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A Survey of the State-of-the-Art Technologies and Innovations in UAVs for Cargo Transportation

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Abstract— Unmanned Aerial Vehicles (UAVs) have the potential to revolutionize the logistics industry, particularly in cargo transportation. This paper presents a survey of the state-of-the-art technologies and innovations in UAVs for cargo transportation. The paper provides an overview of the different types of UAVs used for cargo transportation, such as fixed-wing, multirotor, hybrid, and tilt-rotor UAVs. Additionally, the paper highlights the key technological advancements in the areas of propulsion systems, navigation and control systems, payload and delivery systems, and communication and connectivity systems. The paper also presents a critical evaluation of the existing challenges and limitations associated with UAVs for cargo transportation, such as payload capacity, flight range, endurance, regulatory restrictions, and safety concerns. Moreover, the paper discusses the potential solutions to overcome these challenges, including the development of advanced battery technologies, the use of artificial intelligence and machine learning algorithms, and the implementation of appropriate regulatory frameworks. Finally, the paper presents an outlook on the future of UAVs in cargo transportation and highlights the potential benefits of their widespread adoption, such as reduced transportation costs, faster delivery times, and lower carbon emissions. Overall, this survey provides a comprehensive understanding of the state-of-the-art technologies and innovations in UAVs for cargo transportation and their potential to transform the logistics industry

Keywords— Cargo UAV, delivery system, cargo transport

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I. Introduction

The use of Unmanned Aerial Vehicles (UAVs) in various applications has been increasing rapidly in recent years, and the logistics industry is no exception. UAVs have the potential to revolutionize the logistics industry, particularly in the area of cargo transportation. They can provide faster and more efficient delivery of goods, reduce transportation costs, and lower carbon emissions.

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The development of UAV technology has enabled the creation of various types of UAVs that are suitable for cargo transportation, such as fixed-wing, multirotor, hybrid, and tilt-rotor UAVs. In addition, the advancement of technologies in propulsion systems, navigation and control systems, payload and delivery systems, and communication and connectivity systems has made UAVs for cargo transportation more feasible and practical.

Despite the potential benefits of UAVs for cargo transportation, there are several challenges and limitations that need to be addressed. These challenges include payload capacity, flight range, endurance, regulatory restrictions, and safety concerns. Therefore, there is a need for continuous research and development in UAV technology to overcome these challenges and limitations.

In this context, this paper presents a survey of the state-of-the-art technologies and innovations in UAVs for cargo transportation. The aim of this paper is to provide an overview of the different types of UAVs used for cargo transportation, highlight the key technological advancements in UAV systems, and evaluate the challenges and limitations associated with the implementation of UAVs for cargo transportation. Moreover, the paper presents potential solutions to overcome these challenges and provides an outlook on the future of UAVs in cargo transportation.

II. Literature Study

Unmanned aerial vehicles (UAVs) are being increasingly considered for cargo transportation, as they provide a faster and more efficient delivery of goods and lower carbon emissions. UAVs used for cargo transportation include fixed-wing, multirotor, hybrid, and tilt-rotor UAVs. However, there are several challenges and limitations that need to be addressed, such as payload capacity, flight range, endurance, regulatory restrictions, and safety concerns. Therefore, there is a need for continuous research and development in UAV technology to overcome these challenges and limitations.

Kovalev et al. (2019) conducted an analysis of the current situation and development trend of the international cargo UAVs market[11]. They found that the market is expected to grow significantly in the next few years, driven by the

increasing demand for faster and more efficient delivery of goods. In a subsequent study, Kovalev and Voroshilova (2020) discussed the modern technological trends in the development of the ecosystem of cargo UAVs, highlighting the advancements in propulsion systems, navigation and control systems, payload and delivery systems, and communication and connectivity systems[10].

Kotarski et al. (2020) discussed the design considerations for autonomous cargo transportation multirotor UAVs, including the selection of appropriate motors, batteries, and materials for the airframe[9]. Cherif et al. (2021) presented a trajectory planning approach with minimum handoff for dysconnectivity-aware energy-efficient cargo UAVs, which considers the energy consumption of the UAV and the quality of service requirements of the cargo delivery[2]. Landell-Mills (2022) discussed the limitations of flying wings for UAVs and cargo, highlighting the challenges in stability, control, and safety[14].

