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A Review of The Latest Innovations in UAV Technology

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Abstract— Unmanned Aerial Vehicles (UAVs) have revolutionized various fields, including military, agriculture, transportation, and aerial photography. UAV technology has rapidly advanced over the past few years, leading to a proliferation of new applications and use cases. This paper presents a comprehensive review of the latest innovations in UAV technology, covering recent advancements in areas such as flight control systems, propulsion, sensing and perception, communication and networking, and autonomy. The paper also examines the impact of these advancements on the development of new applications and use cases, such as UAV swarms, package delivery, inspection and maintenance, and search and rescue. Additionally, the paper discusses the challenges and limitations of UAV technology and identifies promising directions for future research and development. Overall, this review provides a valuable resource for researchers, engineers, and practitioners interested in the latest trends and innovations in UAV technology.

Keywords— UAV Technology; Flight Control System; Propulsion; Sensing and Perception; Autonomy

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I. Introduction

Unmanned Aerial Vehicles (UAVs) are remotely piloted or autonomous aircraft that have revolutionized various industries, including agriculture, transportation, delivery, construction, and defense. UAVs are increasingly being employed for tasks that are dangerous, difficult, or expensive for human pilots. They offer several advantages such as high flexibility, mobility, and cost-effectiveness. Over the past few years, the advancements in UAV technology have expanded their capabilities, increasing their potential for diverse applications.

The advancements in UAV technology are driven by various factors such as the miniaturization of electronics, the emergence of new materials, the development of new sensors, and the availability of high-performance computing. These factors have enabled the development of new generations of UAVs that are smaller, lighter, and more capable than their predecessors. The latest UAVs are equipped with advanced sensors, such as LiDAR, thermal imaging, and hyperspectral imaging, which allow them to capture high-resolution images and detect objects from long distances. They also have advanced communication and networking capabilities, enabling real-time data transmission and remote control from a distance.

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One of the critical areas of advancement in UAV technology is flight control systems. The latest UAVs are equipped with advanced flight control systems that enable them to achieve high precision and stability in flight. These systems employ advanced algorithms, such as model-based control and adaptive control, to optimize the performance of UAVs in various flight conditions. Additionally, UAVs are also equipped with advanced propulsion systems that enable them to achieve high-speed flight and extended flight times. These systems employ various technologies such as electric motors, solar panels, and fuel cells, to provide the necessary power for flight.

Another area of advancement in UAV technology is autonomy. The latest UAVs are equipped with advanced artificial intelligence (AI) algorithms, such as machine learning and computer vision, that enable them to make decisions and perform tasks autonomously. These algorithms allow UAVs to navigate through complex environments, detect and track objects, and avoid obstacles without human intervention. UAV autonomy has significant implications for various applications such as package delivery, search and rescue, and inspection and maintenance.

The advancements in UAV technology have led to the emergence of new and innovative applications. For example, UAV swarms have become a popular area of research and development, with potential applications in various fields such as agriculture, transportation, and disaster response. UAV swarms enable multiple UAVs to work together to achieve a common goal, such as mapping large areas, monitoring crops, or delivering packages. UAV swarms can operate autonomously, communicating with each other to optimize their collective performance.

Another emerging application of UAVs is package delivery. Major companies such as Amazon and Google are investing heavily in UAV technology to develop delivery drones that can deliver packages to customers in remote areas or in congested urban environments. Delivery drones offer several advantages over traditional delivery methods such as faster delivery times, reduced traffic congestion, and lower costs.

UAVs are also increasingly being used for inspection and maintenance tasks, such as inspecting power lines, bridges, and buildings. UAVs equipped with advanced sensors can detect cracks, corrosion, and other defects in structures that are difficult to detect using traditional methods. UAVs can also perform maintenance tasks such as cleaning solar panels or painting buildings without the need for human intervention, reducing the risk of injury or death.

Despite the significant advancements in UAV technology, there are several challenges and limitations that need to be addressed. One of the main challenges is the development of reliable and secure communication and networking systems that can support the large-scale deployment of UAVs. Another challenge is the development of regulations and policies that ensure the safe and responsible use of UAVs in various applications.

