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Advancements of Unmanned Aerial Vehicle Technology in the Realm of Applied Sciences and Engineering: A Review

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ABSTRACT

Due to their versatility, which is a result of technological advancements, and their capacity to carry out various civilian tasks safely and effectively, unmanned aerial vehicles (UAVs) have revolutionized applied sciences and engineering. However, UAV technological advancements in applied sciences and engineering have not been fully leveraged. This paper highlights UAV technology in the realm of applied sciences and engineering. The review covers the historical advancement, classification, benefits, and drawbacks of UAV technology applied to science and engineering. The paper begins with a summary of the advancements, then moves on to a recent historical development and an explanation of the UAV categorization criteria. The review then discusses UAV technology's advantages and drawbacks in applied science and engineering. After WWII, UAVs became increasingly versatile and advanced. Their categories follow numerous criteria. UAVs have numerous applications in applied science and engineering. Regulations stimulate UAV innovation and applications while altering them. The paper concludes by offering a comprehensive overview of UAV technology and its uses in applied sciences and engineering. Future UAV applications are likely to be much more creative and significant as the technology develops and advances.

1. Introduction

The technology of unmanned aerial vehicles (UAVs) has advanced quickly in recent years, solidifying its place as a fundamental component of applied sciences and engineering. Aerial robots, or drones, which are also known as UAVs, are becoming more popular and adaptable due to the remote control stations or autonomous capabilities that direct their flying missions. UAVs were originally created for military use, but because of their improved stability and endurance, they have come to have substantial utility in scientific and commercial applications.

Due to their improved stability and endurance in different operations, UAVs have become an accessible instrument for data collection, benefiting a variety of stakeholders and actors, including governmental agencies, commercial operators, scientific organizations, and people [1]. They allow

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mapping at temporal and spatial scales that were previously impossible with conventional remote sensing platforms [2,3]. There are many civil domains covered by the wide range of applications, including high-resolution surface reconstruction, object detection and tracking, documentation of cultural heritage, agriculture, environmental monitoring, disaster management, delivery of services, wildlife observation, and search and rescue operations [3-12].

UAV flight missions provide considerable operational flexibility in terms of cost, location, platforms, time, and repeatability when compared to satellite-based operations and conventional manned photogrammetric surveys [3]. Due to their versatility, UAVs can potentially replace some measures currently taken by satellites, manned aircraft, or ground-based surveying, making them a valuable supplement to established remote sensing platforms.

Shakhatreh *et al.,* [13] concentrated on categorizing UAVs according to their communication platforms. Norasma *et al.,* [7] review of UAV use in agricultural applications was constrained. Mohamad *et al.,* [14] examine the potential uses for integrating UAVs in smart cities, their effects, and the technical and non-technical challenges that surround such integration. A summary of current advancements in the use of UAVs in the three main transportation fields is presented in Outay *et al.,* [15]. According to their operations, Jyoti and Batth [12] present a mirror assessment of UAV categorization. The primary VTOL technologies and the corresponding aircraft layouts are highlighted in Zhou *et al.,* [16] review. Alladi *et al.,* [17] provided a comprehensive overview of UAV technology, including classifications based on several criteria and operational rules. A review of the design, development, and deployment of UAVs was presented by Bange *et al.,* [2]. Zhang *et al.,* [18] thoroughly examine the development and use of UAVs in Chinese agriculture while describing their technological and payload capabilities, benefits, and drawbacks. A review of recent literature is presented by Ajith and Jolly [19] begins with an overview of the UAV and its various types, parts, advancements, and possible uses. An overview of the use of UAVs to evaluate air quality was presented by Lambey and Prasad [20]. The architecture, categorization, and applications of UAV systems are briefly described in Alghamdi *et al.,* [21]. In terms of application status, application areas, proposed models, and drone characteristics, Gohari *et al.,* [22] give a systematic review of the use of surveillance drones in smart cities. Shakhatreh *et al.,* [13] explain UAV civil applications and their difficulties, talk about existing research trends, and give prospective UAV users future insights. A review of how airspace regulations affect UAVs operating in the last mile was done by Elsayed and Mohamed [23]. The economic potential and technological limitations for the application of intelligent UAV technology (IUAVT) in many fields are taken into consideration by Mukhamediev *et al.,* [4] in their review. Sabino *et al.,* [24] did a systematic review to determine how the general public felt about drones and to evaluate the key influencing elements. In his review, Henderson [25] looks at the aviation safety regulatory framework for unmanned aircraft from the viewpoint of the users of unmanned aircraft, with a focus on New Zealand. In his writing, Fox [26] mixes socio-legal, law/policy, and strategic approaches that take into account the development of technology that hovers over society and usually has a connection to conflict. A systematic review employing multiple comparisons was carried out by Lee *et al.,* [27], with additional comparisons taken from rules for similar cyber-physical systems. A thorough overview of UAVs, swarms, types, classification, charging, and standardization was presented by Mohsan *et al.,* [3].

There is still a lot of potential for research, despite the fact that a few scholars have released review papers on UAV applications in applied science and engineering technology. Aspects like UAV classification based on communication platforms or their applicability in certain fields like agriculture, smart cities, transportation, and air quality measurement have been the topic of previous review studies. However, up to now, far too little attention has been paid to the evolution of UAV technology, its categorizations, its current applications and limitations in the field of applied science and engineering.

2. Historical Development of UAV

Airborne cameras have produced amazing photographs of our planet for hundreds of years, and visionaries are still revolutionizing how we see the environment. There are several techniques to acquire airborne images nowadays, but this was not always the case. We have come to this point in time thanks to a lengthy history of innovation. UAVs have been around for considerably longer than most people realize, as stated by claim Keane and Carr [28]. In 2006, Arjomandi *et al.,* [29] made the observation that balloons are likely the earliest platforms for aerial observation. In actuality, a Frenchman by the name of "Nadar" managed to successfully take aerial shots of Paris from a hot-air balloon 262 feet above the ground in 1858. Later, when camera technology became more accessible, different methods for aerial photography, including kites (1882) and rockets (1897), were employed. According to Colomina and Molina [30], one of the most intriguing early studies was mounting tiny cameras on the breasts of pigeons from the Bavarian Pigeon Corps in 1903. Figure 1 shows the original platforms.

