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Exploring drone classifications and applications: a review

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Abstract

This review comprehensively investigates the development and diverse application of drone technologies across various industries through a systematic literature review. The study employs a rigorous methodology, beginning with a detailed literature search across major scientific databases to capture the most recent and relevant studies concerning drone technology. The findings synthesize critical insights into the evolving drone technologies, from compact models designed for tight spaces to advanced systems capable of high-altitude, long-duration missions. Emphasizing their operational versatility, the review highlights the adaptation of drones for a multitude of tasks, such as environmental monitoring, disaster management, agricultural optimization, infrastructure analysis, and military operations. Future studies are encouraged to explore the potential for autonomous drone operation through the integration of artificial intelligence and machine learning, aiming to enhance efficiency and adaptability across various sectors.

1. Introduction

In the current global situation, it has been witnessed that the unexpected spread of a highly contagious disease, such as COVID-19, has had significant and extensive effects on human lives, research endeavors, economies, and industries worldwide. Drone technology offers considerable advantages and creates various opportunities across multiple domains. Drones, which are known as Unmanned Aerial Vehicles (UAVs), are crucial in activities such as surveys, humanitarian missions, disaster preparedness, research initiatives, the agricultural sector, and transportation services. In the agricultural sector, drones are indispensable, providing real-time imagery and sensor data from remote farmland that would be challenging to acquire rapidly through conventional methods like walking or standard vehicles. Employing drones for prompt distribution of vital medications to the entire population can play a critical role in advancing the aim of achieving healthcare coverage for all. Moreover, incorporating drones into the logistics and transportation industries offers scenarios for enhancing the efficiency of moving both goods and passengers [1-3].

Drones were originally designed as simple devices but have changed the complexity of their designs to meet the demands of increasingly intricate missions. The range of drones is an essential element in establishing their functional capabilities, with their size, power, and usage conditions playing defining roles [4]. In general, drones can be sorted according to their performance characteristics, which include factors like weight, wingspan, wing loading, range, maximum altitude, speed, endurance, engine types, and production costs [5].

Disasters, whether natural or man-made, seriously threaten the well-being and safety of affected populations, with mass disasters having a particularly devastating impact. Swift and effective disaster management is essential to aid affected individuals, reduce casualties, and mitigate economic repercussions. Disaster management involves various phases, including mitigation, preparedness, response, and recovery [6]. Collecting accurate data during emergencies is challenging due to insufficient coordination among the agencies involved [7]. The development of new methodologies and technologies, combining telecommunication tools, remote sensing, and spatial/temporal-oriented databases, is proposed to enhance disaster management efficiency [6]. Drones play a crucial role in disaster response by rapidly covering large areas, aiding rescuers in locating victims, and offering critical information for search and rescue operations. Equipped with sensors like noise, binary, vibration, and heat sensors, drones can effectively detect survivors under debris [8, 9].

This study aims to outline the scope and purpose encompassing an in-depth exploration of drone classifications and their various applications across a spectrum of industries. Through a systematic review, this investigation seeks to explain the developing roles of drones, ranging from military operations and disaster response to innovative applications in agriculture, delivery services, and space exploration. By examining various drone configurations, including fixed-wing, multi-rotor, and hybrid models, the study highlights the technological advancements that have broadened the utility and effectiveness of drones. Furthermore, it highlights the potential of drones to transform operational efficiencies, enhance data collection methodologies, and address critical challenges within multiple domains. The ultimate goal is to provide a comprehensive overview that not only enriches the academic discourse on drone technology but also identifies emerging trends and areas necessitating further research, thereby contributing to the sustainable development and integration of drone capabilities into future societal frameworks.

2. Methodology for the Review

This section outlines the systematic methodology employed to conduct the comprehensive literature review. This methodology guarantees the transparency, reproducibility, and consistency of the review process, enabling the identification of relevant studies spanning a wide range of drone technologies and their implementations. A schematic diagram of the research methodology is shown in Scheme 1.

Scheme 1. Schematic diagram of the research methodology

2.1. Search strategy

A comprehensive literature search was designed to cover a broad spectrum of scientific databases and search engines, with priority given to those known for their extensive repository of engineering and technological research. Primary databases included a broad selection, chosen for their exhaustive inclusion of peer-reviewed journals, conference proceedings, and technical reports in the realms of engineering, robotics, and aerospace technologies.

The initial search generated a significant number of records. Titles and abstracts were meticulously screened against the defined inclusion criteria, which excluded articles not directly relevant to the scope of the research. The articles that remained were subjected to a thorough full-text review to assess their relevance based on the detailed criteria specified earlier. This two-tiered screening process ensured a focused and pertinent collection of literature for the review.

Data extraction from each article in the final selection concentrated on key information relevant to the objectives of the review, such as drone classifications, technological progress, and application domains. This involved summarizing the principal findings, methodologies, and conclusions of each study, paying special attention to innovations in drone design, operational capabilities, and real-world applications. The extracted data underwent thematic analysis, structuring the literature according to drone classifications, technological advancements, and applications tailored to specific sectors. This approach facilitated a comprehensive understanding of the current state of drone technology and highlighted areas for future research.

2.2. Inclusion and exclusion criteria

Inclusion criteria were meticulously defined to select articles offering profound insights into drone classifications, technological advancements, and their multifaceted applications across various industries. The review concentrated on articles published mainly since 2010 to reflect the rapid developments in drone technologies within this timeframe. Included studies featured original research, reviews, or case studies on drone technology, its classifications, and its implementations in areas such as agriculture, disaster management, military usage, and environmental monitoring.

Exclusion criteria were applied to omit articles that did not focus specifically on unmanned aerial vehicles, such as those addressing manned aircraft or other forms of robotics not relevant to aerial applications. Articles lacking in-depth technical analysis, preliminary findings without substantial data, or those not available in full-text format were also excluded.

2.3. Limitations

Several limitations within this review methodology are recognized. The search was limited to articles published in English, potentially overlooking relevant studies published in other languages. Although the review sought comprehensiveness, the swift pace of drone technology evolution means that some recent developments might not be covered. The selection process, though systematic, might reflect the subjective judgment of the individuals conducting the review, particularly in evaluating the relevance and contribution of each article.

The structured approach to this literature review on drone classifications and applications has furnished a detailed overview of the field's current state, identifying both established technologies and emerging trends. Adhering to a rigorous methodology ensures the reliability and relevance of the findings, providing a robust foundation for future research in drone technology.

3. Categorization of Drones

Various classifications are employed to categorize drones based on different parameters. Watts et al. [10] explored a range of drone platforms and highlighted the specific advantages of each in meeting the requirements of users in scientific research. The drones were organized for both civilian scientific and military applications, considering their different factors. In their classification system, drones were grouped as MAVs (Micro or Miniature Air Vehicles), NAVs (Nano Air Vehicles), pico air vehicles (PAVs), HTOL (horizontal takeoff and landing), VTOL (Vertical Take-Off & Landing), LASE (Low Altitude, Short-Endurance), Smart dust (SD), LASE Close, LALE (Low Altitude, Long Endurance), MALE (Medium Altitude, Long Endurance), and HALE (High Altitude, Long Endurance). The classification of air drones provided in Figure 1 shows different drone models based on their configurations. This figure also takes into account the bio models of micro and nano air vehicles, which are described as live controllable birds or insects and flying taxidermy birds [4, 11].

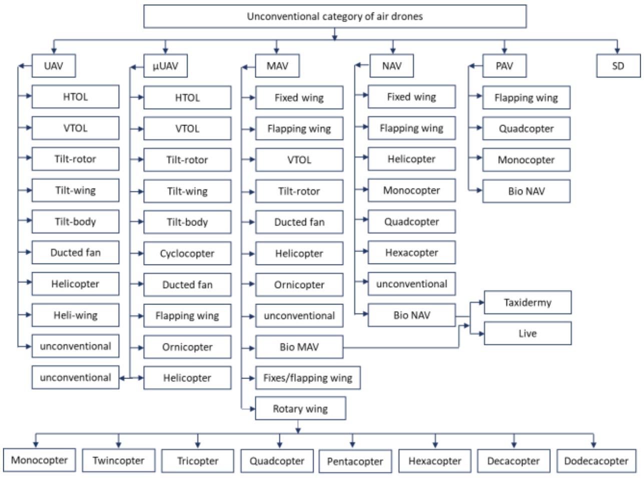


Figure 1. Different types of drones [11]

3.1. UAVs category

The classification of UAVs is based on several key factors that distinguish them from other small drones, such as their operational purpose, the materials used in their construction, and the complexity and cost of their control systems. UAVs vary widely in terms of size and configuration, ranging from wingspans as broad as a Boeing 737 to smaller, radio-controlled drones [12]. Various mission requirements have given rise to different types of UAVs, which are often categorized based on their mission capabilities. These categories include HTOL (horizontal takeoff and landing), VTOL (vertical takeoff and landing), hybrid models (such as tilt-wing, tilt-rotor, tilt-body, and ducted fan), helicopter and heli-wing UAVs, as well as unconventional types [13]. In HTOL and VTOL UAVs, there are different configurations based on lift/mass balance and stability and control, including tailplane-aft, tailplane forward, tail-aft on booms, and tailless or flying wing UAVs. VTOL drones are more efficient in hovering flight but may have limitations in cruise speed due to blade stalling, making them suitable for short-range missions [14].

Hybrid drones combine the capabilities of both VTOL and HTOL drones and include tilt-rotor, tilt-wing, tilt-body, and ducted fan UAVs [15]. Tilt-rotor UAVs have rotors that tilt from vertical to horizontal for different flight modes [16]. Tilt-wing UAVs have engines fixed to wings that tilt with the wing [17], while tilt-body UAVs have a free-rotating wing with a lifting body [18]. The ducted fan UAVs enclose their thrusters within a duct, offering versatility in vertical takeoff and landing as well as cruising [19]. Helicopter UAVs come in various types, including single-rotor, coaxial-rotor, tandem-rotor, and quad-rotor configurations [20]. Heli-wing UAVs utilize a rotating wing for both vertical and fixed-wing flight [21, 22]. Finally, unconventional UAVs encompass drones that do not fit into previously defined categories. This group includes bio-inspired flying robots, like the FESTO AirJelly, which mimics the flight of a jellyfish, and other drones with unique flying mechanisms, such as the FESTO flying penguin [23, 24]. Figure 2 shows the different types of presented UAVs. HTOL drones have progressed over time, culminating in four distinct configurations based on considerations of lift/mass balance and stability and control. These configurations encompass tailplane-aft, tailplane forward, tail-aft on booms, and tailless or flying wing UAVs [25]. Notably, propulsion systems for these configurations can be situated either at the rear or the front of the UAV. Conversely, fixed-wing VTOL UAVs utilize a vertical propulsion system at the front of the fuselage and feature cross wings, allowing them to achieve vertical take-off and landing without the need for a runway.

Figure 2. Different types of UAVs, (a) HTOL, (b) VTOL, (c) tilt-rotor UAV, (d) tilt-wing UAV, (e) tilt-body UAV, (f) ducted fan UAV, (g) helicopter, (h) heli-wing, and (i) unconventional UAV [11, 26, 27]

VTOL drones are recognized for their efficiency in hovering flight but encounter limitations in terms of cruise speed due to issues with stalling blades. Consequently, missions requiring longer ranges often demand UAVs with higher cruise speeds [28]. The concept of hybrid drones has emerged to address these challenges, aiming to combine the capabilities of both VTOL and HTOL types [29]. As a result, various hybrid drone types have been developed, including tilt-rotor, tilt-wing, tilt-body, and ducted fan UAVs [30]. The free wing tilt-body UAV stands out from traditional fixed-wing and rotary-wing drones. It features a unique design where the wing can freely rotate along the pitch axis, and the fuselage serves as a lifting body. Both the right/left wing pair and central lifting body can rotate independently of the relative wind and each other. This unconventional design includes a boom attachment to the fuselage for adjusting the incidence angle in response to external commands. The key benefits of this design are its capability for short take-offs and landings (STOL), low-speed loitering, and reduced sensitivity to changes in the center of gravity (CG) [31, 32]. Ducted fan UAVs are drones with thrusters enclosed in a duct, allowing for vertical take-off, hovering, and controlled flight with counter rotors and control surfaces. However, there is a challenge related to flow separation when transitioning to and from cruise flight [28, 33].

Presently, researchers are engaged in designing unmanned helicopters with diverse features, including vertical takeoff, landing, and hovering capabilities. These helicopter UAVs can be classified into four types: single rotor, coaxial rotor, tandem rotor, and quadrotor. Additionally, there are Heli-wing UAVs, a special class of drones utilizing rotating wings, enabling them to perform both vertical and fixed-wing flight modes [34].

Unconventional UAVs, including bio-inspired models, defy traditional categorization. One such example is the FESTO AirJelly, inspired by jellyfish, capable of gliding through the air using a helium-filled ballonet and a peristaltic drive system based on recoil principles. These unconventional UAVs showcase distinct flight characteristics compared to conventional counterparts, and the FESTO flying penguin is another noteworthy illustration of this category [24, 35].

3.2. μUAVs category

A μUAV, or small UAV, is a compact unmanned aerial vehicle that can be carried by a person and typically launched manually, eliminating the need for a runway. These μUAVs vary in design and fall into categories such as HTOL, VTOL, hybrid models, helicopters, ornithopters with flapping wings, and unconventional types. These μUAVs are typically smaller and lighter than their larger UAV counterparts (Figure 3).

An ornithopter is an aircraft that mimics bird flight by flapping its wings. This concept has historical roots dating back to ancient Greek legends and was endorsed by early visionaries like Roger Bacon and Leonardo da Vinci. The first ornithopter, built by Gustav Trouvé in 1870, achieved a notable flight distance. Modern researchers have also developed flapping-wing drones, including FESTO's Smart-Bird, which emulates the flight of seabirds [38, 39]. An ornicopter is a distinctive aircraft that blends helicopter characteristics with bird-like wing flapping. The term "ornicopter" reflects its nature as a helicopter with wing-flapping abilities. A team of aeronautical engineers devised this concept to eliminate the need for a tail rotor and enhance maneuverability through bird-like wing motion, departing from conventional tail rotor and NOTAR systems [40]. Cyclocopters, or cyclogyros, are a class of μUAVs that employ cycloidal rotors with rotating airfoils to achieve lift and thrust forces. These innovative aircraft can perform vertical takeoffs, landings, and hovering, much like helicopters. The cyclocopter's wing design resembles a paddle wheel with airfoils.

Figure 3. Different types of μUAVs, (a) HTOL, (b) VTOL, (c) tilt-rotor, (d) tilt-wing, (e) tilt-body, (f) ducted fan μUAV, (g) helicopter, (h) ornithopter, (i) ornicopter, (j) cyclocopter, and (k) unconventional μUAV [11, 36, 37]

3.3. MAVs category

MAVs are compact aircraft, typically under 100 cm in length and weighing less than 2 kg, with nine categories, including fixed wing, flapping wing, VTOL, rotary wing, tilt-rotor, ducted fan, helicopter, ornicopter, and unconventional types, enabling diverse sensor applications across engineering fields [41]. Different types of MAVs are shown in Figure 4. While the Defense Advanced Research Projects Agency (DARPA) originally defined MAVs as less than 150 mm and 50-100 g, their dimensions have evolved to 15-100 cm and 50 g to 2 kg [42, 43]. MAVs, which emerged in the early 1990s, are prized for their low-speed, low-altitude capabilities in tasks like monitoring, tracking, and mapping, although turbulence in the atmospheric boundary layer necessitates precise design [44]. These drones often deviate from conventional UAV design due to their unique missions and shorter timelines. VTOL, tilt-rotor, ducted fan, helicopter, ornicopter, and unconventional MAVs resemble μUAV models but are smaller and lighter.

