IJEAST

INTERNATIONAL JOURNAL
OF ENGINEERING APPLIED SCIENCE
AND TECHNOLOGY

VOLUME : 11 **ISSUE : 01** **Print / Issue Publication Date: 02-Jun-2026**

ISSN : 2455-2143

DOI : 10.33564/IJEAST.2026.v11i01.008

Indexed In

Google Scholar
OPEN ACCESS
doi
Crossref

WWW.IJEAST.COM

editor@ijeast.com

International Journal of Engineering Applied Sciences and Technology, 2026
Vol. 11, Issue 01, ISSN No. 2455-2143, Pages 51-62
Published Online May 2026 in IJEAST (http://www.ijeast.com)

A COMPREHENSIVE REVIEW OF UNMANNED AERIAL VEHICLE TECHNOLOGY: CURRENT STATE AND FUTURE POSSIBILITIES

Rabinder Henry
Professor,
ATLAS SkillTech University, Mumbai, India,

Nilima Zade
Faculty, Symbiosis Institute of Technology Pune Campus,
Symbiosis International (Deemed University), Pune, India,

Abstract: **Unmanned Aerial Vehicles (UAVs), commonly referred to as drones, have evolved from rudimentary military tools into sophisticated, AI-enabled autonomous platforms. They have been constantly transforming civilian, commercial, and defence ecosystems across the world. This paper presents a comprehensive review of UAV technology, tracing its development from the earliest radio-controlled aircraft of the 1930's through the Cold War surveillance era. It also emphasizes the emergence of weaponised platforms and the contemporary explosion of civilian applications. A structured classification framework is presented, followed by an analysis of the seven-subsystem functional architecture common to modern UAVs. The current state of the art is surveyed across ten application domainsincluding precision agriculture, logistics and urban air mobility, infrastructure inspection, disaster response, environmental monitoring, archaeological survey, defence, molecular nano-drone medicine, space exploration, and construction. It also enumerates a comprehensive review of the innovative applications emerging from recent research. The paper concludes with a forward-looking synthesis of future possibilities including autonomous swarm intelligence, bio-inspired and morphologically adaptive designs, quantum-enhanced sensing and communication, cognitive AI and neuromorphic autonomy, and planetary drone systems. Throughout, the convergence of artificial intelligence, advanced materials, 5G/6G communications, aerodynamics, and biomimetics are identified as the main drivers of next-generation UAV capabilities.**

Index Terms — **UAV, Drone Technology, Autonomous Systems, Swarm Intelligence, Precision Agriculture, Urban Air Mobility, Archaeological Survey, Molecular Drones, Quantum Sensing, Cognitive AI, Bio-inspired Design, Space Exploration, AI in Drones, Industry 5.0.**

I. INTRODUCTION

The word 'drone' can be traced to the Old English root words 'dran' or 'draen,' denoting the male honeybee which is an organism known for its characteristic buzzing and its unarmed nature [5]. In the early 1930s the British Royal Navy developed a radio-controlled aircraft for target practice called the 'Queen Bee,' and both American and British militaries subsequently adopted the term 'drone' for similar unmanned platforms [5,6]. Over the nine decades, starting as a simple target aircraft drone technology has evolved into one of the most consequential technology categories of the twenty-first century.

Unmanned Aerial Vehicles are redefining mobility, data acquisition, logistics, exploration, and security across every sector of human activity [5,8]. They have emerged as a true convergence of multiple technologies including Artificial Intelligence (AI), communication technologies, mechatronics, material science, biomimetics, electrical engineering, fluid dynamics, and aerodynamics [5]. They are recognised as one of the foundational pillars of Industry 5.0, a paradigm that emphasises human-machine collaboration, sustainability, and resilience [5].

This paper presents a structured, peer-reviewed account of UAV technology. Section II traces the historical evolution of drones. Section III provides a multi-axis classification framework. Section IV describes the functional subsystem architecture. Section V surveys the current state of the art across ten civilian and defence application domains, with particular attention to innovative applications highlighted in recent research. Section VI synthesises emerging future possibilities, and Section VII concludes with reflections on the interdisciplinary research priorities ahead.

II. HISTORICAL EVOLUTION OF UAV TECHNOLOGY

A. Early Origins: From Aerial Target to Cold War Reconnaissance

The conceptual origins of the UAV lie in the First World War, when the British Royal Flying Corps developed the Aerial Target. It was a pilotless aircraft designed to function as an aerial torpedo [5,14]. The true technological catalyst, however, was the Cold War. The United States recognised the strategic value of unmanned platforms for high-risk reconnaissance over denied airspace, where the loss of a manned aircraft and its pilot could trigger dangerous diplomatic escalation [5,14].

The Ryan Firebee, a jet-powered target drone developed in the 1950s, was adapted into the Ryan Model 147 Lightning Bug for operational reconnaissance during the Vietnam War (1955–1975) [5,14]. UAVs equipped with cameras provided Imagery Intelligence (IMINT) wherever and whenever satellites failed to deliver detailed, rapid tactical information [5]. More than 3,400 sorties were flown without risking pilots, firmly establishing the UAV as a credible strategic asset [14]. Concurrently, more autonomous, stealthier UAVs were developed during the Cold War for electronic warfare. Most of the classified programmes from this era have laid the conceptual foundations for modern autonomous UAV systems [14].

B. Israel and the Tactical Maturation of UAVs

Israel emerged as a pioneering force in the tactical development and deployment of UAVs. During the Yom Kippur War of 1973, the Israeli Defence Forces deployed remotely piloted vehicles to serve as electronic decoys, drawing fire from Egyptian surface-to-air missile batteries and exposing their radar for subsequent manned strikes [5,15]. This represented a conceptual leap beyond reconnaissance. This led to the evolution of UAV's as an active force multiplier.

In the Lebanon War of 1982, Israel deployed Scout and Mastiff UAVs for real-time surveillance, providing commanders with live video feeds. This led to the emergence of unmanned Real-Time Surveillance (RTS) and Real-Time Intelligence capabilities which are unprecedented in modern warfare [5,15]. This laid the foundation for strategic combat capabilities based on drone technology and influenced rapid UAV development programmes across the world, most notably in the United States [5,15].

C. The Predator Era, Weaponisation, and the Civilian Transition

The 1990s saw the operational deployment of the RQ-1 Predator, developed by General Atomics, offering long endurance via satellite command-and-control links [5,16]. Its subsequent armament with AGM-114 Hellfire missiles thereby creating the MQ-1. It established the weaponised strike drone as a central instrument of American counterterrorism strategy in the post-9/11 era [16]. Loitering munitions such as the Israeli Harop and the American Switchblade later extended this concept, combining persistent UAV surveillance with precision strike in a single expendable platform [16,18].

