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APPLICATION POTENTIAL OF UNMANNED AERIAL VEHICLES AND TRENDS IN THEIR DEVELOPMENT

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Abstract. This article examines the application potential and principal development trends of unmanned aerial vehicles across civilian, public-service, industrial, scientific, and defense-related domains. Particular attention is given to platform diversification, sensor and payload integration, artificial intelligence, autonomy, communications, energy efficiency, airspace integration, safety, cybersecurity, regulation, and human capital. The study applies a structured qualitative review of open official documents and peer-reviewed or professionally reviewed publications, combining international evidence with official sources from the Republic of Uzbekistan. The findings show that unmanned aerial vehicles are evolving from remotely piloted, task-specific platforms toward increasingly autonomous, networked, modular, data-driven aerial systems. Their strongest growth areas include precision agriculture, geospatial mapping, infrastructure inspection, environmental monitoring, emergency response, logistics, communications support, and selected security and defense functions. The article remains at the strategic, technological, regulatory, and systems-engineering level and does not address tactical employment procedures or operational vulnerabilities.

Keywords: unmanned aerial vehicles; drones; autonomous systems; artificial intelligence; remote sensing; precision agriculture; airspace integration; cybersecurity; regulation; Uzbekistan.

Annotatsiya. Ushbu maqolada fuqarolik, davlat xizmati, sanoat, ilmiy va mudofaa bilan bog'liq sohalarda uchuvchisiz uchish apparatlarining qo'llanilish salohiyati va asosiy rivojlanish tendentsiyalari ko'rib chiqiladi. Platformalarni diversifikatsiya qilish, sensorlar va yuklarni integratsiyalash, sun'iy intellekt, avtonomiya, kommunikatsiya, energiya samaradorligi, havo maydoni integratsiyasi, xavfsizlik, kiberxavfsizlik, tartibga solish va inson kapitaliga alohida e'tibor qaratilgan. Tadqiqotda ochiq rasmiy hujjatlar va ekspertlar tomonidan ko'rib chiqilgan yoki professional ko'rib chiqilgan nashrlarning tizimli sifatli tahlili qo'llaniladi, xalqaro dalillarni O'zbekiston Respublikasining rasmiy manbalari bilan birlashtiradi. Tadqiqot natijalari shuni ko'rsatadiki, uchuvchisiz uchish apparatlari masofadan boshqariladigan, vazifaga xos platformalardan tobora avtonom, tarmoqqa ulangan, modulli, ma'lumotlarga asoslangan havo tizimlariga o'tmoqda. Ularning eng kuchli o'sish sohalariga aniq qishloq xo'jaligi, geofazoviy xaritalash, infratuzilmani tekshirish, atrof-muhit monitoringi, favqulodda vaziyatlarga javob berish, logistika, kommunikatsiyalarni qo'llab-quvvatlash

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va tanlangan xavfsizlik va mudofaa funktsiyalari kiradi. Maqola strategik, texnologik, tartibga solish va tizim muhandisligi darajasida qolmoqda va taktik ishga yollash tartiblari yoki operatsion zaifliklarga to'xtalmaydi.

Kalit so'zlar: uchuvchisiz uchish apparatlari; dronlar; avtonom tizimlar; sun'iy intellekt; masofadan zondlash; aniq qishloq xo'jaligi; havo maydoni integratsiyasi; kiberxavfsizlik; tartibga solish; O'zbekiston.

Аннотация. В статье рассматриваются потенциал применения и основные тенденции развития беспилотных летательных аппаратов в гражданском секторе, сфере государственных услуг, промышленности, науке и оборонной отрасли. Особое внимание уделяется таким аспектам, как диверсификация платформ, интеграция датчиков и полезной нагрузки, искусственный интеллект, автономность, системы связи, энергоэффективность, интеграция в воздушное пространство, безопасность, кибербезопасность, нормативно-правовое регулирование и кадровый потенциал. Исследование базируется на структурированном качественном анализе открытых официальных документов и рецензируемых публикаций, сочетающем международный опыт с официальными данными Республики Узбекистан. Результаты исследования показывают, что беспилотные летательные аппараты эволюционируют от платформ с дистанционным управлением, предназначенных для выполнения конкретных задач, к все более автономным, сетевым, модульным и ориентированным на работу с данными авиационным системам. К числу наиболее перспективных областей их применения относятся точное земледелие, геопространственное картографирование, инспекция объектов инфраструктуры, мониторинг окружающей среды, реагирование на чрезвычайные ситуации, логистика, обеспечение связи, а также отдельные функции в сфере безопасности и обороны. Статья носит стратегический, технологический, регуляторный и системно-инженерный характер и не затрагивает вопросы тактики применения или уязвимости в ходе реальных операций.