Fixed-wing MAVs (Figure 4a) are suitable for different environments, from jungles to urban areas and even the Arctic [45]. Their small size, low power requirements, and cost-effective production make them discreet and challenging to detect. In obstacle-rich urban or forested settings, MAVs use short wings with low aspect ratios for efficient maneuvering [46]. Ensuring high endurance and range is vital for MAVs involved in tasks like data collection and patrolling, with better performance often linked to higher lift-to-drag ratios. Mueller's research highlights the aerodynamic benefits of camber and wing shapes, favoring cambered plates [41, 47] . Fixed-wing MAVs excel in range, endurance, and altitude, compared to flapping and rotary-wing MAVs typically employed for slower indoor missions. Various wing planforms, such as rectangular, tapered wings with swept leading edges, Zimmerman, inverse Zimmerman, and elliptical, are employed in fixed-wing MAV designs [45].

Flapping-wing drones, categorized into MAVs, PAVs, and NAVs, draw inspiration from various organisms, such as birds, insects, and creatures like hummingbirds and dragonflies, respectively [48, 49]. These drones feature flexible and lightweight wings, mirroring the natural aerodynamics observed in birds and insects, which significantly influence their flight efficiency and stability. The complex aerodynamics of flapping wings pose challenges, and research in aerospace engineering has intensified due to growing interest in this field [50]. Reduced wing area in smaller drones leads to low Reynolds numbers and a flow transition, impacting aerodynamic efficiency. Drones with low Reynolds numbers utilize different methods to generate aerodynamic forces, but they may encounter issues like flow separation, leading to increased drag and reduced efficiency [51]. Flapping-wing drones offer unique movability advantages due to their biologically inspired design, making them ideal for applications like search and rescue. They can be configured as monoplanes, biplanes, or tandems, each with its own advantages and characteristics, presenting promising opportunities for drone development and application [52].

Drawing inspiration from the flight dynamics of insects, specifically the dragonfly, researchers have embarked on innovative approaches to micro UAV design, showcasing the potential for biomimicry in advancing aerial robotics. The TechJect Dragonfly (Figure 4k), a product of Georgia Tech's interdisciplinary team, emerges as a prime example of this inspiration. After four years of rigorous research and development, supported by a $1 million grant from the U.S. Air Force, this robotic ornithopter embodies the combined flight functionalities of quadricopters, helicopters, and fixed-wing aircraft within a compact form factor. Notably, the TechJect Dragonfly, resembling its natural counterpart in both form and maneuverability, spans 15 cm in length and is lightweight at 25 grams, powered by a lithium polymer battery allowing for significant flight and hover times. Its design emphasizes modular customization, enabling the incorporation of up to 20 onboard sensors to cater to diverse applications ranging from aerial photography to military reconnaissance. Offering various models (Alpha, Delta, Gamma, and Omega) (Figure 4(l,m,n,o)) each tailored for specific functionalities and user needs, the Dragonfly promotes a new era of versatile, customizable UAVs. This initiative not only signifies a leap in drone technology but also sets a precedent for future developments in robotic flight, with TechJect leveraging crowdfunding to bring this pioneering technology to market and foster a community of innovation through shared applications and development support [53].

Research in low Reynolds number unsteady aerodynamics and flapping-wing propulsion has led to the development of unconventional MAVs that utilize both fixed and flapping wings (fixed/flapping-wing MAVs) for propulsion, creating a hybrid design. In this configuration, the MAV incorporates a low aspect ratio fixed wing along with a trailing set of higher aspect ratio flapping wings that move in a counterphase, as demonstrated in Figure 4c. The integration of flapping wings improves efficiency, maintains a mechanically and aerodynamically balanced structure, and prevents stall over the fixed wing by entraining flow. A similar concept is observed in dragonflies with tandem wings, where they employ two pairs of wings to enhance lift and thrust forces, offering unique advantages in micro air vehicle design [54].

Figure 4. Different types of MAVs, (a) fixed wing, (b) flapping wing, (c) fixed/flapping-wing, (d) rotary wing, (e) VTOL, (f) ducted fan, (g) tilt-rotor, (h) helicopter, (i) unconventional, (j) ornicopter [11], (k) TechJect Dragonfly fits in the palm of a hand, (l) Alpha model Dragonfly, (m) Delta model Dragonfly, (n) Gamma model Dragonfly, (o) Omega model Dragonfly [53]

Compared to other drone types like UAVs, MAVs offer a significant advantage in their compact size, enabling them to navigate through confined spaces [55]. Rotary wing MAVs, illustrated in Figure 4d, are particularly adept at this due to their hovering capability and exceptional maneuverability [56]. These drones, referred to as rotary wing drones, employ rotary blades or propeller-based systems, allowing them to move in various directions, including horizontal and vertical flight, as well as stationary hovering [28]. This flexibility makes them well-suited for inspecting challenging locations like pipelines and bridges [57]. Similar to helicopters, rotary wing MAVs use rotor blades to generate lift. These drones come in a range of configurations, from mono-copters with one motor and blade inspired by whirling seeds falling from trees, to twin-copters, tri-copters, quad-copters, penta-copters, hexa-copters, octo-copters, deca-copters, and dodeca-copters, featuring two to twelve motors, each known for specific capabilities [58, 59].

3.4. NAVs category

In addition to micro air vehicles, DARPA initiated a separate program focused on nano air vehicles (NAVs) [60]. NAVs come in various configurations, including fixed wings, rotary wings, and flapping wings, as illustrated in Figure 5. NAVs are characterized by their extremely small size, with a maximum wing span of 15 cm, and low weight, typically under 50 g [61] . These miniature drones have a limited range of less than 1 km and can reach maximum flight altitudes around 100 m [60].

Figure 5. Different types of NAVs, (a) fixed wing [62], (b) flapping wing [63], (c) helicopter [64], (d) monocopter, (e) quadrotor, (f) hexacopter, and (g and h) unconventional [11]

3.5. PAVs category

In recent years, there has been a concerted effort among researchers to create drones on a minuscule scale, comparable to that of insects [65]. This endeavor has led to the emergence of a new category of drones known as pico air vehicles (PAVs) [65]. These PAVs, characterized by their small size and light weight, primarily feature quadrotors and flapping wings. Flapping-wing PAVs have gained prominence for their insect-like flight abilities, such as hovering and agile maneuvering [66]. Various research teams have explored the development of micro-robotic drones. For instance, a design with an exoskeleton and elastic joints inspired by insects was proposed by Shimoyama et al. [67]. Dickinson et al. [68] aimed to create an insect-sized drone with a 25 mm wingspan and 100 mg weight. The range of PAV types is shown in Figure 6 [11].

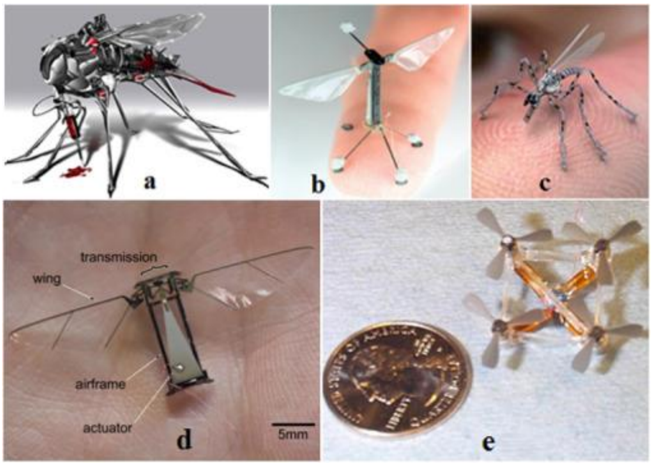
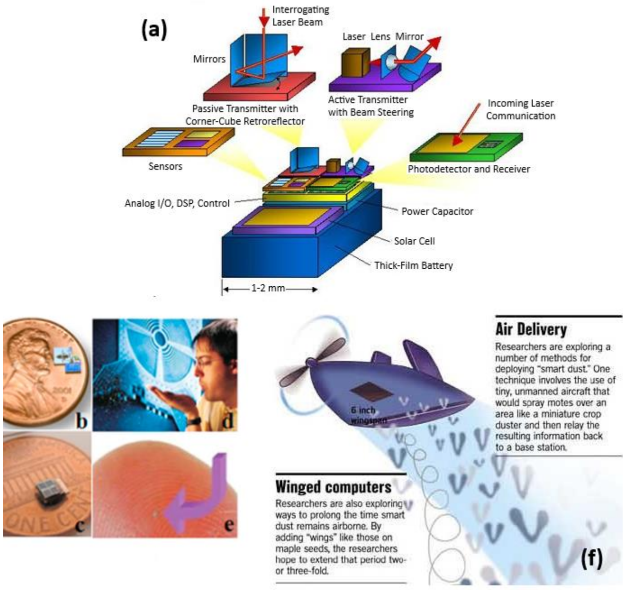


Figure 6. Different types of PAVs, (a, b, c, and d) flapping wing, and (e) quadrotor [11, 69, 70]

3.6. SD category

Currently, the fusion of nanotechnology, wireless sensor networks, and micro-electro-mechanical systems (MEMS) plays a vital role in numerous applications like climate control, building safety, and environmental monitoring [71]. A noteworthy illustration is the 'smart dust' project, comprising hundreds to thousands of tiny MEMS that can detect light, temperature, vibration, magnetism, or chemicals. These tiny robots are typically deployed across various areas to carry out specific tasks. For instance, they can be transported by wind or suspended in the air to monitor weather, air quality, and more [72]. Each smart dust mote encompasses sensors, a power source, analog circuitry, bi-directional communication, and a programmable microprocessor, with mote sizes ranging from 1 mm to 3 mm based on the power source [73]. These versatile motes find applications in both commercial and military contexts, equipped with sensors for acoustics, vibration, and magnetic fields, and they can be deployed via unmanned air vehicles (UAVs) or micro air vehicles (MAVs) [74]. Ongoing efforts seek to integrate chemical and biological sensors into smart dust motes, as depicted in Figure 7.



Air Delivery

Researchers are exploring a number of methods for deploying "smart dust." One technique involves the use of tiny, unmanned aircraft that would spray motes over an area like a miniature crop duster and then relay the resulting information back to a base station.

Winged computers

Researchers are also exploring ways to prolong the time smart dust remains airborne. By adding "wings" like those on maple seeds, the researchers hope to extend that period two- or three-fold.

Figure 7. (a) Structure of smart dust motes [75], (b, c, d, and e) smart dust motes [11], and (f) smart dust application [76]

3.7. Bio-drone category

Investigation and patrolling in civil and military contexts have sparked interest in novel tools for these tasks. While large drones like the Global Hawk have been deployed for such missions, the attention has turned towards smaller, bio-inspired micro drones. These drones, inspired by birds and insects, are developed using various design techniques. Some unconventional methods suggest using live or deceased birds and insects equipped with electronic chips for missions instead of creating artificial drones. This categorizes bio-drones into two types: taxidermy and live drones [77, 78].

A recent novel concept involves employing the preserved bodies of deceased animals or birds as the framework for drones. The taxidermy bodies are integrated with electrical batteries and sensors to form structural elements. Jansen [79] was a pioneer in this field, using taxidermy animal bodies, including cats, rats, and an ostrich, to create various drones, such as quad-copters (Orvillecopter and OstrichCopter) and a tricopter (Ratcopter). While the deceased cat and rat bodies might not seem like naturally flight-efficient structures, the concept, when applied to taxidermied birds, offers potential for new platforms for flapping-wing drones. Researchers at Duke University used a taxidermied dead bird known as Robosparrow, animated by robotics, to explore the behavior of the swamp sparrow species [80]. Although originally utilized for biological studies, this taxidermy bird offers fresh insights for potential applications as drones.

The integration of low-power radio systems and miniature digital circuits, along with the study of neurophysiology and the dynamics of bird and insect flight, presents an opportunity to control the flights of these creatures. Despite strides in microfabrication technology and insect flight understanding, creating tiny flyers capable of navigating real-world environments remains a complex task. The smallest micro drone is the microroboticfly developed at Harvard Microrobotics Laboratory, weighing a total of 60 mg. However, these small drones encounter challenges in matching the mechanical efficiencies and power densities of current power sources [81]. Researchers have explored solutions by merging synthetic control and communication systems into living insects to guide their free flight. For example, scientists at Shandong University of Science and Technology in China managed to remotely control pigeon movements by attaching an electronic chip to the bird's brain [78]. Using thin electrodes implanted in areas of the brain responsible for movement, they achieved remote control. Additionally, these birds can be outfitted with GPS, modems, and cameras, then released in target areas to perform missions without direct control over their actions.

3.8. Hybrid drone category

Significant efforts are underway to create drones with diverse capabilities suitable for various environments. These drones exhibit the capacity to navigate across land, water, and air. Figure 8 illustrates a range of hybrid drones designed for air-ground and air-water operations. A company known as 'B' has developed a hybrid tank-quadcopter, allowing the drone to transition from ground mobility to aerial flight with a simple switch (Figure 8(a)) [11]. Additionally, the DALER robot combines the features of flight and terrestrial locomotion, taking inspiration from the vampire bat Desmodus rotundus to achieve both long-distance flight and local exploration on foot (Figure 8(b)) [11]. The micro air-land vehicle (MALV), designed by Bachmann and colleagues, can traverse challenging terrains by incorporating passively compliant wheel-leg running gear, enabling it to fly and move on the ground (Figure 8 (c)). Another innovative creation is the Parrot Hydrofoil, a hybrid drone seamlessly functioning in both air and water environments (Figure 8(d)) [11].

Further expanding the horizon, researchers at Rutgers University have developed a versatile flying and diving drone designed to assist in search-and-rescue missions, defusing underwater mines, and monitoring oil spills (Figure 8(e)) [82]. The HexH2O is another type of hybrid drone, boasting the ability to operate in both aerial and aquatic domains (Figure 8(f)) [83]. Engineers at the Aerial Robotics Laboratory of Imperial College London have introduced a multimodal flapping wing Micro Air Vehicle (MAV) inspired by amphibious birds, capable of flying, diving into water, and taking flight once more. This versatile Aquatic Micro Air Vehicle (AquaMAV) is intended for tasks such as water quality monitoring, search and rescue operations, and underwater exploration (Figure 8(g)) [84].

Table 1 offers a concise overview of the pros and cons of various drone classifications, highlighting significant considerations for their deployment across different scenarios and applications. This discussion allows for an informed decision-making process when choosing a drone for specific needs based on the trade-offs between advantages and disadvantages. MAVs are particularly beneficial for operations in confined spaces due to their small size and agility. However, their limited range and payload capacity restrict their use to shorter, more localized tasks. This makes MAVs ideal for indoor surveillance or tasks where space is constrained but less suitable for extended missions. NAVs push the boundaries of miniaturization even further, offering unparalleled access to extremely tight spaces. Their covert nature allows for applications in sensitive or otherwise inaccessible areas. Yet, their practicality is hampered by very limited payloads and susceptibility to environmental disturbances, which could significantly impact their operational reliability. Hybrid UAVs stand out due to their versatile capabilities. They merge the endurance and speed of fixed-wing UAVs with the vertical take-off and landing abilities of rotary-wing UAVs. This makes them highly adaptable to varied mission profiles, though at the cost of increased complexity and maintenance needs.