II. Literature Study

Unmanned Aerial Vehicles (UAVs) have become an essential tool for many applications, and sensors play a critical role in their performance and capabilities. This section starts with the review of the current state of the art of sensor technologies for UAVs. Popescu et al. (2019) analyzed collaborative UAV-WSN systems for efficient monitoring, discussing communication protocols, energy management, localization, and task allocation[33]. Hassani and Dackermann (2023) conducted a systematic review of advanced sensor technologies for non-destructive testing and structural health monitoring, including acoustic emission, ultrasonic, magnetic, and optical sensors[17]. Horstrand et al. (2019) developed a UAV platform based on a hyperspectral sensor for image capturing and on-board processing, with real-time anomaly detection and classification of land cover types[20]. Basso et al. (2019) presented the DART project, a high-precision UAV prototype exploiting on-board visual sensing, with a visual-inertial system for high-accuracy navigation and control[1]. Butler (2001) discussed the use of UAVs for intelligence, surveillance, and reconnaissance (ISR) missions, analyzing the latest developments in sensor technologies, including electro-optical, infrared, and radar sensors[4]. Nonami (2007) reviewed the prospects and recent research and development for civil use autonomous unmanned aircraft as UAV and MAV, including sensors, control systems, and communication networks[28]. These studies have highlighted the potential applications of sensor technologies in various fields, including agriculture, infrastructure inspection, and environmental monitoring. Further research is needed to address the challenges and opportunities for the application of these sensor technologies in UAVs.

Guidance and navigation are critical aspects of unmanned aerial vehicle (UAV) technology. Several studies have been conducted to develop systems that ensure safe and accurate movement of UAVs. Wilson et al. (2015) proposed a guidance and navigation system that enables autonomous docking of a UAV with a moving platform[44]. Kim et al. (2006) developed a real-time navigation and guidance system for UAVs using low-cost sensors[22]. Cesetti et al. (2010) proposed a vision-based guidance system for UAV navigation and safe landing using natural landmarks[8]. Elkaim et al. (2015) provided an overview of the principles of guidance, navigation, and control of UAVs[10]. Watanabe et al. (2016) proposed a navigation and guidance strategy planning system for UAVs that operate in urban areas[43]. Goerzen et al. (2010) conducted a survey of motion planning algorithms from the perspective of autonomous UAV guidance[13]. Kendoul et al. (2010) developed a guidance and nonlinear control system for autonomous flight of minirotorcraft unmanned aerial vehicles[21]. Li et al. (2018) proposed a novel distributed architecture for UAV indoor navigation that provides accurate location information in GPS-denied environments[25]. These studies highlight the importance of guidance and navigation in UAV technology and provide various approaches to solve these critical problems.

Propulsion systems play a critical role in determining the performance of unmanned aerial vehicles (UAVs). The advancement in UAV technology has led to the development of a wide range of propulsion systems. The study conducted by Zhang et al. (2022) provides an overview of different propulsion systems for UAVs, including jet engines, turboprop engines, electric motors, and hybrid systems[45]. Electric propulsion systems are receiving increasing attention in the UAV community due to their low weight, high efficiency, and lower environmental impact. The study by Gohardani (2013) highlights the potential of distributed propulsion technology and electric aircraft concepts for future unmanned air vehicles and commercial/military aviation[14]. Fuel cells are another promising technology for UAV propulsion, and their recent advancements have enabled their use in UAVs. Pan et al. (2019) discuss the recent developments in fuel cells based propulsion systems for UAVs[30]. Finger et al. (2019) evaluated the impact of electric propulsion technology and mission requirements on the performance of VTOL UAVs[11]. Hybrid-electric propulsion systems, which combine electric and traditional fuel-based systems, offer several benefits, including improved efficiency and reduced environmental impact. The study by Sliwinski et al. (2017) focuses on the integration of hybrid-electric propulsion in unmanned aircraft[36]. Lieh et al. (2011) discuss the design of hybrid propulsion systems for UAVs, while Matlock et al. (2019) evaluated the energy-efficient propulsion technologies for UAVs. Zong et al. (2021) evaluated and compared hybrid wing VTOL UAV with four different electric propulsion systems. Lastly, Wang et al. (2020) discussed the current technologies and challenges of applying fuel cell hybrid propulsion systems in UAVs[32].