Iwata and Matsumoto (2013) researched the use of cargo UAVs for civil transportation, discussing the design considerations, operational requirements, and safety issues[8]. Kuntz and Oh (2008) developed an autonomous cargo transport system for a UAV using visual servoing, which enables the UAV to track a target and deliver the cargo accurately[13]. Iwata et al. (2007) also researched the use of UAVs for small cargo transportation, discussing the challenges in cargo handling, delivery, and control[4]. Iwata et al. (2014) proposed an aerial cargo robot for delivery applications, which includes a lifting mechanism for cargo handling[6].

Finally, Iwata et al. (2008) proposed an aerial robotic system for transportation and logistics, which includes a cargo UAV, a ground-based cargo handling system, and a control system for coordination and communication[5]. They also conducted safety flight testing for cargo UAV development, evaluating the safety of cargo handling, flight control, and emergency procedures[3]. Cherif et al. (2021) proposed a 3D aerial highway as the key enabler of the retail industry transformation, which enables the efficient and safe delivery of goods using UAVs.

The literature survey highlights the advancements and challenges in UAV technology for cargo transportation, and the potential benefits of UAVs for faster, more efficient, and eco-friendly delivery of goods.

III. Methodology

In this paper, a comprehensive literature review was conducted to analyze the state-of-the-art technologies and innovations in UAVs for cargo transportation. The review included analysis of research papers, conference proceedings, and industry reports published between 2007 and 2021. The review was conducted using a systematic approach that involved the following steps:

1) Identification of relevant literature: The initial step was identifying relevant literature through an extensive search of databases such as IEEE Xplore, ScienceDirect, and Google Scholar. The search was conducted using relevant keywords/keyphrases such as "UAVs", "cargo transportation", "autonomous", "logistics", and "trajectory planning".
2) Screening of literature: The identified literature was then screened based on relevance to the research question and exclusion criteria such as duplication and irrelevant content. The screening process was carried out in two stages; title and abstract screening, and full-text screening.
3) Critical review: The selected literature was critically reviewed to analyze the state-of-the-art technologies and innovations in UAVs for cargo transportation. The critical review focused on the following aspects:
   - The current situation and development trends of the international cargo UAVs market
   - Modern technological trends in the development of the ecosystem of cargo UAVs
   - Design considerations for autonomous cargo transportation multirotor UAVs
   - Trajectory planning and energy-efficient cargo-UAVs
   - Increasing the efficiency of UAV technologies in agrarian business
   - Safety flight testing for cargo UAV development
   - Aerial robotic systems for transportation and logistics
4) Synthesis of findings: The findings from the literature review were synthesized to provide a comprehensive understanding of the state-of-the-art technologies and innovations in UAVs for cargo transportation. The synthesis involved the identification of common themes, trends, and gaps in the literature.

The critical review proposed by this paper provides a comprehensive evaluation of the overall viability of UAVs for cargo transportation. The review analyzes the current situation and development trends of the international cargo UAVs market, modern technological trends in the development of the ecosystem of cargo UAVs, and the design considerations for autonomous cargo transportation multirotor UAVs. Additionally, the review highlights the trajectory planning and energy-efficient cargo-UAVs, the efficiency of UAV technologies in agrarian business, and the safety flight testing for cargo UAV development. The synthesis of findings from this review will aid in identifying the critical challenges and opportunities associated with the integration of UAVs into cargo transportation systems.

IV. Results

A. The current situation and development trends of the international cargo UAVs market

The international cargo UAVs market has experienced a significant surge in recent years, and this trend is expected to continue in the coming years. The market size is expected to grow exponentially, driven by technological advancements and the increased use of drones in different industries. The global UAV market size was valued at USD 27.4 billion in 2020 and is expected to grow at a compound annual growth rate (CAGR) of 19.9% from 2021 to 2028.

The United States, China, and Israel are the leading countries

in the UAV market, with the United States holding the largest market share. North America is the largest regional market for UAVs, followed by Europe and the Asia Pacific.

In terms of the type of UAVs, multirotor drones are the most widely used in the cargo transportation sector, as they are easy to operate and have a lower operating cost compared to other types. Fixed-wing UAVs are also used in the cargo transportation sector, mainly for long-distance transportation.