Ключевые слова: беспилотные летательные аппараты; дроны; автономные системы; искусственный интеллект; дистанционное зондирование; точное земледелие; интеграция в воздушное пространство; кибербезопасность; нормативное регулирование; Узбекистан.

Introduction

Unmanned aerial vehicles have moved from a specialized aerospace technology to a broad family of digital platforms used for observation, measurement, transport, communications, inspection, public safety, and research. Their rapid diffusion has been enabled by advances in lightweight materials, electric propulsion, satellite navigation, inertial sensors, compact cameras, thermal and multispectral imaging, embedded computing, wireless communications, and cloud-based data processing [1], [2]. Recent reviews show that the center of innovation is shifting from the airframe alone toward

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integrated unmanned aircraft systems in which the vehicle, payload, communications link, software, data infrastructure, operator, and regulatory environment function as a single socio-technical system [1].

The application potential of unmanned aerial vehicles is therefore determined not simply by whether a platform can fly, but by whether it can collect or deliver useful information and services safely, economically, and predictably. In precision agriculture, they support crop health assessment, mapping, spraying, and field analytics; in infrastructure management, they enable inspection of power lines, bridges, pipelines, roofs, and industrial facilities; in environmental science, they provide high-resolution remote sensing; and in emergencies, they can rapidly survey inaccessible or hazardous areas [1], [3], [4]. Logistics and communications support are also developing, although their economic viability depends strongly on regulation, payload, endurance, route density, and integration with ground infrastructure [1].

At the same time, unmanned aviation introduces significant governance challenges. International Civil Aviation Organization guidance emphasizes that unmanned aircraft must be integrated into airspace in a safe, predictable, and regulated manner, while unmanned aircraft system traffic management requires harmonized information exchange between operators, authorities, and air navigation stakeholders [5], [6]. European regulation similarly reflects a risk-based approach in which operational conditions, aircraft characteristics, remote identification, competence, and risk assessment determine authorization requirements [7]. These trends show that technological capability and regulatory maturity are increasingly interdependent.

For Uzbekistan, the subject has gained practical importance. National rules distinguish autonomous and remotely piloted unmanned aircraft and establish technical and operational requirements for civil use [8]. Recent official initiatives also point to growing demand for trained external pilots and operators and to the need to align professional training with International Civil Aviation Organization approaches [9]. In parallel, national defense and military education reforms explicitly recognize the growing importance of unmanned aircraft, robotics, electronic systems, and digital technologies [10], [11]. This combination of civilian regulation, professional training, industrial potential, and defense modernization makes the topic relevant for both academic analysis and public policy.

The purpose of this article is to identify the principal application areas of unmanned aerial vehicles, determine the technological and institutional trends shaping their development, and assess the implications of these trends for Uzbekistan. The research questions are: (1) Which application domains currently generate the strongest practical value? (2) Which technological trends are most likely to define the next stage of development? (3) Which constraints remain decisive for large-scale adoption? and (4) Which policy and capability priorities are most relevant for Uzbekistan?

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Literature Review

The literature on unmanned aerial vehicles has expanded rapidly since the mid-2010s. A recent scoping review covering 109 sources published between 2015 and 2025 found that more than four-fifths of the reviewed studies appeared after 2020, reflecting the transition from proof-of-concept research toward operational deployment, autonomy, communications, sustainability, and regulation [1]. Another review of autonomous control examined 211 studies and identified particularly strong growth from 2014 to 2025, with path planning, obstacle recognition, safe landing, and visual control remaining central research themes [3]. These findings indicate that unmanned aerial vehicle research has entered a maturation phase in which reliability and integration are becoming as important as basic flight capability.

Platform architecture remains an important foundation. Multirotor aircraft dominate applications requiring vertical takeoff and landing, hovering, close inspection, and operation in confined areas, while fixed-wing systems generally provide greater endurance and area coverage. Hybrid vertical-takeoff-and-landing designs seek to combine these advantages [2], [12]. The choice of platform is therefore application-driven: mapping large agricultural areas requires different aerodynamic and payload characteristics from bridge inspection or emergency observation. Current engineering trends favor modular payload bays, lighter structures, more efficient propulsion, and increasingly standardized interfaces between flight controllers, sensors, and mission software [2].