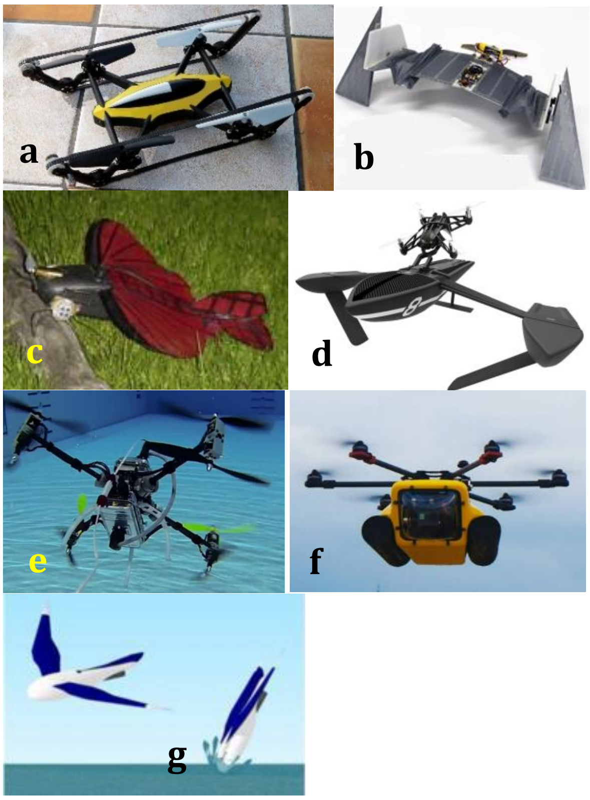


Figure 8. Air-ground hybrid drones (a) tank quadcopter [85], (b) DALER robot [86], (c) MALV [87], (d) Parrot Hydrofoil [88], (e) Rutgers University drone [89], (f) HexH20 [90], and (g) AquaMAV [91]

Fixed-wing UAVs excel in tasks requiring long-distance travel and high speeds, such as aerial mapping or large-scale surveillance. Their need for a runway, however, limits their deployability in environments without the necessary infrastructure, and their fixed wings limit maneuverability in constrained spaces. Rotary-wing UAVs, with their ability to hover and perform vertical takeoffs and landings, are excellent for precise, stationary tasks, such as detailed inspections or targeted payload deliveries. However, their energy consumption reduces their operational time, which can be a critical limitation in prolonged missions.

Bio-inspired UAVs represent a cutting-edge area of drone development, drawing from nature to potentially revolutionize drone efficiency and capabilities. Despite their innovative design, the practical application of such UAVs remains largely experimental and costly, with significant technical challenges to overcome.

In conclusion, the selection of a drone type involves balancing these pros and cons against the specific requirements of the intended application. As technology advances and new designs emerge, these classifications may evolve, further expanding the capabilities and addressing the current limitations of UAVs. Future research should continue to refine these classifications and explore new possibilities in drone technology, aiming for an optimal blend of performance, efficiency, and adaptability.

Table 1. Drone classification evaluation

Category	Pros	Cons
Micro Air Vehicles (MAVs)	- Highly maneuverable in tight spaces - Lightweight and portable	- Limited payload capacity - Shorter range and endurance
Nano Air Vehicles (NAVs)	- Extremely small and discreet for covert operations - Can access very confined areas	- Very limited range and payload - Often more susceptible to environmental factors like wind
Hybrid UAVs	- Combine capabilities of fixed-wing and rotorcraft - Versatile in various flight conditions	- Complex mechanics can lead to higher maintenance costs - Often larger and less efficient at hovering
Fixed-wing UAVs	- Longer endurance and faster speed - Suitable for covering large distances	- Requires runway or large area for takeoff and landing - Less maneuverable in tight spaces
Rotary-wing UAVs	- Can hover and perform vertical take-offs and landings - Good for precise maneuvering	- Generally have shorter flight times due to higher energy use - Slower speeds compared to fixed-wing
Bio-inspired UAVs	- Innovative designs inspired by natural fliers like birds and insects - Potential for highly efficient aerodynamics	- Still largely experimental - High cost of development and potentially high failure rates in initial designs

The classification of drones, as reviewed in this article, serves as a foundational element to understanding the variety within drone technology. While the classification framework provided organizes various drone types based on size, function, and design specifications, analysis reveals some common patterns and notable gaps across the literature. Commonly, studies emphasize the operational capabilities and design optimization of drones, focusing mainly on enhancing efficiency and adaptability for specific tasks such as VTOL (Vertical Take-Off and Landing) capabilities or endurance improvements. However, a critical shortfall in current classifications is the lack of representation of emerging technologies, such as biomimicry-inspired designs, and their categorization. These innovative approaches suggest a potential development in drone capabilities that could influence future classifications. An inferential analysis suggests the need for a dynamic classification system that can integrate new technological advancements and provide a more detailed understanding of drone capabilities, particularly in response to the rapidly changing landscape of drone applications in both civilian and military contexts.

4. Different applications of drones

In light of the significance of disaster control and effective management, following the examination of diverse drone types in the previous section, this section of the paper explores the impact and efficiency of UAVs across various applications, with the main focus on the drones' application in search and rescue, and disaster management and recovery. The applications of drones can be categorized in various ways, including by the nature of the mission (civilian or military), the type of flight zone (indoors or outdoors), and the environment (underwater, on water, ground, air, or space) [11]. Currently, drones are not only utilized in military contexts but are regularly used in firefighting, disaster evaluation, search and rescue missions, and the entertainment industry for multimedia and film production. They are employed extensively for aerial surveillance, covering activities like law enforcement, counter-terrorism operations, managing large public events, protecting high-value targets and VIPs, monitoring ground and sea traffic, and controlling environmental pollution. Additionally, they find applications in telecommunications, agricultural monitoring, wildlife surveillance, safeguarding fisheries, exploring minerals, conducting ground mapping and photography, observing weather patterns, inspecting pipelines and power lines, transporting goods, and facilitating mail and delivery services [92-95]. Figure 9 illustrates a flowchart detailing the diverse applications of various drone types.

Over recent years, flying robots have increasingly become crucial and provide invaluable assistance in a wide range of tasks, covering from surveying, humanitarian efforts, disaster risk management, and research initiatives to transportation services. Furthermore, over the past few decades, researchers have been dedicated to devising new drone designs for a wide array of uses. In the context of the ongoing pandemic, drones have emerged as crucial assets in the delivery of essential medical supplies, including drugs and food. Drones exhibit the potential to serve as reliable platforms for transporting laboratory samples, emergency medical gear, vaccines, pharmaceuticals, and more. Government agencies have prioritized the utilization of drones, and future endeavors will encompass robust safety research initiatives, heightened public awareness, industry growth, and increased participation [2, 21].

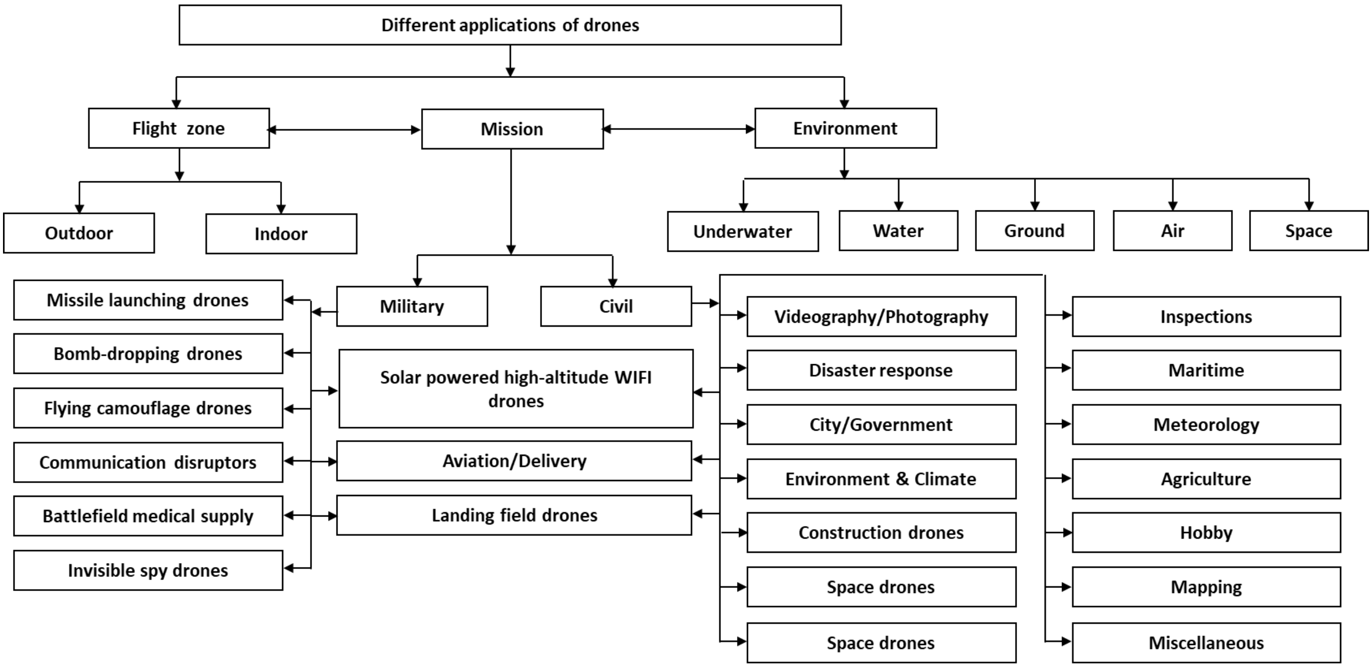


Figure 9. Different applications of drones [11]

4.1. Disaster management

Natural disasters like earthquakes, mudslides, and wildfires pose severe threats to life, property, and the economy in affected regions. Over the last 50 years, the occurrence of such disasters has increased nearly five-fold globally [96]. The emergence of UAVs integrated with artificial intelligence has revolutionized disaster response methodology. Owing to their affordability, mobility, and adaptability, UAVs can penetrate hard-to-reach disaster zones, creating digital maps and facilitating communication relay for swift post-disaster rescues [97, 98].

However, utilizing UAVs for post-disaster rescue encounters substantial engineering challenges. Their onboard battery's limited capacity due to strict weight and space requirements implies restricted service time and coverage. Moreover, UAVs have limited computational capabilities, leading to delays in real-time applications like image processing and video streaming [99]. Intensive computation tasks can diminish battery life, mandating the offloading of missions to nearby devices with greater computational capabilities [100].

Disaster occurrences, both natural and human-made, lead to profound impacts, as evidenced by an increased disaster rate recorded between 2001-2020. The year 2021 notably experienced 432 disaster events, underscoring the gravity of this issue [101]. The aftermath of such incidents results in not only physical damage but also societal and economic losses, disrupting entire regions. These losses encompass structural damage, infrastructure impairment, and economic setbacks [102]. Swift action during such crises is critical, especially in rescue operations, to contain the losses and impacts, hence advocating for proactive disaster management strategies [103]. Disaster management involves multifaceted stages, spanning pre, during, and post-disaster phases, each demanding unique tasks and considerations [104, 105].

Various technologies and hardware chips have been employed for disaster management tasks, integrating sensors, cameras, and artificial intelligence (AI) for enhanced search and rescue endeavors [106]. Among these technologies, wireless communication and Unmanned Aerial Vehicles (UAVs) have proven effective in managing disaster situations [107]. UAVs serve diverse purposes in disaster scenarios and offer solutions to critical disaster management tasks [108]. Researchers have integrated different technologies and functions with UAVs, such as sensors for data collection and wireless servers for communication with rescue teams [106]. Figure 10 illustrates various applications for drones involved in search and rescue operations and disaster management.

In times of both natural and human-made disasters like terrorist attacks, floods, or wildfires, UAVs offer invaluable assistance. Their capabilities extend to assessing disaster-stricken areas where human intervention may be hazardous, notably in areas with damaged communication infrastructure, transport, and utilities. Equipped with radars, sensors, and high-quality cameras, UAVs assist rescue teams in damage assessment, swift recovery operations, and the delivery of critical resources like medical kits and manned helicopters. Notably, UAVs play a significant role in search and rescue operations (SAR) due to their low cost and reduced human risk, particularly in situations such as earthquakes, floods, and threats to infrastructure [14, 111].

The importance of quick and efficient response in search and rescue missions is undeniable. Drones are instrumental in rapidly assessing disaster scenarios, surpassing the time needed for readiness that manned aircraft require [11, 14]. They possess sensors for imaging, vision, or thermal cameras and relay real-time visual data to ground control systems, expediting the initial scan of affected areas. Moreover, they significantly contribute to the localization of survivors or victims through various means, such as GPS and RF emitters [106]. Further innovative approaches include Wi-Fi-based object location estimation and weight-based exploration tactics, enabling quicker search and retrieval operations [112]. UAVs' ability to capture high-resolution images from multiple angles is crucial for gathering valuable visual data [113]. Survivors located in perilous or inaccessible areas often require essential provisions such as water, food, and medications to ensure their safety until rescue efforts are successful [114, 115]. UAVs have proven to be highly effective in delivering medical assistance and supplies to aid those injured in disasters. Furthermore, these aerial vehicles are utilized to transport medical resources to hospitals and clinics that have become unreachable due to damaged roads in the aftermath of catastrophic events [116].

Figure 10. Application of drones in search and rescue missions and disaster management [11, 109, 110]

Drones have emerged as superior alternatives to manned aerial vehicles for swift search and rescue missions, leveraging drones' autonomy, speed, and agility to tackle tasks beyond human capability [117]. Drones are pivotal in collecting crucial evidence and conducting surveillance, despite the challenges in these operations, such as time constraints, risk to human life, and harsh conditions like disaster zones and wooded areas. Over recent years, various drone designs and concepts have advanced, focusing on control, imaging, human identification algorithms, and configurations, with potential applications in diverse natural and man-made disasters, including storms, floods, earthquakes, and accidents [118]. Search and rescue missions conducted by drones are categorized into four types based on their environments: wilderness, maritime, combat, and urban settings. Wilderness operations aim to find lost individuals or items, utilizing medical drones for urgent care in remote areas [119]. Maritime missions deal with locating individuals lost at sea, facing challenges such as weather conditions and limited energy, affecting mission success. Various projects have employed fixed-wing and multirotor configurations in SAR missions, with researchers developing autonomous quadrotors for indoor and outdoor urban searches and quadrotors specifically for mountain avalanche incidents. These diverse applications illustrate the extensive capabilities of drones in search and rescue endeavors [120]. For example, Erdos et al. introduced a typical fixed-wing design for search and rescue endeavors [120], while Goodrich et al. utilized a flying wing Unmanned Aerial System (UAS) for wilderness search and rescue missions [121]. Multirotor configurations, particularly quadrotors, are also commonly used in SAR missions. Tomic et al. [122] developed a fully autonomous quadrotor suitable for indoor and outdoor urban search and rescue missions, while Scherer et al. [123] employed an autonomous Multi-UAV system with multiple multi-rotors for SAR operations.

Survival following disasters heavily relies on the speed and effectiveness of search and rescue missions. UAVs significantly contribute to surveillance operations and localization of survivors, reducing costs and search times. Various methodologies, from sensing technologies to auditory estimation techniques, are employed for these tasks, bolstering the efficiency and accuracy of search and retrieval missions. Their low altitude capability allows UAVs to gather detailed images from various perspectives, a critical advantage in search and rescue operations.

