AUVSI
RESEARCH

AUVSI UNCREWED INSIGHTS

2024 Volume 3

As the uncrewed systems industry continues to evolve, understanding the interplay between European manufacturing, government investments, and emerging technologies is essential. While some attention remains on military applications, the ripple effects extend across commercial and civil domains, shaping a dynamic and interconnected ecosystem.

The articles in this publication explore pivotal areas where challenges—whether in policy alignment, market harmonization, or technological integration—should be seen not as barriers but as opportunities to foster collaboration and innovation. These dynamics highlight the need for transatlantic cooperation and continued investment to unlock the full potential of uncrewed systems.

Key highlights include:

- An analysis of European drone technologies and use cases, revealing that European manufacturers account for 30% of all unique vehicle models historically produced. With France, the United Kingdom, and Germany leading the way, innovations in delivery, resilience, and autonomy are driving global impact across military and civilian markets.

- A review of the UK government's investments in uncrewed systems, which includes over £2 billion in contract awards from 2020 to 2024 and a £4.5 billion commitment, from the Ministry of Defense, for the coming decade. These investments signal a robust strategy to advance uncrewed capabilities, particularly in the air domain.

- An examination of generative AI's role in transforming uncrewed systems, showcasing its ability to enhance autonomy, improve predictive modeling, and strengthen cybersecurity. From simulating complex scenarios to advancing system reliability, generative AI is paving the way for the next generation of adaptive, resilient technologies.

As we prepare for the XPONENTIAL Europe Trade Fair and Conference in Düsseldorf, Germany, this coming February, the insights presented here serve as a foundation for meaningful dialogue and collaboration. With so many organizations operating across both Europe and the United States, there is a growing imperative to achieve harmonization and foster commercialization to meet shared goals.

By addressing these themes, this publication provides a lens through which to understand the industry's trajectory and its broader implications. We invite you to explore the research and to join us in February, where these critical conversations will continue, shaping the future of uncrewed systems.

KEELY GRIFFITH
VP Strategic Programs,
AUVSI

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ADVOCACY UPDATE

Trusted Programs

Uncrewed Maritime Systems (UMS) Operator Training & Certification

In October at AUVSI Defense, AUVSI announced the formation of a new committee dedicated to developing a comprehensive certification program for uncrewed maritime systems operators.

This initiative will focus on setting industry-wide standards for training, proficiency, and operational safety, ensuring that UMS operators are equipped with the necessary skills and knowledge to safely navigate the complex maritime environment.

The program will be the first of its kind, tailored specifically to the unique challenges faced by operators of uncrewed systems in the maritime domain. The program will cover areas such as navigation, vessel recovery, underwater communication, and coordination with manned vessels. The certification builds on the success of AUVSI's Trusted Operator program for drones.

> " **AUVSI has long been a leader in setting standards for uncrewed systems operations. With the growing use of maritime uncrewed systems across commercial, research, and defense sectors, it's essential that we establish a clear framework to ensure operator proficiency, safety, and compliance with regulatory requirements.**
>
> *– **Casie Ocana**, Director of Trusted Programs at AUVSI*

The committee will bring together experts from across the maritime and uncrewed systems sectors, including training providers, regulators, and industry leaders. Founding members include representatives from:

ABS | Chance Maritime | Embry-Riddle Aeronautical University | Exail | Hydrographic Department of the Naval Oceanographic Office | Kongsberg | Leidos | National Center for Autonomous Technologies | Ness-Sea Consulting | NOAA | SUNY Maritime College | University of Delaware | University of Southern Mississippi

Together, they collaborate to design a training and certification framework that meets the diverse needs of UMS operators and addresses the evolving demands of this rapidly expanding industry.

Key objectives of the committee include:

- Developing a tiered certification program with specific training and proficiency benchmarks for various levels of UMS operations
- Establishing standardized training modules that address both theoretical knowledge and practical skills
- Collaborating with regulatory bodies to ensure alignment with current and future regulations
- This certification initiative will provide a benchmark for training providers and operators, fostering trust across the industry and enhancing the safety, efficiency, and reliability of maritime uncrewed systems operations.

Learn more

ANALYSIS OF EUROPEAN DRONE TECHNOLOGIES AND USE CASES

Major Investments and Priorities

*Author: **David Klein**, Research Analyst for Systems, Technology, and Defense, AUVSI*

Key Takeaways

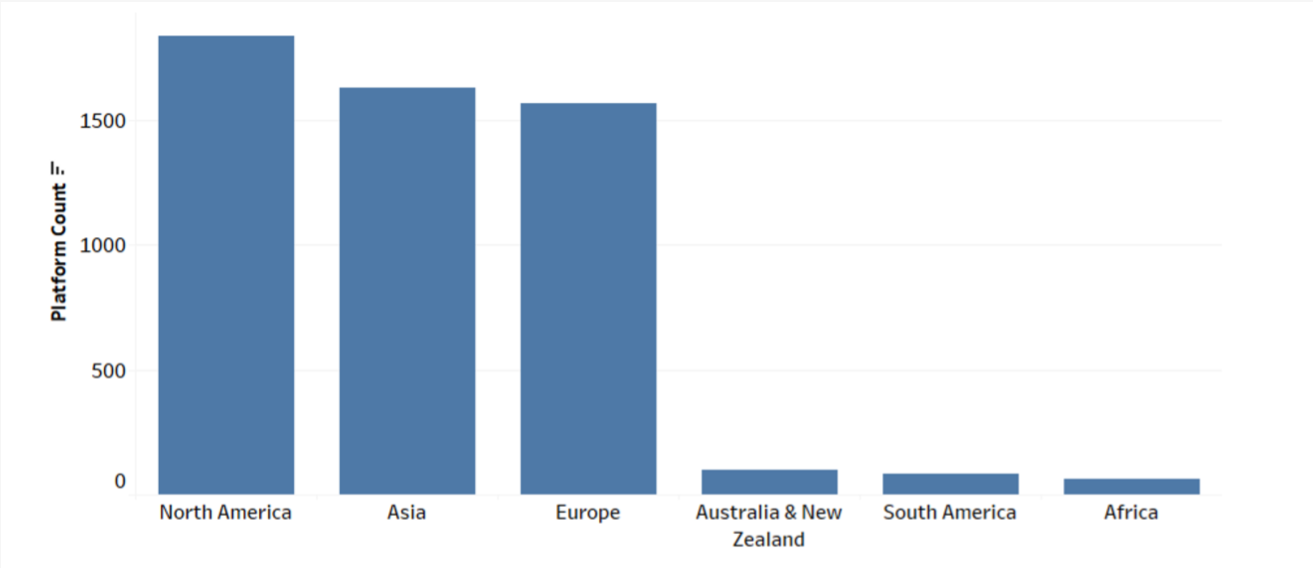
- European drone companies account for 30% of all unique vehicle models designed and manufactured historically, with France in the lead followed by the United Kingdom, Russia, and Germany.
- Drone delivery offers significant potential for economic and societal benefits with European manufacturers offering a range of systems to support short-, mid-, and long-range capabilities.
- European manufacturers supporting the military drone sector are focusing on system resilience, versatility, precision, cybersecurity, rapid deployment, endurance, payload capacity, and autonomy.
- European drone technology is being advanced with new and innovative technologies and use cases emerging which will continue to have a growing impact on commercial, military, and civil markets worldwide.

Introduction

The designs and technologies employed by manufactures of drones, or uncrewed aircraft, in a given region are influenced by a range of factors. These include regulatory guidelines, technological expertise, design philosophy and standardization, region-specific market applications, and environmental considerations. Using AUVSI's Uncrewed Systems and Robotics Database (USRD) as a reference, this article will uncover how some of these factors have shaped the drone technologies that are being developed in Europe and some of the key focus areas for future technological advancements.

Before we dig into specific vehicle designs and integrated component systems, let's take a macro-level approach to the data we capture in the USRD. Across more than a decade, over five thousand unique uncrewed aircraft models have been added to this resource along with information on their design, size and performance specifications, subsystem descriptions, manufacturer data, as well as noteworthy news releases covering contracts, operations, deliveries, technological advancements, etc. Historically, drone companies headquartered in Europe account for approximately 30% of all vehicle models manufactured and developed (Figure 1 which represents unique vehicle models – not sales volumes).

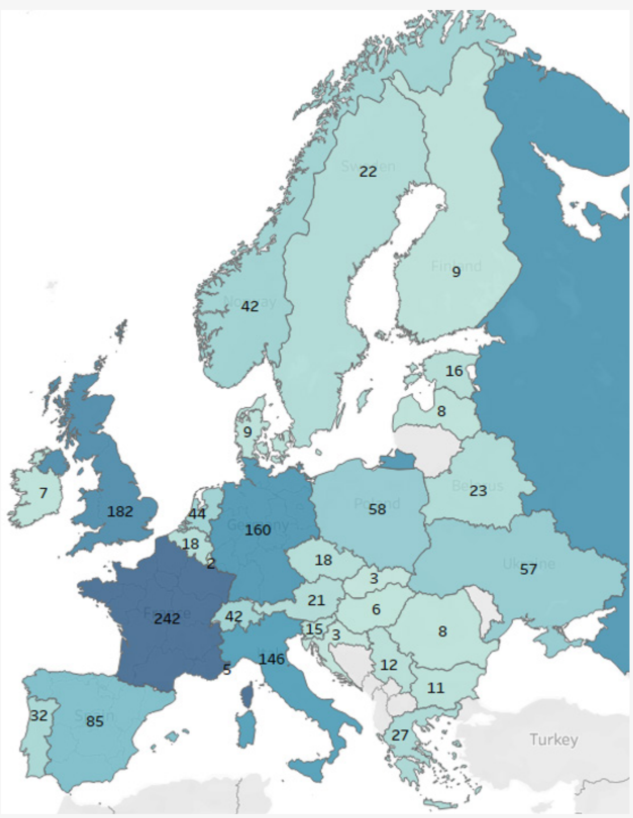
Fig 1: Count of unique drone models by continent in which the manufacturer is headquartered



Sources: https://www.auvsi.org/usrd, AUVSI Research

Looking at Europe specifically, there is a good distribution of drone models across the entire continent with the strongest representation in France, the United Kingdom, Russia, Germany, Italy, Spain, Poland, Ukraine, the Netherlands, and Switzerland (Figure 2). These top 10 countries account for nearly 75% of all European vehicle designs captured in the USRD historically.