Simultaneously, miniaturisation, GPS technology maturation, and falling component costs enabled a parallel civilian revolution. The FAA granted its first commercial drone permits in 2006. Amazon announced its Prime Air drone delivery concept in 2013. The FAA introduced mandatory drone registration in 2015 [5,17]. Civilian UAV applications gained dramatic traction from 2010 onward, and by 2020 drones were being deployed globally in response to the COVID-19 pandemic for disinfection, medical supply delivery, and public monitoring [8,18]. By 2023, AI-driven autonomous drone swarms had become an operational reality in both military and civilian contexts [1,8]. A summary of the evolution of UAV technologies are listed in Table 1.

TABLE I: Timeline of UAV / Drone Technological Evolution

Year	Milestone / Event	Technological Progress
1916	British Royal Flying Corps develops the Aerial Target: First pilotless aircraft [5,14]	Concept of unmanned aerial weapon established
1935	British Royal Navy develops the "Queen Bee" radio-controlled target drone [5,6]	Introduction of radio-controlled flight; origin of the term 'drone'
1950s	U.S. develops Ryan Firebee jet-powered target drone [5,14]	Jet propulsion integrated into unmanned aircraft
1960s	Ryan Model 147 Lightning Bug deployed in Vietnam War for IMINT [5,14]	Surveillance cameras and long-range data links; over 3,400 sorties
1973	Israel pioneers tactical UAV use in Yom Kippur War [5,15]	Real-time surveillance (RTS), decoy and electronic intelligence roles

Year	Milestone / Event	Technological Progress
1982	Scout and Mastiff UAVs deployed in Lebanon War [5,15]	Live video relay to commanders; foundation of modern ISR doctrine
1980s	U.S. develops stealth and first-generation autonomous UAVs [14]	Stealth technology and partial AI-guided systems
1990s	RQ-1 Predator deployed for long-endurance surveillance [5,16]	Satellite-linked endurance platform; precursor to weaponised drones
2000	MQ-1 Predator armed with Hellfire missiles [16]	Strike drones enter operational service; UAV warfare doctrine established
2006	FAA grants first commercial drone permits [5]	Civilian regulatory framework for UAV operations begins
2013	Amazon announces Prime Air drone delivery concept [17]	Commercial last-mile logistics via UAV enters public discourse
2015	FAA introduces mandatory drone registration [5]	Formalised airspace governance for civilian UAVs
2010s	AI integration, swarm algorithms, consumer UAV boom [1,8]	Machine learning, miniaturisation, autonomous navigation at scale
2020s	Drones in COVID-19 response, Ukraine conflict, delivery networks [8,18]	5G/IoT connectivity, battery improvements, regulatory maturation
2023	AI-driven autonomous drone swarms demonstrated operationally [1,8]	Real-time collective decision-making across large drone formations

III. CLASSIFICATION OF UAV SYSTEMS

UAVs can be classified based on various parameters. They categorization is generally based on size, range, application, payload, control mode, and propulsion [5,6,9]. This structured classification supports targeted development, deployment, and regulation of drones across industries, defence, and government sectors [5]. The term DRONEsometimes expanded as 'Dynamically Remotely Operated Navigation Systems' is used in common discourse, though it is not an officially accepted acronym [5]. A generic classification of UAV systems is shown in Figure 1.

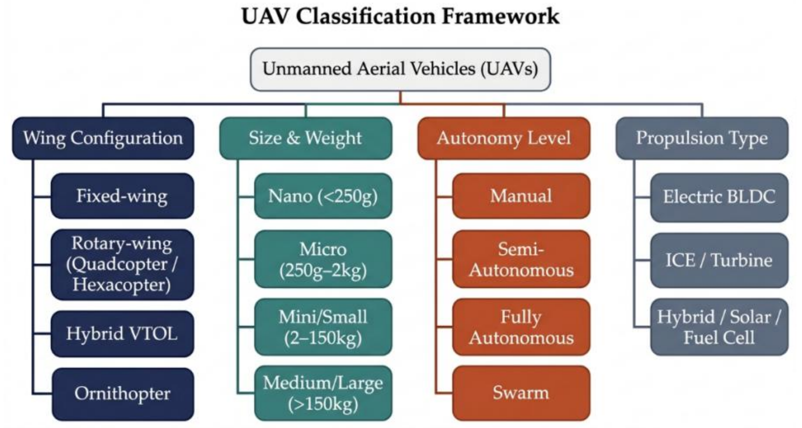

Figure 1: Generic classification of UAV systems

A. By Wing Configuration

Fixed-wing UAVs offer high aerodynamic efficiency and long endurance, making them ideal for long-range surveillance and wide-area mapping, But they require runways or catapult systems for launch [4,6]. Rotary-wing platforms like quadcopters, hexacopters, and octocopters provide VTOL capability and precise hover at the cost of shorter endurance, making them optimal for delivery, inspection, and confined-space operations [1,6]. Hybrid VTOL designs combine fixed-wing cruise efficiency with rotary-wing launch and recovery flexibility. This is the configuration increasingly favoured for both commercial logistics and military applications [6]. Flapping-wing ornithopters, inspired by birds and insects have been studied extensively. This has led towards the bioinspired aerodynamic and structural properties [2]. It offers low acoustic and visual signatures suited to covert and ecology-sensitive deployments.

B. By Size and Weight

UAV size spans an extraordinary range [5,6,9]. Nano-class drones (under 250 g) include insect-scale flapping-wing designs explored for indoor surveillance and biomedical nano-applications [5,21]. Micro-class platforms (250 g–2 kg) encompass consumer quadcopters. Mini and small-class systems (2–150 kg) address tactical military, commercial agriculture, and logistics roles [6,9]. Medium and large-class systems (150 kg to over 14,000 kg) encompass strategic military platforms such as the Global Hawk and MQ-9 Reaper [6,16]. Regulatory frameworkslike FAA, EASA, DGCA have imposed distinct operational requirements based on maximum take-off weight [9,22].

C. By Autonomy Level

Manual UAVs require continuous pilot input for all the flight parameters [5]. Semi-autonomous platforms incorporate stabilisation, GPS-hold, and waypoint navigation while retaining human oversight for mission decisions [1,8]. Fully autonomous systems execute complete mission profiles including take-off, navigation, task execution, and landing. This is without real-time human intervention. And executed by leveraging AI-based path planning and onboard decision-making operations thereby enabling Human-Out-of-Loop (HOL) intelligent & autonomous operations [1,8]. Swarm drones which add a collective intelligence layer using distributed algorithms enable coordinated behaviour across multiple agents without centralised control. This is a paradigm receiving intense research and operational investment [8,23].