Developing drones to operate under radiation conditions presents a unique set of challenges that require innovative solutions across materials science, electronics, and operational strategies. The primary concern in such environments is protecting the drone's electronic systems and onboard sensors from radiation-induced damage, which can lead to malfunction or failure. Materials engineering plays a crucial role in this development process. The use of radiation-hardened components and shielding materials is essential. Manufacturers often employ materials like lead or tungsten for shielding sensitive electronics; however, their weight impacts the drone's flight capabilities. Consequently, there's a growing interest in lighter composite materials that can provide effective radiation protection without compromising performance. Electronically, drones destined for high-radiation areas need components that are resistant to ionizing radiation. This includes everything from the processors and memory to the sensors and communication systems. Radiation-hardened electronics, designed to withstand the effects of high-energy particles, are a critical component of these drones. These specialized parts undergo rigorous testing to ensure reliability under exposure. Operationally, the design and flight paths of drones may be adapted to minimize radiation exposure. This could involve limiting the time spent in high-radiation zones or utilizing autonomous navigation algorithms to identify and avoid areas of higher radiation intensity. Finally, ongoing monitoring and maintenance are vital to address any radiation-induced degradation over time. Advanced diagnostics and remote monitoring technologies can help in early detection of potential issues, allowing for timely maintenance or component replacement [124-128].

With growing curiosity in surveying and examining environments impacted by radiation, from nuclear disaster zones to the realms of space exploration, the creation of drones designed to function in these challenging conditions presents a significant opportunity for research and technological advancement.

4.2. Agriculture and environmental protection

UAVs are increasingly integrated into precision agriculture applications, playing a crucial role in tasks such as collecting ground sensor data, conducting pesticide spraying, disease and weed detection, irrigation scheduling, and crop monitoring. These applications in precision agriculture contribute to cost-effective and time-efficient methods, ultimately enhancing the profitability and productivity of farming systems. The utilization of UAVs enables crop management, pest damage control, and weed monitoring, directly affecting improved crop yields and aiding in meeting specific production needs. Additionally, with the incorporation of remote sensing technology, UAVs offer multifaceted observations, including temporal, spatial, and spectral resolution, supporting detailed vegetation height data and multi-angular observations [111, 224, 225].

While drones are commonly associated with military applications, they have an expand8ing role in environmental missions, notably in the management of national parks, agriculture, and wildlife tracking, as well as climate change observations. These UAVs are instrumental in studying and monitoring ecosystems across various environments, ranging from rainforests to oceans [129]. Their use is not only limited to environmental observation but extends to disaster recognition and investigation, particularly in scenarios like forest fires and avalanches [130]. A study on Amazon river dolphin populations by Oliveira-da-Costa et al. [131] revealed that aerial drones provided a more accurate, cost-effective estimation compared to traditional visual surveys. Similarly, research by Colefax et al. [132] indicated the effectiveness of drones in monitoring marine fauna along coastal beaches, suggesting their significant potential for environmental monitoring.

Drones have been effectively used for nature conservation purposes, such as automatic animal population localization and counting, demonstrated by Gemert et al. [133] using object recognition techniques. Furthermore, Van Andel et al. [134] utilized a typical fixed-wing drone to locate Chimpanzee nests and identify fruiting trees. These studies showcase the varied applications of drones in environmental protection and wildlife research. Various types of drones have been employed in environmental protection efforts, with fixed-wing and quadrotor configurations being particularly popular. These drones have been utilized for diverse studies and wildlife observations. For instance, Pirotta et al. [135] developed a cost-effective quadrotor for assessing whale health, while Hartman et al. [136] studied the social dynamics among male Risso's Dolphins using quadrotors.

In smart agriculture, UAVs perform various tasks such as crop management, weed and disease detection, pesticide spraying, and irrigation scheduling, offering a cost-effective and efficient alternative to traditional methods. These aerial tools generate real-time data and high-resolution images, enabling remote access to crop-related data through cloud-based platforms [14]. Furthermore, several applications discussed by Radoglou-Grammatikis et al. [137] highlight the diverse monitoring techniques used in precision agriculture, including the use of different sensors (thermal, multispectral, hyperspectral cameras) and spraying systems, optimizing pesticide and fertilizer selection based on plant diseases and pests. The research examines UAV architecture, methodologies, technical specifications, and the types of crops studied, outlining trends and future research directions. The prospective work involves developing a Decision Support System (DSS) managing a Fleet Ad Hoc Network (FANET) and a ground-based Wireless Sensor Network (WSN) for crop monitoring and spraying processes. The envisioned system utilizes fixed-wing UAVs for acquiring images to estimate vegetation health using deep learning models and terrestrial sensors for critical chemical data. Simultaneously, the FANET with rotary-wing UAVs equipped with spraying devices covers specific subareas. The WSN supplies weather data to inform DSS decisions on UAV motions, enhancing agility, direction, and velocity adjustments for optimal spraying.

UAVs are crucial in precision agriculture, contributing to essential farming tasks like data collection, pesticide spraying, and crop monitoring through remote sensing technology. These drones have expanded beyond military roles, playing a significant part in environmental missions, wildlife tracking, and disaster investigations. The research highlights their diverse applications, including wildlife monitoring and environmental protection, showcasing their potential in smart agriculture for tasks such as crop management and disease detection. It also emphasizes ongoing work developing a sophisticated Decision Support System to manage crop monitoring and spraying processes, utilizing innovative technology to optimize crop health and management.

4.3. Inspection, survey and mapping

Numerous researchers have utilized images for managing critical scenarios through UAVs [106, 138], effectively implementing monitoring and surveillance across various fields like disaster management [139]. The elevated perspective provided by UAVs enhances the perception of the area, enabling the efficient use of UAV photogrammetry technology for recognizing surface deformations, critical in estimating the timing of a disaster event [140]. These drones serve as valuable instruments for data collection in a range of applications such as surveillance, inspections, mapping, and 3D modeling [141-144, 229]. The aerial vehicles are considered cost-effective in comparison to traditional manned aerial photography, offering various functionalities, including photogrammetric data acquisition using diverse camera types, generating contours, 3D surfaces, and vector information for large areas. The primary specifications required for mapping with drones, as identified by Nex and Remondino [145], involve adequate payload capacity, wind resistance, autonomous flight, endurance, and portability. Mapping is extensively applied across various domains like archeology, agriculture, forestry, architecture, and environmental sectors, with these essential criteria being commonly shared for inspection and survey missions, showcasing the adaptability of drones designed for mapping purposes to perform inspections and surveys as well.

The multitude of drones used for a wide array of missions is extensive. Some commercial Unmanned Aerial Systems (UASs) are configured as fixed-wing platforms, such as the hand-launched flying wing UAS, SKYCRUISER A22, developed by South Group for surveying and mapping missions with an hour of endurance and an 80 km flight range [146]. Similarly, the Supercam S100 from Unmanned System Group is designed for aerial surveillance in varied weather conditions [147]. In the agriculture realm, the eBee by SenseFly Company operates at a high operational altitude compared to small multirotors, enabling an endurance of about an hour and flying at 400 ft above ground level [147]. These UASs are adapted for precision agriculture tasks. The development of solar-powered UASs like CIES by UAV Instruments Spain and Masterfly by EasyMapUAV are other instances utilizing different configurations for photogrammetry and reconnaissance missions [148, 149].

Various classes of UASs are designed for mapping, inspection, and survey missions. The fixed-wing UASs, such as the SLA-1 by Satlab, typical fixed-wing UAS by Topcon Company, and the drone by Aeromao, are tailored for mapping, surveying, photogrammetry, and other missions [150-152]. Lighter-than-air UASs like the Skyshot Helikite and Halo are used for photogrammetry and unmanned photography, with the former resisting wind gusts of up to 35 mph [153, 154]. Additionally, multirotors play a significant role, with models developed by different companies like Satlab, Italdrone, Ascending Technologies, ECA Group, Applied Airborne, and MetaVista Inc., showcasing various applications in photogrammetry, filming, inspection, and aerial imaging [150, 155-159, 226, 227].

In the construction industry, UAVs have proven to be highly efficient tools for as-built mapping, site monitoring, and infrastructure inspection. These drones aid in project planning through aerial mapping and are essential in the construction process, monitoring workflow and inspecting buildings for maintenance, faults, and unforeseen failures. Utilizing distributed sensors to collect data and combining it with comprehensive geographical information, UAVs play a pivotal role in providing accurate and detailed data to construction investors and stakeholders [14, 111].

4.4. Marine and underwater

Amphibious and waterproof drones, engineered for water and underwater missions, serve a variety of purposes, from marine life study to oil spill detection in both military and civilian sectors (Figure 11). Typically designed with VTOL configurations due to limited space for horizontal take-off and landing, these drones are launched from boats, submarines, ground, or beaches. Yang et al. [160] provide a comprehensive overview of these aquatic-aerial amphibious drones, while Guo et al. [161] conducted a similar review on amphibious robots. These versatile drones are utilized for air and water surface operations, including tasks like enemy status reconnaissance, marine environment monitoring, and surveillance. Companies like UVS [162] and DRS Technologies [163] have developed fixed-wing amphibious drones with various designs, including models powered by solar energy. Furthermore, both fixed-wing and multi-rotor drones are employed for underwater and water surface operations. Due to the absence of runways on marine vehicles like submarines and boats, most drones are vertically launched in these settings. The introduction of underwater drone launches by U.S researchers in 2005 marked a significant advancement.

A waterproof drone, designed for both launching from and returning to aquatic surfaces, facilitated a detailed assessment of the extent of an oil spill, enabling more effective coordination of the response team. The UAV, equipped with standard and thermal cameras, proved efficient for continuous operation, even during nighttime, sustained by a continuous power connection from a support vessel via a tethered power line [164]. To enhance the efficacy of offshore patrol operations, patrol vessels might employ waterproof drones, either rotary-wing or fixed-wing with floats, to detect and document unauthorized fishing activities within marine protected areas [165].

Tauro et al. [170] and others have explored the advantages of employing drones for hydrological studies and marine monitoring, highlighting their utility in analyzing surface flow and assessing hard-to-reach aquatic environments. Waterproof drones, including both surface-operating drones and underwater drones, play a pivotal role in environmental research. Surface drones focus on tasks like water quality assessment and marine ecosystem monitoring, including coral reefs and aquaculture. Meanwhile, underwater drones, categorized into remotely operated vehicles and autonomous underwater vehicles, facilitate in-depth studies of marine life and the exploration of underexplored underwater regions. These drones have contributed significantly to marine biology by enabling automated fish identification, as noted by Meng et al. [171]. Furthermore, Spears et al. [172] demonstrate their application in polar under-ice exploration, showcasing the broad capabilities of waterproof UAVs in augmenting our understanding of aquatic environments.

Several Researchers like Weisler et al. [173] and Esakki et al. [174] have crafted different forms of drones suitable for water and underwater tasks. Inspired by nature, bio-mimetic drones imitating flying fish have been designed by Gao and Tachet [175] and Cherney [176]. These flapping-wing drones, capable of swimming underwater and gliding in the air, present potential applications in ocean exploration, mapping, surveillance, and forecasting. Yet, efficiency differences between air and water propulsion systems pose challenges, as the high RPM propellers in multirotors are less efficient in water due to its differing density. Adaptations for underwater use are essential for achieving maximum efficiency [160].

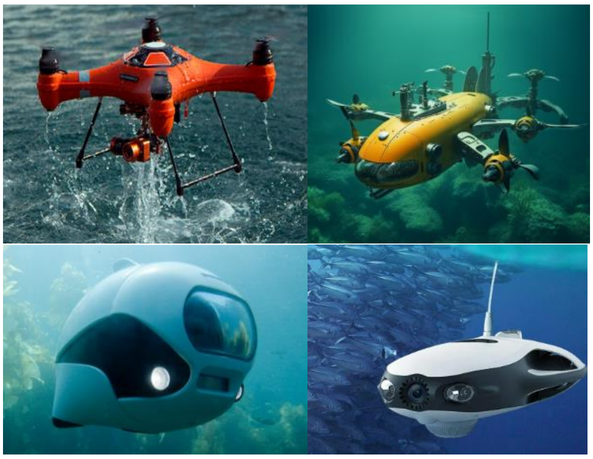


Figure 11. (a) Floating waterproof drone [166], (b) Underwater drone [167], (c) BIKI: First bionic wireless underwater fish drone [168], (d) PowerVision's underwater drone [169]

4.5. Military

In military surveillance, UAVs are integrated into the defense plans of various countries. They play a significant role in tasks like enemy detection, anti-poaching efforts, border control, and monitoring critical sea lanes. UAVs offer a cost-effective, reliable, and versatile solution for aerial surveillance, swiftly detecting threats and monitoring restricted areas with minimal manual intervention [111]. The historical lineage of drone technology traces back to its deployment in warfare during World War I and II. Evolving from its initial use, drones have become essential assets in modern Western warfare. Drones reduce costs and minimize risks to personnel, particularly in surveillance and targeted killings, providing a safer alternative to deploying personnel in hazardous situations [2, 177]. However, the application of drones in lethal surveillance and targeted killings raises complex ethical and legal considerations, questioning accountability, transparency, and adherence to international laws of armed conflict. Although drones offer advantages, their usage for these purposes demands careful ethical and legal considerations for appropriate and accountable military operations [178].

UAVs serve various military purposes, such as deploying munitions, facilitating communication, conducting surveillance, and carrying out medical activities. Fixed-wing drones are the primary choice for most military operations, especially in combat and operational assignments. They differ in wing design, tail, and propulsion systems, and some incorporate morphing wing and flying wing configurations [118].

Multi-rotor drones, particularly quadrotors, have seen increased use in imaging and operational missions. Some have been armed with light and heavy weapons for military purposes, illustrated in Figure 12 [118]. Additionally, balloons function as popular VTOL UASs, providing Intelligence, Surveillance, and Reconnaissance (ISR) functionalities at considerable altitudes. They assist in border security and strategic asset surveillance using various sensors and cameras [179]. Various hybrid configurations, like tail-sitter and dual systems, have also been employed by the military, as seen in Figure 13. Helicopters are also widely utilized in military applications, employing their VTOL capabilities for tasks like imaging, communication, border control, and military support, among others [180].

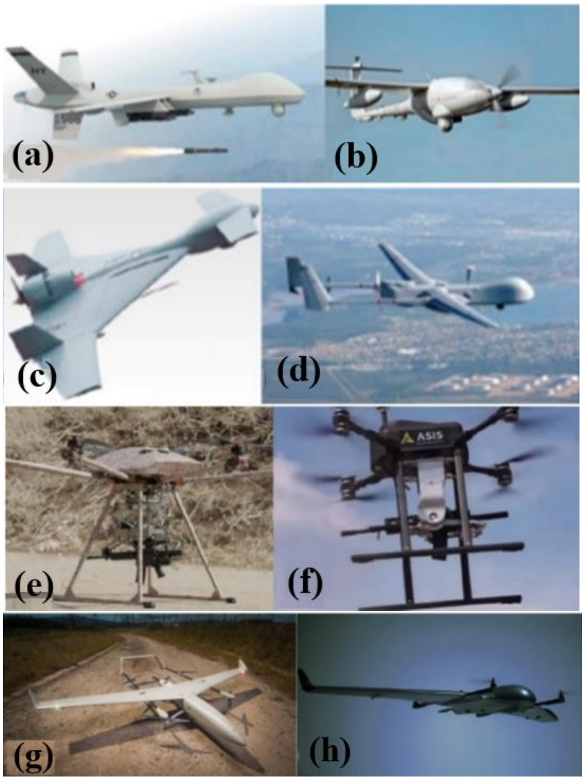


Figure 12. Views of different fixed-wing military drones, (a) V-tail, (b) T-tail, (c) delta wing, and (d) twin tail boom; armed military quadrotors (e) Duke Robotics military quadrotor, (f) Turkey's armed quadrotor; Views of hybrid military drones (g) dual system hybrid drone ALTI, (h) dual system military UAS Bat-2 [118]

Military missions encompass diverse requirements, making it challenging to outline specific UAS specifications without a comprehensive mission analysis. However, it's evident that nearly all UAVs configurations, including bio-based drones, have potential for use in military operations. For example, the Defense Science and Technology Laboratory (DSTL) in the United Kingdom supported a spying drone inspired by dragonflies for covert operations [181].