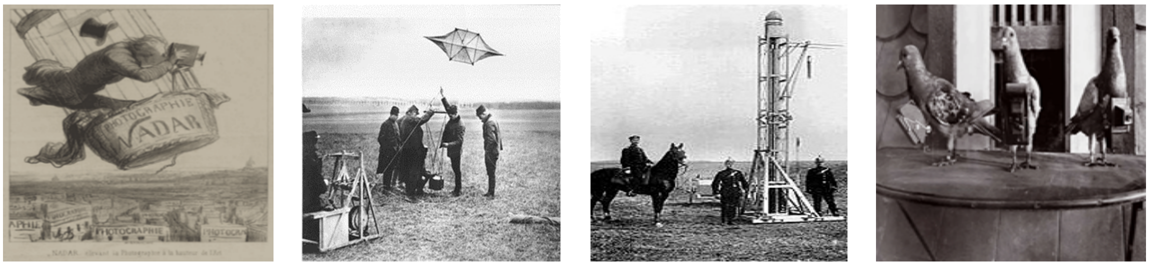

(a) (b) (c) (d)

Fig. 1. (a) Balloon, (b) Kite, (c) Rocket, (d) Pigeon

UAVs date back to the middle of the 19th century, when hot air balloons were employed for military reconnaissance. Both the Navy and the Army tested airborne torpedoes and flying bombs during World War I (WWI). The 20th century saw a rapid development of the idea of UAVs. The US Army created the first UAV, known as the Kettering Bug, in 1916, but it was never successful in actual battle and was subsequently abandoned. UAVs, such as target drones, unmanned reconnaissance aircraft, and multi-purpose drones, have undergone a number of development phases since the world's first UAV was created in the UK in 1917 according to Fan *et al.,* [31]. The earliest systems were created as long-range armament (the precursors to modern cruise missiles) in weapons like the US Navy's 1917 "aerial torpedo," the US Army's 1918 "Kettering bug," and the British Army's 1914 "aerial target" [2]. Figure 2 shows an airborne target, an aerial torpedo, Kettering, and a larynx.

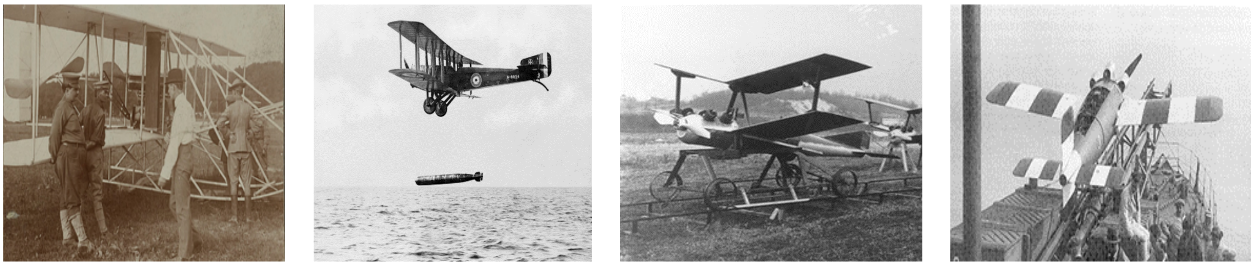

(a) (b) (c) (d)

Fig. 2. (a) Aerial Target (b) Aerial Torpedo (c) Kettering Bug (d) Larynx

None of these weapons were created in a way that allowed for military employment before the end of World War I, but they did herald the birth of a new technology, even though the guidance techniques used were quite rudimentary and unreliable. In the middle of the 1920s, the UK and the Royal Navy in particular showed interest in pilotless systems. The Royal Aircraft Establishment in Farnborough constructed a monoplane, which made its first flight in 1927. Its original name, "long-range gun with Lynx engine," was later abbreviated to "LARYNX." It was equipped with radio control for the launch mode, in contrast to the WWI machines, and the autopilot then constrained it to fly on a pre-set course at a pre-set height within a pre-set range.

UAVs underwent significant research and deployment during World War II. Despite its short range, Great Britain chose to forego the idea of a "cruise missile" and instead focus on target aircraft with full-mission radio control. In the 1930s, the British Royal Navy created Queen Bee, a radio-controlled target aircraft for practicing anti-aircraft gunnery. The US military created Radioplane-OQ2, a smaller, lighter UAV the size of a model aeroplane that is designed for artillery spotting. Through their aeroplane, an early version of radio control technology was developed. The V-1 flying bomb was a UAV created by the Germans that was piloted by an autopilot and gyrocompass and fired from a ramp. Although it used a pulse jet, it was the first missile to use jet propulsion. Figure 3 shows the Queen Bee, V-1 flying bomb, and Radioplane-OQ2 platforms.

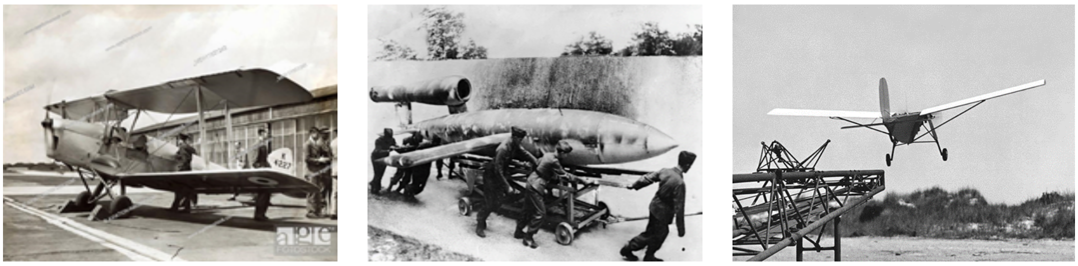

(a) (b) (c)

Fig. 3. (a) Queen Bee (b) V-1 Flying Bomb (c) Radioplane OQ-2

Both the US and the Soviet Union developed numerous types of UAVs for reconnaissance and surveillance during the Cold War. The US Air Force began developing the Lockheed D-21 and Ryan Model 147 drones in the 1950s and 1960s, respectively, and they were finished in the 1960s and 1970s. Without endangering the life of the pilot, these drones could photograph enemy areas while flying at great altitudes.

During the 1980s and 1990s, which are regarded as the contemporary era of technical innovation, UAVs became more advanced and versatile. The 1990s saw the development of navigation technologies, allowing UAVs to operate at considerably greater distances while maintaining precise positioning. As a result, medium- and long-range (General Atomic Gnat) missiles were developed. Ryan Model-147, Lockheed D-21, Denel Seeker, and General Atomic Gnat platforms are shown in Figure 4.


(a) (b) (c) (d)

Fig. 4. (a) Ryan Model-147 (b) Lockheed D-21 (c) Denel Seeker (d) General Atomic Gnat

The 2000s saw a significant growth in the use of UAV for military purposes. In comparison to just thousands in previous decades, several systems, such as the General Atomics Predator, Northrop Global Hawk, and Boeing Insitu ScanEagle, have accumulated operating hours measured in the hundreds of thousands. Platforms for the Boeing Insitu ScanEagle, Global Hawk, and Predator B are shown in Figure 5.

(a) (b) (c)

Fig. 5. (a) Predator B (b) Global Hawk (c) Boeing Insitu ScanEagle

The creation of satellite imaging, the pinnacle of unmanned aerial photography, was directly influenced by the US and Soviet Union's competition to outperform one another in aerospace. Google Street View was introduced in 2007 and has since become available everywhere. Google Street View shows panoramas made from stitched photographs taken by various vehicles, including cars, drones, tricycles, boats, snowmobiles, and underwater equipment. Figure 6 displays orthophotography, Google Street Guide, and satellite imagery.