D. By Propulsion

Electric brushless DC (BLDC) motors driving fixed or variable-pitch propellers dominate consumer and tactical UAV platforms [4]. Internal combustion engines (ICE) and turbojets are used for medium-endurance and high-speed platforms respectively [4]. Solar panels, hydrogen fuel cells, and tethered power systems are pursued for long-endurance and persistent surveillance missions. Such long endurance vehicle performance is being limited by the battery energy density. This has emerged as the principal performance bottleneck [3,4]. The power systems whether battery, solar, or nuclear micro-power are defining design choice shaping endurance, payload capacity, and operational suitability [5].

TABLE II: UAV Classification Framework: Wing Type, Size, Autonomy, and Propulsion

Classification Axis	Category	Description / Examples
Wing Type	Fixed-wing	High endurance, long range; requires runway or catapult launch [4,6]
Wing Type	Rotary-wing	Quadcopter, hexacopter :VTOL, stable hover, ideal for delivery and inspection [1,6]
Wing Type	Hybrid VTOL	Combines fixed-wing cruise efficiency with rotary VTOL capability [6]
Wing Type	Ornithopter	Flapping-wing, bio-inspired; low acoustic and visual signature [2]
Size / Weight	Nano (<250 g)	Insect-scale; indoor surveillance, nano-biomedical applications [5,21]
Size / Weight	Micro (250 g–2 kg)	Consumer quadcopters; photography, hobby, light inspection [6,9]
Size / Weight	Mini / Small	2–150 kg; tactical military ISR, commercial agriculture, logistics [6,9]
Size / Weight	Medium / Large	150 kg–14+ t; strategic platforms e.g. Global Hawk, MQ-9 Reaper [6,16]
Autonomy Level	Manual	Continuous pilot input required for all flight parameters [5]
Autonomy Level	Semi-autonomous	GPS-hold, stabilisation, waypoint navigation with human oversight [1,8]
Autonomy Level	Fully autonomous	Complete mission execution: Take-off, navigation, task, landing [1,8]
Autonomy Level	Swarm	Distributed collective intelligence; no single point of control [8,23]
Propulsion	Electric (BLDC)	Brushless DC motors: Dominant for consumer and tactical UAVs [4]
Propulsion	ICE / Turbine	Internal combustion or turbojets for high speed / long endurance [4]
Propulsion	Hybrid / Solar	Extended endurance via solar harvest or hydrogen fuel cells [3,4]

IV. FUNCTIONAL SUBSYSTEM ARCHITECTURE

Most UAVs, irrespective of their specific application, share a common seven-subsystem architecture. They are propulsion, power management, computing, communication, sensing, navigation and control, and payload [5,6]. Understanding this architecture is essential both for system design and for appreciating where technological advances are most urgently needed. The general overview of an Unmanned Aerial Vehicle is shown in Figure 2.

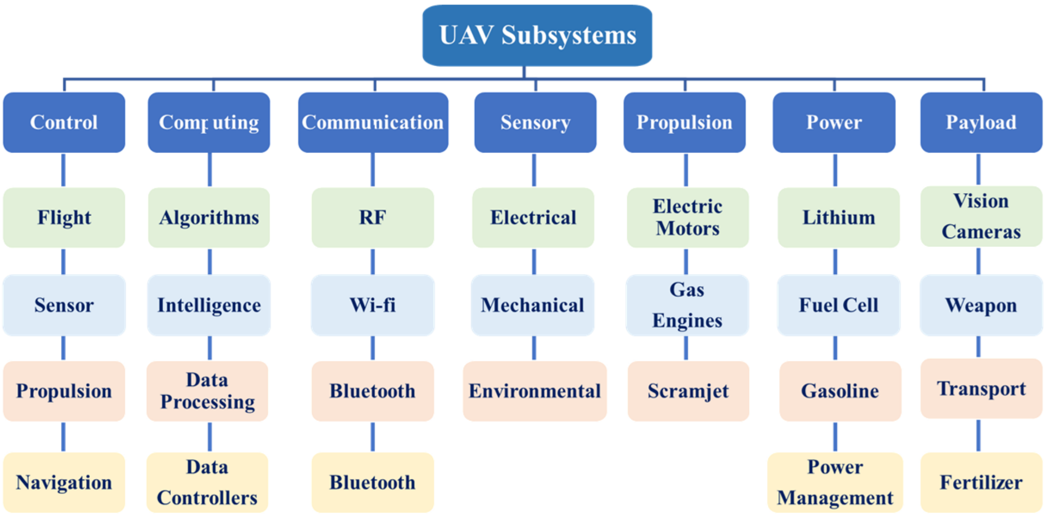

Figure 2: General Overview of UAV Subsystems

A. Propulsion Subsystem

The propulsion subsystem provides motive force for flight [4]. For aerial UAVs this typically comprises BLDC motors driving propellers, or turbojets for high-speed platforms [4]. The type of propulsion depends on the operational environment. Propellers driven through DC or brushless DC motors are generally for aerial platforms. ICE for medium-endurance systems, and thrusters for hybrid aquatic-aerial vehicles [4,5]. Distributed electric propulsion arraysusing multiple smaller motors are also utilized to improve redundancy and aerodynamic controllability [4]. Advances in permanent magnet motor materials, motor controller efficiency, and thermal management are active research frontiers [4].

B. Power Management Subsystem

The power system encompassing energy storage, generation, and management electronics is the primary constraint on UAV endurance [3]. Lithium polymer (LiPo) batteries dominate current consumer and tactical platforms, typically yielding 20–40 minutes for quadcopters [3]. Solar photovoltaic panels, hydrogen fuel cells, and tethered ground power are investigated for extended persistence [3]. Battery management systems (BMS) monitor cell voltage, temperature, and state-of-charge to maximise safety and service life [3]. Solid-state batteries, wireless power transfer, and in-flight solar harvesting are identified as critical research priorities for endurance extension [3,6].

C. Computing Subsystem

The onboard computing subsystem executes flight control algorithms, sensor fusion, path planning, and increasingly, onboard AI inference [1,6]. Modern flight controllers implement real-time operating systems on ARM-based processors; edge AI accelerators such as NVIDIA Jetson and Google Coral enable onboard deep learning inference. This is mainly for object detection and semantic segmentation without reliance on ground-link latency [1,8]. Neuromorphic processors which mimic biological neural circuit architecture are an emerging paradigm offering energy-efficient and event-driven computation. This could dramatically reduce onboard power consumption while enabling human-like perceptual reasoning [8,24].