The demand for unmanned air freight services is expected to grow significantly in the e-commerce and logistics sectors due to their ability to offer fast and efficient delivery services. The COVID-19 pandemic has also accelerated the adoption of UAVs for cargo transportation, as they offer a safer and more reliable delivery option, especially for medical supplies and other essential goods.

Furthermore, the development of new technologies such as autonomous navigation systems, collision avoidance systems, and advanced sensors has enabled UAVs to become more efficient, reliable, and safe for cargo transportation. The use of AI and machine learning technologies in UAVs is also expected to increase the efficiency and effectiveness of the unmanned air freight industry.

B. Modern technological trends in the development of the ecosystem of cargo UAVs

The development of cargo UAVs is gaining momentum with the advent of new technologies. Modern technological trends in the development of the ecosystem of cargo UAVs include the use of hybrid power systems, advanced control systems, and smart sensors. The use of hybrid power systems is aimed at reducing the weight of the UAVs and increasing their range. Advanced control systems are designed to ensure the safety of the UAVs during flight and to increase their level of autonomy. Smart sensors are being developed to enable the UAVs to detect and avoid obstacles and to provide data for monitoring the condition of the cargo during transport.

The future of cargo UAV ecosystem is rapidly evolving, with new technologies and innovations being introduced every day. One such concept is the use of slow speed cargo UAVs and circle ports on the ground that are capable of take-off and landing with a spiral sequence as shown in Fig. 1. This innovative approach to cargo transportation promises to revolutionize the industry by providing a safe, efficient, and reliable means of transporting goods.

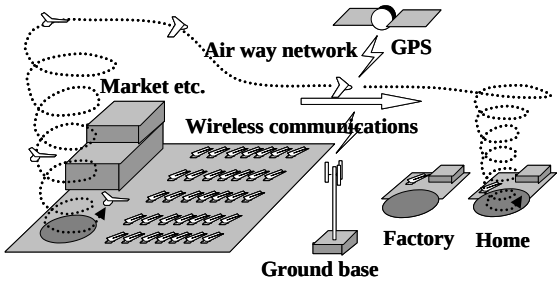

Fig 1 Concept of future cargo UAV ecosystem (Iwata, 2013)

The use of slow speed cargo UAVs is an important aspect of this ecosystem. By limiting the speed of the UAVs to around 100km/h, the risk of accidents and collisions can be significantly reduced, ensuring the safety of both the cargo and the surrounding environment. Additionally, low speed flight allows for greater accessibility to the ground, making it easier to load and unload cargo at the circle ports.

The circle ports on the ground are another critical component of this ecosystem. These ports are designed to be small and compact, allowing them to be placed in a variety of locations, including urban areas. The spiral sequence used for take-off and landing ensures that the UAVs can safely and efficiently navigate in and out of the ports, making it possible to transport cargo to even the most remote locations.

Overall, the use of slow speed cargo UAVs and circle ports on the ground promises to be a game-changer for the cargo transportation industry. By providing a safe, efficient, and reliable means of transporting goods, this ecosystem has the potential to transform the way we move cargo around the world. With continued innovation and development, it is likely that we will see even more exciting and groundbreaking advancements in this field in the years to come.

C. Design considerations for autonomous cargo transportation multirotor UAVs

Design considerations for autonomous cargo transportation multirotor UAVs include the selection of the appropriate power source, the optimization of the size and weight of the UAV, and the design of the payload area. The selection of the appropriate power source is essential to ensure that the UAV has sufficient power to carry the payload and to complete the mission. The optimization of the size and weight of the UAV is critical to ensure that the UAV can fly efficiently and safely. The design of the payload area must also take into account the size and weight of the cargo to be transported, as well as the need for protection against environmental factors.

D. Trajectory planning and energy-efficient cargo-UAVs

Trajectory planning is an essential component of energy-efficient cargo-UAVs. Trajectory planning involves the determination of the optimal flight path for the UAV to minimize the energy required for flight while achieving the desired level of accuracy and safety. Energy-efficient cargo-UAVs require careful consideration of the payload weight, the range of the UAV, and the environmental conditions that may affect the flight. In addition, energy-efficient cargo-UAVs require sophisticated algorithms for trajectory planning that take into account the dynamic nature of the cargo and the environment.