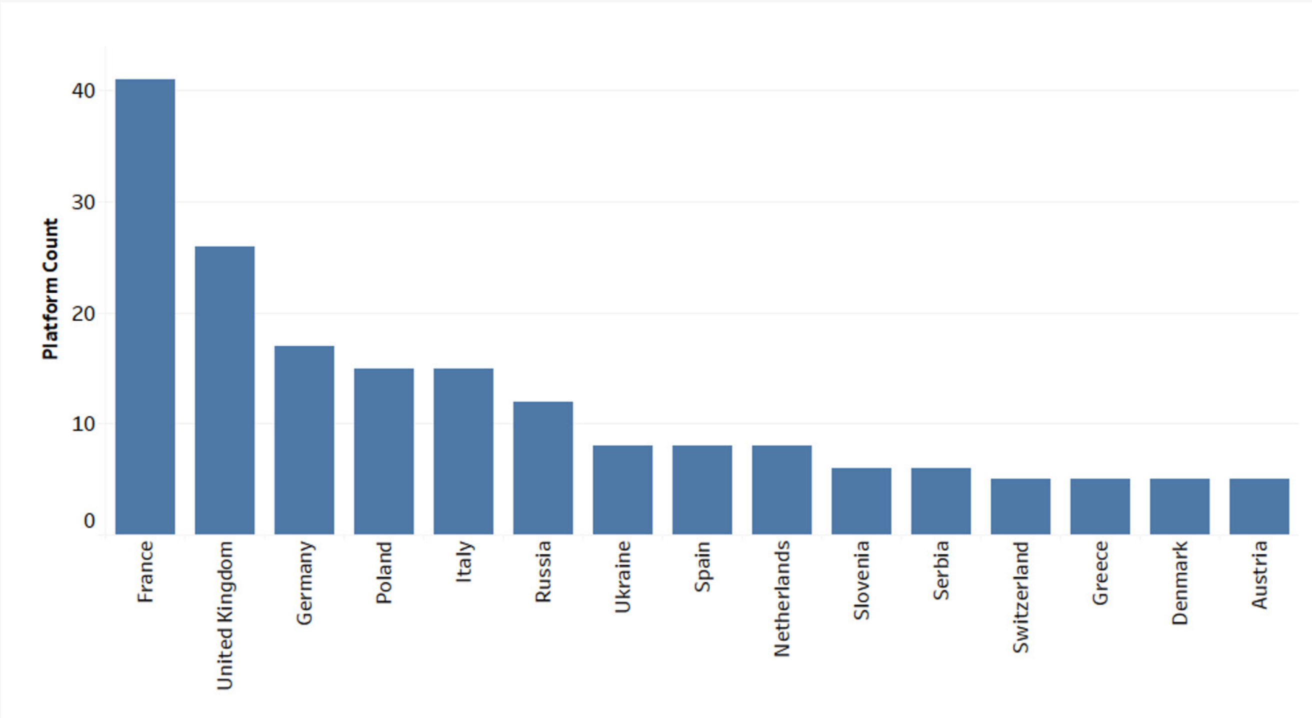
Fig 2: Count of unique drone models by country in Europe



Sources: https://www.auvsi.org/usrd, AUVSI Research

Filtering the USRD to include only platforms added to the USRD since 2022, the distribution slightly shifts, with Slovenia and Serbia entering the top 10, while France remains firmly in the lead. (Figure 3).

Fig 3: Count of drone models added to the USRD since 2022



Sources: https://www.auvsi.org/usrd, AUVSI Research

Drone use cases and their influence on vehicle design

In the more than ten years that the USRD has been active, AUVSI's research team has captured over 5,000 drone models globally. These platforms represent a wide range of sizes from those weighing less than one kilogram to many thousands of kilograms. They have also utilized a diverse range of designs from traditional fixed-wing aircraft to helicopters, multi-rotors, airships, ornithopters, tethered systems, as well as hybrid systems. Likely one of the most important factors that would impact a drone's size and design is the intended application(s). This in turn will define the potential mission profiles for a given operation encompassing key requirements like payload, flight distance and time, operational speed and altitude, environmental conditions, etc. In this section we will investigate some of the key applications being targeted by European manufacturers and offer some specific examples of drone models being employed in recent operations as well as their associated technical characteristics.

Drones used in delivery operations

Drone delivery (also referred to as logistics in the USRD) holds immense potential for economic and societal benefits. Manufacturers of these systems are seeking to cut costs, reduce delivery time, improve safety, efficiency, and environmental sustainability, increase access to remote locations, and enable further scalability relative to traditional delivery methodologies. Drones also open the possibility of novel and innovative business models like those offered by the growing e-commerce sector.

For the purposes of this article, drone delivery will be considered in three different categories based on the distance of the associated operation:

1 **Short-range delivery**

Short-range delivery (often called last-mile delivery) which generally refers to the transport of goods within a five-to-ten-kilometer (km) radius. These services have been used to deliver medical supplies, food, and other lightweight packages like those sold via e-commerce (less than 10 kilograms (kg)).

2 **Long-range delivery**

Long-range delivery refers to operations on the other side of the spectrum with the goal of competing with traditional delivery methods like manned aircraft. As such, this covers operations of more than one thousand kilometers and significantly larger cargo capacities (more than 100 kilograms)

3 **Mid-range delivery**

Mid-range delivery covers any operations within the bounds of the two categories noted above.

Short-range delivery

Given the significant demand for short-range delivery options in recent years, it comes as no surprise that companies have emerged across the globe to capture a portion of this market. While this application has not yet gained widespread adoption or been commercially scaled, there are many examples of successful deployments.

One such example can be found with the Irish company Manna Drone Delivery. In 2020, Manna reported partnerships with Ben & Jerry's ice cream, a local premium food brand Camile Thai, and the delivery platform Just Eat to offer sub-3-minute deliveries to University College Dublin.[1] The company has worked on continued expansion of its delivery operations in the years since and in 2023 reported that more than 150,000 flights had been logged in Europe. In the same press release it was also announced that North American operations had commenced in the Dallas/Fort Worth region.[2] More recently, Manna officially announced services covering a 100,000-household area in Dublin.[3] From a design perspective, the drone platform developed by Manna features a multi-rotor design which enables vertical takeoff and landing (VTOL) along with highly accurate positioning and hovering capabilities. This allows the vehicle to be deployed in most locations, navigate precisely to its destination, gently lower the customer's package to the ground using a tether, and then return to recharge and reload for the next delivery. The maximum travel distance for this vehicle is 16 km with an optimal range of approximately 5 km. With the drone operating in potentially populated locations, it is fitted with a range of redundant safety systems such as an automatic parachute in case of an incident. The propulsion system also utilizes redundancy with a coaxial design in the unlikely event of a motor failure. Manna's solutions have received approval to fly from the European Union Aviation Safety Agency (EASA), opening potential alternatives to traditional delivery methods.

Fig 4: The Manna delivery drone has been successfully deployed in Ireland and in 2023 commenced operations in Texas

Source: https://www.manna.aero/blanch, AUVSI Research

Long-range delivery

On the other side of the spectrum for drone delivery is the Black Swan long-range cargo aircraft which is being developed by the Bulgarian company Dronamics.[4] In 2022, the company announced that it received the European Union's Light UAS Operator Certificate (LUC) setting the stage for preliminary flights and future scalability. Dronamics noted that its potential network encompasses over 42 locations in 14 European countries.[5] In mid-2023 the Black Swan reportedly completed a successful first flight which served as an initial step towards technology validation.[6] From a design perspective, the aircraft utilizes a large fixed-wing configuration with a wingspan of about 16 meters. This offers increased aerodynamic efficiency relative to its rotary wing counterparts but does make the platform reliant on ground infrastructure like runways to takeoff and land. With respect to performance, the vehicle has a range of approximately 2,500 km while carrying an internal cargo capacity of 350 kg. With a focus on environmental and economic sustainability, Dronamics partnered with Cranfield Aerospace Solutions in 2022 to explore the integration of hydrogen fuel-cell technologies and advance towards a goal of zero-emissions aviation. In its current form, the Black Swan can fly using biofuel and synthetic fuel which lowers carbon emissions by 60% relative to other transport options currently available. It also cuts costs by up to 50% operating at an estimated €5/kg or $2.50/lb.