D. Communication Subsystem

Communication links provide command-and-control (C2) uplinks and telemetry/data downlinks between the UAV and its Ground Control Station (GCS) [7,10]. Technologies span radio frequency (RF) links, satellite communication (SATCOM), 4G/5G cellular networks, and mesh network protocols for swarm coordination [7,10]. The integration of UAVs into 5G networks enables beyond-visual-line-of-sight (BVLOS) operations with low-latency control and high-bandwidth data streaming [7,10]. Resistance to jamming, spoofing, and adversarial interference in contested electromagnetic environments remains a critical ongoing research challenge [10].

E. Sensory Subsystem

The sensory subsystem provides situational awareness of the UAV's own state and its operational environment [6,11]. Inertial Measurement Units (IMUs) like accelerometers, gyroscopes, and magnetometers provide attitude and heading data [6]. GPS/GNSS receivers supply absolute position. Optical cameras (RGB, multispectral, thermal, hyperspectral), LiDAR, and radar sensors enable a wide range of mission functions from crop health mapping to obstacle avoidance [6,11,12]. Sensor fusion algorithms including Extended Kalman Filters and factor graph optimisation integrate these diverse data streams into robust state estimates [6].

F. Navigation and Control Subsystem

The navigation and control subsystem translates mission objectives and sensor data into actuator commands [1,6]. Classical PID (Proportional-Integral-Derivative) controllers remain widely used for inner-loop attitude stabilisation [1]. Model Predictive Control (MPC) enables trajectory optimisation under constraints; Simultaneous Localisation and Mapping (SLAM) enable navigation in GPS-denied environments [1,6]. Deep Reinforcement Learning (DRL) is increasingly applied to learn complex flight manoeuvres and adaptive mission planning policies directly from operational experience [1,8]. The flight controller, with AI/ML for autonomy combined with communication links for command and telemetry, constitutes the intelligent operational core of the modern UAV [5].

G. Payload Subsystem

The payload defines the UAV's mission utility. Cameras and gimbals are used foror aerial photography and inspection. LiDAR scanners for 3D mapping and location. Spray nozzles and tanks are used for agricultural application. Delivery packages for logistics systems.Weapons systems and electronic warfare equipment are for defence. And scientific instruments are used for environmental, atmospheric, or space research [5,6,12]. Payload integration imposes constraints on weight, power budget, centre-of-gravity, and aerodynamic profile, requiring careful co-design with the airframe and propulsion system from the earliest design stages [4,6].

V. CURRENT APPLICATIONS: STATE OF THE ART

UAV technology has transitioned from a predominantly military domain to a diverse commercial and civilian ecosystem spanning ten major application areas [5,8,9]. The global commercial drone market was valued at approximately USD 26 billion in 2023 and is projected to exceed USD 55 billion by 2030, driven by expanding civilian deployments [9,17]. A block diagram showing the current application of UAV systems is shown in Figure 3.

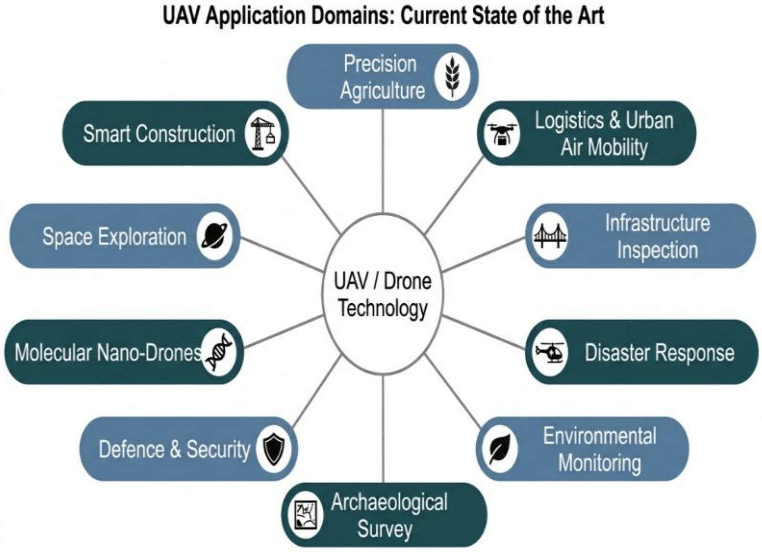

Figure 3: Current state of the art applications of UAV technology

A. Precision Agriculture

Agricultural drones are redefining farming practices by enhancing efficiency, precision, speed, and sustainability [5,12]. UAVs are deployed for crop monitoring, soil analysis, planting, spraying pesticides or fertilisers, and assessing crop health using multispectral or thermal imaging [5,12]. Equipped with GPS and enabled by machine learning algorithms, drones provide real-time survey data across large fields. They identify stressed plants through thermal cameras, monitor irrigation systems, and generate actionable intelligence to optimise yields and reduce wastage [5,12]. Labour and time cost reductions allow for higher profitability, making drones an essential component of industrial-scale farming [5,12].

AI-based weed and pest detection algorithms trained on UAV-acquired multispectral imagery can identify problem areas with high precision, enabling targeted intervention that dramatically reduces pesticide and fertiliser volumes compared to blanket application [12]. Automated irrigation scheduling and GPS-guided variable-rate application for seeding, spraying, and fertilising at exact prescription rates across the field further conserve resources and improve environmental outcomes [5,12]. Drones are becoming an essential component of industrial-scale farming and are central to precision agriculture's ambition to produce more with less [5,12].

B. Logistics, Delivery, and Urban Air Mobility

Last-mile delivery represents one of the most commercially significant drone frontiers [5,17]. Amazon Prime Air, Wing (Alphabet), Zipline, and Manna Drone Delivery have received regulatory approval for limited commercial drone delivery operations [17]. Zipline has demonstrated particular humanitarian impact in healthcare logistics. This includes delivering blood products, vaccines, and medicines to remote clinics in Rwanda, Ghana, and Nigeria.This has demonstrated that drone logistics can address critical infrastructure gaps in developing economies [17].