Flight control technology is a critical aspect of unmanned aerial vehicles (UAVs) that determines their stability, maneuverability, and autonomy during flight. To achieve reliable flight control, various techniques and tools have been developed and implemented. Vachtsevanos et al. (2005) presented a comprehensive strategy for integrating mission planning and flight control of UAVs using model-based design and system identification techniques[41]. Hadi et al. (2016) proposed a switching control approach to ensure stable transition states during takeoff and landing of hybrid vertical take-off and landing UAVs. Ebeid et al. (2018) surveyed open-source UAV flight controllers and flight simulators, highlighting their features and limitations[9]. Peng et al. (2009) designed and implemented an autonomous flight control law for a UAV helicopter using a dynamic model-based approach. Ducard and Allenspach (2021) reviewed designs and flight control techniques of hybrid and convertible VTOL UAVs, focusing on their unique characteristics and control challenges[32]. Zhang and Chamseddine (2012) proposed fault-tolerant flight control techniques with application to a quadrotor UAV testbed[46]. Christopherson et al. (2004) presented small adaptive flight control systems for UAVs using FPGA/DSP technology[6]. Sebbane (2015) discussed smart autonomous aircraft flight control and planning for UAVs[34]. Finally, Paw and Balas (2011) developed an integrated framework for small UAV flight control development using a model-based approach[31]. The literature suggests that flight control technology for UAVs has come a long way and can be enhanced further by developing new techniques and tools, such as machine learning, adaptive control, and advanced sensors.

Formation and swarm technology has become a topic of great interest in unmanned aerial vehicle (UAV) research. Li and Liu (2008) proposed a formation flight control method based on virtual structure and motion synchronization[24]. Spanogianopoulos et al. (2017) presented a fast formation method for a swarm of UAVs in congested urban environments. Sudiyanto et al. (2020) developed an aggregation scheme for collision avoidance control and formation forming & keeping by topology switching[37]. Sudiyanto et al. (2018) proposed equations that appear in collision avoidance control methods for modeling a multi-agent system[38]. Shao et al. (2020) proposed an efficient path planning method for UAV formation using a comprehensively improved particle swarm optimization[35]. Duan et al. (2013) proposed a hybrid particle swarm optimization and genetic algorithm for multi-UAV formation reconfiguration[7]. Bennet et al. (2011) presented an autonomous three-dimensional formation flight method for a swarm of UAVs[2]. Bürkle et al. (2011) proposed a method towards autonomous micro UAV swarms[3]. Maza et al. (2015) classified multi-UAV architectures[27]. Ouyang et al. (2023) conducted a comprehensive review of formation control of UAV swarms, highlighting research trends, challenges, and future directions[29]. These studies provide different formation and swarm control methods for UAVs, including collision avoidance, formation keeping, and path planning, which are important for various applications, such as surveillance, search and rescue, and transportation.

III. Frontiers of UAV Technology

A. *Advanced Sensors and Perception Technologies*

Advanced sensors and perception technologies are essential for the successful operation of unmanned aerial vehicles (UAVs). The development of these technologies has made it possible for UAVs to perform a wide range of tasks, including surveillance, reconnaissance, and search and rescue operations. Some of the key sensor technologies used in UAVs include optical sensors, infrared sensors, radar systems, lidar, and sonar. These sensors provide real-time information about the UAV's surroundings, enabling it to navigate and interact with the environment autonomously. Perception technologies, such as computer vision and machine learning algorithms, help to interpret the sensor data, enabling the UAV to recognize and track objects and make informed decisions. These technologies have advanced significantly in recent years, leading to the development of more sophisticated and capable UAVs with increased levels of autonomy and precision.

B. *Machine Learning and Computer Vision Algorithms*

Machine learning and computer vision algorithms have been increasingly used in unmanned aerial vehicles (UAVs) to enable autonomous decision-making and advanced functionalities. Computer vision techniques are used to extract information from visual data captured by onboard cameras and sensors. Object detection, tracking, and recognition algorithms are used to enable UAVs to navigate through complex environments and detect and avoid obstacles. Additionally, machine learning algorithms are used for tasks such as classification, prediction, and decision-making. For example, supervised learning algorithms can be used to train the UAV to recognize specific objects or patterns in the environment, while reinforcement learning algorithms can be used to enable the UAV to learn from its experiences and optimize its behavior. These technologies enable UAVs to perform a variety of tasks such as aerial mapping, inspection, search and rescue, and surveillance with greater efficiency, accuracy, and autonomy.