Figure 5: The Black Swan uncrewed cargo aircraft is being developed as a fuel-efficient long range system

Source: https://www.dronamics.com/theblackswan, AUVSI Research

Mid-range delivery

Drone solutions supporting the mid-range delivery category are being manufactured by a range of companies globally. Much of the demand for operations in this range was driven historically by the need for delivery of medical supplies to remote and often difficult to reach locations. In Europe, the German manufacturer Wingcopter GmbH was one of the first startups to initiate testing and deployment of their systems. In 2018, one of the first iterations of their market-ready drone platforms, the Wingcopter 178 (dubbed Parcelcopter 4.0 at the time) was tested over a six-month period and successfully recorded a total of approximately 2,200 km / 2,000 minutes of flights. Each delivery during this phase of testing took place over a flight distance of 60 km between the mainland to an island in Lake Victoria.[7] The company also reported operations in the following years that enabled the transport of prescription medications, patient blood samples, COVID-19 test kits, and other emergency medical supplies. In 2021, their new flagship drone model, the Wingcopter 198 was released offering improved performance and expanded capabilities like the world's first triple-drop mechanism that allowed the transport and delivery of three separate packages in one flight.[8] In more recent news, Wingcopter received an investment of €40m (US$43.6m) from the European Investment Bank (EIB) in mid-2023 to support increased production and operation. A few months later it was announced that new operations were being initiated to provide residents of remote and isolated villages in Germany with access to basic groceries (like eggs, milk, fruits, vegetables, etc.) and non-prescription medical supplies.[9] Mid-range delivery drones like those being developed by Wingcopter have taken a hybrid approach to their design using both a fixed wing for efficient forward flight as well as a multi-rotor configuration to enable VTOL and precise hovering capabilities. The Wingcopter 198 integrates a fully electric propulsion system which offers a range of just over 72 km while carrying a maximum payload of 4.7 kg. With an emphasis on safety and reliability, the drone employs multiple system redundancies for its power supply, communication systems, airspeed sensors, magnetometers, and navigation systems. It is also designed to employ high levels of autonomy to simplify the setup process, increase the efficiency of operations, and reduce the required oversight.

Fig 6: The Wingcopter 198 delivery drone optimized for healthcare logistics operations

Source: https://wingcopter.com/wingcopter-198, AUVSI Research

Drones being developed and deployed for military applications

Drones employed in the military market sector have proven their potential to improve the efficiency and effectiveness of missions on the battlefield. Through applications like surveillance, reconnaissance, targeting, offensive strikes, battle damage assessment, logistics, search and rescue, etc., this agile and rapidly developing technology has served as a force multiplier while reducing risk to soldiers. They have also become available at a more cost-effective price point relative to traditional solutions thus opening access to more resource-constrained governments and enabling operations that were not previously viable. Drones utilized by military organizations represent a diverse set of technologies with manufacturers focusing on system resilience, versatility, precision, cybersecurity, rapid deployment, endurance, payload capacity, and autonomy.

International conflicts like the ongoing conflict in Ukraine have highlighted the role of drones in current and future military operations. With the ability to provide enhanced situational awareness, conduct precision strikes, support battlefield logistics, and disrupt conventional warfare tactics, drone technologies are reimagining the ways that wars are being fought. For the purposes of this article, a few examples from European manufacturers will be examined along with their technical characteristics. We will also detail some recent updates pertaining to how they are being developed and deployed.

Drones for Intelligence, Surveillance, Reconnaissance, and Target Acquisition

The German company Quantum-Systems GmbH has experienced significant growth since it was founded almost ten years ago. With a focus on the development of electric VTOL (eVTOL) drones, this company's technologies have gained rapid adoption by a range of commercial and military organizations globally. One such platform, the Vector™ has been delivered to Ukrainian forces, the Dutch Ministry of Defense (MoD), the New Zealand MoD, the Australian Defense Force (ADF), the Romanian MoD, the German Armed Forces, and others. Featuring a hybrid airframe configuration, the drone offers VTOL using three rotors which can tilt from a vertical to a horizontal configuration transitioning the aircraft from stable hovering to efficient forward flight. This enables both precise, persistent surveillance in confined urban environments while hovering as well as long-range missions of up to three hours while in forward motion, all in the same platform. Vector™ can be transported and deployed by one person even in challenging terrain making this drone a great option for a wide range of intelligence, surveillance, reconnaissance (ISR), and security missions. Quantum-Systems is also actively engaged in the continued research and development of novel solutions which will enhance their drones' capabilities in challenging and increasingly complex environments. A couple recent initiatives that exemplify these efforts are detailed below:

- In July 2023, the Planning Office of the German Armed Forces awarded a contract to Airbus Defence and Space GmbH, Quantum-Systems GmbH, and Spleenlab GmbH. Through their combined expertise in trusted swarming algorithms, simulation environments, artificial intelligence (AI), edge computing, object recognition, and advanced navigation systems, the goal of this program is to demonstrate the AI building blocks that would enable swarms of tactical drones to function in complex, communication denied environments.[10] In September 2024 the results of this study titled KITU 2 (Künstliche Intelligenz für taktische UAS; Artificial Intelligence for tactical UAS) revealed that sophisticated deep-reinforcement learning techniques were employed to enable drones like the Vector™ to autonomously complete missions such as joint ISR and target acquisition in GPS-denied conditions.[11]

- In mid-2024, Quantum-Systems announced that an AI sensor upgrade called "Receptor AI" had been integrated on the Vector™ and was deployed for the first time in Ukraine. Based on the Jetson Orin Nvidia chip, this upgrade aids in optical (inclusive of infrared) navigation even at night and in poor visibility conditions while also offering automated AI-supported object recognition, classification, identification, and tracking.

Fig 7: The Quantum-Systems GmbH Vector™ 2-in-1 ISR System

Source: https://quantum-systems.com/vector/, AUVSI Research

Fig 8: The Donaustahl MAUS FPV drone used for reconnaissance and strike missions

Source: https://quantum-systems.com/vector/, AUVSI Research

Drones deployed as loitering munitions

Another use case which has had a profound impact on battlefield operations is the loitering munition. These platforms combine the versatility, precision, and control attributed to drones used in other applications while being equipped with highly destructive payloads to execute targeted strikes against an adversary. In many instances, loitering munitions can also be employed for ISR and scouting missions prior to detonation, further increasing their utility. Additionally, given their cost-effectiveness relative to alternative solutions, they can be deployed in vast quantities, or swarms, to overwhelm the enemy's defense systems. Some other ways that loitering munitions have influenced modern warfare include the ability for smaller units to independently deploy these systems without relying on decision-making and oversight from a higher command. They have also had a significant psychological impact on soldiers with the ever-present threat of a drone attack reducing morale and disrupting operational efficiencies.

One of the newer market entrants in this technology sector is the MAUS drone being manufactured by the German company Donaustahl.[12] While many of the loitering munitions developed globally have mimicked the form of a missile with a fixed wing design, a central fuselage, and a warhead integrated on the nose of the platform, the MAUS utilizes a quadrotor design which further increases its agility and precision. This drone is capable of reconnaissance and strike missions against personnel and armored vehicles while offering a maximum range of about seven kilometers and a modular quick release payload of 2.7 kg. The manufacturer has also reported promising experimentation with the integration of AI-supported detection software. In July 2024 a press release was issued which indicated that export approval had been granted to support an order by Ukraine's Kraken special operations unit, an independent reconnaissance and sabotage formation of the Main Directorate of Intelligence of the Ministry of Defense of Ukraine.[13]

MALE drones

Medium altitude long endurance (MALE) uncrewed aircraft represent the segment of the drone industry with the most extensive historical presence in military operations. With some of the first operational systems introduced in the late 1990s and early 2000s, MALE drones offered an alternative to manned aircraft for use in persistent surveillance and offensive strike missions. By providing extended endurance, reduced risk to personnel, and lower operational costs, these aircraft were rapidly adopted and integrated into military missions with United States Air Force. New entrants into this sector have surfaced globally in the years since as MALE systems will likely play an increasing role on the battlefield in future conflicts.

One of the most recent examples to emerge in the MALE category is the Aarok from the French manufacturer Turgis & Gaillard. Officially unveiled to the public in August 2023[14] and with initial ground tests including engine runs in early April 2024[15], this next-generation combat drone is being developed to deliver precise, powerful, low-cost long-range weaponry for multi-domain operations. The Aarok features a wingspan of nearly 22 meters, weighs 5.5 tons with over 1.5 tons of armament, and can fly for 24 hours at a cruise speed of 250 knots. Some of the other key features include a SATCOM datalink for operations worldwide, optronic sensors (EO/IR, long-range target illumination, automatic target tracking), multimode radar, precision-guided munitions, SIGINT sensors, and up to 16 air-to-ground missiles with a range of 15 km. As drone technologies like the Aarok continue to advance, they are expected to continue to play a pivotal and increasingly important role in military arsenals.

Figure 9: The Aarok next-generation combat drone.

Source: https://aarok.fr/en/, AUVSI Research

Other innovative technologies and use cases

The drone market for European manufacturers extends vastly beyond those technologies and use cases presented thus far. And while it is not within the scope of this article to cover them all, the final section will investigate some of the novel and cutting-edge solutions that are being developed and deployed.

Commercial solutions

The French startup HyLight is seeking to develop hydrogen fueled, electrically powered airships that can operate over hundreds of kilometers. In April 2024, the company announced a €3.7 million seed round to advance towards further development and certification. Future applications include aerial inspections and surveys of energy infrastructure like power lines, oil and gas pipelines, roads, and rail lines at significantly reduced costs relative to traditional methods.[16]

Figure 10: The HyLighter electric airship

Source: https://www.hylight.aero/technology, AUVSI Research

The Swiss-based company Verity has developed a self-flying warehouse drone to automate inventory management through autonomous, highly accurate data collection. In August 2024, it was announced that this solution would support Ikea's warehouses in Perryville, Maryland.