Urban Air Mobility (UAM) extends the drone logistics vision to passenger transport [5,9]. Companies including Joby Aviation, Lilium, Archer, and Volocopter are developing electric vertical take-off and landing (eVTOL) aircraft for urban passenger movement [9,22]. These aerial corridors will enable drone taxis, medical evacuations, and rapid freight delivery, dramatically reducing ground traffic congestion [5]. UAM frameworks incorporate 5G/6G communication, edge computing, and decentralised flight coordination protocols. These regulations and structural guidance are aiming for real-time route optimisation, obstacle avoidance, and inter-drone communication. These have necessitated new regulations, vertiport urban infrastructure, and airspace zoning [5,7,10,22]. Integration with autonomous vehicle fleets for hybrid air-ground delivery chains represents a near-term commercialisation pathway [5,17].

C. Infrastructure Inspection and Construction

Drones equipped with high-resolution cameras, LiDAR, and thermal sensors are deployed for inspecting power lines, wind turbine blades, oil and gas pipelines, bridges, and building facades. These tasks that are costly, dangerous, and slow when performed by human inspectors are being replaced with drone technologies [8,25]. AI-powered defect detection algorithms identify cracks, corrosion, delamination, and thermal anomalies with accuracy comparable to experienced human inspectors, at a fraction of the time and cost [8,25].

In construction, drones perform aerial surveying and high-resolution 3D mapping, generate as-built photogrammetric models, monitor site progress against plans, and support Building Information Modelling (BIM) workflows [5,8]. Real-time structural health monitoring of active infrastructure and autonomous delivery of tools and materials at worksites are emerging capabilities that could fundamentally transform construction site logistics and safety management [5].

D. Disaster Response and Humanitarian Operations

UAVs have demonstrated significant operational value in disaster response scenarios, where speed of deployment and access to dangerous or inaccessible terrain are critical [8,18]. Following the 2015 Nepal earthquake, 2019 Mozambique Cyclone Idai, and numerous other catastrophes, drones were deployed for damage assessment, survivor identification using thermal imaging, communication relay, and emergency supply delivery [8,18]. The ability to rapidly generate geospatial data including orthomosaics, digital elevation models from drone surveys enables faster and more accurate coordination of humanitarian relief

During the COVID-19 pandemic, drones were deployed across China, India, South Korea, and multiple African nations for disinfection spraying, temperature screening of public spaces, public announcement broadcasts, and contactless delivery of essential medical supplies [8,18]. This extensive operational experience accelerated regulatory approvals for drone operations in urban environments across multiple jurisdictions and demonstrated the value of maintaining drone capability for public health contingencies [8].

E. Environmental Monitoring and Wildlife Conservation

Drones equipped with thermal cameras, infrared sensors, and AI-based pattern recognition are being deployed to monitor deforestation rates, detect wildfires in their earliest stages, track animal population dynamics, and prevent wildlife poaching [5,11]. Their ability to access remote and ecologically sensitive terrains makes them indispensable for real-time ecological monitoring and climate-related research [5,11]. Anti-poaching operations in South Africa's Kruger National Park and Kenya's Maasai Mara have used fixed-wing and rotary UAVs to patrol vast protected areas with significantly reduced human resource requirements [11].

Marine research UAVs monitor coral reef health, track whale and dolphin populations, sample ocean surface conditions, and assess the spatial extent and composition of marine plastic pollution. These monitoring at scales and resolutions previously unattainable [11]. For climate research, drones provide atmospheric sampling capabilities like measuring greenhouse gas concentrations, particulate matter, and aerosol distributions at altitudes and locations impractical for conventional research aircraft or ground stations [11]. AI-driven ecosystem monitoring enables continuous, automated detection of ecological change in near-real time [5,11].

F. Archaeological Survey and Cultural Heritage

Drones integrated with LiDAR and high-resolution photogrammetry tools are revolutionising archaeological studies by revealing buried structures, ancient roadways, and settlement patterns that are invisible at ground level [5,25]. These UAVs can access remote or difficult terrain, creating detailed 3D maps without intrusive excavation; their use accelerates survey timescales from seasons to days, improves spatial accuracy, and aids in preserving delicate sites from disturbance [5,25].

The transformative potential of drone-based archaeological survey was dramatically demonstrated when researchers using airborne LiDAR discovered previously unknown ancient Maya cities beneath dense Guatemalan jungle canopy, revealing settlement patterns invisible to conventional ground survey [25]. Drone-based photogrammetry and 3D point cloud generation support detailed stratigraphic analysis and long-term site management, providing a permanent high-resolution digital record of cultural heritage sites threatened by climate change, development, or conflict [25].

G. Defence and Security Applications

Military UAV applications continue to evolve at pace [5,16,18]. The ongoing conflict in Ukraine has provided extensive operational evidence of tactical drone capabilities like reconnaissance, artillery spotting, electronic warfare, and direct munitions delivery using low-cost commercial quadcopters modified for combat [18]. This has prompted a wholesale reassessment of drone doctrine among all major military powers, with particular focus on counter-drone (C-UAS) systems comprising radar detection, radio-frequency jamming, directed energy weapons, and kinetic interceptors [9,16,18].

Loitering munitions like the Israeli Harop, American Switchblade, and similar systems combine the persistent ISR endurance of a UAV with the precision strike of a guided missile, eliminating the need for a dedicated warhead delivery aircraft [16,18]. AI-controlled autonomous target recognition and engagement is advancing rapidly, raising fundamental questions about accountability and the role of human judgment in lethal decision-making that international humanitarian law is only beginning to address [18,22].

H. Molecular and Nano-Scale Drone Applications

Among the most innovative concepts emerging from recent research is the exploration of molecular or nanoscale drones that could be introduced into the human body [5,21]. These microdrones could navigate through blood vessels, target specific cells for drug delivery, perform in-situ diagnostics, or assist in neural and muscular interfacing. This is a convergence of nanotechnology and biomedicine that could revolutionise personalised healthcare by offering unprecedented precision in both monitoring and intervention [5,21].

While fully functional medical nanodrones remain a future prospect, micro-scale robotic capsules for targeted drug delivery and minimally invasive surgery are already entering clinical trials [21]. Magnetically guided microrobots have demonstrated navigation through the eye's vitreous fluid for retinal drug delivery in laboratory settings [21]. The convergence of microrobotic capabilities with AI-driven onboard control, wireless power delivery, and biocompatible materials is progressively closing the gap between scientific concept and clinical reality [5,21].

I. Space Exploration Drones

NASA's Ingenuity helicopter which has achieved the first powered aircraft flight on another planet (Mars) in April 2021 has opened a new frontier for aerial robotics [20]. Operating in an atmosphere approximately 1% as dense as Earth's, Ingenuity validated the feasibility of rotary-wing flight in extreme low-density environments and has since completed dozens of scouting flights in support of the Perseverance rover [20]. Autonomous drone collectives for planetary exploration offer compelling advantages over single-rover systems: distributed redundancy, wider area coverage, simultaneous multi-point sampling, and relay communication across large distances [5,20].