C. *Communication and Networking Technologies*

Communication and networking technologies are crucial for the successful operation of unmanned aerial vehicles (UAVs) in both civilian and military applications. UAVs require reliable and efficient communication links to transmit data and receive commands from ground control stations. One of the key challenges in UAV communication is to ensure the seamless transfer of data, voice, and video streams between the UAV and the ground station. To overcome this challenge, a range of communication technologies have been developed, including satellite-based communication systems, cellular networks, and dedicated communication links such as Wi-Fi and Bluetooth. These technologies can provide UAVs with real-time access to high-speed data networks, allowing them to perform complex tasks and interact with other UAVs and ground-based systems. In addition, the networking technologies such as ad-hoc networks and mesh networks can help in the formation of swarms of UAVs, allowing them to share information and work collaboratively to achieve a common goal. Overall, communication and networking technologies play a vital role in enabling the effective and efficient operation of UAVs in a variety of applications.

D. Propulsion Technologies

Propulsion is a critical aspect of UAV technology, as it determines the flight duration, range, and payload capacity. The most commonly used propulsion technologies for UAVs are electric motors and internal combustion engines. Electric motors are popular because they are lightweight, efficient, and provide good control of the aircraft. In contrast, internal combustion engines are more powerful and can carry heavier payloads, but they are also heavier and less fuel-efficient. Hybrid propulsion systems that combine electric and internal combustion engines have also been developed to take advantage of the benefits of both technologies. Other propulsion technologies that have been tested for UAVs include fuel cells, solar power, and hydrogen-powered engines. The choice of propulsion system depends on the specific mission requirements of the UAV, such as the range, endurance, altitude, and payload capacity. Furthermore, advances in propulsion technology have led to the development of new types of UAVs, such as fixed-wing, rotary-wing, and hybrid vehicles, which can perform a wide range of applications, including surveillance, mapping, delivery, and search and rescue.

E. Flight Control Systems

Advanced flight control systems allow UAVs to achieve high precision and stability in flight, employing algorithms such as model-based control and adaptive control to optimize performance in various flight conditions. Flight control systems are essential components of UAVs, which enable them to maneuver in the air and carry out their designated tasks. These systems incorporate various hardware and software components, including microcontrollers, sensors, actuators, and algorithms. The basic functions of flight control systems include stabilization, navigation, guidance, and control of the UAV's movements. Advanced flight control systems employ modern technologies such as artificial intelligence, machine learning, and computer vision algorithms to enhance their performance. These technologies enable the UAVs to adapt to different flight conditions and environments, avoid obstacles, and navigate through complex airspace. Furthermore, flight control systems are becoming more autonomous, enabling UAVs to operate without human intervention. As the use of UAVs continues to grow in various industries, advancements in flight control systems will be critical in enhancing their capabilities and improving their safety and reliability.

F. Autonomous Navigation Systems

These enable UAVs to navigate through complex environments and perform tasks autonomously, such as mapping large areas or performing inspections of structures. Autonomous navigation systems for UAVs are crucial for ensuring that unmanned aerial vehicles can safely and efficiently complete missions without human intervention. These systems rely on a combination of sensors, algorithms, and processing power to enable the UAV to perceive its environment and make intelligent decisions. Some key components of autonomous navigation systems for UAVs include GPS, altimeters, magnetometers, accelerometers, gyroscopes, and optical sensors. These sensors feed information into computer algorithms that process the data and provide flight control commands to the UAV's flight control system. Advanced algorithms, such as SLAM (Simultaneous Localization and Mapping), enable the UAV to build a map of its environment in real-time and use that map to plan its flight path. Additionally, machine learning algorithms can help UAVs learn from their experiences and improve their navigation and decision-making capabilities over time. Overall, autonomous navigation systems are essential for enabling UAVs to operate safely and effectively in a wide range of mission scenarios.

G. UAV Swarms

These involve multiple UAVs working together to achieve a common goal, such as monitoring crops or delivering packages. UAV swarms and formation flight have gained much attention