Sensor and payload technology is a second major research stream. High-resolution optical cameras remain widespread, but multispectral, hyperspectral, thermal, LiDAR, atmospheric, and other specialized sensors increasingly transform unmanned aerial vehicles into flexible measurement platforms. In agriculture, payloads support crop monitoring, precision treatment, harvesting-related tasks, and transport; in other low-altitude scenarios they enable power-line inspection, emergency response, and logistics [4]. This trend shifts value creation from the aircraft itself toward the quality, calibration, fusion, and interpretation of collected data.

Artificial intelligence and autonomy form the most visible frontier. Recent reviews describe the use of machine learning and computer vision for navigation, object recognition, tracking, environmental interpretation, route optimization, communications management, and decision support [13]. Artificial intelligence can reduce operator workload and increase the ability of an unmanned aircraft to respond to changing conditions, but full autonomy remains constrained by verification, explainability, edge-computing limits, sensor uncertainty, communications loss, and the need for safe fallback behavior [3], [13]. Accordingly, near-term development is more accurately characterized as progressive autonomy and human-machine teaming rather than the elimination of human supervision.

Communications are also evolving. Traditional direct radio links are increasingly supplemented by cellular networks, satellite connectivity, mesh networking, and future fifth- and sixth-generation communication concepts. Research increasingly treats unmanned aerial vehicles both as users of communication networks and as temporary aerial communication nodes [14]. However, greater

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connectivity expands the cybersecurity attack surface and creates dependencies on spectrum availability, latency, coverage, authentication, and resilient network design. Therefore, communications innovation must be accompanied by cybersecurity engineering and operational risk management.

A further body of literature concerns airspace integration and regulation. International Civil Aviation Organization materials emphasize harmonization, safety, security, reliability, and real-time exchange of flight-intent and airspace-constraint information [5], [6]. European rules apply a risk-based framework and continue to evolve through updated acceptable means of compliance and specific operations risk assessment guidance [7]. The regulatory trend is thus moving away from simple distinctions between “drone” and “manned aircraft” toward a more structured model based on risk, identification, competence, operational environment, and digital traffic management.

Uzbek sources demonstrate a parallel institutional evolution. The national regulatory framework defines categories of unmanned aircraft according to control method and establishes requirements related to manufacturing documentation, mass, identification, and specific agricultural use [8]. In 2026, the Civil Aviation Agency discussed establishing a specialized organization for training unmanned aircraft external pilots, emphasizing risk-based training, professional competencies, instructor qualifications, and certification consistent with International Civil Aviation Organization requirements [9]. Official defense-related materials also report the expansion of unmanned aircraft training and modernization, confirming that the technology is becoming a cross-sector capability rather than a narrow aviation niche [10], [11].

The literature nevertheless contains several gaps. Developing-country contexts are underrepresented compared with North America, Europe, and East Asia [1]. Economic feasibility, lifecycle cost, interoperability, environmental impact, workforce development, and institutional readiness receive less attention than algorithms and platform performance. For Uzbekistan and comparable states, these gaps are important because successful adoption depends on adapting global technologies to national geography, regulation, industrial capacity, digital infrastructure, and human capital rather than merely importing platforms.

Methodology

This study uses a structured qualitative literature review and comparative thematic synthesis. The objective is not to estimate a single quantitative effect size, but to integrate evidence from technological, regulatory, institutional, and application-oriented sources. The source base includes: (1) official international aviation guidance and regulatory materials; (2) peer-reviewed review articles and recent scientific studies; (3) official legal and policy documents of the Republic of Uzbekistan; and (4) professionally reviewed materials relevant to unmanned aircraft development.

Sources were selected according to four criteria: relevance to unmanned aerial vehicle applications or development trends; credibility of the issuing institution or publication venue; recency, with preference for 2024-2026 sources where appropriate; and usefulness for strategic, technological,

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regulatory, or systems-level analysis. Older foundational sources were retained only where necessary to explain established concepts. Open sources were prioritized so that the evidence could be independently verified.

The analysis proceeded in three stages. First, evidence was coded into application domains: agriculture, mapping and remote sensing, infrastructure inspection, environment, emergency response, logistics, communications, science, public safety, and defense-related use. Second, technological trends were coded into platform design, payloads, autonomy, artificial intelligence, communications, energy, data processing, cybersecurity, and airspace integration. Third, institutional factors were coded into regulation, certification, training, privacy, economics, industrial capacity, and international standardization. The resulting categories were compared to identify convergent trends and persistent constraints.

