https://doi.org/10.1186/s41180-020-0033-7.

[2] Y. Zhang, D. J. Love, J. V. Krogmeier, C. R. Anderson, R. W. Heath and D. R. Buckmaster, "Challenges and Opportunities of Future Rural Wireless Communications," *IEEE Communications Magazine*, vol. 59, no. 12, pp. 16-22, 2021, https://doi.org/10.1109/MCOM.001.2100280.

[3] A. Oke and A. Maltz, "Logistics in Emerging Markets," *The Oxford Handbook of Supply Chain Management*, 2020, https://doi.org/10.1093/oxfordhb/9780190066727.013.22.

[4] N. Boysen, S. Fedtke, and S. Schwerdfeger, "Last-mile delivery concepts: a survey from an operational research perspective," *Or Spectrum*, vol. 43, no. 1, pp. 1–58, 2021, https://doi.org/10.1007/s00291-020-00607-8.

[5] M. U. H. Uzir *et al*., "The effects of service quality, perceived value and trust in home delivery service personnel on customer satisfaction: Evidence from a developing country," *Journal of Retailing and Consumer Services*, vol. 63, p. 102721, 2021, https://doi.org/10.1016/j.jretconser.2021.102721.

[6] X. Li *et al*., "Solving the last mile problem in logistics: A mobile edge computing and blockchain-based unmanned aerial vehicle delivery system," *Concurrecy and Computation Practice and Experience*, vol. 34, no. 7, p. e6068, 2022, https://doi.org/10.1002/cpe.6068.

[7] C. Wang, Y. Wang, H. Fang, B. Gao, Z. Weng, and Y. Tian, "Determinants of rural poverty in remote mountains of southeast China from the household perspective," *Social Indicators Research*, vol. 150, pp. 793–810, 2020, https://doi.org/10.1007/s11205-020-02348-1.

[8] P. Zhao and Z. Yu, "Investigating mobility in rural areas of China: Features, equity, and factors," *Transport Policy*, vol. 94, pp. 66–77, 2020, https://doi.org/10.1016/j.tranpol.2020.05.008.

[9] B. Zegeye *et al*., "Breaking barriers to healthcare access: a multilevel analysis of individual-and community-level factors affecting women's access to healthcare services in Benin," *International Journal of Environmental Research and Public Health*, vol. 18, no. 2, p. 750, 2021, https://doi.org/10.3390/ijerph18020750.

[10] X. Li, S. Sohail, M. T. Majeed, and W. Ahmad, "Green logistics, economic growth, and environmental quality: evidence from one belt and road initiative economies," *Environmental Science and Pollution Research*, vol. 28, pp. 30664–30674, 2021, https://doi.org/10.1007/s11356-021-12839-4.

[11] Y. Tim, L. Cui, and Z. Sheng, "Digital resilience: How rural communities leapfrogged into sustainable development," *Information Systems Journal*, vol. 31, no. 2, pp. 323–345, 2021, https://doi.org/10.1111/isj.12312.

[12] P. Velusamy, S. Rajendran, R. K. Mahendran, S. Naseer, M. Shafiq, and J.-G. Choi, "Unmanned Aerial Vehicles (UAV) in precision agriculture: Applications and challenges," *Energies*, vol. 15, no. 1, p. 217, 2021, https://doi.org/10.3390/en15010217.

[13] G. R. Patil and G. Sharma, "Urban Quality of Life: An assessment and ranking for Indian cities," *Transport Policy*, vol. 124, pp. 183–191, 2022, https://doi.org/10.1016/j.tranpol.2020.11.009.

[14] C. Tonne *et al*., "Defining pathways to healthy sustainable urban development," *Environment International*, vol. 146, p. 106236, 2021, https://doi.org/10.1016/j.envint.2020.106236.

[15] A. Khan, S. Gupta, and S. K. Gupta, "Emerging UAV technology for disaster detection, mitigation, response, and preparedness," *Journal of Field Robotics*, vol. 39, no. 6, pp. 905–955, 2022, https://doi.org/10.1002/rob.22075.