4.6. Space drones

Drones are proving their usefulness in unique environments, such as space and planetary exploration, notably on planets like Mars. With their distinct advantages over other robotic technologies, there's a growing trend to design and construct drones capable of flying and executing missions in space environments. Notably, NASA has undertaken the development of drones for planetary exploration [182, 183]. Utilizing UAVs for planetary exploration offers advantages, allowing them to map larger areas with greater precision than current orbiters and rovers. However, it is essential to emphasize that the design and construction of UAVs for space should be tailored to the specific environmental conditions of the targeted planet [14].

Various types of drones have been specifically engineered and manufactured for these space missions and planetary explorations [184]. Some examples of these space drones are depicted in Figure 13 [185]. Notably, the creation and development of space-oriented drones are reliant on the specific environmental conditions of the target celestial body. For instance, considering the gravitational conditions on Mars, the weight of drones differs significantly from their weights on Earth, decreasing by 61.5% [186].

NASA's Dragonfly mission sets a bold path to Saturn's enigmatic moon, Titan, aiming to unravel the mysteries of prebiotic chemistry and the origins of life. Scheduled to launch in 2026 and expected to reach its destination in 2034, the Dragonfly mission embarks on a groundbreaking journey as the first mission to deploy a multi-rotor vehicle for scientific exploration on another planetary body. This rotorcraft, equipped with eight rotors, will exploit Titan's dense atmosphere to transport its full scientific payload across various locations, offering a new paradigm in planetary exploration. The mission seeks to explore Titan's diverse environments, from organic dunes to ancient impact craters, where conditions analogous to early Earth may shed light on biological precursors. Utilizing over a decade of data from the Cassini mission, Dragonfly will commence its journey in the "Shangri-La" dune fields, progressing to the Selk impact crater, a site believed to have harbored water, organics, and life-sustaining energy. This venture into Titan's nitrogen-rich atmosphere and complex organic landscape not only promises to enrich our understanding of life's potential across the universe but also cements NASA's legacy of pioneering exploration through the New Frontiers program [187, 188].

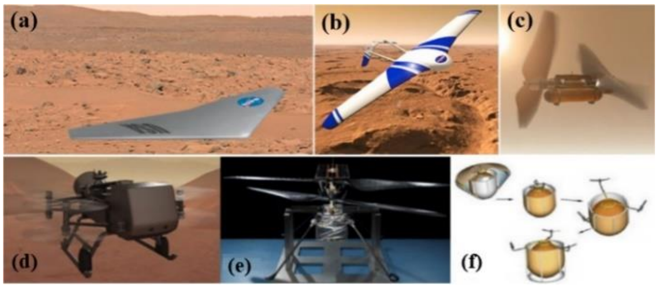


Figure 13. (a-c) Application of drones in space; multirotors drones, (d) NASA's Dragonfly for Titan exploration [189], (e) NASA's coaxial mono-rotor drone for Mars explorations [187], and (f) tri-rotor drone designed by Young et al. [190]

Researchers have proposed various drone designs and concepts for space exploration. NASA, for instance, is developing a quadrotor co-axial drone for Titan exploration scheduled for launch in 2026 to survey Titan for life signs [188]. They've also crafted a co-axial mono-rotor drone for Mars exploration, set to demonstrate the feasibility of heavier-than-air vehicles on Mars, launched in July 2020 [191]. Different designs cater to various missions. Landis et al. [192] suggested fixed-wing drone designs for Venus exploration [193]. Similar exploration concepts have been put forward for Venus by Xiongfeng [194] and other flying-wing concepts by NASA for Mars [195]. Pellerito et al. [196] designed a fixed-wing UAV for Titan exploration. Multirotor concepts are proposed for planetary exploration. Pergola and Cipoll [197] developed a hexarotor for Mars exploration, while Young et al. [190] suggested a tri-rotor UAS for Venus exploration, as illustrated in Figure 14 (f). Hybrid configurations are gaining popularity in space missions. The tilt-rotor drone with a combination of a fixed-wing configuration for Martian exploration designed by Collins [198], and Aguirre et al. [199] proposed a dual system hybrid drone for Mars exploration. A unique concept in planetary exploration involves the hybrid balloon-drone model, offering a solution to the limitations faced by drones. For static or slow-motion applications, balloon-type drones are suggested as they require less power and offer longer flight times and greater flexibility [200]. Various versions of balloon drones are presented by NASA [201] and Global Aerospace [202] for near-space missions and planetary explorations.

Some researchers have explored flapping-wing drones suitable. Zegers et al. [203] and a research group from Mountain Lake Labs (MLABs) [204] developed flapping wing aerobots suited for the Martian atmosphere. Numerous similar concepts regarding flapping-wing drones for space missions are reviewed by Hassanalian et al. [200]. The design of space drones is influenced by the target solar body. For instance, Venus-based drones differ in flight and performance from Martian-based drones due to atmospheric differences. The Martian atmosphere, much thinner than Earth's, influences various design factors, such as the range of Reynolds numbers. On Mars, the Reynolds numbers of drones are notably lower than those on Earth, necessitating larger propellers to generate sufficient thrust due to the lower atmospheric density.

Designing aircraft for space conditions involves unique challenges and considerations, distinct from terrestrial aircraft design, due to the absence of atmospheric air and the presence of microgravity. Such designs are often referred to as spacecraft rather than aircraft and require innovative engineering approaches. For propulsion without air, spacecraft rely on rocket engines or ion thrusters, utilizing Newton's third law of motion for movement. Materials must withstand extreme temperature variations, radiation, and the vacuum of space, leading to the use of specialized, highly durable materials like titanium alloys and carbon-fiber-reinforced polymers. Thermal management systems are critical to protect sensitive instruments and maintain operational temperatures without atmospheric cooling. Solar panels are commonly used for power, capitalizing on the sun's energy. Guidance and navigation systems must be highly reliable, as traditional Earth-based navigation aids are unavailable. The design process often incorporates sophisticated computer simulations and testing in simulated space conditions to validate designs before launch. These principles are embodied in spacecraft developed by agencies such as NASA and the European Space Agency (ESA), with reference missions like the Mars Rovers and the Hubble Space Telescope, showcasing the application of these design strategies in successful space exploration missions [205, 206].

4.7. Mailing and delivery

The global interest in drone delivery services has captivated numerous companies, including major players like Amazon, Google, and DHL [207-209]. These companies have utilized drones to deliver packages directly to customers, deploying designed drones for vertical takeoff and landing while ensuring accurate delivery to the customer's address. These delivery drone services are gaining momentum and represent a significant area of innovation in the industry. UAVs are proving their worth not only in commercial deliveries but also in emergency situations, serving to transport medical supplies [11]. For instance, the Federal Aviation Administration (FAA) conducted the first UAV-based medical delivery in 2015, using GPS for precise location-based deliveries, ensuring packages reached the correct recipients [210]. This trend has seen increased adoption across various industries for swift and efficient deliveries.

Fixed-wing UAVs are found to be suitable for mail and delivery services, with Zipline successfully employing these for distributing medical supplies during the COVID-19 pandemic [211]. Companies like Solent Transport have also developed fixed-wing UASs for delivering medical provisions, showcasing a significant payload capacity and range [212, 223, 228]. While fixed-wing drones are utilized by certain companies for deliveries, others choose multirotor drones, especially those using the quadrotor configuration. Alibaba [213], and SF-Express [214], among others, leverage quadrotor drones for shipping and delivery services. Notably, a variety of multirotors, including octocopters and hexacopters, are employed by companies like FPS and

Flirtey for their delivery operations [215, 216]. Figure 14 displays several delivery drones.

Apart from fixed-wing and multirotor drones, helicopters have also been utilized for goods delivery. Drone Delivery Canada and Yamaha have developed unmanned helicopters with substantial cargo capacities and impressive operational ranges [218, 219]. Moreover, companies like Google and Wingcopter are exploring dual-system hybrid UASs for delivery purposes, offering unique configurations that enable vertical takeoff and landing, as well as prolonged flight endurance [220, 221]. These developments have been instrumental in delivering essential items such as insulin, vaccines, and COVID-19 test kits. DDC has also prototyped a dual-system hybrid drone, combining quadrotor and fixed-wing configurations to enhance payload capacity and delivery range [222].

An ongoing challenge in the realm of delivery drones is their limited flight endurance and cargo capacity, which substantially impacts costs. Companies exploring electrical-powered drones have to carefully balance battery usage to maximize flight endurance without compromising efficiency.

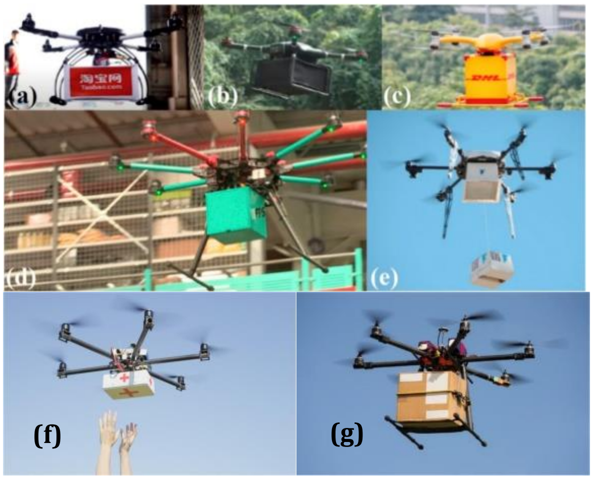


Figure 14. Multirotors delivery drones; (a) Alibaba Tabao's quadrotor, (b) SF-Express's quadrotor, (c) DHL's coaxial quadrotor, (d) FPS's octocopter, and (e) Flirtey's hexacopter [118]; (f) and (g) UAV-based delivery [217]

The utilization of drones across diverse fields, such as agriculture, disaster management, military operations, and environmental monitoring, illustrates their adaptability and the broad spectrum of their capabilities. Each of these domains benefits differently from drone technology, and their advantages and disadvantages are often defined by the specific requirements and challenges of the tasks at hand. In agriculture, drones enhance precision and efficiency through aerial surveillance, significantly improving crop monitoring and management. This allows for targeted applications of pesticides and fertilizers, and more efficient water usage, ultimately reducing the need for manual labor and decreasing the time and resources spent on crop management. However, the high initial costs for advanced drone systems may pose barriers for small-scale farmers, and operating such sophisticated agricultural drones requires a certain level of technical proficiency and training.

In the area of disaster management, drones offer rapid response capabilities and can quickly assess disaster-impacted areas, providing crucial real-time data for effective planning and response. They are particularly valuable in accessing areas that are unsafe or inaccessible for humans, such as during fires, floods, or earthquakes. Nevertheless, drones in disaster scenarios are limited by their endurance and payload capacity, which might restrict their use in transporting essential supplies. Their performance can also be strongly affected by adverse weather conditions, a common challenge during disasters.

For military operations, drones provide enhanced surveillance capabilities crucial for modern warfare, gathering intelligence, and conducting reconnaissance without risking human lives. They offer operational flexibility and can be used in a variety of roles, from offensive operations to logistic support. However, despite these benefits, their exposure to electronic warfare, such as interference and unauthorized access, can diminish their efficacy. Additionally, the use of drones in warfare raises significant ethical and legal questions, especially regarding issues of independence and responsibility.

Environmental monitoring benefits extensively from the ability of drones to collect comprehensive data over large and often inaccessible areas like forests, oceans, and wildlife habitats, with minimal environmental impact. This capability allows for sensitive ecosystem monitoring without significant disturbance. However, limitations in battery life restrict the time drones can operate in the field, potentially missing critical data collection opportunities. Furthermore, the vast amounts of data collected require substantial processing and analysis capabilities, presenting a significant challenge.

By comparing these areas, it becomes clear that while drones offer significant advantages in terms of operational efficiency, flexibility, and cost-effectiveness, they also present challenges such as technical requirements, susceptibility to environmental factors, and ethical concerns. Future advancements in drone technology should aim to address these limitations while enhancing their positive impacts across various fields. This balanced examination not only enriches the academic discourse on drone applications but also guides future technological enhancements and policy formulations.

The review of drone applications highlighted in the current study provides a broad overview of how these technologies are employed across various sectors, from agriculture and disaster management to military and entertainment. The literature collectively highlights the utility of drones in enhancing operational efficiency and providing access to difficult-to-reach areas. A prominent feature among studies is the significant focus on the application of drones in surveillance and data collection, driven by their ability to operate under diverse and challenging conditions. Nevertheless, the literature reveals a notable gap in comprehensive risk assessments concerning privacy concerns and ethical implications, particularly in surveillance applications. The analysis further draws attention to the limited discussion on the environmental impact of widespread drone usage, which presents a crucial area for future research. Inferences from these observations suggest that future studies should not only explore new applications but also address the broader socio-ethical and environmental implications of drone technology to ensure responsible and sustainable advancements.

5. Concluding remarks and future outlook

In conclusion, the world of drones has expanded significantly, featuring a diverse range of designs and configurations tailored for various applications. From military utilization, which incorporates fixed-wing, multi-rotor, hybrid, and even flapping-wing designs, to their remarkable potential in space exploration, drones have proven their versatility across different industries and operational environments. These unmanned aerial vehicles have become instrumental in military surveillance, targeted operations, and exploration, offering unique advantages such as reduced risks to personnel and cost-efficiency.

Drone technology has evolved markedly over the years, transitioning from its initial deployment in World War I and II to its present role in modern Western warfare. Various designs, such as fixed-wing and multi-rotor configurations, have found applications in military missions, demonstrating their adaptability to operational and combat assignments. The deployment of different drone types, from fixed-wing drones to helicopters and hybrid configurations, emphasizes the versatility and adaptability of these aerial vehicles in addressing specific operational needs.

In the context of planetary exploration, drones have become indispensable tools. Companies and space agencies like NASA have been actively involved in developing drones intended for exploration on Mars, Venus, and other celestial bodies. These developments range from fixed-wing and multi-rotor configurations to unique hybrid and flapping-wing designs, each tailored to suit the atmospheric conditions and exploration needs of the respective celestial body.

Moreover, drone delivery services have seen a surge in interest and development from various global companies. The deployment of fixed-wing, multi-rotor, and hybrid drones by entities such as Zipline, DHL, Google, Amazon, and numerous others showcases the widespread use of drones for efficient and rapid delivery of goods, including medical supplies, during emergencies.

The challenge lies in enhancing the flight endurance and cargo capacity of these delivery drones to optimize their performance and reduce costs. Solutions such as optimizing battery use in electric-powered drones have been critical in overcoming these limitations. Despite these challenges, the continual innovation and diverse applications of drones demonstrate their promising future in addressing multifaceted needs across military, space exploration, and delivery services, offering efficient and groundbreaking solutions.