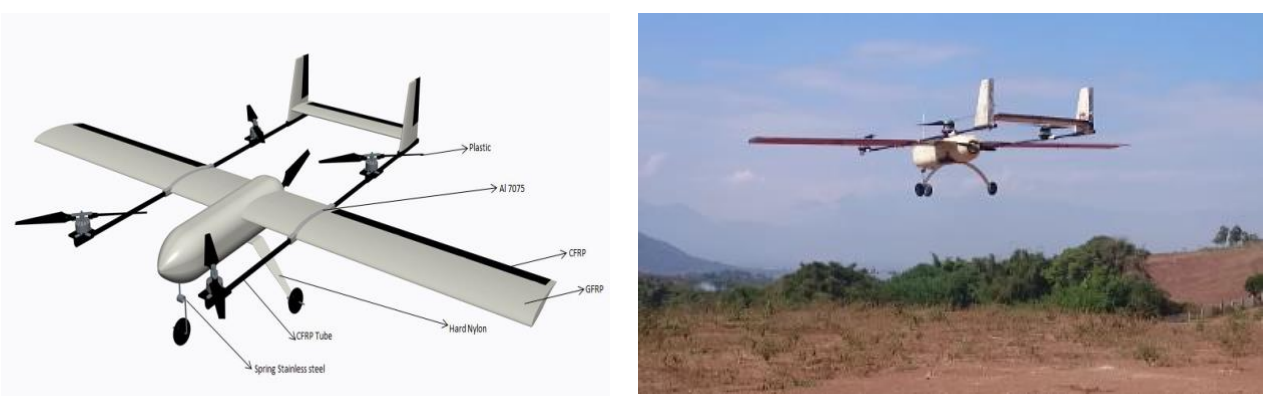

Figure 1 VTOL UAV for Aerial Surveillance Mission (Hadi, 2016)

their potential to enhance the capabilities of UAVs in various applications. UAV swarms are groups of UAVs that coordinate with each other to accomplish a common objective, such as surveillance, reconnaissance, or search and rescue missions. Formation flight is a type of swarm behavior in which UAVs fly in a predefined formation. This formation can be either static or dynamic and can be adapted based on the mission requirements. The use of swarm and formation flight can improve mission efficiency, reduce mission time, and enhance the mission's overall effectiveness. This is accomplished by enabling a larger area to be covered and increasing the robustness of the mission through redundancy. Swarms and formation flight also provide flexibility in mission planning, allowing for adaptive and dynamic mission changes. However, implementing swarm and formation flight requires the development of advanced communication, control, and navigation technologies to enable UAVs to coordinate and interact with each other effectively.

H. Package Delivery Systems

Package delivery systems using UAVs, commonly referred to as drone delivery, have been an emerging area of research and development in recent years. The potential benefits of drone delivery include faster and more efficient delivery, reduced carbon emissions, and increased accessibility in remote or hard-to-reach areas. However, there are also several technical and regulatory challenges that need to be addressed, such as the need for reliable obstacle detection and avoidance, secure and reliable communication systems, and safe and reliable navigation and landing systems. Several companies and research organizations have been exploring different approaches to drone delivery, ranging from small-scale proof-of-concept demonstrations to large-scale commercial operations. Various applications of drone delivery have been proposed, including medical supplies, emergency response, and e-commerce. Despite the challenges, the rapid advancements in drone technology and the growing demand for fast and efficient delivery services are expected to drive the growth of the drone delivery industry in the coming years.

I. Observation, Inspection and Maintenance Systems

Unmanned aerial vehicles (UAVs) have emerged as a promising technology for observation of areas of interest and inspection & maintenance of critical infrastructure, such as bridges, wind turbines, and power lines. They can reduce the risks of accidents and the costs associated with traditional methods of observation, inspection and maintenance. UAVs equipped with cameras and sensors can capture high-resolution images and data to detect anomalies and assess the condition of structures. They can also perform maintenance tasks such as cleaning and painting, and carry tools and spare parts to repair damaged components. In addition, UAVs can operate in challenging environments, such as polar regions, offshore platforms and high-voltage power lines, where human access is difficult or impossible. Several studies have demonstrated the effectiveness of UAVs in observation, inspection and maintenance, showing improved accuracy, efficiency, and safety compared to traditional methods. As technology advances, UAVs are expected to play an increasingly important role in ensuring the integrity and reliability of critical infrastructure.