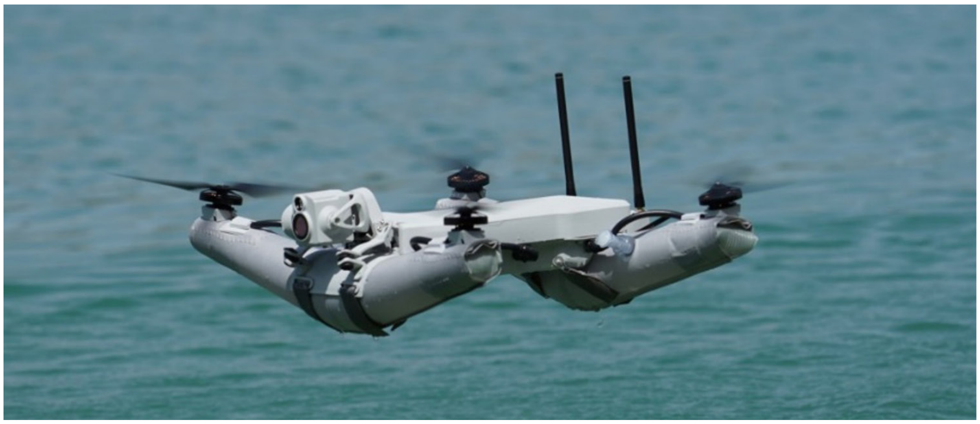
Figure 11: The Verity self-flying warehouse drone

Source: https://verity.net/automated-inventory-management-warehouse-drones-solution/, AUVSI Research

Military solutions

The DIODON HP30 manufactured by the French company DIODON Drone Technology[17] is the world's first inflatable waterproof microdrone intended for ISR operations in maritime environments. In August 2023, a successful demonstration was reported involving the release of the drone from a submarine operating at periscope depth. The drone then surfaced, inflated, and took off from the water after which it established a radio connection with a host boat enabling control from the submarine.

Figure 12: DIODON HP30 inflatable waterproof drone.



Source: https://bssholland.com/product/diodon-hp30-suas-inflatable/, AUVSI Research

The Longreach70, developed by BAE Systems and Sentinel Unmanned is an agile helicopter drone weighing less than 25 kg to facilitate improved situational awareness and laser target designation. In November 2023, the platform conducted a first-of-its-kind operation in the United Kingdom by firing a Class IV laser on an aircraft in this weight range.

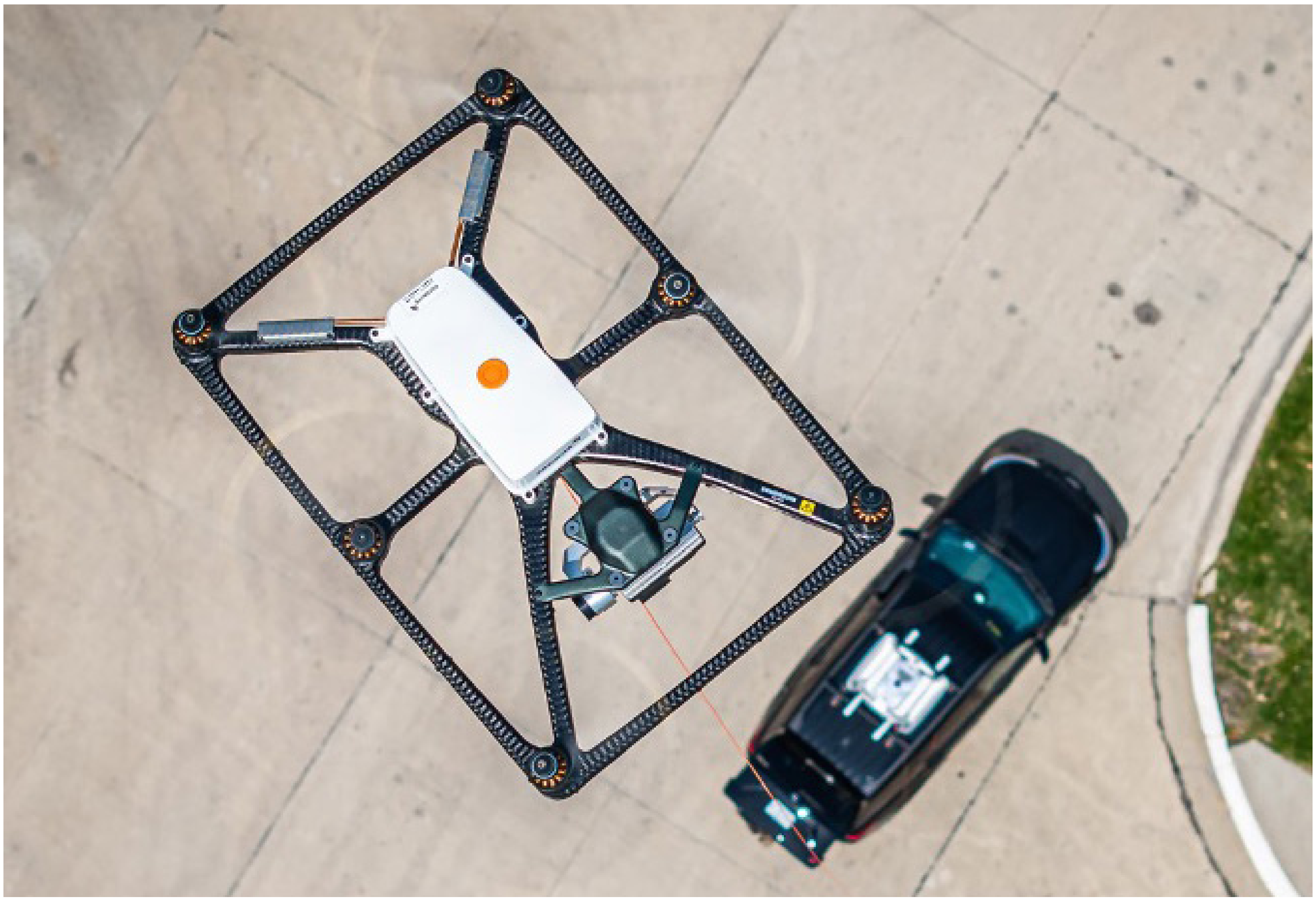
Figure 13: The Longreach70 groundbreaking elevated precision targeting system

Source: https://www.baesystems.com/en/product/longreach, AUVSI Research

Civil solutions

The Fotokite Sigma is manufactured in Switzerland to provide situational awareness for first responders. Tethered to a ground-based power supply, this drone can remain airborne for more than 24 hours at an altitude of 45 meters while providing mission-critical situational awareness for firefighting, search and rescue, and other public safety operations. In April 2024, the company received an estimated $11 million in a Series B financing round to accelerate growth of this technology, enhance R&D efforts, and expand global operations.[18]

Figure 14: The Fotokite Sigma designed to support first responder applications



Source: https://fotokite.com/, AUVSI Research

Looking for more data?

The USRD is a powerful resource that enables detailed investigations into uncrewed vehicle capabilities while also offering the ability to conduct trend analysis on a range of parameters captured for these platforms as demonstrated in the preceding analysis. Access to the searchable USRD interface is provided with an AUVSI organizational membership at the Standard tier and above or can be purchased by non-members as a yearly subscription. Access to the raw data that was used in this report can also be purchased under a custom license. For more information on the searchable interface or custom license options, please reference AUVSI's website. If you are a manufacturer and want to ensure your platform is included in the USRD, this is provided free of charge. Information on your vehicle(s) can be submitted here or by contacting David Klein, AUVSI's Systems and Technology lead (dklein@auvsi.org).

UK GOVERNMENT INVESTMENTS IN UNCREWED SYSTEMS:

Insights from Contract Awards and Future Strategy

Author: ***David Ambrozic****, Junior Research Analyst*

Key Takeaways

- Over £2 billion in contract awards to 226 organizations in 2020-2024
- 92% of contracts allocated to air domain
- UK Ministry of Defense committing £4.5 billion over the next ten years to uncrewed technology.

Introduction

The United Kingdom (UK) has made significant strides to advance its uncrewed systems capabilities in recent years, responding to immediate challenges such as the conflict in Ukraine, rapid advancements in artificial intelligence (AI), and evolving defense and security demands. The UK's strategy highlights its active effort to meet foreign battlefield needs and adapt to technological advancements domestically. Greater investment offers organizations, researchers, and developers new opportunities to support the sector's growth.

This report examines how the UK government allocates resources to uncrewed systems, analyzing 361 contract awards from 2020 to 2024 and using data sourced directly from the UK Government Contracts Finder.[1]

The analysis focuses on three key areas:

Past

Reviewing contract awards for uncrewed systems and artificial intelligence over the last four years.

Present

Evaluating current initiatives, including the UK's support for Ukraine through supplying uncrewed technology.

Future

Exploring the £4.5 billion Defense Drone Strategy and the UK's vision for advancing uncrewed platforms over the next decade.

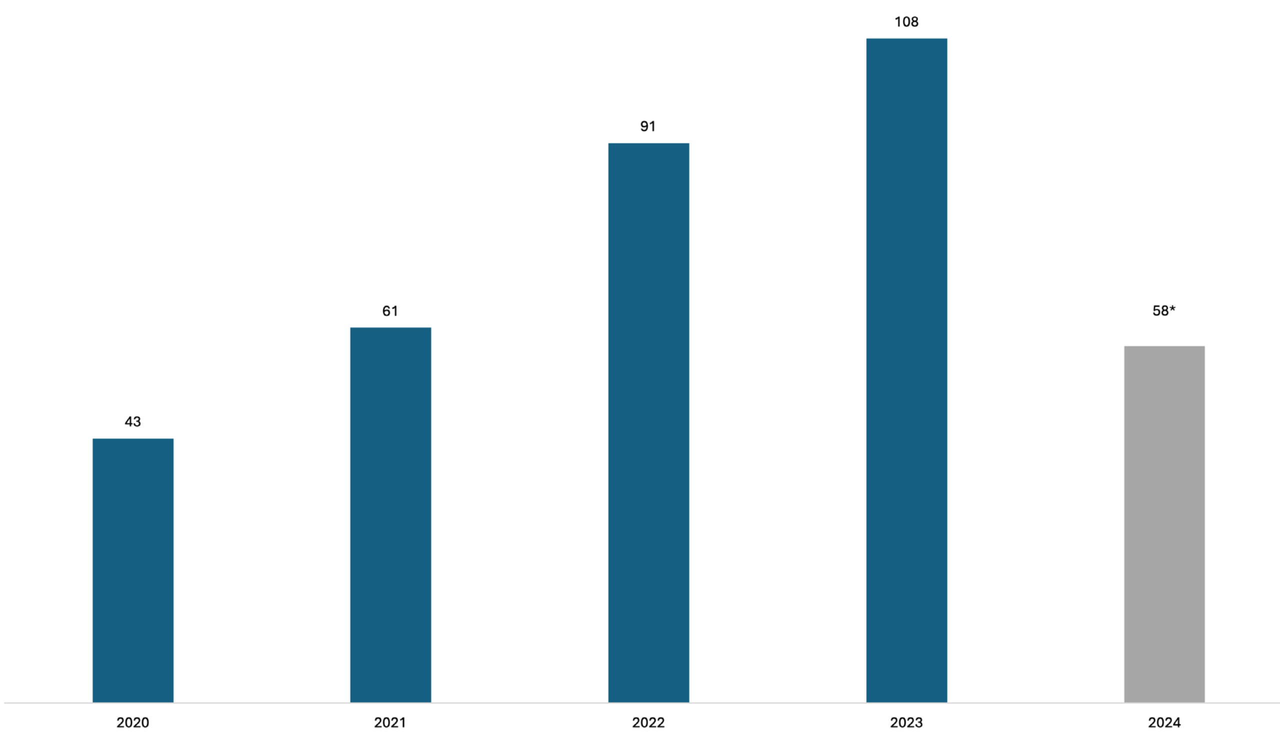
Analysis of government contract awards 2020-2024