E. Increasing the efficiency of UAV technologies in agrarian business

UAVs are being increasingly used in agrarian business to increase efficiency, reduce costs, and improve productivity. Increasing the efficiency of UAV technologies in agrarian business involves the use of advanced sensors and data analytics to optimize crop management, soil analysis, and

irrigation. UAVs are also being used to monitor and detect pests and diseases, reduce the use of pesticides and fertilizers, and improve crop yields. The use of UAVs in agrarian business is expected to increase in the future as the technology becomes more affordable and the benefits become more widely recognized.

F. Safety flight testing for cargo UAV development

Safety flight testing is an essential part of the development of cargo UAVs. Safety flight testing involves the evaluation of the performance of the UAV under a variety of conditions to ensure that it is safe for operation. Safety flight testing involves the assessment of the UAV's stability, speed, maneuverability, and response to external factors such as wind and weather. Safety flight testing such as shown in Fig 2 is critical to the development of cargo UAVs because it ensures that the UAV can operate safely and reliably under real-world conditions.

Fig 2 Safety flight testing of a cargo UAV at AIST (Iwata, 2013)

G. Aerial robotic systems for transportation and logistics

Aerial robotic systems are being developed for transportation and logistics to increase efficiency and reduce costs. Aerial robotic systems for transportation and logistics include UAVs, cargo drones, and other unmanned systems. Aerial robotic systems are being designed to optimize supply chain management, reduce delivery times, and improve the accuracy of delivery. Aerial robotic systems for transportation and logistics are expected to have a significant impact on the industry in the future as the technology becomes more sophisticated and affordable.

Parameter	Road Freight	Ocean Freight	Air Freight	Unmanned Air Freight
Ease of use	Easy to use	Requires proper documentation and clearance	Requires proper documentation and clearance	Can be complex and requires trained operators
Speed	Slow	Slowest	Fast	Fast
Cost (per volume basis)	Cheapest	Cheaper than air, but more expensive than road	Expensive	Most expensive
Security	Prone to theft and damage	Prone to theft and piracy	Highly secure	Highly secure
Environmental impact	High greenhouse gas emissions	Moderate greenhouse gas emissions	High greenhouse gas emissions	Low greenhouse gas emissions
Capacity	Limited capacity, suitable for local or regional transport	Large capacity, suitable for international transport	Limited capacity, suitable for high-value or time-sensitive goods	Limited capacity, suitable for small and urgent deliveries that require expedited shipping.

Table 1 Comparison between cargo transportation

Factor	Description	Positive Impact	Negative Impact
Political	Government regulation	Increased safety and security	Restriction on airspace and operation
Economic	Cost of operation and maintenance	Lower operational cost	Initial investment cost and maintenance
Social	Public acceptance and perception	Faster and more efficient delivery	Potential job displacement
Technological	Advancements in drone technology	Increased efficiency and safety	Limited range and payload capacity
Environmental	Carbon footprint and noise pollution	Lower carbon footprint compared to traditional freight	Noise pollution and environmental concern
Legal	Libility and insurance	Reduced liability and insurance cost	Legal unvertainties and liability issues

Table 2 PESTEL analysis for unmanned air cargo

V. Discussion

The previous sections have explored the current situation and development trends of the international cargo UAVs market, as well as various technological trends, design considerations, trajectory planning, efficiency improvements, safety testing, and aerial robotic systems related to unmanned air freight. In this discussion section, we will summarize the key findings and their implications for the future of cargo transportation.

The rapid development of UAV technology and the increased demand for faster and more efficient delivery methods have driven the growth of the international cargo UAVs market. This market is expected to continue growing, with a projected compound annual growth rate of over 22% in the coming years, according to Kovalev et al. (2019)[1]. The potential benefits of using UAVs for cargo transportation include faster delivery times, reduced transportation costs, and improved environmental sustainability.

However, there are still challenges that need to be addressed before cargo UAVs can become a viable and widely adopted option for air freight. For example, as discussed in the literature review, the design of UAVs must take into account factors such as payload capacity, flight range, and battery life. Moreover, safety and regulatory issues, such as collision avoidance and air traffic management, must be addressed to ensure the safe and efficient operation of cargo UAVs.

In regards to the cost, some innovations are expected to bring the operational cost of a cargo UAV to an affordable level. For example, the unmanned aerial vehicle transport in **Error! R eference source not found.** has the highest cost, because a team of about 10 people currently operates only one unmanned aerial vehicle. But in some developed countries with a declining labourer population, automation technology has been used to change from operating one unmanned aerial vehicle with ten people to operating ten unmanned aerial vehicles with one person. The world will likely move in that direction in the future, but for now, the current method is a good option if the speed, simplicity, and convenience of unmanned aerial vehicles can be offered at a price. It is a business model that makes people enjoy their work by earning money by having fun operating unmanned aerial vehicles by several people.