The work by Higashino et al. in (Higashino, 2013), (Higashino, 2014) and (Higashino, 2014) demonstrates the viability of the use of UAV for observation missions in a polar region[18] [19]. The authors have developed a system for observing and collecting aerosol samples in the Antarctic stratosphere using a combination of a rubber balloon, parachute, and a fixed-wing unmanned aerial vehicle (UAV). The UAV, equipped with an optical particle counter and airborne aerosol sampler, is released from the balloon at stratospheric altitude and glides back to the ground using a two-stage separation method involving a parachute. The system successfully reached 23km in altitude and returned aerosol

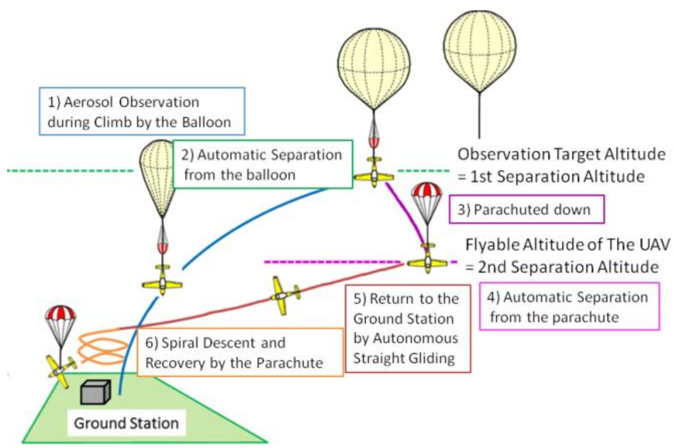

Figure 1 Aerosol observation and sample-return using the two-stage separation method

Figure 2 Appearance of the Phoenix-S UAV mounted on a preparation stand

Fig. 2 shows the mission profile of the observation UAV and Fig. 3 the actual UAV prepared for the mission.

samples. This paper provides details of the UAV system, observation flight results, and preliminary analysis of the collected samples.

The above published work describes the use of a two-stage separation method, combining a rubber balloon, a descent parachute, and a gliding UAV, to observe and collect stratospheric aerosol samples in Antarctica. The method involves launching the UAV with observation instruments suspended by a balloon to the stratosphere, descending by the parachute to a certain altitude where the UAV control system works properly, and then separating the parachute to autonomously glide back to the ground. The article also describes the trajectory prediction system used for operation and the obtained vertical aerosol concentration profile, which showed unusually high concentrations of three sub-layers in the stratosphere. The article concludes that the system is effective and has the potential to produce new knowledge. Figs. 4 and 5 describe the instrumentation system setup and recovery technique for the polar observation UAV.

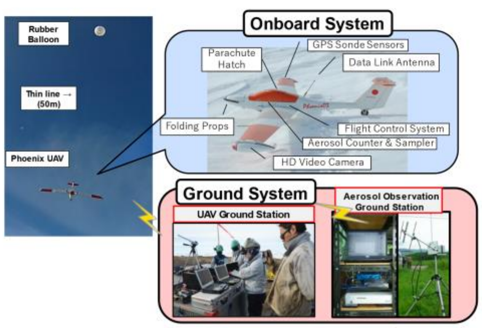

Figure 4 The system setup of the Polar Observation UAV

Figure 5 The recovery system of the Polar Observation UAV

J. Anti-collision and Safety Systems

Anti-collision and safety systems are crucial for unmanned aerial vehicles (UAVs) to operate safely in both controlled and uncontrolled airspace. These systems typically include a combination of sensors, communication technologies, and software algorithms that detect and avoid obstacles, as well as ensure compliance with regulatory requirements. One common sensor used in anti-collision systems is the LIDAR sensor, which can provide 3D maps of the surrounding environment and detect obstacles in real-time. Additionally, cameras and GPS sensors can be used to provide situational awareness and accurate positioning. Communication technologies such as ADS-B and ACAS can be used to broadcast the UAV's location to other aircraft and ground stations, helping to prevent collisions. Software algorithms such as path planning and collision avoidance systems can be used to analyze sensor data and autonomously navigate the UAV around obstacles. Overall, anti-collision and safety systems are essential for ensuring the safe and reliable operation of UAVs in a wide range of applications, including commercial, industrial, and military operations.

IV. Discussion

The advancements in various UAV technologies, including flight control, guidance and navigation, propulsion systems, sensor systems, communication and networking, and other relevant parameters have made UAVs more efficient and reliable for various applications. The integration of machine learning and computer vision algorithms in UAVs has improved their autonomous navigation capabilities. Additionally, advanced sensors and perception technologies have enabled UAVs to operate in challenging environments, such as urban areas and forests. Table 1 shows the evolution of UAV technologies in various fields.