(a) (b) (c)

Fig. 6. (a) Satellite Imagery (b) Google Street Guide (c) Orthophotography

Orthophotography, an airborne image that has been geometrically corrected, was initially used in the 1960s, but it was expensive and time-consuming to make. But technological advancements in the early 1970s made this data source accessible for commercial usage, and its use has since grown.

2010: As was already said, there hasn't been much UAV utilization for civilian tasks. This has mostly been caused by several airworthiness authorities forbidding UAV from using appropriate airspace until they are outfitted with a trustworthy sense-and-avoid system. Due to their diverse possibilities for non-combatant and military applications, UAVs have attracted a lot of attention during the past ten years [32]. UAV technology is being employed in many different industries, such as agriculture, disaster management, environmental monitoring, and military activities, and it has a wide range of capabilities. Overall, new opportunities for remote sensing and data collection have been made possible by the advancement of UAV technology, making UAVs an essential tool in many industries. The historical development of UAV is depicted on Figure 7.

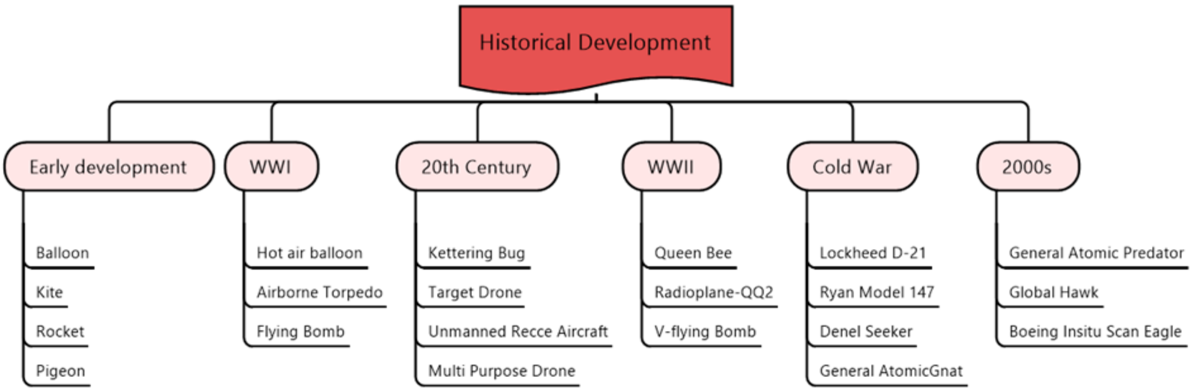


Fig. 7. UAV Historical Development

3. Classification of UAVs

UAVs have a wide range of uses, and according to Arjomandi *et al.,* [29], it is challenging to create a classification scheme that covers all UAVs. However, different authors' standards can be taken into consideration since there is no single classification scheme that systematically describes all UAV classifications [19]. According to Shakhatreh *et al.,* [13], unmanned vehicles can be categorized into five primary groups based on how they function. These consist of unmanned spacecraft, unmanned ground vehicles, unmanned aerial vehicles, unmanned surface vehicles, and unmanned underwater vehicles. According to Mohsan *et al.,* [3], there are many classes of UAVs based on different factors, including configuration, engine type, weight, range, and size. UAVs were divided into two categories by Mohamed *et al.,* [11] in 2020: their performance requirements and their mission requirements. Table 1 is a summary table of previous (2019 to data) research on UAV technology in the applied sciences and engineering technology domains, highlighting review themes and comments from various researchers.

Sections 3.1 to 3.6 classified UAVs based on performance, weight, flight mechanism, altitude, engine type and number of propellers.

Table 1
Summary of Previous Studies on UAV Technology

Author	Review Topics	Remarks
Tsouros *et al.,* [33]	UAV-based crops monitoring, UAV data acquisition, UAV data processing, Limitations in the use of UAV for precise agriculture	Multi-rotors have been used in recent precision agriculture research due to their manoeuvrability, low cost, slower speed, and ease of maintenance.
Outay *et al.,* [15]	Road safety, Traffic monitoring and management, Highway infrastructure management. Wide-scale developments of UAVs	Image processing and computer vision algorithms are key components for the advancement of UAV technology.
Śledź and Ewertowski [34]	Previous, Current, Potential future UAV applications	The majority of the research was conducted in the Arctic and the Alps, and the study areas were typically less than 1 square km.
Polidori and El Hage [35]	Prerequisite-definition of the nominal terrain; DEM as a cartographic product; Main DEM quality assessment approaches; DEM validation at different levels; Resolution dependency on DEM validation	The performance of the DEM prediction approach requires a significant amount of knowledge gathered via the study of numerous DEMs or simulation-based research.
Mesa-Mingorance and Ariza-López [36]	Approaching vertical accuracy in DEM. Material and methods. Results and analysis	DEM accuracy evaluation remains an open and complicated problem that requires the continued attention of the whole geospatial community.

Deliry and Avdan [37]	The effect of various factors on accuracy of UAS-SfM products; Comparison of UAS-SfM and TLS 3D models; Performance of SfM software; UAS-SfM accuracy in challenging terrain; Advantages and limitations	There is insufficient description of the link between errors and their closeness to GCPs.
Jiménez-Jiménez *et al.,* [38]	UAV data collection system; Flight planning and image acquisition; Photogrammetric DEM generation; Geomorphology and land use/cover; Accuracy assessment	UAV photogrammetry enables low-cost DM capture with high precision and spatial resolution.
Yao *et al.,* [39]	UAV sensors, UAVs remote sensing data analysis, UAVs remote sensing applications	UAV sensors and platforms are now used in practically every application that requires top-down or oblique observation.
Zhang [40]	Image based 3D reconstruction technology, UAV path planning technology	A 3D reconstruction technique based on UAV aerial photography is a recent topic in the field of 3D reconstruction.
Shakhatreh *et al.,* [13]	UAV civil applications and their challenges, current research trends and future insights for potential UAV users, key challenges for UAV civil applications	Unmanned aerial vehicles (UAVs) are becoming increasingly important in situations where humans are unable to reach or complete dangerous or risky tasks in a timely and effective manner.
Norasma *et al.,* [7]	Applications of UAV in agriculture Advantages and limitations	An appropriate sensor and UAV must be selected before deploying a UAV to collect accurate data and perform precise analysis.
Mohamed *et al.,* [11]	UAV application in smart cities, UAVs utilization issues, enabling technologies, regulations, potential impact and risks	In the near future, several innovations will alter the world and transform the economy.
Jyoti and Batth [12]	UAV classification, search and rescue, remote sensing	Researchers and corporate groups are interested in the usage of unmanned aerial vehicles (UAVs) in a range of applications
Zhou *et al.,* [16]	Basic concepts of VTOL aircraft, historical development of VTOL aircraft, challenges and constraints of VTOL aircraft, a glimpse on the STOL aircraft	VTOL capabilities are desirable in both UAVs and MAVs, assuming they achieve comparable flight performance.
Alladi *et al.,* [17]	Fundamentals of UAVs and blockchain technology, Various applications of blockchain in UAV networks, challenges and future research directions	The application scenarios have immense potential for real-time implementation in both the military and commercial arenas.
Zhang *et al.,* [18]	Development of history, data processing, current application and future prospective of UAV-LARS	UAV-LARS is a unique sensor application of information monitoring technology with high spatial and temporal precision.
Ajith and Jolly [19]	Types, components, developments, potential applications of UAV in search and rescue	UAVs and UAS technologies open up new possibilities in a variety of fields.
Lambey and Prasad [20]	Types of UAVs and their requirements for air quality monitoring Current opportunities, challenges, and future applications of UAVs	UAVs are more versatile and operationally visible than ground-based techniques or other aerial systems such as piloted planes and satellites.
Alghamdi *et al.,* [21]	UAV architecture, classification of UAVs, application of UAVs in different domains, future of UAVs and associated challenges	Using UAVs for commercial and military missions is becoming more realistic, if not advantageous.
Gohari *et al.,* [22]	Status of applications and application areas of surveillance drones in smart cities, characteristics of implemented drones	Compared to traditional surveillance methods, the employment of a single or several UAVs, either as a stand-alone technology or in conjunction with other technologies, can provide efficient and long-term solutions.
Elsayed and Mohamed [23]	Synthesized and classified international UAV flight regulation, Utilizing real-world delivery data	The fuel mix used in power generation has a significant impact on UAV emissions.