Where contracts are coming from

We identified 361 contracts related to uncrewed technology, valued at £2.017 billion, and 433 contracts related to Artificial Intelligence (AI), valued at £1.630 billion, during the period from 2020 to 2024. These investments highlight a growing emphasis on uncrewed systems and the supporting technologies driving their effectiveness.

Uncrewed industry contracts steadily increased from 2020 to 2023, with an average annual growth rate of 36% based on the number of contracts awarded yearly.

Figure 1: UK government contract awards for uncrewed systems by year

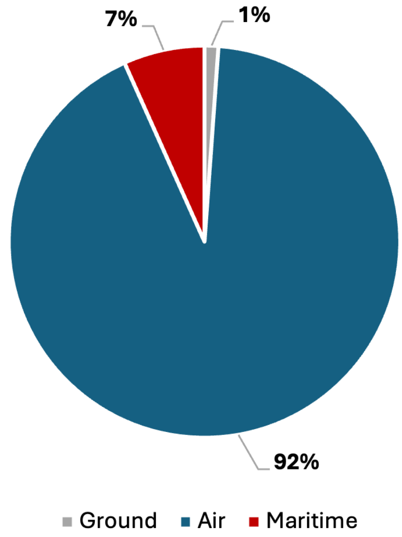


**As of 10/1/2024 Source: https://www.gov.uk/contracts-finder, AUVSI Research*

92% of contracts awarded in the air domain

As expected, the air domain accounts for most contract awards by value, representing 92% of the total, followed by 7% allocated to the maritime domain and 1% to the ground domain. However, when analyzing the distribution by the number of contracts awarded, the spread is more balanced: 60% of contracts went to the air domain, with the maritime and ground domains each receiving 20%.

Figure 2: Distribution of contract awards by domain by £ value



Source: https://www.gov.uk/contracts-finder, AUVSI Research

Civil sector value of contracts is higher than defense

In the UK, civil government entities awarded contracts with a greater total value than defense entities—a contrast to our analysis of United States government awards[2], where 78% of awards originated from defense agencies. In the UK, the split is more balanced, with 55% of contract value coming from civil government and 45% from defense. This discrepancy is due to a civil high-value multiyear contract worth up to £1 billion[3], awarded to the Portuguese firm TEKEVER. This contract focuses on monitoring the UK's southern border to combat illegal maritime immigration, highlighting the role of uncrewed systems in non-defense applications.

Contracts awarded from 122 different government organizations

Contracts were awarded by 122 different government organizations, showing significant diversity in funding sources. The Ministry of Defense (MOD) and the Home Office, which oversees immigration, security, and law enforcement, working with 28 agencies and public bodies[4] (comparable to the U.S. Department of Homeland Security) account for 94% of the total value of contracts.

Figure 3: Contract award by government sector

Organization	Share of Contract Value	Share of Contracts by Count
Home Office	50%	3%
Ministry of Defense	44%	42%
Other	6%	55%

Source: https://www.gov.uk/contracts-finder, AUVSI Research

While the Home Office and Ministry of Defense (MOD) account for most of the spending, they represent a smaller share of contracts by count, at 3% and 42%, respectively. The majority of contracts (55%) are awarded by other government organizations, reflecting a broader distribution of funding.

Contract value analysis reveals that 44% of awards are worth less than £100k, and 80% fall below £1 million. These smaller-scale contracts focus heavily on services, research, and development rather than large-scale platform acquisitions. This emphasis on smaller awards makes the uncrewed systems market particularly accessible to small and medium-sized enterprises (SMEs), which excel in delivering niche capabilities and driving incremental innovation.

However, the limited availability of high-value opportunities may deter larger foreign companies, which typically focus on securing more lucrative contracts. By balancing significant investments from the MOD and Home Office with smaller awards across other entities, the government supports both strategic advancements and diverse solutions to advance the uncrewed systems sector.

Integration of uncrewed systems across civil applications

Despite being in its early stages, the uncrewed systems industry in the UK is already addressing a variety of needs through innovative applications. Civil government organizations play a key role in deploying these technologies. Key contributors include the Department for Environment Food and Rural Affairs (DEFRA), the Home Office and National Highways

Figure 4: Top 10 Civil organizations by contract count

Organization Name	Count
DEFRA -Department of Environment Food and Rural Affairs	12
Home Office	11
National Highways	9
Highways England	8
University of Sheffield	6
UK Shared Business Services Limited	6
MCA - Maritime and Costguard Agency	6
University of East Anglia	5
Offshore Renewable Energy Catapult	5
Historic England	5

Source: https://www.gov.uk/contracts-finder, AUVSI Research

Examples of civil applications include:

Infrastructure Maintenance:
National Highways and Highways England use uncrewed systems for transport monitoring and maintenance.

Environmental Monitoring:
DEFRA and the Forestry Commission deploy these technologies for agricultural and environmental management.

Maritime Operations:
The Maritime and Coastguard Agency and the Home Office leverage uncrewed systems for coastal surveillance and border control.

Research and Innovation:
Universities such as the University of Sheffield and University of East Anglia focus on advancing capabilities and exploring new applications.

Renewable Energy Projects:
Offshore Renewable Energy Catapult uses uncrewed systems to optimize maritime operations and support renewable energy initiatives.

Early-stage development and future integration

The UK's uncrewed systems industry remains in its formative stages, with contracts reflecting a cautious and exploratory government procurement strategy. These contracts focus significantly on research and development, allowing stakeholders to evaluate capabilities and test applications across domains. The air domain, driven by immediate battlefield needs, has seen the most investment and serves as a testing ground for uncrewed systems. Other domains remain in earlier phases, with acquisitions aimed at exploring potential and assessing success.

This approach aligns with the trajectory of emerging industries, where smaller-scale investments prioritize foundational capabilities over large-scale commitments. Some of this early research informs forthcoming legislation for broader societal integration, including advanced air mobility (AAM) and urban infrastructure.

The integration of uncrewed systems into diverse applications is steadily increasing, driven by their ability to reduce risks to personnel, perform hazardous tasks, and provide cost-effective alternatives to traditional methods. These systems enhance operational efficiency and streamline workflows across sectors, thanks to advancements in autonomy, artificial intelligence, and system capabilities. As these technologies continue to evolve, uncrewed systems are poised to transition from specialized tools to essential assets in both civilian and defense operations. This progression signals a shift toward larger-scale investments and widespread adoption across multiple domains.

Recipients of UK contract awards

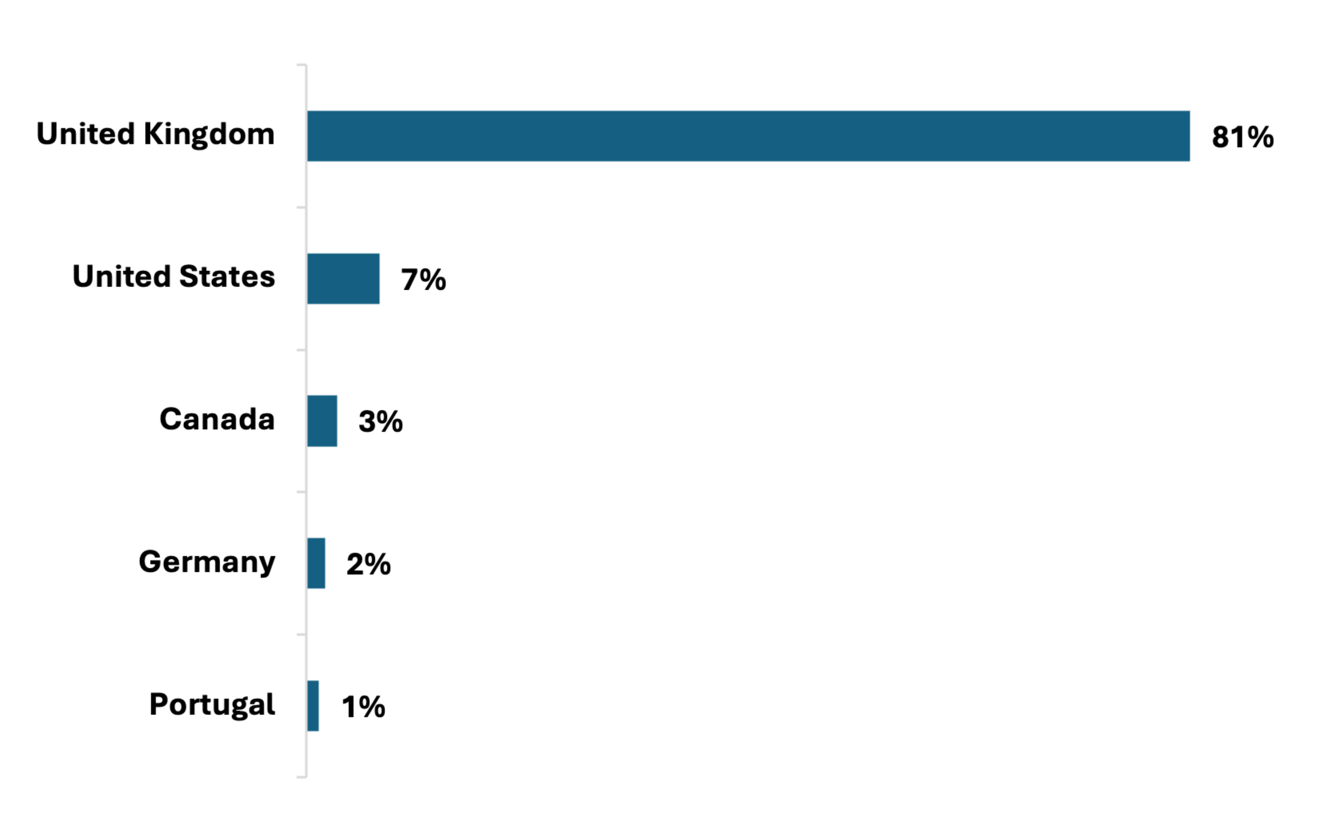
Contract awards to 221 companies from 19 countries