[16] M. G. D'Urso, V. Manzari, S. Lucidi, and F. Cuzzocrea, "Rescue Management and Assessment of Structural Damage by Uav in Post-Seismic Emergency," *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. 5, pp. 61–70, 2020, https://doi.org/10.5194/isprs-annals-V-5-2020-61-2020.

[17] M. Matracia, N. Saeed, M. A. Kishk and M. -S. Alouini, "Post-Disaster Communications: Enabling Technologies, Architectures, and Open Challenges," *IEEE Open Journal of the Communications Society*, vol. 3, pp. 1177-1205, 2022, https://doi.org/10.1109/OJCOMS.2022.3192040.

[18] B. Lawson *et al*., "How to start up a national wildlife health surveillance programme," *Animals*, vol. 11, no. 9, p. 2543, 2021, https://doi.org/10.3390/ani11092543.

[19] S. Babatunde, R. Oloruntoba, and K. Agho, "Healthcare commodities for emergencies in Africa: review of logistics models, suggested model and research agenda," *Journal of Humanitarian Logistics and Supply Chain Management*, vol. 10, no. 3, pp. 371–390, 2020, https://doi.org/10.1108/JHLSCM-09-2019-0064.

[20] V. Sukhwani and R. Shaw, "Urban--rural linkages and their implication to human security in pandemic time," *Global Pandemic and Human Security*, pp. 147–163, 2022, https://doi.org/10.1007/978-981-16-5074-1_8.

[21] R. Vos and A. Cattaneo, "Poverty reduction through the development of inclusive food value chains," *Journal of Integrative Agriculture*, vol. 20, no. 4, pp. 964–978, 2021, https://doi.org/10.1016/S2095-3119(20)63398-6.

[22] T. Benarbia and K. Kyamakya, “A literature review of drone-based package delivery logistics systems and their implementation feasibility,” *Sustainability*, vol. 14, no. 1, p. 360, 2021, https://doi.org/10.3390/su14010360.

[23] S. Jagtap, F. Bader, G. Garcia-Garcia, H. Trollman, T. Fadiji, and K. Salonitis, “Food logistics 4.0: Opportunities and challenges,” *Logistics*, vol. 5, no. 1, p. 2, 2020, https://doi.org/10.3390/logistics5010002.

[24] S. A. R. Khan, A. Razzaq, Z. Yu, A. Shah, A. Sharif, and L. Janjua, “Disruption in food supply chain and undernourishment challenges: An empirical study in the context of Asian countries,” *Socio-Economic Planning Sciences*, vol. 82, p. 101033, 2022, https://doi.org/10.1016/j.seps.2021.101033.

[25] T. Elmokadem and A. V Savkin, “Towards fully autonomous UAVs: A survey,” *Sensors*, vol. 21, no. 18, p. 6223, 2021, https://doi.org/10.3390/s21186223.

[26] M. Bachofner, C. Lemardelé, M. Estrada, and L. Pagès, “City logistics: Challenges and opportunities for technology providers,” *Journal of Urban Mobility*, vol. 2, p. 100020, 2022, https://doi.org/10.1016/j.urbmob.2022.100020.

[27] A. Tullu, B. Endale, A. Wondosen, and H.-Y. Hwang, “Machine learning approach to real-time 3D path planning for autonomous navigation of unmanned aerial vehicle,” *Applied Science*, vol. 11, no. 10, p. 4706, 2021, https://doi.org/10.3390/app11104706.

[28] L. Watkins, N. Sarfaraz, S. Zanlongo, J. Silbermann, T. Young and R. Sleight, "An Investigative Study Into An Autonomous UAS Traffic Management System For Congested Airspace Safety," *2021 IEEE International Conference on Communications Workshops (ICC Workshops)*, pp. 1-6, 2021, https://doi.org/10.1109/ICCWorkshops50388.2021.9473838.