Mukhamediev *et al.,* [4]	Prerequisites for using UAVs in some spheres of economy, limitations in the process of IUAVT adaptation in the sectors of economy	Possibilities in a number of economic sectors
Fox [26]	History……lessons from the skies, the fine line: evolution- fear and risk, Enter the drone, Governance and control, Drones and ‘the police’: (A UK update), Conclusion: future predictions…….	Finally, further safeguards are needed before the societal benefits of drones may be exploited.
Lee *et al.,* [27]	Multiple comparative prospective	Most privacy legislation complies with broader digital privacy rules.
Mohsan *et al.,* [3]	UAVs, UAV battery charging, UAVs in 5G and IoT networks, UAV applications areas	Unmanned aerial vehicles (UAVs) have numerous applications.
Idrissi *et al.,* [32]	Enabling technologies and applications, UAV mechanical architecture, multi-rotor aircraft (VTOL) structures, Quadrotor dynamics, simulation tools, control strategies	Using proper control techniques or mechanical modifications, the dynamic system limits can be decreased.
Fan *et al.,* [31]	Technical composition of UAV systems, technological development trend analysis for UAV systems, application prospects of UAV systems	Emerging trends will have a substantial impact on future economic, social, and military growth.
Kim *et al.,* [8]	Agricultural UAV platforms, Control of agricultural UAVs, Applications of agricultural UAVs	Agricultural unmanned aerial vehicles offer virtually infinite applications in agriculture.
Mozaffari *et al.,* [41]	Potential benefits and applications in wireless communication, challenges and fundamental trade-offs, analytical frameworks and mathematical tools	A manual for assessing, analysing, and building wireless communication systems for unmanned aerial vehicles (UAVs).
Fotouhi *et al.,* [42]	UAV types and characteristics, standardization: enabling UAV cellular communications, aerial base stations: challenges and opportunities, prototyping and field tests, security	Research the advantages and disadvantages of serving UAVs using existing 4G cellular networks.
Nawaz *et al.,* [43]	Application areas of UAVs, (agricultural, military, and civilian usage)	Unmanned aerial vehicles (UAVs) may fly in a variety of situations and zones and perform a variety of missions.
Albeaino *et al.,* [9]	Current status of UAVs in the AEC research, contexts of application and their technology use, UAV technology in the AEC domain, analysis of task and technology characteristics	Most prevalent video and thermal cameras used on UAVs were readily available or 'off-the-shelf' technology, followed by LiDAR and laser scanning systems.

3.1 Based on Performance

The size of a UAV can be as small as an insect or as large as a traditional piloted aircraft [44,45]. Weight, endurance, range, speed, and wing loading are a few crucial characteristics that set distinct UAV types apart and lead to practical classification schemes [29]. UAVs can be classified depending on their size, range, and payload, per Mozaffari *et al.,* [41]. Table 2 shows the classification of UAV from low to category, and Table 3 shows the classification from micro to male category.

Table 2
Low to High UAV

Category	Endurance	Range	Max Altitude	Wing Loading
High	>24 hours	>1500 km	>10000 m	>100 kg/m^2
Medium	5-24 hours	100-400 km	1000-10000 m	50-100 kg/m^2
Low	<5 hours	<100 km	<1000 m	<50 kg/m^2

Table 3
Micro to MALE UAV

Categories	Acronym	Range (km)	Max. Alt (m)	Endurance (h)	Mass (kg)
Micro	M	<10	250	1	<5
Mini	Mini	<10	150-300	<2	150
Close range	CR	10 a 30	3000	2-4	150
Short range	SR	30 a 70	3000	3-6	200
Medium range	MR	70 a 200	5000	6-10	1250
Medium range endurance	MRE	>500	8000	10-18	1250
Low altitude deep penetration	LADP	>250	50-9000	0.5-1	350
Low altitude long endurance	LALE	>500	3000	>24	<30
Medium altitude long endurance	MALE	>500	14000	24-48	1500

3.2 Based on Weight

UAVs are often categorized by civil aviation authorities based on their gross weight. According to their overall weight, UAV systems are divided into the following weight categories by the Civil Aviation Safety Authority (CASA), Australia: micro, very small, small, medium, and large weight [42]. Table 4 displays the weight-based classification.

Table 4
Classification by weight

Designation	Weight Range
Super Heavy	>2000 kg
Heavy	200-2000 kg
Medium	50-200 kg
Light	5-50 kg
Micro	<5 kg

3.3 Based on the Mechanism of Flight

UAVs can be classified depending on a number of factors, including the flying mechanism, weight, flying altitude, and wing type, as stated by Alladi *et al.,* [17], based on the mechanism for flight, UAVs were divided into three categories by Fotouhi *et al.,* [42]: multirotor or rotary-wing, fixed-wing, and hybrid-fixed/rotary-wing. UAV platforms are divided into four categories by Gupta *et al.,* [46]: fixed-wing, rotary-wing, blimps, and flapping-wing UAVs. Based on their design characteristics, Tsouros *et al.,* [33] divided UAVs into five major categories: fixed-wing, rotary-wing, blimps, flapping wings, and parafoil wings. UAVs can be classified as either fixed or rotary-wing aircraft, according to Idrissi *et al.,* [32]. Fixed-wing UAVs that can fly quicker and higher are recommended for rough inspection and vegetation monitoring, according to Mohsan *et al.,* [3]. Figure 8 shows the classification of UAVs according to their flight mechanisms.

UAVs with fixed wings: Fixed wings are the primary lift-producing components in reaction to accelerating forward speed. According to Hassanalian and Abdelkefi [47] and Mueller [48], fixed-wing drones need to accelerate more quickly and have a thrust-to-load ratio of less than one before taking off. On a runway, they take off and land.