Considering the extensive exploration of drone classifications and applications, it becomes evident that future research should shift towards enhancing drone autonomy, fostering integration with cutting-edge technologies, and conducting comprehensive environmental impact assessments. An imperative area for future investigation is the advancement of autonomous drone navigation systems through the utilization of artificial intelligence (AI) and machine learning (ML) algorithms. This research could focus on augmenting the capabilities of drones to independently navigate complicated environments, adapt to developing conditions, and make real-time decisions without human oversight. Investigating the capabilities of drones for navigating challenges, planning flight paths, and adjusting mission strategies due to changes in the environment or situation stands to greatly enhance sectors, including search and rescue missions, agricultural oversight, and environmental monitoring. By focusing on these advanced navigational and decision-making processes, the efficiency, precision, and functional capabilities of drones can be significantly improved across a variety of conditions.

Furthermore, the incorporation of drones with developing technologies like blockchain for secure data communication, the Internet of Things (IoT) for enhanced data collection and connectivity, and augmented reality (AR) for superior operational control and visualization presents promising directions for scholarly inquiry. These integrations could pave the way for novel applications and operational frameworks, such as secure and transparent logistic networks in drone delivery services, real-time environmental monitoring ecosystems, and sophisticated command and control systems for coordinated multi-drone operations. Furthermore, researching the environmental consequences of drone operations, including their contributions to carbon emissions, noise pollution, and effects on wildlife, is crucial for ensuring the sustainable development of this technology. This line of research should endeavor to develop environmentally friendly drone technologies and methodologies, including the adoption of renewable energy sources, biodegradable materials, and navigation systems considerate of wildlife. These proposed research paths not only promise to broaden the scope and applicability of drones but also ensure their responsible and sustainable integration into social frameworks.

Author contributions

Vahdettin Demir: Conceptualization, Methodology, Writing-original draft preparation, Writing-reviewing and editing.

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Naren, N., et al., IoMT and DNN-Enabled Drone-Assisted Covid-19 Screening and Detection Framework for Rural Areas. IEEE Internet of Things Magazine, 2021. 4(2): p. 4-9.
2. Emimi, M., M. Khaleel, and A. Alkrash, The Current Opportunities and Challenges in Drone Technology. International Journal of Electrical Engineering and Sustainability (IJEES), 2023. 1(3): p. 74-89.
3. Gholami, A., Role of Drone Technology in Alleviating the Pandemic and Disasters. International Journal of Research Publication and Reviews, 2024. 5(4): p. 6679-6708.
4. Petrides, P., et al., Disaster Prevention and Emergency Response Using Unmanned Aerial Systems, in Smart Cities in the Mediterranean: Coping with Sustainability Objectives in Small and Medium-sized Cities and Island Communities, A. Stratigea, E. Kyriakides, and C. Nicolaides, Editors. 2017, Springer International Publishing: Cham. p. 379-403.
5. Shahmoradi, J., et al., A Comprehensive Review of Applications of Drone Technology in the Mining Industry. Drones, 2020. 4(3): p. 34.
6. Apvrille, L. and L.W. Li, 9 - Safe and Secure Support for Public Safety Networks, in Wireless Public Safety Networks 3, D. Câmara and N. Nikaein, Editors. 2017, Elsevier. p. 185-210.
7. Baxter, P.J., Catastrophes - Natural and Man-Made Disasters, in Conflict and Catastrophe Medicine: A Practical Guide, J. Ryan, et al., Editors. 2002, Springer London: London. p. 27-48.
8. Thavasi, P.T. and C.D. Suriyakala, Sensors and Tracking Methods Used in Wireless Sensor Network Based Unmanned Search and Rescue System -A Review. Procedia Engineering, 2012. 38: p. 1935-1945.
9. Van Tilburg, C., First report of using portable unmanned aircraft systems (drones) for search and rescue. Wilderness & environmental medicine, 2017. 28(2): p. 116-118.
10. Watts, A.C., V.G. Ambrosia, and E.A. Hinkley, Unmanned Aircraft Systems in Remote Sensing and Scientific Research: Classification and Considerations of Use. Remote Sensing, 2012. 4(6): p. 1671-1692.
11. Hassanalian, M. and A. Abdelkefi, Classifications, applications, and design challenges of drones: A review. Progress in Aerospace Sciences, 2017. 91: p. 99-131.
12. Cai, G., J. Dias, and L. Seneviratne, A survey of small-scale unmanned aerial vehicles: Recent advances and future development trends. Unmanned Systems, 2014. 2(02): p. 175-199.
13. Yahuza, M., et al., Internet of Drones Security and Privacy Issues: Taxonomy and Open Challenges. IEEE Access, 2021. 9: p. 57243-57270.
14. Elmeseiry, N., N. Alshaer, and T. Ismail, A Detailed Survey and Future Directions of Unmanned Aerial Vehicles (UAVs) with Potential Applications. Aerospace, 2021. 8(12): p. 363.
15. Zhang, C., et al., A comprehensive review of electrochemical hybrid power supply systems and intelligent energy managements for unmanned aerial vehicles in public services. Energy and AI, 2022. 9: p. 100175.
16. Liu, Z., et al., Control techniques of tilt rotor unmanned aerial vehicle systems: A review. Chinese Journal of Aeronautics, 2017. 30(1): p. 135-148.
17. Cetinsoy, E., et al., Design and construction of a novel quad tilt-wing UAV. Mechatronics, 2012. 22(6): p. 723-745.
18. Ro, K., J. Kamman, and J. Barlow, Flight Perfornance Analysis of Freewing Tilt-Body Unmanned Aerial Vehicle, in AIAA Atmospheric Flight Mechanics Conference and Exhibit. 2012.
19. Indriyanto, T. and Y.I. Jenie. Modeling and simulation of a ducted fan unmanned aerial vehicle (uav) using x-plane simulation software. in Regional Conference on Mechanical and Aerospace Technology, Bali. 2010.
20. Nonami, K., et al., Autonomous Flying Robots: Unmanned Aerial Vehicles and Micro Aerial Vehicles. 2010: Springer Japan.
21. Kamal, M.V., et al., Drone/UAV Design Development is Important in a Wide Range of Applications, in Drone Technology. 2023. p. 53-67.
22. Gholami, A., Analyzing Fixed-Wing Drone Design and Evaluating Financial Viability in Unmanned Aerial Vehicle, Journal of Multidisciplinary Engineering Science Studies (JMESS), 2023, 9(9): p. 5186-5193.
23. Tiwari, M., et al., Contemporary Research in Electronics, Computing and Mechanical Sciences. 2020.
24. Francesco, R., et al. Design in nature and engineering: knowledge transfer trough a data-base of biological solutions. in Proceedings of TMCE 2010 Symposium. 2010. Delft Univ technology.
25. Stefanovic, V., M. Marjanovic, and M. Bajovic. Conceptual system designs civil UAV for typical aerial work applications. in Proceedings of the 5th International Scientific Conference on Defensive Technologies, Belgrade, Serbia. 2012.
26. DARPA looking for VTOL UAV to plant covert spy devices. 2010 [cited 2024 4 April 2024]; Available from: https://www.homelandsecuritynewswire.com/darpa-looking-vtol-uav-plant-covert-spy-devices.
27. Naval-technology. Bell Eagle Eye Tiltrotor UAV. 2010 [cited 2024 4 April 2024]; Available from: https://www.naval-technology.com/projects/belleagleeyeuav/.
28. Austin, R., Unmanned aircraft systems: UAVS design, development and deployment. 2011: John Wiley & Sons.
29. Bell Boeing V-22 Osprey. 2023 [cited 2023 4 November 2023]; Available from: https://en.wikipedia.org/wiki/Bell_Boeing_V-22_Osprey.
30. Salazar, R.D., M. Hassanalian, and A. Abdelkefi. Defining a conceptual design for a tilt-rotor micro air vehicle for a well-defined mission. in 55th AIAA Aerospace Sciences Meeting. 2017.

31. Ro, K., et al., Flight testing of a free-wing tilt-body aircraft, in AIAA Infotech@ Aerospace 2010. 2010. p. 3449.
32. Porter, R.F., et al., Analytical Study of a Free-wing/free-trimmer Concept. 1978.
33. Ko, A., O. Ohanian, and P. Gelhausen, Ducted Fan UAV Modeling and Simulation in Preliminary Design, in AIAA Modeling and Simulation Technologies Conference and Exhibit. 2012.
34. Romero, H., R. Benosman, and R. Lozano. Stabilization and location of a four rotor helicopter applying vision. in 2006 American Control Conference. 2006.
35. AirJelly. 2023 [cited 2023 4 NOvember 2023]; Available from: https://www.festo.com/us/en/e/about-festo/research-and-development/bionic-learning-network/highlights-from-2006-to-2009/airjelly-id_33841/.
36. Alpha Unmanned Systems, SL Takes Off in Israel. 2015 [cited 2024 4 April 2024]; Available from: https://www.asiapacificsecuritymagazine.com/alpha-unmanned-systems-sl-takes-off-in-israel/.
37. Muraoka, K., N. Okada, and D. Kubo, Quad Tilt Wing VTOL UAV: Aerodynamic Characteristics and Prototype Flight, in AIAA Infotech@Aerospace Conference. 2009, American Institute of Aeronautics and Astronautics.
38. Chronister, N., The Ornithopter Design Manual. Published by the Ornithopter Zone, 2008.
39. SmartBird. 2023 [cited 2023 15 November 2023]; Available from: https://www.festo.com/us/en/e/about-festo/research-and-development/bionic-learning-network/highlights-from-2010-to-2012/smartbird-id_33686/.
40. van Holten, T., M. Heiligers, and G.-J. van de Waal. The Ornicopter: a single rotor without reaction torque, basic principles. in 24th international congress of the aeronautical sciences. 2004.
41. Mueller, T.J., Fixed and flapping wing aerodynamics for micro air vehicle applications. 2001: AIAA.
42. Hassanalian, M., et al., A novel methodology for wing sizing of bio-inspired flapping wing micro air vehicles: theory and prototype. Acta Mechanica, 2017. 228(3): p. 1097-1113.
43. Hassanalian, M., H. Khaki, and M. Khosravi, A new method for design of fixed wing micro air vehicle. Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 2014. 229(5): p. 837-850.
44. Mohamed, A., et al., Development and Flight Testing of a Turbulence Mitigation System for Micro Air Vehicles. Journal of Field Robotics, 2016. 33(5): p. 639-660.
45. Hassanalian, M. and A. Abdelkefi, Design, manufacturing, and flight testing of a fixed wing micro air vehicle with Zimmerman planform. Meccanica, 2017. 52(6): p. 1265-1282.
46. Taylor, S.E., Biologically inspired wing planform optimization. 2009, Worcester Polytechnic Institute.
47. Zhang, F., et al. A Novel Micro Air Vehicle with Flexible Wing Integrated with On-board Electronic Devices. in 2008 IEEE Conference on Robotics, Automation and Mechatronics. 2008.
48. Quick, D. TechJect's Dragonfly micro UAV flies like a bird and hovers like an insect. 2012 [cited 2024 3 April 2024]; Available from: https://newatlas.com/techject-dragonfly-microuav/24900/.
49. Fenelon, M.A.A. and T. Furukawa, Design of an active flapping wing mechanism and a micro aerial vehicle using a rotary actuator. Mechanism and Machine Theory, 2010. 45(2): p. 137-146.
50. Shyy, W., et al., Aerodynamics of low Reynolds number flyers. 2008.
51. Shyy, W., et al., An Introduction to Flapping Wing Aerodynamics. Cambridge Aerospace Series. 2013, Cambridge: Cambridge University Press.
52. Viieru, D., et al. Flapping and flexible wing aerodynamics of low Reynolds number flight vehicles. in 44th AIAA Aerospace Sciences Meeting and Exhibit. 2006.
53. Orlowski, C.T. and A.R. Girard, Dynamics, stability, and control analyses of flapping wing micro-air vehicles. Progress in Aerospace Sciences, 2012. 51: p. 18-30.
54. Jones, K.D., et al., Bio-inspired design of flapping-wing micro air vehicles. The Aeronautical Journal, 2005. 109(1098): p. 385-393.
55. Joshi, P.M., Wing analysis of a flapping wing Unmanned aerial vehicle using CFD. Development, 2015. 2(5).
56. Schauwecker, K., et al. Markerless Visual Control of a Quad-Rotor Micro Aerial Vehicle by Means of On-Board Stereo Processing. 2012. Berlin, Heidelberg: Springer Berlin Heidelberg.
57. Charavgis, F., Monitoring and assessing concrete bridges with intelligent techniques. 2016.
58. Tafreshi, M., I. Shafieenejad, and A. Nikkhah, Open-loop and closed-loop optimal guidance policy for Samarai aerial vehicle with novel algorithm to Consider wind Effects. Int. J. Eng. Tech. Res.(IJETR), 2014. 2(12): p. 41-44.
59. Ubaya, H. and M. Iqbal, First person view on flying robot for real time monitoring. ICON-CSE, 2015. 1(1): p. 41-44.
60. Petricca, L., P. Ohlckers, and C. Grinde, Micro-and nano-air vehicles: State of the art. International journal of aerospace engineering, 2011. 2011.
61. Franceschini, M.R., D.W. Meyers, and K.P. Muldoon, Transponder-based beacon transmitter for see and avoid of unmanned aerial vehicles. 2011, Google Patents.
62. Micro Air Vehicle. 2024 [cited 2024 2 April 2024]; Available from: https://www.menzelphoto.com/image/I0000cEu3zYbZaBA.
63. Tech-Briefs. Wing-Flapping Aircraft Hovers and Flies. 2014 [cited 2024 2 April 2024]; Available from: https://www.techbriefs.com/component/content/

article/20422-wing-flapping-aircraft-hovers-and-flies.