Advanced sensors and perception technologies have been developed to enhance the capabilities of UAVs to operate in challenging environments. UAVs can operate in different types of environments, from wide-open areas to highly cluttered urban areas and dense forests, which pose a challenge for navigation and sensing. Advanced sensors such as LIDAR, RADAR, and cameras can provide accurate and high-resolution data for UAVs to perceive and navigate through their surroundings. These sensors help UAVs to detect and avoid obstacles, terrain, and other objects in their path, and enable them to fly autonomously with precise control. For example, LIDAR sensors can measure the distance to objects and create 3D maps of the environment, while RADAR can provide real-time information on weather conditions, terrain, and other obstacles. Furthermore, computer vision algorithms can analyze the data collected by these sensors, enabling UAVs to identify and track objects, such as people, animals, and vehicles. These technologies have enabled UAVs to perform a range of tasks, including search and rescue operations, environmental monitoring, and precision agriculture, in challenging environments.

The potential applications of UAVs are constantly expanding, with new fields emerging, such as package delivery systems, inspection and maintenance, and anti-collision and safety systems. In addition, UAVs are being used in agriculture, mapping and surveying, disaster relief, and search and rescue operations, among others.

UAVs are also increasingly used in package delivery systems as they are more efficient and cost-effective compared to traditional delivery methods. Amazon and Google are already testing their drone delivery systems. UAVs are also employed for inspection and maintenance purposes. They can conduct visual and thermal inspections of buildings, bridges, and wind turbines, which is safer and less time-consuming than traditional methods. Anti-collision and safety systems are becoming increasingly important as UAVs become more widely used. The systems help prevent mid-air collisions between UAVs and other aircraft or objects, which is crucial for safety. UAVs are also used in agriculture for crop monitoring and analysis, in mapping and surveying for creating highly detailed maps, and in disaster relief and search and rescue operations for quickly assessing damage and finding survivors. These are just a few examples of the potential applications of UAVs, and there are many more emerging fields where UAVs can be utilized. These new and potential applications are expected to contribute significantly to the growth of the UAV market.

Despite the significant advancements, fully utilizing UAVs has its limitations. The limited flight time, limited payload capacity, and regulatory challenges associated with airspace integration are some of the major constraints. In addition, the reliability of communication and networking technologies in challenging environments is still a significant concern.

The future trends of UAV technologies include developing more efficient propulsion systems to increase flight time and payload capacity, improving communication and networking technologies for reliable and secure data transmission, and enhancing autonomous navigation capabilities using advanced machine learning and computer vision algorithms. The use of swarm technology and formation flight for UAVs is also expected to increase, enabling them to perform complex tasks and missions. Table 2 shows notable UAVs that utilize the latest technologies in the flight control, guidance and navigation, propulsion systems, sensor systems, and communication.

UAV technology advancements have led to the development of more efficient and reliable UAVs with significant potential for new and emerging applications. However, challenges such as limited flight time and payload capacity, regulatory constraints, and communication and networking reliability must be addressed to fully utilize the potential of UAVs. The future trends in UAV technology suggest continued development in propulsion, communication and networking, and autonomous navigation capabilities.

V. Conclusion

The UAV technology advancements in various aspects have significantly contributed to the efficiency and reliability of UAVs for various applications. The integration of advanced sensors and perception technologies, as well as machine learning and computer vision algorithms, has enhanced the autonomous navigation capabilities of UAVs, enabling them to operate in challenging environments. Furthermore, the potential applications of UAVs continue to expand, with new fields emerging, including package delivery systems, inspection and maintenance, and anti-collision and safety systems. However, the limited flight time, limited payload capacity, and regulatory challenges remain major constraints for fully utilizing UAVs. Moreover, the reliability of communication and networking technologies in challenging environments is still a significant concern.

The future trends of UAV technologies point towards developing more efficient propulsion systems, improving communication and networking technologies for secure and reliable data transmission, and enhancing autonomous navigation capabilities using advanced machine learning and computer vision algorithms. Additionally, the use of swarm technology and formation flight for UAVs is expected to increase, enabling them to perform complex tasks and missions.

Overall, the advancements in UAV technologies have led to the development of more efficient and reliable UAVs with significant potential for new and emerging applications. However, challenges such as limited flight time and payload capacity, regulatory constraints, and communication and networking reliability must be addressed to fully exploit the potential of UAVs. Continued research and development in UAV technologies will enable them to fulfill their potential and contribute significantly to various sectors, including agriculture, mapping and surveying, disaster relief, and search and rescue operations.