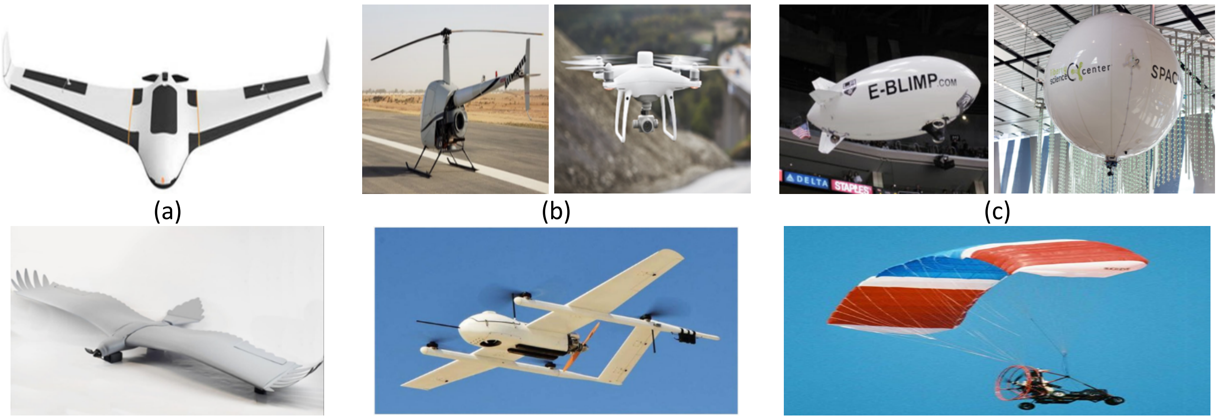
In contrast to fixed-wing aircraft, multi-rotor or rotary-wing UAVs may perform vertical takeoff and landing (VTOL) and may hover in one spot [49]. Rotary-wing aircraft provide the benefits of sustained flight at a single location while maintaining UAVs with hybrid fixed and rotary wings combine the aforementioned two mechanisms and are capable of switching between them. Using its rotors, the parrot type, for instance, can lift off vertically, glide through its path, and then switch back to hovering [42].

According to Chen *et al.,* [50], insects like small hummingbirds and huge dragonflies are the main inspiration for flapping-wing UAVs [51]. In contrast to fixed-wing drones, flapping drones can maintain stable flight in a windy environment.

According to Jones *et al.,* [52], hybridization with fixed and flapping wings improves overall efficiency and aerodynamic balance. While flapping wings are used to produce propulsion, stationary wings are used to generate lift. These drones are modelled after dragonflies.

Blimps are larger in size compared to the other varieties, lighter than air, have a high endurance rating, and fly at low speeds. Even in the case of a complete loss of electricity, they stay in the air [33]. Balloons and airships are examples of blimps and UAVs.

In order to manage their flight path and harness the power of the air to fly without expending a lot of energy, parafoil-wing aircraft typically include one or more propellers at the back [33].



(a) (b) (c)

(d) (e) (f)

Fig. 8. Flight Mechanism UAV Classification; (a) fixed-wing, (b) rotary/multi-rotor wing, (c) blimps: balloon/airship, (d) flapping-wing, (e) hybrid, (f) parapoil-wing

Lift-induced drag is the same for both fixed-wing and rotary wings; the only difference is that the fixed-wing moves in a linear manner to engulf the air, whereas the rotary wing moves in a circular motion while hovering. In contrast to the former, which receives air horizontally and accelerates it downward, the latter draws in "new" air from above in order to add energy to it and speed it downward [42].

3.4 Based on Altitude

Based on how they are used as air base stations in communication networks, UAVs can be divided into different categories [12]. Depending on the operational platforms, this can be classified as low altitude (LAP) or high altitude (HAP) [41,42,53]. According to Reynaud and Rasheed [54] and Al-

Hourani and Gomez [55], the three main UAVs identified in this group are VTOL, boats, planes, and balloons. LAP operates at an altitude of less than 10 kilometers. According to Karapantazis and Pavlidou [56], HAP is well above the altitude of 10 km, and the primary types of UAVs that fall into this category are aircraft, balloons, and airships [57].

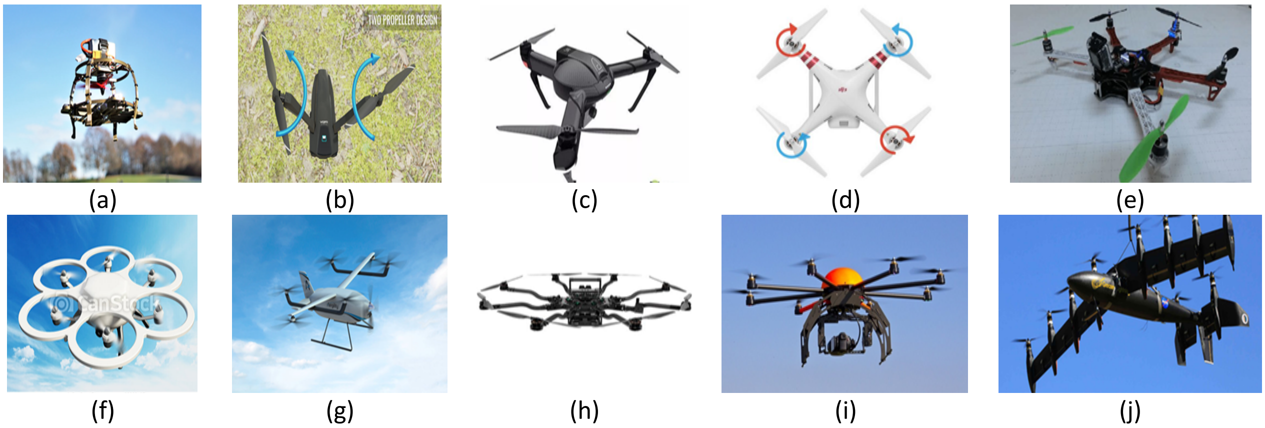
(i) Low Altitude Platforms (LAPs): Due to their great mobility and efficiency, LAP-type UAVs are excellent for quick and flexible deployment. They can only fly for a few hours at a time.
(ii) High Altitude Platforms (HAPs): These large gas balloon-like UAVs may fly for days or even months at a time. They typically function in a quasi-stationary manner at altitudes exceeding 10 km.

3.5 Based on Engine Type

Turbofans, Two Strikes, Piston, Rotary, Turboprop, Push and Pull, Electric, and Propeller are a few of the several engine types used in UAVs. While the heavier, more combat-ready UAVs often use piston engines, the lighter, smaller UAVs typically use electric motors.

3.6 Based on number of Propellers

The specifications, equipment, sizes, operating ranges, and shapes of UAVs vary. According to Mohsan *et al.,* [3] and Hassanalian and Abdelkefi [47], UAVs are classified how many propellers they have. These divisions are not mutually exclusive, and a UAV may fit into more than one category depending on its characteristics. Figure 9 displays the mono to deca propeller classification.