[29] H. Wei, B. Lou, Z. Zhang, B. Liang, F. -Y. Wang and C. Lv, "Autonomous Navigation for eVTOL: Review and Future Perspectives," *IEEE Transactions on Intelligent Vehicles*, vol. 9, no. 2, pp. 4145-4171, 2024, https://doi.org/10.1109/TIV.2024.3352613.

[30] S. A. H. Mohsan, M. A. Khan, F. Noor, I. Ullah and M. H. Alsharif, “Towards the Unmanned Aerial Vehicles (UAVs): A Comprehensive Review,” *Drones*, vol. 6, no. 6, p. 147, 2022, https://doi.org/10.3390/drones6060147.

[31] J. Tang, S. Lao and Y. Wan, "Systematic Review of Collision-Avoidance Approaches for Unmanned Aerial Vehicles," *IEEE Systems Journal*, vol. 16, no. 3, pp. 4356-4367, 2022, https://doi.org/10.1109/JSYST.2021.3101283.

[32] A. Hafeez *et al.*, “Implementation of drone technology for farm monitoring \& pesticide spraying: A review,” *Information Processing in Agriculture*, vol. 10, no. 2, pp. 192–203, 2023, https://doi.org/10.1016/j.inpa.2022.02.002.

[33] N. Delavarpour, C. Koparan, J. Nowatzki, S. Bajwa, and X. Sun, “A technical study on UAV characteristics for precision agriculture applications and associated practical challenges,” *Remote Sensing*, vol. 13, no. 6, p. 1204, 2021, https://doi.org/10.3390/rs13061204.

[34] A. P. Singh, A. Yerudkar, V. Mariani, L. Iannelli, and L. Glielmo, “A bibliometric review of the use of unmanned aerial vehicles in precision agriculture and precision viticulture for sensing applications,” *Remote Sensing*, vol. 14, no. 7, p. 1604, 2022, https://doi.org/10.3390/rs14071604.

[35] S. K. Phang, T. H. A. Chiang, A. Happonen and M. M. L. Chang, "From Satellite to UAV-Based Remote Sensing: A Review on Precision Agriculture," *IEEE Access*, vol. 11, pp. 127057-127076, 2023, https://doi.org/10.1109/ACCESS.2023.3330886.

[36] A. Albanese, V. Sciancalepore and X. Costa-Pérez, "SARDO: An Automated Search-and-Rescue Drone-Based Solution for Victims Localization," *IEEE Transactions on Mobile Computing*, vol. 21, no. 9, pp. 3312-3325, 2022, https://doi.org/10.1109/TMC.2021.3051273.

[37] W. Zhao, M. Wang, and V. T. Pham, “Unmanned aerial vehicle and geospatial analysis in smart irrigation and crop monitoring on IoT platform,” *Mobile Information Systems*, vol. 2023, no. 1, pp. 1-12, 2023, https://doi.org/10.1155/2023/4213645.

[38] V. Moysiadis, P. Sarigiannidis, V. Vitsas, and A. Khelifi, “Smart farming in Europe,” *Computer Science Review*, vol. 39, p. 100345, 2021, https://doi.org/10.1016/j.cosrev.2020.100345.

[39] F. Aminifar and F. Rahmatian, "Unmanned Aerial Vehicles in Modern Power Systems: Technologies, Use Cases, Outlooks, and Challenges," *IEEE Electrification Magazine*, vol. 8, no. 4, pp. 107-116, 2020, https://doi.org/10.1109/MELE.2020.3026505.

[40] S. A. Wich, M. Hudson, H. Andrianandrasana, and S. N. Longmore, "Drones for conservation," *Conservation Technology*, 2021, https://doi.org/10.1093/oso/9780198850243.003.0003.

[41] P. Mishra and G. Singh, "Unmanned aerial vehicles in sustainable smart cities," *Sustainable smart* cities, pp. 221–238, 2023, https://doi.org/10.1007/978-3-031-33354-5_10.