Parameters	Early Development	Mature Trends	Future Trends
Flight Control Technology	Basic RC controllers and manual flight	Semi-autonomous and fully autonomous flight control systems	Advanced AI-based flight control systems for complex operations
Guidance & Navigation	GPS-based navigation with limited accuracy	Integration of GPS, Inertial Measurement Units, and visual odometry	Use of advanced computer vision algorithms and AI for navigation
Propulsion System	Simple electric motors and basic propellers	High-efficiency brushless motors and propellers	Hybrid propulsion systems with greater efficiency and endurance
Sensor System	Basic cameras and obstacle sensors	Integration of advanced cameras, LIDAR, and multi-spectral sensors	Use of advanced sensors such as hyperspectral and acoustic sensors

Communication & Networking	Simple radio communication and limited range	Integration of advanced communication protocols and long-range links	Use of 5G and satellite communication for long-distance operations
Other Relevant Parameters	Limited payload capacity and endurance	Higher payload capacity and endurance for long-range operations	Use of advanced materials for lightweight and durable designs

Table 1 Trend of UAV Technology

Name of UAV	Types	Sensors Used	Type of Propulsion	Range	Endurance	Applications
MQ-9 Reaper	Fixed-Wing	Synthetic aperture radar, electro-optical/infrared (EO/IR) camera	Turboprop	1,850 km	27 hours	Intelligence, surveillance, and reconnaissance (ISR), airstrikes
RQ-4 Global Hawk	Fixed-Wing	Multi-spectral targeting system, radar, electro-optical/infrared (EO/IR) camera	Jet	22,780 km	34 hours	High-altitude ISR, weather monitoring, scientific research
ScanEagle	Fixed-Wing	Electro-optical/infrared (EO/IR) camera	Internal combustion engine	1,600 km	24 hours	ISR, search and rescue
DJI Mavic 2 Pro	Rotary-Wing	Hasselblad camera, obstacle avoidance sensors	Electric	8 km	31 minutes	Aerial photography and videography
DJI Phantom 4 RTK	Rotary-Wing	RTK, obstacle avoidance sensors	Electric	7 km	30 minutes	Surveying and mapping
DJI Matrice 300 RTK	Rotary-Wing	RTK, obstacle avoidance sensors, LiDAR, thermal camera	Electric	15 km	55 minutes	Inspection and monitoring
DJI Agras T20	Rotary-Wing	Agricultural spraying system	Gasoline	7 km	20 minutes	Agriculture
V-22 Osprey	VTOL	Multi-spectral targeting system, radar, electro-optical/infrared (EO/IR) camera	Tiltrotor	2,100 km	6 hours	Military transport, search and rescue
K-MAX	Rotary-Wing	K-MAX pilotage system	Internal combustion engine	267 km	6 hours	Cargo delivery
MQ-1 Predator	Fixed-Wing	Synthetic aperture radar, electro-optical/infrared (EO/IR) camera	Turboprop	1,160 km	24 hours	ISR, airstrikes
Anafi USA	Rotary-Wing	FLIR Boson thermal camera, 4K HDR camera	Electric	4 km	32 minutes	Public safety, search and rescue
AeroVironment Puma AE	Fixed-Wing	Day/Night camera, infrared camera	Electric	20 km	2 hours	ISR, search and rescue
AeroVironment Raven	Fixed-Wing	Infrared camera	Electric	10 km	1.5 hours	ISR, search and rescue
EHang 216	VTOL	Lidar, RGB camera, obstacle avoidance sensors	Electric	35 km	21 minutes	Urban air mobility, air tourism
Alti Transition	Fixed-Wing	EO/IR camera	Gasoline	160 km	5 hours	Mapping, surveying, agriculture
Skydio 2	Rotary-Wing	4K camera, obstacle avoidance sensors	Electric	3.5 km	23 minutes	Aerial photography and videography

Boeing Insitu RQ-21 Blackjack	Fixed-Wing	Electro-optical/infrared (EO/IR) camera	Gasoline	100 km	16 hours	ISR, search and rescue
Schiebel Camcopter S-100	Rotary-Wing	Electro-optical/infrared (EO/IR) camera	Gas turbine	200 km	6 hours	ISR, search and rescue, maritime patrol

Table 2 Notable UAVs for various missions

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