(a) (b) (c) (d) (e)
(f) (g) (h) (i) (j)

Fig. 9. Mono to Decacopter Propeller Classification; (a) Monocopter, (b) Duocopter, (c) Tricopter, (d) Quadcopter, (e) Pentacopter, (f) Hexacopter, (g) Heptacopter, (h) Octacopter, (i) Nanocopter, (j) Decacopter

Figure 10 summaries the classification of UAVs based performance, weight, fight mechanism, altitude, engine type and number of propellers.

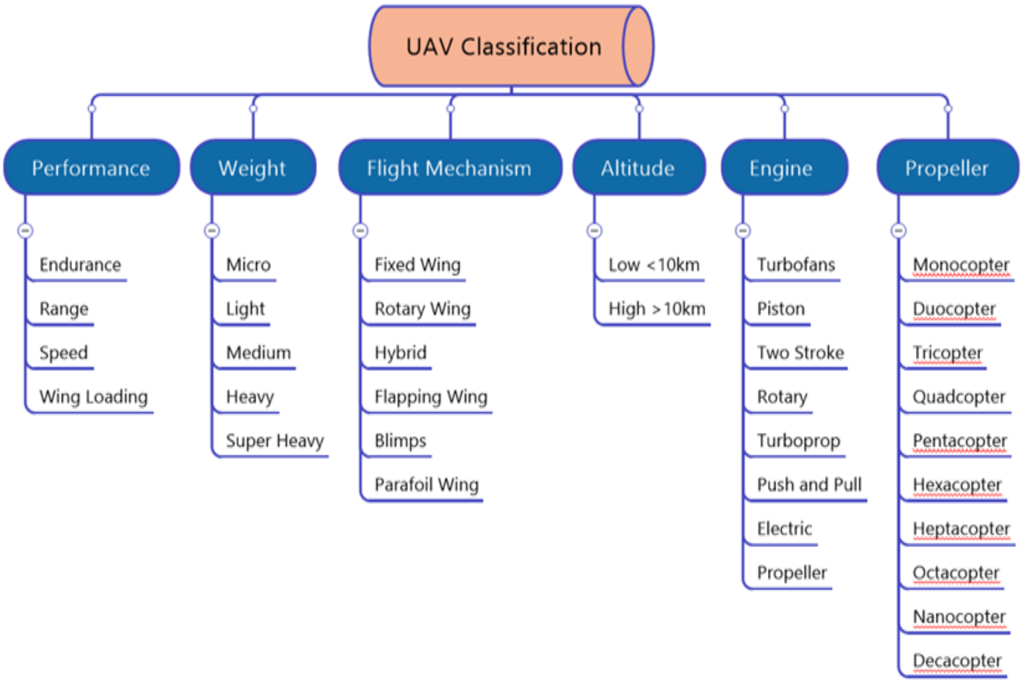


Fig. 10. UAV Classifications

4. Benefits of UAV Technology in Applied Sciences and Engineering

In order to support commercial applications in applied sciences and engineering, UAVs can deliver cloud-free and high-resolution photos, according to Singhal *et al.,* [1]. The technique, according to Laporte-Fauret *et al.,* [58], has a number of advantages, including low cost, survey automation, high repeatability, direct video return, and the capacity to swiftly pause and resume a mission if an issue emerges. In 2019; Shakhatreh *et al.,* [13] claimed that because of their simplicity in deployment, low maintenance costs, great mobility, and hovering capabilities, UAVs can be employed in a variety of civil applications. UAVs are used in a variety of industries, including agriculture, forestry, archaeology, architecture, traffic monitoring, environmental monitoring, and emergency management, according to Giordan *et al.,* [6]. A year later, in 2019, Nawaz *et al.,* [43] highlighted the numerous UAV applications that are in line with the current demand for autonomous technology in a variety of applied sciences and engineering fields. Environmental-based applications and industrial-based applications are the fields of UAV applications in the realm of applied science and engineering, according to Al-Turjman *et al.,* [59]. According to Alladi *et al.,* [17], the recent development in UAV manufacturing processes, communication, and networking technologies has resulted in an increase in their use in civilian and commercial applications.

In the field of applied sciences and engineering, UAVs have been employed in a range of applications [5,11]. UAVs are expanding quickly in various areas of civil activity, according to Mukhamediev *et al.,* [4] and Jyoti and Batth [12]. According to Fan *et al.,* [31], the use of UAV systems has broader and more significant application opportunities. As highlighted in 2021 by Ajith and Jolly [19] and Alghamdi *et al.,* [21] further emphasized that the UAV is an emerging technology that is rapidly expanding across many warfare domains and enabling new civilian domains, such as cinematography, agriculture, search and rescue, surveying and mapping, logistics and delivery, inspection, and monitoring. Practically speaking, UAVs are suited for a variety of applications that can advance applied sciences and engineering, according to Mugnai and Tucci [60]. Mohsan *et al.,* [3], Mukhamediev *et al.,* [4] and Fox [26] emphasized the commonly cited contributions already being made by drones in a variety of fields, as did the fact that technology has emerged in a large diversity of numerous applications. According to Mohsan *et al.,* [3], UAV technology has enhanced efficiency, decreased prices, boosted safety, and increased accessibility for a variety of applied sciences.

This sub-section of the review focused on enhanced productivity, cost saving, increased safety, greater accessibility, precision and accuracy, and real time data collection in the realm of applied sciences and engineering.

4.1 Enhanced Productivity

Compared to people, UAVs are faster and more effective at performing a variety of jobs. With UAVs, precision agriculture's full potential may be utilized—not just at the information gathering stage, but also at the decision-implementation stage [10,61,62]. UAVs offer a wide range of chances for data collection in numerous sectors, according to Gaffey and Bhardwaj [63]; their view from a bird's-eye perspective overcomes surveyors' (ground-based) positional view restrictions [64]. Babatunde *et al.,* [65] claim that UAVs are an alternative to conventional image acquisition techniques. According to Tsouros *et al.,* [33], Deliry and Avdan [37], and Congress and Puppala [66], the technology has demonstrated itself to be quick, safe, efficient, and user-friendly.

4.2 Cost Savings

In several fields of applied sciences and engineering, UAVs can also help cut costs. UAV use enhances performance while decreasing risk and costs less than using manned aircraft, according to Fan *et al.,* [31]. Al-Turjman *et al.,* [59] stated in 2020 that technology is proving to be more time- and money-efficient. According to Mukhamediev *et al.,* [4] and Ajayi and Ajulo [67] in 2021, the method is more precise and offers a reliable substitute for the meticulous ground survey method.

4.3 Increased Safety

Increased safety is another benefit of UAV technology in the fields of applied sciences and engineering. By offering scenarios and providing vital data for specified areas, UAVs can significantly reduce the need for labour, resources, and time. UAV use in search and rescue (SAR) operations frequently lowers people's costs, time, and risk, according to Jyoti and Batth [12] and Shakhatreh *et al.,* [13]. According to Karaca *et al.,* [68], technology has the ability to reduce the amount of time needed for searches and hasten subsequent intervention in all of these populations. According to Outay *et al.,* [15], UAVs carry out air activities that are difficult for manned aviation, and their employment reduces the risk to human life while clearly saving money and benefiting the environment. UAVs can quickly scan the region and give rescue crews useful information that will help them find the missing or assess damage in disaster-stricken areas.