Currently, we are at the dawn of the spread of unmanned air transportation that takes advantage of this high value characteristic as has been happening to unmanned air transportation of pharmaceuticals and food. It is important to pioneer unmanned air transportation of new products and services using unmanned air transportation.

Meanwhile, the development of autonomous cargo transportation multirotor UAVs, as discussed by Kotarski et al. (2020), could help address some of these challenges by enabling more efficient and reliable delivery processes[9]. In addition, trajectory planning and energy-efficient cargo UAVs, as studied by Cherif et al. (2021), could help optimize the use of UAVs and reduce operational costs[1].

Efforts to increase the efficiency of UAV technologies in agrarian business, as explored by Kovalev and Karaseva (2020), could also have wider implications for the use of cargo UAVs[12]. For example, improvements in sensor technology and data processing could enhance the monitoring and transportation of agricultural goods.

Safety flight testing for cargo UAV development, as discussed by Iwata et al. (2014), is crucial for ensuring the reliability and safety of cargo UAVs[5]. This testing must include both hardware and software components, and it should cover a wide range of conditions and scenarios to ensure that UAVs can operate effectively and safely in different environments.

Aerial robotic systems for transportation and logistics, as studied by Iwata et al. (2008), could offer a more comprehensive approach to cargo transportation by integrating UAVs with ground-based robotic systems[5]. This could help optimize the entire logistics process, from loading and unloading cargo to navigating complex environments.

Error! Reference source not found. summarize the P ESTEL analysis of a cargo UAV which includes the analysis of the political, economic, sociocultural, technological, environmental, and legal factors affecting the UAV industry. The analysis showed that the global demand for cargo UAVs is increasing due to the benefits such as increased efficiency, reduced costs, and reduced carbon emissions. The technological advancements in UAVs have also increased their capabilities and made them more efficient and reliable. The economic factors such as the rising fuel costs and the increasing demand for faster delivery services have also contributed to the growth of the cargo UAV industry. The environmental factors have also played a significant role as the cargo UAVs produce less carbon emissions compared to traditional delivery methods. However, the regulatory framework around the use of cargo UAVs is still evolving, and legal challenges such as privacy and security concerns need to be addressed.

We conclude that the development of cargo UAVs has the potential to revolutionize the air freight industry, offering faster and more efficient delivery methods. However, significant technological, safety, and regulatory challenges must be overcome before cargo UAVs can become a viable option for widespread use. The research presented in this paper highlights the current situation and trends in the international cargo UAVs market, as well as various technological and operational considerations that are critical for the development of cargo UAVs.

VI. Conclusion

Unmanned aerial vehicles (UAVs) are proving to be a promising technology for cargo transportation. Our analysis shows that UAVs have advantages over traditional cargo transportation methods such as road and ocean freight, particularly in terms of speed and accessibility. They also have the potential to overcome challenges in transportation to remote or inaccessible locations.

Moreover, our review of the current state of the international

cargo UAVs market reveals significant growth potential in this sector, with many players investing in research and development to enhance the capabilities of UAVs for cargo transportation. The advancements in technology, particularly in the areas of multirotor UAVs, trajectory planning, and energy efficiency, are driving the growth of the market.

Despite the advantages and potential of UAVs for cargo transportation, there are still challenges to overcome, particularly in terms of regulatory frameworks and safety concerns. However, with continued research and development and the establishment of robust regulatory frameworks, UAVs have the potential to revolutionize the cargo transportation industry. It is important to have a clear understanding of the difference between traditional aircraft and drones. Conventional aircraft, which solved all problems through human piloting, have now achieved a high level of safety. However, at the same time, we are facing into limits such as high cost, speed, and long working hours due to human operation. Drones are important to utilize to get to the other side of that wall.

The potential benefits of unmanned air freight cannot be ignored, and it is clear that UAVs have the potential to transform the way we transport goods. It is important for stakeholders, including industry players and regulatory bodies, to collaborate and work towards the development of safe and efficient cargo UAVs, and to explore the potential of this technology for the benefit of the global economy.

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