64. Infodron. Midgets for the Polish army. 2014 [cited 2024 2 April 2024]; Available from: https://info.dron.pl/mikrusy-dla-polskiego-wojska/.
65. Wood, R.J., et al. Progress on “pico” air vehicles. in Robotics Research: The 15th International Symposium ISRR. 2017. Springer.
66. Tanaka, H., et al. Flight dynamics of a butterfly-type ornithopter. in 2005 IEEE/RSJ International Conference on Intelligent Robots and Systems. 2005. IEEE.
67. Shimoyama, I., et al., Insect-like microrobots with external skeletons. IEEE Control Systems Magazine, 1993. 13(1): p. 37-41.
68. Dickinson, M.H., F.-O. Lehmann, and S.P. Sane, Wing Rotation and the Aerodynamic Basis of Insect Flight. Science, 1999. 284(5422): p. 1954-1960.
69. Lim, H. Animal Photo Manipulation: 26 Photoshopped Robotic Animals. 2018 [cited 2024 4 April 2024]; Available from: https://www.hongkiat.com/blog/photo-manipulation-26-excellent-photoshopped-robotic-animals/.
70. Royofinnigan.blogspot. Was Drohnt denn da? 2014 [cited 2024 4 April 2024]; Available from: https://royofinnigan.blogspot.com/2014_05_01_archive.html.
71. Sun, L., S. Baek, and D. Pack, Distributed Probabilistic Search and Tracking of Agile Mobile Ground Targets Using a Network of Unmanned Aerial Vehicles, in Human Behavior Understanding in Networked Sensing: Theory and Applications of Networks of Sensors, P. Spagnolo, P.L. Mazzeo, and C. Distante, Editors. 2014, Springer International Publishing: Cham. p. 301-319.
72. Römer, K. Tracking Real-World Phenomena with Smart Dust. 2004. Berlin, Heidelberg: Springer Berlin Heidelberg.
73. Song, Y., Optical Communication Systems for Smart Dust. 2002, Virginia Tech.
74. Hsu, V., J.M. Kahn, and K.S. Pister, Wireless communications for smart dust. 1998: Electronics Research Laboratory, College of Engineering, University of ….
75. Kayvan. SMARTDUST. 2008 [cited 2024 2 April 2024]; Available from: https://kayvan-ibrahimovic.blogspot.com/.
76. Kupfer, P. Spies in the Skies / Researchers are developing tiny, airborne devices that can look and listen as they float. 2000 [cited 2024 2 April 2024]; Available from: https://www.sfgate.com/green/article/Spies-in-the-Skies-Researchers-are-developing-3302554.php.
77. Ibrahim, M.M.S., P. Shanmugaraja, and M.M.T. Vini, The Roles, Benefits and Design Challenges of Multi Versatile Unmanned Drones in Flying Ad-hoc Network. Contemporary Research in Electronics, Computing and Mechanical Sciences, 2018. 1.
78. Chen, S. Chinese scientists use solar energy to power control of bird brains. 2022 [cited 2023 4 October 2023]; Available from: https://www.scmp.com/news/china/science/article/3197162/chinese-scientists-use-solar-energy-power-control-bird-brains.
79. 4 Taxidermy Drones: Yes, That’s a Thing. 2015 2023]; 2 November 2023]. Available from: https://makezine.com/article/maker-news/4-taxidermy-drones-yes-thats-thing/.
80. Anderson, R.C., et al., Male response to an aggressive visual signal, the wing wave display, in swamp sparrows. Behavioral Ecology and Sociobiology, 2013. 67(4): p. 593-600.
81. Wood, R.J. Liftoff of a 60mg flapping-wing MAV. in 2007 IEEE/RSJ International Conference on Intelligent Robots and Systems. 2007. IEEE.
82. Santos, N.M.A.d., Software platform to control squads of unmanned vehicles in realtime. 2016.
83. Coxworth, B. Amphibious HexH2o drone shoots both aerial and underwater video. 2014 [cited 2023 2 November 2023]; Available from: https://newatlas.com/hexh20-amphibious-drone/35347/.
84. Siddall, R. and M. Kovač, Launching the AquaMAV: bioinspired design for aerial–aquatic robotic platforms. Bioinspiration & Biomimetics, 2014. 9(3): p. 031001.
85. Spendlove, T. B-Unstoppable, the Tank Drone Hybrid. 2015 [cited 2024 4 April 2024]; Available from: https://www.engineering.com/story/b-unstoppable-the-tank-drone-hybrid.
86. Daler, L., et al., A bioinspired multi-modal flying and walking robot. Bioinspiration & Biomimetics, 2015. 10(1): p. 016005.
87. Bachmann, R.J., et al., A biologically inspired micro-vehicle capable of aerial and terrestrial locomotion. Mechanism and Machine Theory, 2009. 44(3): p. 513-526.
88. Wired. Parrot Hydrofoil, il drone marino. 2016 [cited 2024 4 April 2024]; Available from: https://www.wired.it/gadget/outdoor/2016/07/12/parrot-hydrofoil-drone-marino/.
89. Techcentral. Rutgers’ drone at home in water and the sky. 2016 [cited 2024 4 April 2024]; Available from: https://www.techcentral.ie/rutgers-drone-home-water-sky/.
90. Coxworth, B. Amphibious HexH2o drone shoots both aerial and underwater video. 2014 [cited 2024 4 April 2024]; Available from: https://newatlas.com/hexh20-amphibious-drone/35347/.
91. Rheakumar. Launching the AquaMAV: bioinspired design for aerial–aquatic robotic platforms. 2020 [cited 2024 4 April 2024]; Available from: https://biodesign.berkeley.edu/2020/03/15/paper-launching-the-aquamav-bioinspired-design-for-aerial-aquatic-robotic-platforms/.
92. Rodríguez, R.M., et al. Autonomous management of an UAV Airfield. in proceedings of the 3rd international conference on application and theory

of automation in command and control systems, Naples, Italy. 2013.

93. Microdrones. 2023 [cited 2023 4 NOvember 2023]; Available from: https://www.microdrones.com/en/integrated-systems/.
94. Oruç, M.E., The possibilities of data usage obtained from UAV. Advanced UAV, 2022. 1(1): p. 15-23.
95. Kabadayı, A., Unmanned aerial vehicle usage in rough areas and photogrammetric data generation. Advanced UAV, 2022. 1(1): p. 8-14.
96. Zheng, Y.J., et al., Rescue Wings: Mobile Computing and Active Services Support for Disaster Rescue. IEEE Transactions on Services Computing, 2016. 9(4): p. 594-607.
97. Su, Z., et al., LVBS: Lightweight Vehicular Blockchain for Secure Data Sharing in Disaster Rescue. IEEE Transactions on Dependable and Secure Computing, 2022. 19(1): p. 19-32.
98. Wang, Y., et al. Lifesaving with RescueChain: Energy-Efficient and Partition-Tolerant Blockchain Based Secure Information Sharing for UAV-Aided Disaster Rescue. in IEEE INFOCOM 2021 - IEEE Conference on Computer Communications. 2021.
99. Bai, T., et al., Energy-Efficient Computation Offloading for Secure UAV-Edge-Computing Systems. IEEE Transactions on Vehicular Technology, 2019. 68(6): p. 6074-6087.
100. Messous, M.A., et al., A Game Theory Based Efficient Computation Offloading in an UAV Network. IEEE Transactions on Vehicular Technology, 2019. 68(5): p. 4964-4974.
101. 2021 Disasters in numbers. 2022 [cited 2023 20 October 2023]; Available from: https://reliefweb.int/report/world/2021-disasters-numbers.
102. Cred, U., Human Cost of Disasters. An Overview of the last 20 years: 2000–2019. CRED, UNDRR, Geneva, 2020.
103. Zhang, D., et al., Evaluation of a Sensor System for Detecting Humans Trapped under Rubble: A Pilot Study. Sensors, 2018. 18(3): p. 852.
104. Alsamhi, S.H., et al., UAV Computing-Assisted Search and Rescue Mission Framework for Disaster and Harsh Environment Mitigation. Drones, 2022. 6(7): p. 154.
105. Hanifa, N.R., et al., Unmanned Aerial Vehicles for geospatial mapping of damage assessment: A study case of the 2021 Mw 6.2 Mamuju-Majene, Indonesia, earthquake during the coronavirus disease 2019 (COVID-19) pandemic. Remote Sensing Applications: Society and Environment, 2022. 28: p. 100830.
106. AlAli, Z.T. and S.A. Alabady, A survey of disaster management and SAR operations using sensors and supporting techniques. International Journal of Disaster Risk Reduction, 2022. 82: p. 103295.
107. Amarasingam, N., et al., A review of UAV platforms, sensors, and applications for monitoring of sugarcane crops. Remote Sensing Applications: Society and Environment, 2022. 26: p. 100712.
108. Nyamekye, C., et al., Examining the performances of true color RGB bands from Landsat-8, Sentinel-2 and UAV as stand-alone data for mapping artisanal and Small-Scale Mining (ASM). Remote Sensing Applications: Society and Environment, 2021. 24: p. 100655.
109. Smith, M. Pars is a Search and Rescue Drone Capable of Saving Lives. 2014 [cited 2024 4 April 2024]; Available from: https://www.industrytap.com/pars-search-rescue-drone-capable-saving-lives/23729.
110. Szczerba, R.J. The Future of HealthTech - Ambulance Drones. 2014 [cited 2024 4 April 2024]; Available from: https://www.forbes.com/sites/robertszczerba/2014/12/14/ambulance-drone/.
111. Mohsan, S.A.H., et al., Towards the Unmanned Aerial Vehicles (UAVs): A Comprehensive Review. Drones, 2022. 6(6): p. 147.
112. Acuna, V., et al. Localization of WiFi Devices Using Probe Requests Captured at Unmanned Aerial Vehicles. in 2017 IEEE Wireless Communications and Networking Conference (WCNC). 2017.
113. Aicardi, I., et al., An Image-Based Approach for the Co-Registration of Multi-Temporal UAV Image Datasets. Remote Sensing, 2016. 8(9): p. 779.
114. Gomez, R., Vulnerability and Information Practices among (Undocumented) Latino Migrants. THE ELECTRONIC JOURNAL OF INFORMATION SYSTEMS IN DEVELOPING COUNTRIES, 2016. 75(1): p. 1-43.
115. Jordan, K., The disaster survivor’s hierarchy of needs: what every disaster mental health worker should know. American Counseling Association: Alexandria, VA, USA, 2015. 7.
116. Soesilo, D., et al., Drones in Humanitarian Action: A guide to the use of airborne systems in humanitarian crises. FSD Report, 2016: p. 1-60.
117. Waharte, S. and N. Trigoni. Supporting Search and Rescue Operations with UAVs. in 2010 International Conference on Emerging Security Technologies. 2010.
118. Darvishpoor, S., et al., Configurations, flight mechanisms, and applications of unmanned aerial systems: A review. Progress in Aerospace Sciences, 2020. 121: p. 100694.
119. Alotaibi, E.T., S.S. Alqefari, and A. Koubaa, LSAR: Multi-UAV Collaboration for Search and Rescue Missions. IEEE Access, 2019. 7: p. 55817-55832.
120. Erdos, D., A. Erdos, and S.E. Watkins, An experimental UAV system for search and rescue challenge. IEEE Aerospace and Electronic Systems Magazine, 2013. 28(5): p. 32-37.
121. Goodrich, M.A., et al., Supporting wilderness search and rescue using a camera-equipped mini UAV. Journal of Field Robotics, 2008. 25(1-2): p. 89-110.
122. Tomic, T., et al., Toward a Fully Autonomous UAV: Research Platform for Indoor and Outdoor Urban Search and Rescue. IEEE Robotics & Automation Magazine, 2012. 19(3): p. 46-56.
123. Scherer, J., et al., An Autonomous Multi-UAV System for Search and Rescue, in Proceedings of the First

Workshop on Micro Aerial Vehicle Networks, Systems, and Applications for Civilian Use. 2015, Association for Computing Machinery: Florence, Italy. p. 33–38.

124. Bakari, M.J., K.M. Zied, and D.W. Seward, Development of a Multi-Arm Mobile Robot for Nuclear Decommissioning Tasks. International Journal of Advanced Robotic Systems, 2007. 4(4): p. 51.
125. Keys, A.S., et al., High-Performance, Radiation-Hardened Electronics for Space and Lunar Environments. AIP Conference Proceedings, 2008. 969(1): p. 749-756.
126. Zinkle, S.J. and G.S. Was, Materials challenges in nuclear energy. Acta Materialia, 2013. 61(3): p. 735-758.
127. Weber, W.J., et al., Radiation effects on materials in high-radiation environments: A workshop summary. Journal of Nuclear Materials, 1991. 184(1): p. 1-21.
128. Velazco, R., P. Fouillat, and R. Reis, Radiation Effects on Embedded Systems. 2007: Springer Netherlands.
129. Gallagher, K. The Sky's the Limit with Drone-assisted Mapping. 2016 [cited 2023 20 October 2023]; Available from: https://www.simulyze.com/blog/drone-assisted-mapping-applications.
130. Restas, A., Drone Applications for Supporting Disaster Management. World Journal of Engineering and Technology, 2015. Vol.03No.03: p. 6.
131. Oliveira-da-Costa, M., et al., Effectiveness of unmanned aerial vehicles to detect Amazon dolphins. Oryx, 2020. 54(5): p. 696-698.
132. Colefax, A.P., et al., Reliability of marine faunal detections in drone-based monitoring. Ocean & Coastal Management, 2019. 174: p. 108-115.
133. van Gemert, J.C., et al. Nature Conservation Drones for Automatic Localization and Counting of Animals. 2015. Cham: Springer International Publishing.
134. van Andel, A.C., et al., Locating chimpanzee nests and identifying fruiting trees with an unmanned aerial vehicle. American Journal of Primatology, 2015. 77(10): p. 1122-1134.
135. Pirotta, V., et al., An economical custom-built drone for assessing whale health. Frontiers in Marine Science, 2017: p. 425.
136. Hartman, K., P. Van der Harst, and R. Vilela, Continuous focal group follows operated by a drone enable analysis of the relation between sociality and position in a group of male Risso's dolphins (Grampus griseus). Frontiers in Marine Science, 2020. 7: p. 283.
137. Radoglou-Grammatikis, P., et al., A compilation of UAV applications for precision agriculture. Computer Networks, 2020. 172: p. 107148.
138. Escobar-Flores, J.G. and S. Sandoval, Unmanned aerial vehicle (UAV) for sea turtle skeleton detection in the Mexican Pacific. Remote Sensing Applications: Society and Environment, 2021. 22: p. 100501.
139. Zhao, N., et al., Antenna and Propagation Considerations for Amateur UAV Monitoring. IEEE Access, 2018. 6: p. 28001-28007.
140. Wang, Z., et al., Study on Extraction of Landslide Information Based on UAV Survey. IOP Conference Series: Earth and Environmental Science, 2021. 658(1): p. 012042.
141. MakİNecİ, H.B. and K. Erdal, Adaptation analysis of produced 3D models from UAV-SLAM and UAV-TLS data combinations. Mersin Photogrammetry Journal, 2023. 5(1): p. 18-23.
142. SİLwal, A., S. Tamang, and R. AdhİKarİ, Use of unmanned aerial vehicle (UAV) for mapping, and accuracy assessment of the orthophoto with and without using GCPs: A case study in Nepal. Mersin Photogrammetry Journal, 2022. 4(2): p. 45-52.
143. Nazar, M., et al., 3D positioning accuracy and land cover classification performance of multispectral RTK UAVs. International Journal of Engineering and Geosciences, 2023. 8(2): p. 119-128.
144. Kaplan, G., E. Senkal, and U. Avdan, Accuracy assessment of digital surface models from unmanned aerial vehicles' imagery on archaeological sites. International Journal of Engineering and Geosciences, 2021. 6(2): p. 81-89.
145. Nex, F. and F. Remondino, UAV for 3D mapping applications: a review. Applied Geomatics, 2014. 6(1): p. 1-15.
146. SKYCRUISER A22. 2023 [cited 2023 15 October 2023]; Available from: https://southinstrument.com/product/details/pro_tid/1/id/156.html.
147. Supercam S100. 2023 [cited 2023 15 October 2023]; Available from: https://geo-matching.com/products/supercam-s100.
148. CIES 2.2 SOLAR POWERED. 2023 [cited 2023 20 October 2023]; Available from: https://geo-matching.com/products/cies-2-2-solar-powered.
149. Mirzaeinia, A. and M. Hassanalian, Minimum-Cost Drone–Nest Matching through the Kuhn–Munkres Algorithm in Smart Cities: Energy Management and Efficiency Enhancement. Aerospace, 2019. 6(11): p. 125.
150. Satlab SLA-1. 2023 [cited 2023 20 October 2023]; Available from: https://gpsnavstar.com/satlab-sla-1/.
151. Topcon releases new UAS for aerial mapping. 2023 2023]; 1 November 2023]. Available from: https://www.topconpositioning.com/insights/topcon-releases-new-uas-aerial-mapping.
152. Aeromapper Talon. 2023 [cited 2023 4 November 2023]; Available from: https://aeromao.com/products/aeromapper-talon/.
153. SKYSHOT HELIKITE AEROSTATS. 2023 [cited 2023 2 November 2023]; Available from: https://www.helikites.com/skyshot-tethered-aerostats.
154. Murison, M. Safer, Quieter and Less Ominous: Could Spacial's Halo Rival Quads? 2017 [cited 2023 1 November 2023]; Available from: https://dronelife.com/2017/05/08/spacial-halo-drone/.
155. Italdron. 2023 [cited 2023 1 November 2023]; Available from:

https://www.italdron.com/professionals-drones-and-accessories/professionals-drones/bigone-8hse-pro.