Ion-propelled or solar-powered micro-drones could operate in the thin atmospheres of Mars or the dense methane atmosphere of Titan [5,20]. The Dragonfly mission to Saturn's moon Titan, scheduled for the 2030s, will deploy a rotorcraft-lander to explore methane lakes and search for biosignatures. It is a direct descendant of the capabilities demonstrated by Ingenuity [20]. Orbital drone swarm concepts envision constellations of small autonomous spacecraft for asteroid mapping, space debris remediation, and interplanetary resource surveillance [5,20].

J. Construction and Smart Infrastructure

Beyond the inspection role discussed above, drones are being integrated into active construction workflows as autonomous agents [5,8]. Aerial surveying at project inception generates centimetre-accurate topographic basemaps that inform earthwork planning. Throughout the construction cycle, drones conduct regular progress surveys, comparing as-built conditions to BIM models and flagging deviations in near-real time [8,25]. Autonomous delivery of tools, fasteners, and small material packages to elevated or remote areas of large construction sites reduces crane dependency and worker risk at height [5].

Looking towards smart infrastructure management, permanently installed drone-in-a-box systems like autonomous charging and storage stations co-located with infrastructure assets are entering commercial deployment for continuous structural health monitoring of bridges, dams, and transmission towers [8,25]. These systems schedule routine inspection flights autonomously, upload data to cloud analytics platforms, and alert operators when anomalies meeting predefined thresholds are detected. Thereby, enabling a shift from periodic manual inspection to continuous, data-driven asset management [8].

VI. FUTURE POSSIBILITIES AND EMERGING DIRECTIONS

The journey of drones from early military devices to intelligent, autonomous systems embedded in every sector of modern life demonstrates an extraordinary technological trajectory [5]. As UAVs increasingly operate in tandem with AI and communication technologies, their roles will expand beyond current imagination [5,8]. The following subsections synthesise the most significant emerging directions, grounded in active research and development. The emerging domains of application of UAV technology is shown in Figure 4.

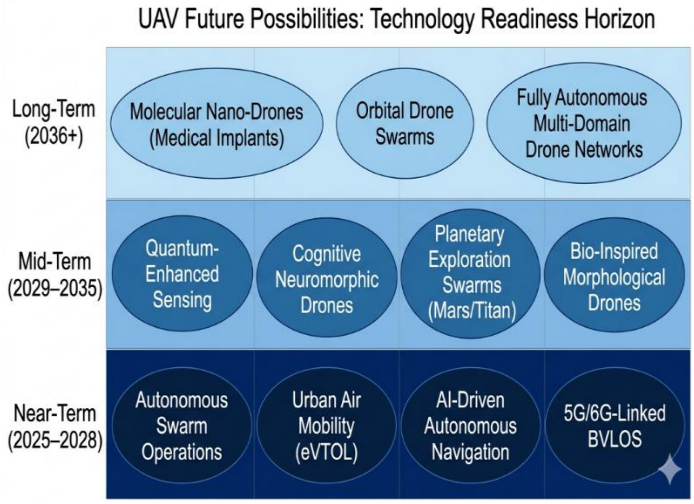

Figure 4: Future Applications of UAV Technology

A. Autonomous Swarm Intelligence

Swarm technology represents perhaps the most consequential near-term development in UAV systems. Inspired by the collective behaviour of social insects like ants, bees, termites. The swarm algorithms enable large numbers of individual drones to exhibit coordinated, emergent behaviours without centralised control [5,8,23]. Each agent operates according to local interaction rules, producing global patterns of organised activity that are robust to individual failures [23]. DARPA's OFFensive Swarm-Enabled Tactics (OFFSET) programme and the US Navy's Low-Cost UAV Swarming Technology (LOCUST) project have demonstrated coordinated swarms of over 100 drones operating in realistic environments [23].

For defence, drone swarms offer saturation attack capabilities, reconnaissance-in-force, and distributed electronic warfare. This with AI coordination providing resilience to jamming and enabling real-time mission adaptation [5,23]. Counter-swarm systems and intelligent swarm technologies are areas of intense global military investment [9,23]. For civilian applications, swarms enable coordinated forest fire mapping, environmental monitoring arrays, large-area search-and-rescue, and precision agricultural surveys covering vast areas in minimal time [5,8,23]. Mesh-network coordination and real-time mission reprogramming are key enablers of multi-domain swarm capability [5,7,23].

B. Bio-Inspired and Morphologically Adaptive Designs

Inspired by birds, insects, and marine life, future drones may adapt their structure and movement dynamically depending on the environment thereby blurring the boundary between air, water, and ground navigation [2,5]. Bioinspired multi-flapping-wing designs have been studied extensively for their aerodynamic efficiency at small scales and their potential for novel lift generation mechanisms unavailable to conventional fixed or rotary-wing configurations [2]. Ornithopters modelled on swifts, hawkmoths, and dragonflies produce substantially lower acoustic and visual signatures, making them suitable for ecological research, covert surveillance, and applications in noise-sensitive environments [2].

Self-reconfiguring morphological drones which are capable of changing their physical structure between narrow-gap traversal configurations and efficient long-range cruise shapes represent a further frontier [2,5]. Soft robotics principles, drawing on compliant materials and pneumatic actuation, enable drones that safely interact with humans and delicate environments without the impact hazard of rigid structures [2,8]. Research into aquatic-aerial hybrid vehicles like drones that can transition seamlessly between flight and underwater swimming could unlock entirely new classes of oceanographic and search-and-rescue mission [2,5].

C. Quantum-Enhanced Sensing and Secure Communication

Emerging quantum technologies are poised to dramatically extend UAV sensing and communication capabilities [5,24]. Quantum drones leveraging quantum sensors and communication links will enable ultra-precise navigation, imaging through dense obstructions such as smoke, foliage, and building materials, and secure quantum-encrypted data transmission resistant to any computational attack [5,24]. Quantum gravimeters and magnetometers can detect subsurface geological features, mineral deposits, buried infrastructure, and even submerged vessels with precision far exceeding classical sensors [24].

Quantum Key Distribution (QKD) implemented via satellite-to-drone or drone-to-drone optical free-space links offers information-theoretically secure communication channels that are unconditionally immune to interception [24]. Research groups in China and Europe have demonstrated QKD over drone-mounted optical terminals in field conditions, suggesting near-term deployability [24]. For military UAV communication in contested electromagnetic environments, quantum-secured links represent a strategically significant capability that adversary electronic warfare systems cannot defeat [10,24].