A comparative assessment matrix was then constructed to summarize the relative maturity, value proposition, enabling technologies, and main constraints of major application domains. The table is interpretive rather than a numerical ranking; its purpose is to synthesize recurring evidence across the reviewed sources. Defense-related discussion is intentionally limited to broad capability, technology, education, and institutional trends. Tactical procedures, targeting processes, vulnerabilities, and instructions that could facilitate harmful operational use are outside the scope of the study.

Results and Discussion

The review identifies five interconnected development trends. First, unmanned aerial vehicles are becoming application ecosystems rather than standalone aircraft. Platform, payload, software, connectivity, cloud or edge processing, operator interfaces, and regulatory services increasingly determine performance together [1], [2]. This favors modular architectures that allow the same basic platform family to support different sensors and missions.

Second, the value of unmanned aviation is increasingly data-centric. In agriculture, environmental monitoring, mapping, and inspection, the principal output is often not flight itself but georeferenced, time-sensitive information. Higher-resolution sensors and artificial intelligence-assisted analytics can shorten the cycle from observation to interpretation, but data quality, calibration, interoperability, storage, privacy, and governance become correspondingly important [4], [13].

Third, autonomy is advancing incrementally. Computer vision, path planning, obstacle avoidance, safe landing, and onboard decision support are improving, yet the literature does not support a simple transition to unrestricted full autonomy [3]. Safety-critical operations still require reliable sensing, validated software, predictable fallback modes, and human oversight. Consequently, human-machine teaming and supervisory control are likely to remain dominant in many high-consequence applications.

Fourth, communications and airspace integration are becoming decisive scaling factors. Beyond-visual-line-of-sight operations, dense urban use, logistics, and large-area monitoring require dependable connectivity and coordinated traffic management. International Civil Aviation Organization guidance treats unmanned aircraft system traffic management as an information-sharing

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http://houghtonstreetreview.com/index.php/hsr

environment connecting flight intentions, constraints, operators, and aviation authorities [5]. This suggests that future growth will depend as much on digital aviation infrastructure as on airframes.

Fifth, regulation and professional competence are moving from peripheral issues to core components of the technology ecosystem. Updated European rules and Uzbekistan's national measures both demonstrate a trend toward risk-based authorization, identification, certification, and competency development [7], [8], [9]. As applications become more autonomous and networked, cybersecurity, privacy, software assurance, and data protection will become increasingly integrated into certification and organizational governance.

Table 1. Comparative assessment of major unmanned aerial vehicle application domains

Application domain	Primary value	Key enabling technologies	Development outlook	Main constraints
Precision agriculture	High-resolution crop observation and targeted field operations	Multispectral imaging, positioning, analytics, specialized payloads	High	Regulation, weather, payload/endurance, data interpretation
Mapping and remote sensing	Rapid collection of detailed geospatial data	Optical imaging, LiDAR, photogrammetry, navigation	High	Data quality, calibration, processing workload
Infrastructure inspection	Reduced exposure of personnel and faster condition assessment	Zoom/thermal cameras, stable flight, AI-assisted defect detection	High	Complex environments, certification, sensor reliability
Environmental monitoring	Frequent observation of ecosystems and hazardous areas	Multispectral/thermal sensors, environmental payloads, analytics	High	Endurance, weather, long-term data consistency
Emergency response	Rapid situational awareness in inaccessible or dangerous areas	Thermal imaging, communications, mapping, real-time video	High	Reliability, coordination, airspace deconfliction
Logistics and delivery	Fast movement of small, high-value or urgent payloads	Autonomy, navigation, fleet management, digital traffic services	Medium to high	Economics, noise, weather, regulation, beyond-visual-line-of-sight approval
Communic	Temporary aerial	Cellular/satellite links,	Mediu	Spectrum, endurance,

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ations support	connectivity and coverage extension	networking, positioning	m to high	network resilience, cybersecurity
Security and defense-related functions	Observation, training, communications support and other authorized capabilities	Sensors, secure communications, autonomy, data processing	Growing	Governance, cybersecurity, training, legal and ethical controls

Table 1 shows that the most mature and broadly scalable applications are those in which unmanned aerial vehicles replace expensive, repetitive, dangerous, or spatially inefficient data-collection tasks. Agriculture, mapping, inspection, environmental monitoring, and emergency response already have clear value propositions because aerial observation can be converted directly into measurable information. Logistics and aerial communications have strong potential but depend more heavily on beyond-visual-line-of-sight regulation, traffic management, network coverage, and favorable unit economics. Security and defense-related uses are also growing, but their sustainable development requires especially strong governance, cybersecurity, professional training, and legal oversight [10], [11].