156. Asctec Falcon 8. 2023 [cited 2023 2 November 2023]; Available from: https://aerial-robotix.com/asctec-falcon-8/.
157. UAV IT180-120 / UNMANNED AERIAL VEHICLE. 2023 [cited 2023 1 November 2023]; Available from: https://www.ecagroup.com/en/solutions/uav-it180-120-unmanned-aerial-vehicle.
158. Applied Airborne - X-Mapper PPK (GNSS PPK). 2023 [cited 2023 4 November 2023]; Available from: https://geo-matching.com/products/x-mapper-ppk-gnss-ppk.
159. Metavista Breaks Guinness World Record of Multi Rotor UAV Flight Time Using Intelligent Energy Fuel Cell Power Module. 2019 [cited 2023 1 November 2023]; Available from: https://dronemajor.net/editorials/metavista-breaks-guinness-world-record-of-multi-rotor-uav-flight-time-using-intelligent-energy-fuel-cell-power-module.
160. Yang, X., et al., Survey on the novel hybrid aquatic–aerial amphibious aircraft: Aquatic unmanned aerial vehicle (AquaUAV). Progress in Aerospace Sciences, 2015. 74: p. 131-151.
161. Guo, Z., T. Li, and M. Wang. A Survey on Amphibious Robots. in 2018 37th Chinese Control Conference (CCC). 2018.
162. UVS. 2023 [cited 2023 1 November 2023]; Available from: http://www.uvssys.com/en/product.php?cid=23#tk.
163. DRS RQ-15 Neptune. 2023 [cited 2023 2 November 2023]; Available from: https://www.unols.org/sites/default/files/Neptune%20UAV.pdf.
164. Asadzadeh, S., W.J.d. Oliveira, and C.R.d. Souza Filho, UAV-based remote sensing for the petroleum industry and environmental monitoring: State-of-the-art and perspectives. Journal of Petroleum Science and Engineering, 2022. 208: p. 109633.
165. Jiménez López, J. and M. Mulero-Pázmány Drones for Conservation in Protected Areas: Present and Future. Drones, 2019. 3, DOI: 10.3390/drones3010010.
166. Margaritoff, M. Floating Waterproof Drone Makes a Kickstarter Splash. 2017 [cited 2024 4 April 2024]; Available from: https://www.thedrive.com/article/10924/floating-waterproof-drone-makes-a-kickstarter-splash.
167. Joshi, N. 4 Ways Underwater Drones Enhance Safety And Efficiency In The Energy And Utilities Sector. 2023 [cited 2024 4 April 2024]; Available from: https://www.allerin.com/blog/4-ways-underwater-drones-enhance-safety-and-efficiency-in-the-energy-and-utilities-sector.
168. Kickstarter. BIKI: First Bionic Wireless Underwater Fish Drone. 2018 [cited 2024 4 April 2024]; Available from: https://www.kickstarter.com/projects/1114649432/biki-first-bionic-wireless-underwater-fish-drone/faqs?lang=fr.
169. Stone, Z. These Six Luxury Underwater Drones Are Disrupting Fishing and Fun. 2017 [cited 2024 4 April 2024]; Available from: https://www.forbes.com/sites/zarastone/2017/06/15/these-six-luxury-underwater-drones-are-disrupting-fishing-and-fun/?sh=34b8d75d9789.
170. Tauro, F., M. Porfiri, and S. Grimaldi, Surface flow measurements from drones. Journal of Hydrology, 2016. 540: p. 240-245.
171. Meng, L., T. Hirayama, and S. Oyanagi, Underwater-Drone With Panoramic Camera for Automatic Fish Recognition Based on Deep Learning. IEEE Access, 2018. 6: p. 17880-17886.
172. Spears, A., et al. Design and development of an under-ice autonomous underwater vehicle for use in Polar regions. in 2014 Oceans - St. John's. 2014.
173. Weisler, W., et al., Testing and Characterization of a Fixed Wing Cross-Domain Unmanned Vehicle Operating in Aerial and Underwater Environments. IEEE Journal of Oceanic Engineering, 2018. 43(4): p. 969-982.
174. Esakki, B., et al., Design of Amphibious Vehicle for Unmanned Mission in Water Quality Monitoring Using Internet of Things. Sensors, 2018. 18(10): p. 3318.
175. Gao, A. and A.H. Techet. Design considerations for a robotic flying fish. in OCEANS'11 MTS/IEEE KONA. 2011.
176. Cherney, J.H., et al., Split Application of Nitrogen vs. Dairy Manure on Temperate Perennial Grasses. Forage & Grazinglands, 2010. 8(1): p. 1-13.
177. Lee, J. and S. Kwon, A Basic Study on the Selection of Required Operational Capability for Attack Drones of Army TIGER Units Using AHP Technique. J. KIMS Technol, 2023. 26(2): p. 197-204.
178. Rauch, M.S., Drones in Military Warfare: The moral and emotional implications of an emerging technology. Academy of Management Proceedings, 2021. 2021(1): p. 10599.
179. Ralston, S. DRNE: Drone Aviation Is Well-Positioned In The Tethered Aerostat Industry. 2014 [cited 2023 1 November 2023]; Available from: https://scr.zacks.com/news/news-details/2014/DRNE-Drone-Aviation-is-Well-Positioned-in-the-Tethered-Aerostat-Industry/default.aspx.
180. Imumbhon, J.O., M.D. Alam, and Y. Cao, Design and Structural Analyses of a Reciprocating S1223 High-Lift Wing for an RA-Driven VTOL UAV. Aerospace, 2021. 8(8): p. 214.
181. Excell, J. Insect inspiration: UK defence drone mimics dragonfly flight. 2016 [cited 2023 4 November 2023]; Available from: https://www.theengineer.co.uk/content/in-depth/insect-inspiration-uk-defence-drone-mimics-dragonfly-flight.
182. Hassanalian, M., et al., Performance analysis of fixed wing space drones in different solar system bodies. Acta Astronautica, 2018. 152: p. 27-48.

183. NASA Langley Plane Chosen as Mars Candidate. 2002 [cited 2023 20 October 2023]; Available from: https://mars.nasa.gov/news/446/nasa-langley-plane-chosen-as-mars-candidate/.
184. NASA's Ingenuity Mars Helicopter Succeeds in Historic First Flight. 2021 [cited 2023 26 October 2023]; Available from: https://mars.nasa.gov/news/8923/nasas-ingenuity-mars-helicopter-succeeds-in-historic-first-flight/.
185. Menges, P.A. Artificial Neural Membrane Flapping Wing NIAC Phase I Study Final Report. 2006.
186. Sjogren, W.L., et al., Mars gravity field based on a short-arc technique. Journal of Geophysical Research (1896-1977), 1975. 80(20): p. 2899-2908.
187. Mars Helicopter to Fly on NASA's Next Red Planet Rover Mission. 2018 [cited 2023 25 October 2023]; Available from: https://www.nasa.gov/news-release/mars-helicopter-to-fly-on-nasas-next-red-planet-rover-mission/.
188. NASA's Dragonfly Will Fly Around Titan Looking for Origins, Signs of Life. 2019 [cited 2023 30 October 2023]; Available from: https://www.nasa.gov/news-release/nasas-dragonfly-will-fly-around-titan-looking-for-origins-signs-of-life/.
189. NASA Selects Flying Mission to Study Titan for Origins, Signs of Life. 2019 [cited 2023 24 October 2023]; Available from: https://solarsystem.nasa.gov/news/986/nasa-selects-flying-mission-to-study-titan-for-origins-signs-of-life/.
190. Young, L.A., et al. Rotary-wing decelerators for probe descent through the atmosphere of venus. 2004.
191. NASA's Mars Helicopter Testing Enters Final Phase. 2019 [cited 2023 30 October 2023]; Available from: https://www.nasa.gov/missions/mars-2020-perseverance/ingenuity-helicopter/nasas-mars-helicopter-testing-enters-final-phase/.
192. Landis, G.A., Robotic exploration of the surface and atmosphere of Venus. Acta Astronautica, 2006. 59(7): p. 570-579.
193. Landis, G.A., A. Colozza, and C.M. LaMarre, Atmospheric Flight on Venus: A Conceptual Design. Journal of Spacecraft and Rockets, 2003. 40(5): p. 672-677.
194. Xiongfeng, Z., G. Zheng, and H. Zhongxi, Sun-Seeking Eternal Flight Solar-Powered Airplane for Venus Exploration. Journal of Aerospace Engineering, 2015. 28(5): p. 04014127.
195. Pekar, N.J. Could This Become the First Mars Airplane? 2015 [cited 2023 29 October 2023]; Available from: https://www.nasa.gov/aeronautics/could-this-become-the-first-mars-airplane/.
196. Pellerito, V., M. Olivas, and M. Hassanalian, Design a Fixed-Wing Unmanned Aerial Vehicle with Dynamic Soaring Capability for Titan Exploration, in AIAA Scitech 2020 Forum.
197. Pergola, P. and V. Cipolla, Mission architecture for Mars exploration based on small satellites and planetary drones. International Journal of Intelligent Unmanned Systems, 2016. 4.
198. Collins, N.S., System design and nonlinear state-dependent Riccati equation control of an autonomous Y-4 tilt-rotor aerobot for Martian exploration, C.I. Underwood and S. University of, Editors. 2016.
199. Aguirre, J., et al. Mars Intelligent Reconnaissance Aerial and Ground Explorer (MIRAGE). 2007.
200. Hassanalian, M., D. Rice, and A. Abdelkefi, Evolution of space drones for planetary exploration: A review. Progress in Aerospace Sciences, 2018. 97: p. 61-105.
201. Scientific Balloons. 2023 [cited 2023 1 November 2023]; Available from: https://www.nasa.gov/scientificballoons/.
202. MARS BALLOONS. 2023 [cited 2023 2 November 2023]; Available from: https://www.gaerospace.com/space-exploration/planetary-aerobots/mars-balloons/.
203. Zegers, T.E., et al., ExoFly: a flapping wing aerobot for planetary survey and exploration. 2008.
204. Egan, P. MLABs Bat Wing UAV Ornithopter Unveiled for Mission to Mars. 2013 [cited 2023 3 November 2023]; Available from: https://www.suasnews.com/2013/07/mlabs-bat-wing-uav-ornithopter-unveiled-for-mission-to-mars/.
205. Griffin, M.D., Space vehicle design. 2004: AIAA.
206. Soler, M., Fundamentals of Aerospace Engineering: An introductory course to aeronautical engineering. 2014: Manuel Soler.
207. Pope, D.K. Two delivery drones built by Google will soon be tested in the US. 2015 [cited 2023 2 November 2023]; Available from: https://www.techspot.com/news/62412-two-delivery-drones-built-google-soon-tested-us.html.
208. Fingas, R. Amazon teases new details of planned Prime Air drone delivery service. 2015 [cited 2023 1 November 2023]; Available from: https://appleinsider.com/articles/15/11/30/amazon-teases-new-details-of-planned-prime-air-drone-delivery-service.
209. DRONES. 2023 [cited 2023 1 November 2023]; Available from: https://www.dhl.com/global-en/home/insights-and-innovation/thought-leadership/trend-reports/drones-logistics.html.
210. Howell, C.T.I., et al. The First Government Sanctioned Delivery of Medical Supplies by Remotely Controlled Unmanned Aerial System (UAS). 2016 [cited 2023 30 October 2023]; Available from: https://ntrs.nasa.gov/citations/20160009120.
211. UAV. 2023 [cited 2023 30 October 2023]; Available from: https://www.uav.org/zipline-begins-drone-delivery-of-covid-19-tests-in-ghana-is/.
212. Drones will be used to transport medical supplies across the Solent to support the response to COVID-19. 2020 [cited 2023 30 October 2023]; Available from: https://www.solent-transport.com/?s=drone.
213. LIN, J. and P.W. SINGER. Meet China's growing fleet of automated delivery drones. 2018 [cited 2023 2

November 2023]; Available from: https://www.popsci.com/china-drone-deliveries/.

214. Brett, D. SF Express expects to have 1,000 VTOL cargo drones by 2031. 2021 [cited 2023 28 October 2023]; Available from: https://www.aircargonews.net/airlines/sf-express-expects-to-have-1000-vtol-cargo-drones-by-2031/.

215. Maksel, R. Delivery by Drone. 2015 [cited 2023 28 October 2023]; Available from: https://www.smithsonianmag.com/air-space-magazine/delivery-by-drone-180955988/.

216. Straight, B. Flirtey firing up production, taking preorders for delivery drone. 2021 [cited 2023 4 November 2023]; Available from: https://www.freightwaves.com/news/flirtey-firing-up-production-taking-preorders-for-delivery-drone.

217. Boukoberine, M.N., Z. Zhou, and M. Benbouzid, A critical review on unmanned aerial vehicles power supply and energy management: Solutions, strategies, and prospects. Applied Energy, 2019. 255: p. 113823.

218. Drone Delivery Applications. 2023 [cited 2023 28 October 2023]; Available from: https://dronedeliverycanada.com/applications/.

219. Industrial Drone with Maximum Payload 35kg, Maximum Altitude 2,800m, Cruising Range of 90km Yamaha Motor: FAZER R G2 Automated Navigation Unmanned Helicopter Showcased at the October "Japan International Aerospace Exhibition 2016". 2016 [cited 2023 29 October 2023]; Available from: https://global.yamaha-motor.com/news/2016/1011/fazer_r_g2.html.

220. Transforming the way goods are transported. 2023 [cited 2023 28 October 2023]; Available from: https://x.company/projects/wing/.

221. Wingcopter. 2023 [cited 2023 30 October 2023]; Available from: https://wingcopter.com/.

222. Drone Delivery Technology. 2023 [cited 2023 2 November 2023]; Available from: https://dronedeliverycanada.com/technology/.

223. Villi, O., & Yakar, M. (2022). İnsansız Hava Araçlarının Kullanım Alanları ve Sensör Tipleri. Türkiye İnsansız Hava Araçları Dergisi, 4(2), 73-100.

224. Donmez, C., Villi, O., Berberoglu, S., & Cilek, A. (2021). Computer vision-based citrus tree detection in a cultivated environment using UAV imagery. Computers and Electronics in Agriculture, 187, 106273.

225. Yakar, M., Ulvi, A., Fidan, Ş., Karabacak, A., Villi, O., Yiğit, A. Y., ... & Hamal, S. N. G. (2023). İnsansız Hava Aracı Teknolojisi ve Operatörlüğü Eğitim Kitabı. Mersin Üniversitesi Harita Mühendisliği Kitapları.

226. Yakar, M., & Villi, O. (2023). İnsansız hava aracı uygulama alanları. Mersin Üniversitesi Harita Mühendisliği Kitapları.

227. Villi, O., & Yakar, M. (2024). İnsansız Hava Araçlarının Segmentasyon Çalışmalarında Kullanımı. Türkiye İnsansız Hava Araçları Dergisi, 6(1), 30-41.

228. Villi, O., & Yakar, M. (2023). İnsansız Hava Araçları ve Coğrafi Bilgi Sistemleri Uygulamaları. Türkiye Coğrafi Bilgi Sistemleri Dergisi, 5(1), 20-33.

229. Villi, O., Villi, Ö., & Yakar, M. (2023). 3 Boyutlu Yazıcıların İnsansız Hava Aracı Uygulamalarında Kullanımı. Türkiye İnsansız Hava Araçları Dergisi, 5(2), 81-97.