D. Cognitive AI and Neuromorphic Autonomy

Cognitive drones are the ones that are infused with neuromorphic processors and bio-inspired learning frameworks. These will mimic human-like perception, allowing contextual understanding, situational awareness, and real-time decision-making in complex, unstructured environments [5,8,24]. These systems could revolutionise disaster response, search and rescue, and personalised delivery, pushing UAVs toward fully autonomous agents that learn and adapt continuously across missions [5,8]. Intel's Loihi neuromorphic chip and IBM's TrueNorth demonstrate the hardware trajectory including SLAM and motor control algorithms have been demonstrated on neuromorphic substrates at orders-of-magnitude lower energy consumption than GPU-based alternatives [24].

Large Language Models (LLMs) and Vision-Language Models (VLMs) are beginning to be integrated into UAV systems as high-level mission planning interfaces. These are enabling operators to issue complex directives in plain language and have the drone autonomously generate, validate, and execute detailed flight plans [8,24]. Federated learning architectures allow drone fleets to collectively improve shared AI models from distributed field experience without centralising sensitive data, a capability critical for both privacy preservation and operational resilience [8,10]. Deep Reinforcement Learning for agile autonomous flight like obstacle racing, pursuit, formation flying continues to advance, with performance surpassing trained human pilots in controlled conditions [1,8].

E. Planetary and Space Exploration Drone Swarms

Building on the success of Ingenuity, swarms of autonomous drones for planetary exploration offer capabilities impossible for single-rover systems [5,20]. Envisioned as autonomous collectives operating as a coordinated unit, exploration swarms can map planetary surfaces across large areas simultaneously, search for subsurface resources using quantum or gravimetric sensors, and relay communication signals across distances beyond individual radio range [5,20]. Their redundancy and adaptability make them ideal for Mars, asteroids, and the moons of the outer solar system [5,20].

Ion-propelled or solar-powered units could sustain operations in the near-vacuum of Mars' upper atmosphere or in the low gravity of asteroid surfaces [5,20]. Potential applications include asteroid resource mapping for in-situ space resource utilisation, active terrain modification for future human landing site preparation, and distributed seismic monitoring networks on planetary bodies [5,20]. Orbital drone swarm concepts including constellations of small autonomous spacecraft functioning as an integrated remote sensing array are also proposed for space debris remediation and interplanetary surveillance [5,20].

F. Regulatory, Ethical, and Societal Dimensions

The rapid expansion of UAV capability poses significant regulatory, ethical, and societal challenges that must be addressed in parallel with technological development [9,22]. Privacy is a primary concern: the pervasive aerial surveillance capability of modern drones’ challenges established legal norms around personal privacy and freedom from observation [9,22]. Noise pollution from drone operations in urban environments is an emerging quality-of-life concern that will require acoustic design standards and operational zoning frameworks [9,22].

Airspace safety integration with respect to autonomous drones into airspace shared with manned aircraft requires the development of robust Detect-and-Avoid (DAA) systems and new UAV Traffic Management (UTM) paradigms [9,22]. Cybersecurity is a critical vulnerability. UAV systems dependent on GPS, radio command links, and networked AI inference are susceptible to GPS spoofing, RF jamming, and adversarial machine learning attacks [10]. The autonomous lethality of weaponised drone systems and the ethical questions this raises about human judgment, accountability, and proportionality in lethal decision-making are matters of urgent international policy attention [18,22]. A unified interdisciplinary approach encompassing engineers, ethicists, lawyers, policymakers, and affected communities are essential to shaping the future of drone technology responsibly [5,22].

VII. CONCLUSION

This paper has presented a comprehensive review of UAV technology spanning nine decades of historical development, a multi-axis classification framework, the seven-subsystem functional architecture of modern drones, ten current application domains, and six categories of future possibility. From the British Aerial Target of 1916 to AI-driven autonomous swarms of 2023, the trajectory of unmanned aerial technology is one of accelerating capability and expanding reach [5,14].

The ten application domains surveyed including precision agriculture, logistics and urban air mobility, infrastructure inspection, disaster response, environmental monitoring, archaeological survey, defence, molecular nano-drone medicine, space exploration, and construction illustrate that a technology has moved far beyond its military origins to become foundational civilian and scientific infrastructure. The innovative applications highlighted from discovering lost civilisations beneath jungle canopy with LiDAR-equipped UAVs, to navigating microrobots through blood vessels for targeted drug delivery, to mapping the surface of Mars from the air exemplify the extraordinary breadth of UAV technology's transformative potential.

The six future directions are swarm intelligence, bio-inspired adaptive designs, quantum-enhanced sensing and communication, cognitive AI and neuromorphic autonomy, planetary exploration swarms, and responsible governance. These are not speculative conceits but trajectories actively pursued in funded research and operational programmes worldwide. Drones are no longer isolated flying machines but they are complex systems embedded in the technological and strategic fabric, and their governance is a matter of global importance. Continued interdisciplinary research and development and a commitment to deploying these capabilities responsibly will determine whether their extraordinary potential is realised in the service of humanity .

VIII. ACKNOWLEDGEMENT

The authors gratefully acknowledge the support of ATLAS SkillTech University, Mumbai, and Symbiosis Institute of Technology, Pune Campus, Symbiosis International (Deemed University), Pune. The authors declare no conflicts of interest.

IX. REFERENCES

[1]. J. Peksa and D. Mamchur, "A Review on the State of the Art in Copter Drones and Flight Control Systems," Sensors, vol. 24, no. 11, p. 3349, 2024. https://doi.org/10.3390/s24113349

[2]. E. Billingsley, M. Ghommem, R. Vasconcellos, and A. Abdelkefi, "On the Aerodynamic Analysis and Conceptual Design of Bioinspired Multi-Flapping-Wing Drones," Drones, vol. 5, no. 3, p. 64, 2021. https://doi.org/10.3390/drones5030064

[3]. A. Pekias, G. S. Maraslidis, M. G. Tsipouras, F. N. Koumboulis, and G. F. Fragulis, "Power Supply Technologies for Drones and Machine Vision Applications: A Comparative Analysis and Future Trends," Telecom, vol. 4, no. 3, pp. 459–476, 2023. https://doi.org/10.3390/telecom4030024

[4]. B. Zhang, Z. Song, F. Zhao, and C. Liu, "Overview of Propulsion Systems for Unmanned Aerial Vehicles," Energies, vol. 15, no. 2, p. 455, 2022. https://doi.org/10.3390/en15020455

[5]. R. Henry and N. Zade, "From Inception to Innovation: A Comprehensive Overview and Future Vision for UAV/Drone Systems," Unpublished manuscript, ATLAS SkillTech University and Symbiosis Institute of Technology, 2024.