The contracts analyzed were distributed across 221 companies, averaging 1.6 contracts per company. Highlighting the remarkable diversity in contract allocation, this demonstrates the availability of opportunities for companies of varying sizes and capabilities.

Contract awards also represented organizations located in 19 countries and spanning four continents. 81% of these contracts were issued to UK-based companies with these entities securing 84% of contracts under £1 million. In comparison, for contracts over £1 million, the figure drops to 70%, indicating that foreign companies are more likely to compete for and secure higher-value contracts. Lower-value contracts tend to attract bids from domestic companies, likely due to their focus on localized services, research, and incremental innovation. In comparison, larger contracts often involve specialized capabilities that attract foreign organizations.

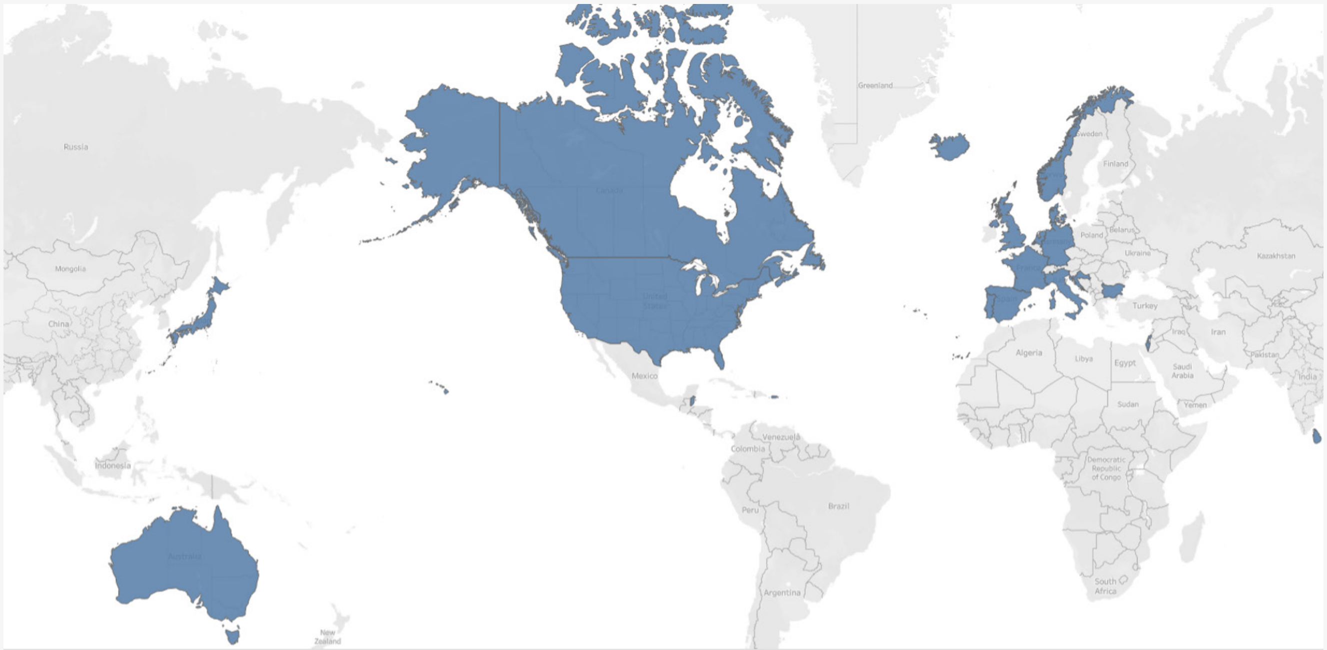
As the demand and requirements of the government increase over time, the larger contracts will likely attract more foreign bidding.

Figure 5: Contract awards by awardee country



Source: https://www.gov.uk/contracts-finder, AUVSI Research

Figure 6: Global distribution of contract awards



Source: [https://www.gov.uk/contracts-finder,](https://www.gov.uk/contracts-finder) AUVSI Research

Figure 7: Distribution of contract awards to UK companies

Source: https://www.gov.uk/contracts-finder, AUVSI Research

Contracts analysis by domain

Ground domain focus is on autonomy research and small uncrewed platform purchases

The ground domain accounted for 69 contracts valued at £20 million, notably less than investments in the maritime and air domains. The contracts show two primary focus areas: autonomy research and small platform purchases. Together, they represent the UK government's efforts to advance autonomous technologies and acquire tools for specific operational needs.

Figure 8: Ground domain contract distribution

Category	Value	Count
Autonomy Research	£ 13,379,346.00	49%
Platform Purchases	£ 6,689,281.00	51%

Source: https://www.gov.uk/contracts-finder, AUVSI Research

Investments in autonomy research

Autonomy research accounted for 49% of the contracts, with efforts primarily focused on advancing connected and autonomous vehicle (CAV) systems, including the development of standards and testing infrastructure. Other key areas of research involve robotics for inspecting and operating in hazardous environments, as well as the integration of autonomous technologies into agriculture and transportation systems.

Ground platform purchases

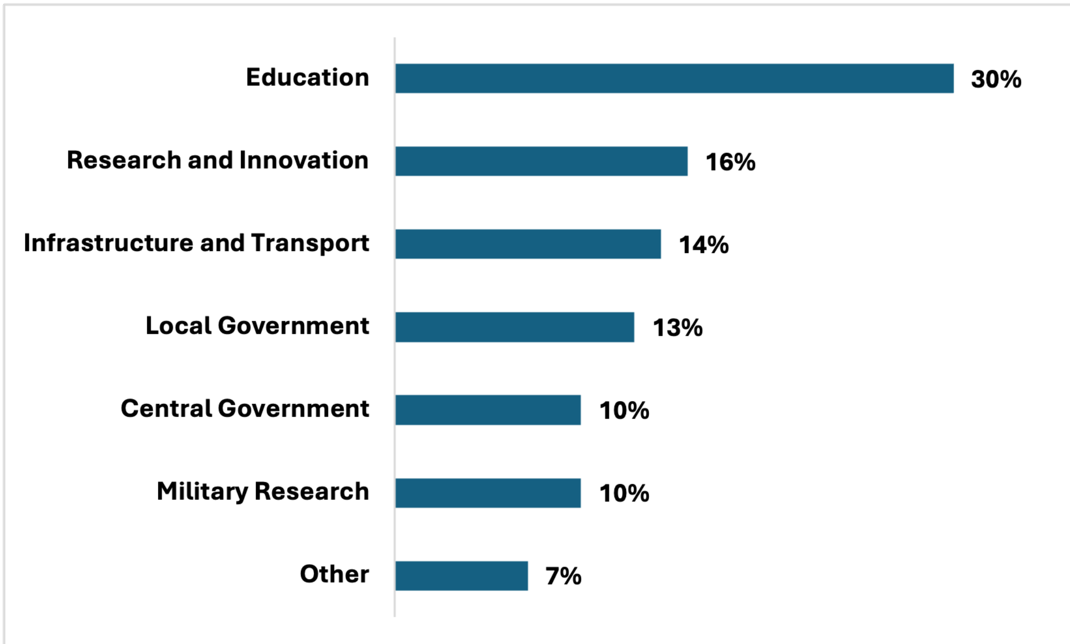
Platform purchases accounted for 51% of contracts, with universities and research institutions representing most of these acquisitions. These platforms, including quadruped and mobile robotic systems, are likely being used for testing and educational purposes. Research institutions' use of such systems highlights their role in evaluating uncrewed technologies across various environments, from industrial settings to agriculture and logistics.

Figure 9: The Boston Dynamics Spot robot[5], recently purchased by three UK universities

Source: https://www.gov.uk/contracts-finder, AUVSI Research

A range of organization types received contracts in the ground domain, displaying the diversity of applications:

Figure 10: Distribution by organization type



Source: https://www.gov.uk/contracts-finder, AUVSI Research

Early-stage testing and evaluation

Contracts predominantly awarded to educational and research institutions highlight the exploratory nature of the ground domain. This phase focuses on testing and evaluating technologies to build foundational knowledge and capabilities. Current activities emphasize experimentation and refinement rather than widespread deployment, signaling that the ground domain remains in its early stages of development.

Maritime domain: Defense-driven investments with civil market potential

The maritime uncrewed domain accounts for 74 contracts totaling £135 million. Making it the second-largest area of investment after air. The UK's longstanding naval tradition has transitioned into an era of modern innovation, with uncrewed technologies playing an important role in defense and emerging civil applications.