[42] F. B. Sorbelli, "UAV-Based Delivery Systems: a Systematic Review, Current Trends, and Research Challenges," *Journal on Autonomous Transportation Systems*, vol. 1, no. 3, pp. 1–40, 2024, https://doi.org/10.1145/3649224.

[43] A. Minnaar, "Border Security: An Essential but Effective Tool in Combatting Cross-Border Crime," *The Handbook of Security*, pp. 357–378, 2020, https://doi.org/10.1007/978-3-030-91735-7_17.

[44] V. Manjarrez Jr, "The Rise of "Border Security"," *Global Human Smuggling: Buying Freedom in a Retreating World*, 2023, https://books.google.co.id/books?id=-PywEAAAQBAJ&dq=The+Rise+of+%E2%80%98Border+Security&lr=&source=gbs_navlinks_s.

[45] Y. Pi, "Artificial Intelligence for Aerial Information Retrieval and Mapping in Natural Disasters," *Electronic Theses, Dissertations, and Records of Study*, 2020, https://oaktrust.library.tamu.edu/items/cda37285-1c28-431d-ae89-e2358f70e19c.

[46] S. M. S. M. Daud *et al*., "Applications of drone in disaster management: A scoping review," *Science & Justice*, vol. 62, no. 1, pp. 30-42, 2022, https://doi.org/10.1016/j.scijus.2021.11.002.

[47] F. Wedyan and S. Abufakher, "Impact of design patterns on software quality: a systematic literature review," *IET Software*, vol. 14, no. 1, pp. 1–17, 2020, https://doi.org/10.1049/iet-sen.2018.5446.

[48] X. Chen *et al*., "DDL: Empowering Delivery Drones With Large-Scale Urban Sensing Capability," *IEEE Journal of Selected Topics in Signal Processing*, vol. 18, no. 3, pp. 502-515, 2024, https://doi.org/10.1109/JSTSP.2024.3427371.

[49] S. Mugala, D. Okello and J. Serugunda, "Unmanned Aerial Vehicles: Opportunities for Developing Countries and Challenges," *2020 IST-Africa Conference (IST-Africa)*, pp. 1-10, 2020, https://ieeexplore.ieee.org/document/9144040.

[50] P. Loukinas, "Drones for border surveillance: multipurpose use, uncertainty and challenges at EU borders," *Geopolitics*, vol. 27, no. 1, pp. 89–112, 2022, https://doi.org/10.1080/14650045.2021.1929182.

[51] P. Aela, H. Chi, A. Fares, T. Zayed, and M. Kim, "UAV-based studies in railway infrastructure monitoring," *Automation in Construction*, vol. 167, p. 105714, 2024, https://doi.org/10.1016/j.autcon.2024.105714.

[52] N. Mohamed J. Al-Jaroodi, I. Jawhar, A. Idries, F. Mohammed, "Unmanned aerial vehicles applications in future smart cities," *Technological Forecasting and Social Change*, vol. 153, p. 119293, 2020, https://doi.org/10.1016/j.techfore.2018.05.004.

[53] M. Szóstak, T. Nowobilski, A.-M. Mahamadu, and D. C. Pérez, "Unmanned aerial vehicles in the construction industry-Towards a protocol for safe preparation and flight of drones," *International Journal of Intelligent Unmanned Systems*, vol. 11, no. 2, pp. 296–316, 2023, https://doi.org/10.1108/IJIUS-05-2022-0063.

[54] S. MahmoudZadeh, A. Yazdani, Y. Kalantari, B. Ciftler, F. Aidarus, and M. O. Al Kadri, "Holistic Review of UAV-Centric Situational Awareness: Applications, Limitations, and Algorithmic Challenges," *Robotics*, vol. 13, no. 8, p. 117, 2024, https://doi.org/10.3390/robotics13080117.

[55] S. Mishra and P. Palanisamy, "Autonomous Advanced Aerial Mobility—An End-to-End Autonomy Framework for UAVs and Beyond," *IEEE Access*, vol. 11, pp. 136318-136349, 2023, https://doi.org/10.1109/ACCESS.2023.3339631.