4.4 Greater Accessibility

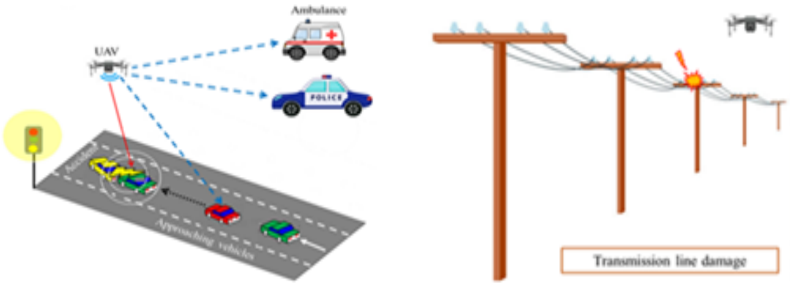
UAVs can also make isolated or hard-to-reach regions more accessible. UAV technology has made it possible to securely, accurately, and precisely collect geospatial data in mountainous terrain and difficult or inaccessible places for proper periodic recording [69]. The UAV platform is an effective tool for producing high-accuracy maps and classifications of slopes for landslide monitoring and prevention, especially in difficult-to-reach locations for task implementation, which is essential for creating a temporal database for long-term rock slope surveillance and monitoring [70,71]. UAVs are used for enemy identification, anti-poaching, border control, and marine monitoring of important sea lanes, according to Mohsan *et al.,* [3]. In addition to reducing the cost and risk of surveying hazardous or dangerously landslip-prone regions, UAV imagery enables the accurate detection of landslip information.

4.5 Precision and Accuracy

UAVs are capable of carrying out operations with a great degree of precision and accuracy thanks to the sensors, cameras, and other cutting-edge technology that can be added to them [72]. UAVs are used to map, survey, and keep an eye on wildlife and natural resources. According to Singhal *et al.,* [1], technology offers superiority over traditional remote sensing techniques, and their advantages make them a great option for surveying and mapping. In order to identify changes in the environment and take preventative actions to protect it, scientists can use data on air quality, water quality, and vegetation health measurement and monitoring [20,72]. Employing UAVs for construction site inspection, progress monitoring, and urban planning, according to Albeaino *et al.,* [9], led by Śledź and Ewertowski [34], helps decrease material waste. The reliability and use of UAV products in engineering and construction planning were further emphasized by Patrick *et al.,* [73].

4.6 Real-time Data Collection

UAVs are capable of gathering and transmitting real-time data, which has a variety of uses in the film and entertainment sectors for aerial photography and filming. They may capture stunning aerial photographs and offer a different viewpoint on situations and surroundings. UAVs can be used to fully automate the transportation sector, as indicated by Menouar *et al.,* [74]. According to Elloumi *et al.,* [75], it can help prevent traffic jams and heavy congestion by detecting over speeding and accidents in vehicles. Inspection of distribution and transmission lines for power at a cheaper cost than with helicopters and with lower danger than with traditional foot patrol. In particular, the UAV's real-time use and the removal of human danger, according to Karantanellis *et al.,* [76], make it a practical and comprehensive data collection instrument. Figure 11 provides a summary of UAV services for power line and highway inspection.



(a) (b)

Fig. 11. (a) Highway Assistance (b) Power lines Inspection

In general, the advantages of UAV technology in applied sciences and engineering are substantial and keep expanding as the technology develops. UAV use is changing how we approach activities and operations, making them more effective, safe, and cost-effective. Applied science and engineering benefits of UAV technology is presented in Figure 12.

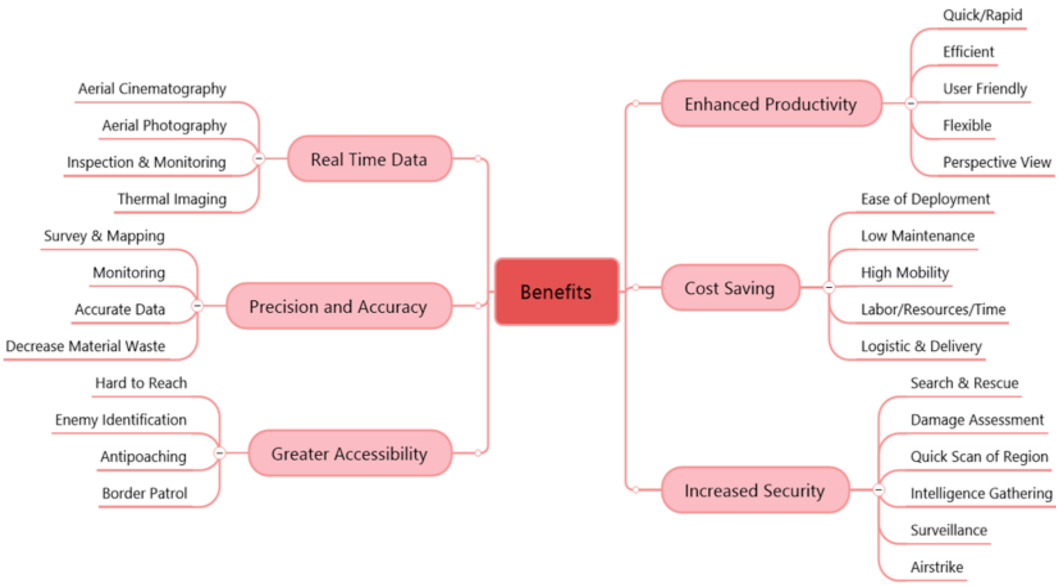


Fig. 12. UAV Benefits

5. UAV Technology's Limitations in Applied Science and Engineering

UAVs have historically been used for reconnaissance and surveillance, but today they are being used in roles and applications that their creators never imagined, according to Bone and Bolkcom [44]. Villa *et al.,* [72] emphasized that, given that flying robots are using the same national airspace as manned aircraft, they must also abide by applicable aviation safety standards. In order to assure the safe, secure, and authenticated usage of UAVs, regulatory difficulties are required due to the innovation and accelerated use of UAVs in commercial applications [77,78]. According to Stöcker *et al.,* [78], UAV laws in general only apply to specific civil UAV situations that are categorized and constrained by the weight of the UAV and/or the region, operational range, or purpose of its use. Nakamura and Kajikawa [79] stated that regulation fosters innovation while also stifling it.

In 2018, Singhal *et al.,* [1] reported that drones experience windy weather and unfavourable climate changes. A year later, Shakhatreh *et al.,* [13] emphasized once more how challenging weather conditions may be for UAVs because they may cause them to stray from their intended paths. Weather presents a difficult and crucial problem in situations of natural or man-made disasters (tsunamis, hurricanes, or terrorist strikes). According to Lambey and Prasad [20], aviation legislative bodies have outlined regulations and restrictions on the use of national airspace in order to safeguard the general population and other airspace users. According to Bange *et al.,* [2], there are currently fewer UAVs in civilian use than in military use as a result of more challenges in their introduction to the civilian market. The necessity for regulation is becoming more widely recognized a year later, according to Lee *et al.,* [27], as commercial and recreational use of UAVs increases. In addition, Mohsan *et al.,* [3] emphasized that a number of significant variables are limiting UAV performance. Some of these limitations include movement restrictions, autonomy limitations, and flying time limitations.