Defense as the primary demand driver

97% of award spending in the maritime domain is toward military applications. Investments focus on autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs), and uncrewed surface vessels (USVs), supporting operations such as mine countermeasures, anti-submarine warfare, and maritime surveillance. Recent notable procurements include the L3Harris IVER AUV and the HII Remus 300m and 100m, which have been the AUVs of choice for multiple Navies across Europe in the past decade including Belgium, Germany, The Netherlands, Croatia and Ireland. The UK also provided REMUS AUVs to Ukraine as part of a military aid package in 2022.[6] Furthermore, investments have been made in capability demonstrators for uncrewed surface vessels, reflecting the Ministry of Defense's increased focus on enhancing maritime operational capabilities beyond just underwater operations. Exploring the integration of full autonomy on large surface vessels has been a growing R&D priority for the UK, a trend that aligns with the and U.S. Navy's current budget strategy.

Figure 11: Notable UK government uncrewed maritime platform purchases 2020-2024

Make	Model	Type
Atlantas Marine	Videoray	ROV
Atlas Elektronik	MAUV. SeaFox	AUV
HII	Remus 100m, 300m	AUV
L3Harris	Iver 4	AUV
Maritime Robotics	Otter	USV
SAAB	Tiger	ROV
Teledyne	Gavia 1000m	AUV

Source: https://www.gov.uk/contracts-finder, AUVSI Research

Figure 12: HII Remus 100m[7], a popular choice for navies across Europe

Emerging civil maritime applications

The maritime uncrewed domain accounts for 74 contracts totaling £135 million. Making it the second-largest area of investment after air. The UK's longstanding naval tradition has transitioned into an era of modern innovation, with uncrewed technologies playing an important role in defense and emerging civil applications.

Research and development contributions

Universities and research organizations are integral to advancing maritime technologies. Their work includes testing AUVs, developing subsea communication networks, and improving hydrographic surveying capabilities. This collaboration between academia, industry, and government ensures that the maritime domain benefits from continuous innovation across defense and civil sectors.

Relative maturity compared to the ground domain

The maritime domain exhibits greater maturity than ground-based systems, particularly in defense. High-value investments in large-scale platforms highlight advanced capabilities within the sector. However, civil applications still need to be developed, reflecting maritime systems' higher costs and operational complexities and the less immediate need for such technologies. Despite this, ongoing investments in smaller-scale civil technologies suggest a pathway for broader integration in the future.

Air domain: A landscape of rapid changes and strategic evolution

The air domain represents the most significant investment in the UK's uncrewed systems spending, with £1.8 billion spent across 217 contracts awarded to 87 organizations between 2020 and 2024. As the most mature of the three domains, it showcases the government's willingness to commit to larger, more ambitious projects. This maturity has also positioned it as the domain experiencing the most rapid evolution, shaped by operational lessons and shifting priorities. The increasing role of uncrewed aerial vehicles (UAVs) on modern battlefields, particularly in Ukraine, has directly influenced the UK's approach, driving a reassessment of current capabilities and future strategies.

Civil applications in the air domain: Significant investments in border security

The uncrewed aerial systems (UAS) sector has driven technological advancements with increasing applications in civil operations. The Home Office exemplifies this trend through its £1 billion contract with TEKEVER to enhance border and coastal surveillance capabilities. Unlike the maritime and ground domains, where civil investments remain limited, the aerial domain demonstrates the government's willingness to make substantial commitments. However, such large-scale programs could be closely scrutinized for their success in meeting operational goals. Their outcomes could shape the trajectory of future investments, setting a benchmark for the broader integration of uncrewed systems into civil applications. Recent cuts in the defense budget highlight the importance of operational efficiency as we will discuss in the next section.

Figure 13: The TEKEVER AR5[8] fixed-wing UAVs used for maritime border monitoring

Changes in defense strategy and the retirement of the Watchkeeper: A Pragmatic approach

In November 2024, the UK Ministry of Defense announced the retirement of the Watchkeeper UAV program.[9] This decision reflects a pragmatic shift in defense priorities, recognizing the platform's significant challenges throughout its lifecycle despite over £1 billion in investments since the program's inception in 2000. The Watchkeeper struggled with operational readiness and high maintenance and development costs. While it was envisioned to provide strategic advantages as a domestically developed system, the realities of modern defense—particularly the interoperability afforded by NATO partnerships—have reduced the necessity for bespoke platforms when proven allied technologies are readily available.

However, this decision does not signal an overall departure from investments in larger UAS. The UK MOD has continued to invest in such technologies, demonstrated by recent procurements of platforms such as the General Atomics Reaper (MQ-9A) and Protector RG Mk1 (MQ-9B) as well as the Schiebel CAMCOPTER S-100. These acquisitions underline a continuous commitment to leveraging field-proven large UAS platforms that align with NATO priorities and deliver operational effectiveness.

Figure 14: Recent large UAS purchases by UK MOD from foreign militaries

Make	Model	Supplier	Type	Year
Schiebel	Camcopter S-100	Austria	Rotorcraft UAV	2023
General Atomics	MQ-9A (Reaper)	United States	Armed UAV	2021
General Atomics	MQ-9B (Protector RG Mk1)	United States	Armed UAV	2021
AeroVironment	Switchblade 300	United States	Loitering Munition	2020

Source: Stockholm International Peace Research Institute (SIPRI)

Ukraine conflict: An era of change

The ongoing conflict in Ukraine has reshaped the landscape of uncrewed aerial warfare, ushering in an era of rapid adaptation and innovation. The unprecedented deployment of sUAS and loitering munitions has underscored the battlefield effectiveness of smaller, versatile systems. Valued for their rapid deployment, adaptability, and cost efficiency, these technologies have proven indispensable in dynamic conflict environments. This evolving reality highlights the growing importance of scalable, adaptable solutions. The UK's defense strategy reflects this shift. Although not directly engaged in the conflict, the UK has played a critical role in arming Ukraine, providing uncrewed technologies that have been instrumental on the battlefield. This support not only aids Ukraine's defense but also offers valuable insights into the practical applications of uncrewed systems in high-stakes scenarios.

Rather than a retreat, the retirement of the Watchkeeper represents a strategic reallocation of resources informed by these lessons. By balancing fiscal constraints with operational needs, the MOD is adapting to the shifting demands of defense. This approach positions the UK to address emerging challenges in an era of rapid technological change while maintaining readiness for future conflicts.

Figure 15: The recently discontinued Thales Watchkeeper[10] fixed-wing UAV

The ongoing effort to support Ukraine

The United Kingdom has been a leading supporter of Ukraine in its conflict by providing weapons and leveraging uncrewed systems as a critical component of its assistance. This effort has significantly shaped the European defense industry and underscored the relevance of uncrewed technologies in modern conflict. Key developments include:

Significant financial commitment and global leadership

£325 Million Investment: In 2024, the UK Ministry of Defense committed £325 million to supply 10,000 drones to Ukraine, representing 10% of its £3 billion military assistance package.[11]

Co-creators of the International Drone Coalition:[12] Co-led by the UK and Latvia, the coalition now includes 17 nations and has pledged £1.55 billion[13] in drone-related support for Ukraine in 2024.

Impact on the UK uncrewed systems Industry

The heightened need for uncrewed systems has spurred significant growth and diversification within the UK's defense industry. The Ministry of Defense has partnered with over 30 companies to rapidly scale production, focusing on smaller, agile platforms that align with evolving battlefield requirements. This collaboration has expedited delivery timelines and strengthened the industrial base by integrating smaller and medium-sized enterprises (SMEs) into defense production. Previously focused on commercial applications, these SMEs have contributed innovative, scalable solutions, demonstrating their adaptability and value.

The increased demand has also driven strategic acquisitions among larger defense firms, highlighting the sector's readiness to adapt. Key developments include:

- BAE Systems acquired Malloy Aeronautics in 2024 to bolster heavy-lift drone capabilities.[14]
- Thales acquired Cobham Aerospace in 2024 to enhance ISR and communications technologies.[15]
- Saab Acquired BlueBear in 2023 to strengthen its capabilities in autonomous systems.[16]
- Plymouth Rock acquired Tetra Drones in 2021 to expand its portfolio of compact UAS platforms. [17]

To meet rising procurement needs, industry leaders have expanded their production capacities. For instance, TEKEVER has opened an additional production facility in the UK, exemplifying the sector's proactive approach to scaling operations. These collective efforts underscore the resilience and innovation of the UK's uncrewed systems industry in responding to domestic and international defense demands.

Lessons from Ukraine are shaping uncrewed systems development

The ongoing conflict in Ukraine has fundamentally transformed the landscape of uncrewed warfare. The battlefield has become a proving ground, demonstrating the value of uncrewed systems in contested environments characterized by electronic warfare and high attrition rates. These experiences have provided critical insights into the UK's evolving defense strategy.

Adapting to battlefield realities

The ongoing use of UAVs on the battlefield has caused immediate changes to procurement/supply strategies.

Focus on FPV drones: First-person view (FPV) drones are a tactical priority, offering high-impact results at low costs. Their success on the battlefield underscores their role in addressing dynamic and rapidly evolving military requirements. The UK is actively working to procure 300 Large FPV drones.[18]

Quantity over complexity:[19] The growing prevalence of counter-UAS (C-UAS) technologies, including electronic warfare, has made it increasingly challenging to keep high-value drones operational on the battlefield. In response, the focus has shifted toward deploying many low-cost and often one-way attack drones. This approach reduces the cost of inevitable losses while maintaining the persistent capability to execute critical missions. However, it also necessitates a robust and scalable production pipeline to ensure an adequate and continuous supply.

Rise of C-UAS threats: The rise of sophisticated C-UAS systems highlights the need for a forward-looking strategy. While scaling low-cost platforms addresses current challenges, the long-term viability of fielding uncrewed systems on battlefields will depend on integrating adaptability and innovation to counteract future C-UAS advancements.