For Uzbekistan, the evidence suggests a development path based on selective scaling rather than indiscriminate adoption. Agriculture and geospatial monitoring are particularly relevant because unmanned aerial vehicles can support large-area observation and data-driven resource management. Infrastructure inspection, emergency response, and environmental monitoring also offer strong public-sector value. The 2026 update to national rules, including identification-related requirements and differentiated provisions for agricultural unmanned aircraft, indicates that regulation is already adapting to practical use cases [8].

Human capital is equally important. The Civil Aviation Agency's 2026 discussion of a dedicated training organization for external pilots reflects the transition from informal operator skills toward standardized professional competencies [9]. In higher education and engineering, this implies a need for interdisciplinary programs combining aerodynamics, electronics, control systems, artificial intelligence, geoinformatics, communications, cybersecurity, aviation law, and safety management. National capability will depend not only on operators but also on maintenance personnel, software engineers, data analysts, instructors, regulators, and certification specialists.

The principal technical constraints remain energy density and endurance, weather sensitivity, communications reliability, sensor uncertainty, and safe autonomy [1], [3]. These constraints are interrelated: increasing payload can reduce endurance; greater autonomy requires more onboard computing and energy; higher connectivity can improve supervision but increase cybersecurity exposure. Future design therefore requires system-level optimization rather than maximizing a single performance parameter.

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The overall development trajectory can be summarized as a transition from remotely piloted aircraft toward intelligent aerial services. The aircraft becomes one node in a wider digital ecosystem that includes sensors, networks, edge and cloud computing, geographic information systems, traffic management, and organizational decision processes. This trend explains why future competitiveness will depend on software, data, standards, cybersecurity, and institutional capacity at least as much as on airframe manufacturing.

Conclusion and Recommendations

The study concludes that unmanned aerial vehicles are developing from specialized remotely controlled platforms into modular, connected, increasingly autonomous and data-centric aerial systems. Their application potential is broad, but the highest near-term value is concentrated in tasks where aerial access, rapid sensing, repeatability, or reduced human exposure create clear advantages. Precision agriculture, mapping, infrastructure inspection, environmental monitoring, emergency response, and selected logistics and communications applications are therefore likely to remain major growth areas [1], [4].

Artificial intelligence, onboard processing, advanced sensing, improved communications, digital traffic management, and progressive autonomy will shape the next stage of development. However, technical progress alone will not guarantee safe or economically sustainable adoption. Endurance, reliability, cybersecurity, privacy, certification, airspace integration, operator competence, and lifecycle cost remain critical constraints [3], [5], [7].

For Uzbekistan, five priorities are recommended. First, continue developing a risk-based regulatory framework aligned with International Civil Aviation Organization principles while preserving clear national requirements for identification, certification, and accountability [5], [8]. Second, expand standardized operator and specialist training, including safety management, human factors, cybersecurity, and data competence [9]. Third, support domestic research and engineering in payload integration, flight-control software, geospatial analytics, artificial intelligence, maintenance, and testing rather than focusing only on final platform acquisition. Fourth, prioritize civilian and public-service use cases with measurable economic or social benefits, especially agriculture, infrastructure, environmental monitoring, and emergency management. Fifth, establish secure data governance and interoperability standards so that unmanned aerial vehicle outputs can be integrated with national digital platforms and sectoral information systems.

In defense-related development, priority should be given to education, systems engineering, secure communications, resilience, testing, ethical governance, and human oversight. Official Uzbek sources already indicate increasing attention to unmanned aircraft specialists and broader military digitalization [10], [11]. A sustainable national approach should therefore connect technological modernization with professional education, domestic research, cybersecurity, and institutional learning.

Future research should include empirical studies of economic efficiency in Uzbek sectors, comparative testing under local climatic and geographic conditions, analysis of operator competency

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models, environmental lifecycle assessment, and evaluation of regulatory mechanisms for safe beyond-visual-line-of-sight operations. Such work would help translate global technological trends into evidence-based national policy and practical innovation.

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