Regulations governing the use of UAVs in a certain area are a crucial problem because they are one of the things that prevent UAV networks from being deployed, according to Alladi *et al.,* [17]. Numerous operational difficulties, such as collision avoidance, data security, privacy, etc., must be handled, and different UAV parameters, such as kind, spectrum, speed, etc., must be taken into consideration [35]. According to Stöcker *et al.,* [78], operating restrictions, administrative requirements, and the need for human resources were UAV obstacles in 2017. Singhal *et al.,* [1] identified safety, privacy, and security concerns, as well as issues with controlling bodies and legislation, as the main challenges. In 2019, Fotouhi *et al.,* [42] stated the difficulties as applicability, operational constraints, administrative and legal restrictions, technical specifications and requirements, and moral and ethical concerns. When developing UAV regulation regimes, essentially five key areas must be taken into consideration [42]. Weather, law, and energy restrictions are only a few of the UAV's issues stated in Jyoti and Batth [12] article.

These restrictions emphasize the need for careful planning and thought while utilizing UAV technology in the applied sciences, by being aware of the restrictions and difficulties posed by UAV technology. Researchers can devise plans to reduce their negative effects and increase their positive effects on scientific research.

The UAVs operational, moral and ethical, administrative procedure, human resource requirements, weather and energy limitations are explained in the following sub-sections.

5.1 Operational Limitations

As unmanned aircraft pose a serious risk to manned aircraft, they are typically not permitted to fly in controlled airspace or in close proximity to locations where manned aircraft land or take off. However, special authorization may be possible on a case-by-case basis. A safe distance from persons, property, and vessels that are not connected to the UAV flight itself is another crucial operational restriction. The word "general limitations" refers to ceiling height, horizontal range, and visibility distances.

5.2 Moral and Ethical Concerns

Here, the focus is primarily on the privacy and security concerns of the general populace. Since modern methods to address these problems are inadequate and do not provide assurance for the safety of the use of a drone, airworthiness, malevolent practices, and interference with public property are the main safety concerns. This raises serious doubts about the use of drones. The goal of safety is to prevent harm to people, pets, and other property due to UAV malfunctions. It also aims to prevent harm or damage from UAV and other flying vehicle collisions.

5.3 Administrative Procedures

This term refers to the collection of guidelines established by the local authority to regulate the use of UAVs. The UAV operators in that area must adhere to these established protocols and laws. According to the application process, the requirement for UAV registration, and the requirement for insurance coverage, administrative procedures make distinctions between different variables. A substantial amount of heterogeneity can be seen in this area. The intricacy of UAV operations often determines how much work is required to apply for flying authorization. Since diverse UAV operation scenarios were initially classified, almost all application procedures are multi-layered and require different tactics to be used in various situations.

5.4 Human Resource Requirements

Many rules place requirements on the UAV pilot in addition to the UAV itself. The most typical criteria include practical training, theoretical knowledge tests, aeronautical testing, and medical evaluations. Similar to application procedures, the complexity and risk of the flight mission typically determine the level of necessary pilot skills.

5.5 Weather

Because of the unpredictable nature of the environment, UAVs face a hurdle while planning their paths. In the event of either natural disasters or man-made calamities like terrorism attacks, earthquakes, or tsunamis, the climate is a challenging and fundamental barrier. UAVs may experience difficulty during their missions in these circumstances due to the unfavourable weather conditions.

5.6 Limitations on Energy

One of the main problems UAVs faces is energy use. Typically, batteries power UAVs. In some SAR operations, UAVs must be flown over disaster-affected areas for longer periods of time. Given the power limitations of UAVs, it should be decided whether to execute data and image processing on board in real time or save the UAVs for later research to save power.

Figure 13 depicts UAV technology limitations in applied science and engineering fields.

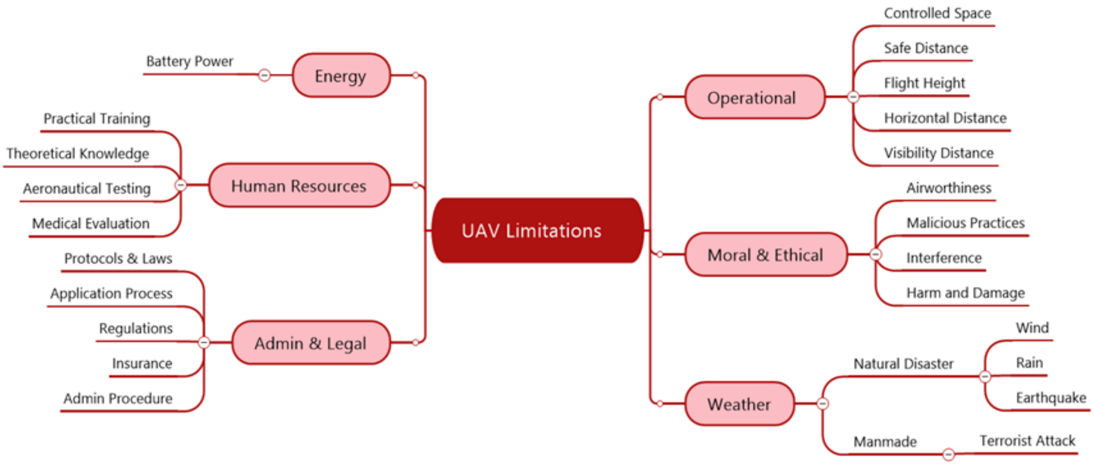


Fig. 13. UAV Limitations

6. Conclusions

In conclusion, this review article has presented a comprehensive analysis of the existing research on the technological advancement of UAVs in the realm of applied sciences and engineering. By examining a diverse range of research papers, books, and articles that cover different aspects of UAV technology, we have synthesized key findings and identified common themes. A thorough overview of UAV technology and its different applications in applied sciences and engineering technology is given in the sources listed in this article. These sources emphasize the potential advantages of UAV technology as well as the difficulties that must be overcome in order to realize its full potential. These publications are excellent resources for anybody interested in UAV technology and its applications, even though some of the content may be out of date. The article also provides a historical overview of the state-of-the-art in UAVs. The classification of UAVs based on their performance, weights, mechanism of flight, altitude, engine type, and quantity of propellers were explored. Although UAVs have many benefits, including better productivity, lower costs, increased safety, and greater accessibility, they are nevertheless constrained by legal and ethical difficulties as well as technical and regulatory issues. Overall, the application of UAVs in applied sciences offers enormous potential to transform how data is gathered and analyzed, but careful consideration is required to guarantee that the advantages are realized while minimizing potential hazards. Future UAV applications are likely to be much more creative and significant as the technology develops and improves.

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