[6]. K. Osmani and D. Schulz, "Comprehensive Investigation of Unmanned Aerial Vehicles (UAVs): An In-Depth Analysis of Avionics Systems," Sensors, vol. 24, no. 10, p. 3064, 2024. https://doi.org/10.3390/s24103064

[7]. Y. Zeng, R. Zhang, and T. J. Lim, "Wireless Communications with Unmanned Aerial Vehicles: Opportunities and Challenges," IEEE Communications Magazine, vol. 54, no. 5, pp. 36–42, 2016. https://doi.org/10.1109/MCOM.2016.7470933

[8]. H. Shakhatreh et al., "Unmanned Aerial Vehicles (UAVs): A Survey on Civil Applications and Key Research Challenges," IEEE Access, vol. 7, pp. 48572–48634, 2019. https://doi.org/10.1109/ACCESS.2019.2909530

[9]. M. Mozaffari, W. Saad, M. Bennis, Y. Nam, and M. Debbah, "A Tutorial on UAVs for Wireless Networks: Applications, Challenges, and Open Problems," IEEE Communications Surveys & Tutorials, vol. 21, no. 3, pp. 2334–2360, 2019. https://doi.org/10.1109/COMST.2019.2902862

[10]. V.Hassija et al., "Fast, Reliable, and Secure Drone Communication: A Comprehensive Survey," IEEE Communications Surveys & Tutorials, vol. 23, no. 4, pp. 2802–2832, 2021. https://doi.org/10.1109/COMST.2021.3097916

[11]. T. F. Villa et al., "An Overview of Small Unmanned Aerial Vehicles for Air Quality Measurements: Present Applications and Future Prospectives," Sensors, vol. 16, no. 7, p. 1072, 2016. https://doi.org/10.3390/s16071072

[12]. U. R. Mogili and B. B. V. L. Deepak, "Review on Application of Drone Systems in Precision Agriculture," Procedia Computer Science, vol. 133, pp. 502–509, 2018. https://doi.org/10.1016/j.procs.2018.07.063

[13]. K. P. Valavanis and G. J. Vachtsevanos, Handbook of Unmanned Aerial Vehicles. New York, NY, USA: Springer, 2014.

[14]. U. Fahlstrom and T. Gleason, Introduction to UAV Systems, 4th ed. Chichester, UK: Wiley, 2012.

[15]. Y. Altshuler, A. Bruckstein, and I. Wagner, "Swarm Robotics for a Dynamic Cleaning Problem," in Proc. IEEE Swarm Intelligence Symposium, 2005, pp. 209–216. https://doi.org/10.1109/SIS.2005.1501627

[16]. R. J. Austin, Unmanned Aircraft Systems: UAVs Design, Development and Deployment. Chichester, UK: Wiley, 2010.

[17]. M. Tavana, K. Khalili-Damghani, F. J. Santos-Arteaga, and S. Rahimi, "Drone Shipping vs. Truck Delivery in a Cross-Docking System with Multiple Fleets and Shipments," Computers & Industrial Engineering, vol. 108, pp. 187–204, 2017. https://doi.org/10.1016/j.cie.2017.04.031

[18]. P. J. Zuluaga, "Unmanned Aerial Vehicles in Modern Warfare: Ethical, Legal, and Operational Considerations," Journal of Military Ethics, vol. 19, no. 1, pp. 34–51, 2020. https://doi.org/10.1080/15027570.2020.1734960

[19]. D. W. Casbeer, D. B. Kingston, R. W. Beard, and T. W. McLain, "Cooperative Forest Fire Surveillance Using a Team of Small UAVs," International Journal of Systems Science, vol. 37, no. 6, pp. 351–360, 2006. https://doi.org/10.1080/00207720500438480

[20]. J. N. Balaram et al., "Mars Helicopter Technology Demonstrator," in Proc. AIAA Atmospheric Flight Mechanics Conference, Kissimmee, FL, 2018, p. 0023. https://doi.org/10.2514/6.2018-0023

[21]. B. J. Nelson, I. K. Kaliakatsos, and J. J. Abbott, "Microrobots for Minimally Invasive Medicine," Annual Review of Biomedical Engineering, vol. 12, pp. 55–85, 2010. https://doi.org/10.1146/annurev-bioeng-010510-103409

[22]. Federal Aviation Administration, "Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap," U.S. Dept. of Transportation, 2nd ed., Washington, DC, 2018. [Online]. Available: https://www.faa.gov/uas/resources/policy_library

[23]. E. Ferrante and M. Dorigo, "Designing Swarm Robot Systems: From Properties to Behaviours," in Handbook of Collective Robotics. Singapore: Pan Stanford Publishing, 2014, pp. 1–38.

[24]. C. L. Degen, "Quantum Sensing," Reviews of Modern Physics, vol. 89, no. 3, p. 035002, 2017. https://doi.org/10.1103/RevModPhys.89.035002

[25]. T. G. Whitley et al., "Unmanned Aerial Vehicles (UAVs) in Archaeological Investigation," Journal of Field Archaeology, vol. 45, no. 7, pp. 471–485, 2020. https://doi.org/10.1080/00934690.2020.1713898

IJEAST

INTERNATIONAL JOURNAL
OF ENGINEERING APPLIED SCIENCE AND TECHNOLOGY

ABOUT IJEAST

International Journal of Engineering Applied Science and Technology (IJEAST) is a peer-reviewed, open access journal that publishes high-quality research papers in the field of Engineering, Applied Science and Technology.

IJEAST aims to provide a platform for researchers, academicians, and professionals to share their innovative ideas, research findings, and practical experiences with the global scientific community.

FOCUS AREAS

- Engineering
- Applied Science
- Technology
- Innovation & Development
- Interdisciplinary Studies

PEER REVIEWED
All submissions are rigorously peer reviewed to ensure quality.

OPEN ACCESS
Free and unrestricted access to research for all.

GLOBAL REACH
Connecting researchers and professionals worldwide.

TIMELY PUBLICATION
We ensure a swift and efficient publication process.

For more information, visit our website
www.ijeast.com

INTERNATIONAL JOURNAL
OF ENGINEERING APPLIED SCIENCE
AND TECHNOLOGY

✉ editor@ijeast.com
www.ijeast.com
India

2455-2143