Developing adaptable, resilient platforms: The lessons of rapid innovation, mass deployment, and supply chain adaptability have directly influenced the UK's focus on creating scalable, cost-effective solutions capable of meeting evolving threats.

While these lessons have reshaped immediate tactical decisions, they also inform the UK's broader, long-term defense strategy over the next ten years.

Looking ahead: A £4.5 billion commitment

In February 2024, the United Kingdom unveiled its Defense Drone Strategy,[20] a historic £4.5 billion investment over the next decade to enhance uncrewed capabilities across air, land, and sea. This landmark plan reflects the Ministry of Defense's transition from reactive, ad-hoc procurement to integrated, future-focused planning. Shaped by lessons learned from Ukraine, the strategy underscores the Ministry's commitment to leveraging uncrewed systems as a core element of its long-term defense apparatus.

The strategy prioritizes four key areas:

1. **Naval mine clearance:** Developing uncrewed solutions to ensure maritime safety.
2. **Precision one-way attack drones:** Deploying cost-effective drones optimized for high-impact results.
3. **Heavy-lift systems:** Creating platforms capable of supporting logistics in complex environments.
4. **ISR (Intelligence, Surveillance, and Reconnaissance) Platforms:** Advancing technologies to improve real-time situational awareness.

From reactive to strategic: The UK's vision for uncrewed systems

The £4.5 billion investment reflects a broader acknowledgment within the Ministry of Defense: uncrewed systems are central to UK defense planning, extending beyond their role in current conflicts. This strategy marks a shift from reactive procurement to deliberate, integrated planning that addresses both immediate operational needs and future challenges. It ensures that lessons from rapid deployment and contested environments are applied to develop systems designed for the evolving landscape of uncrewed warfare. Such investments demonstrate the potential of advancing uncrewed technologies in ways that yield benefits beyond the defense sector.

Defense R&D investments in autonomy, sensor integration, and supply chain resilience not only enhance military capabilities but also create opportunities to transition technological advancements to broader commercial applications. For instance, an AUV designed for military ISR operations could, with minimal adjustments and modular payloads, support scientific research or environmental monitoring. This adaptability allows technologies to scale across various vertical markets, making them indispensable tools for enhancing defense, civil, and commercial operations. Such multi-use potential underscores how improving technology for defense can also catalyze growth across the commercial sector.

Historical parallels reinforce this trajectory. Early military investments in traditional aviation drove technological breakthroughs that laid the foundation of the modern commercial aviation industry. Similarly, uncrewed systems, still in their nascent commercial stages, can benefit from sustained government investment to drive innovation and long-term growth—by funding research and advancements that might otherwise face financial barriers in the commercial private sector.

However, innovation in uncrewed systems technology has proven to flow both ways. The air domain has seen the rapid adaptation of commercial sUAS for defense purposes, driven by battlefield needs and enabled by the willingness of agile commercial companies to pivot and meet immediate requirements in defense. This dynamic exchange of advancements between defense, commercial, and other sectors accelerates innovation and unlocks new possibilities for collaborative growth.

The multi-directional flow of technological advancements and the adaptability of use cases across all sectors provide an exciting outlook for the future of the uncrewed industry. This dynamic is mirrored in increasing government contract awards in the UK, which reveal key strategies and R&D priorities shaping the UK's approach to uncrewed systems.

ADVANCEMENT IN GENERATIVE AI AND ITS POTENTIAL FOR UNCREWED SYSTEMS

Author: ***Marko Sudar***

Key Takeaways

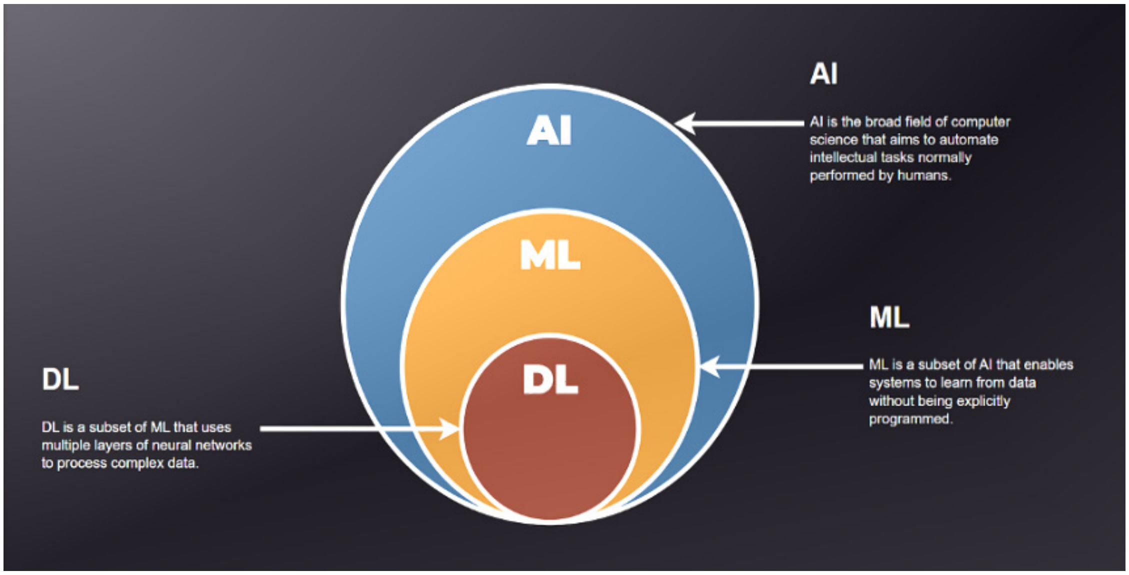
- Generative AI is revolutionizing the uncrewed systems industry by enhancing autonomy, predictive modeling, and system resilience, paving the way for more advanced and reliable applications.
- Advancements in AI, ML, and DL technologies provide the foundation for generative AI's capabilities, offering robust tools for decision-making, data synthesis, and adaptation in dynamic environments.
- Generative AI enables uncrewed systems to simulate complex scenarios, improve operational readiness, and address edge cases, making them more resilient and reliable in high-stakes applications.
- Integration of generative AI with cybersecurity tools strengthens anomaly detection and fault tolerance in autonomous systems, mitigating cyber threats and enhancing system safety.
- Large Language Models (LLMs) are reshaping the interface between human operators and autonomous systems, improving collaboration, mission planning, and system interpretability.
- Generative AI's ability to create synthetic data accelerates innovation by reducing reliance on costly real-world data collection, particularly in defense, logistics, and disaster response.
- Ethical and regulatory considerations remain critical in the deployment of generative AI, ensuring transparency, bias reduction, and societal alignment while fostering innovation and trust.

Introduction to AI, different types of AI, and how AI differs from ML and Deep Learning

The global AI market size was valued at USD 95.6 billion in 2021 and is predicted to reach USD 1,847.58 billion by 2030, registering a CAGR (Compound Annual Growth Rate) of 32.9% from 2022 to 2030. Readers already familiar with AI can explore its transformative potential in the uncrewed systems industry through this review. However, for some, the concept of AI might be new, so let's start with an explanation of what it is.

With recent developments in the technology sector, the term "Artificial Intelligence (AI)" has been used more than ever before. The general public tends to equate Artificial Intelligence with Machine Learning (ML) and Deep Learning (DL), especially when discussing topics like big data, predictive analysis, and other digital transformation topics. Later in this article, we will dive into more specific terms related to the AI field, which might seem like a lot to grasp at once, but we will try to expand on everything. Let's first look at a Figure 1 that shows the relationship between AI, ML and DL.

Figure 1- Relation between AI, ML, and DL



Source: https://blog.nilayparikh.com/the-perennial-debate-of-artificial-intelligence-ai-versus-machine-learning-ml-93b526925318

As seen in Figure 1, AI represents a broader range of capabilities encompassing both ML and DL. It refers to replication of human-like-intelligence, behavior, decision making, and cognitive functions in computer systems. Moreover, it is not a system itself, but rather a set of technologies implemented in a specific computer system, and it is able to learn and act to solve a complex problem. ML is a subset of AI focused on enabling machines to extract patterns from data. In other words, it improves from iteration and quality training. ML algorithms are extremely efficient for fault detection given that one of their main benefits is pattern recognition. ML models are the output, or what the program learns from running an algorithm on training data. The more data the ML model is trained on, the better it is in practice. DL, a further subset of ML, leverages neural networks to solve complex problems. (A neural network is a ML model designed to make decisions in a way that resembles the human brain.) The original idea behind the neural networks was to create a system that will artificially resemble the structure of the human brain. It uses processes that imitate how biological neurons collaborate to recognize patterns, evaluate choices, and reach conclusions. These technologies allow AI systems to learn, adapt, and act to address intricate challenges. Let's expand a bit on all three terms and see how they work independently and collaboratively.

AI is designed to equip machines with processing and analytical abilities similar to those of humans. Serving as the backbone of ML, AI is now essential across numerous industries[1]:

- Approximately 60% of the videos viewed on YouTube come from AI-powered recommendations.
- AI-driven suggestions lead to around 40% of the app installations from the PlayStore.
- Implementing AI can boost business productivity by up to 40%.
- The percentage of AI-based start-ups has surged by 14% since the early 2000s.

But how does AI actually work? An AI system relies on algorithms and extensive data. Initially, it is trained on large datasets applied to mathematical models or algorithms. These algorithms identify patterns and make predictions in a process known as training. Once the data is prepared, machine learning models are trained using various techniques, depending on the type of problem and the nature of the data. The three primary types of machine learning training are:

1 **Supervised Learning**
Supervised learning is the most common approach, where the model is trained on a labeled dataset. In this case, each training example consists of an input (or feature) and a corresponding output (or label). The goal is for the model to learn a mapping from inputs to outputs, so it can predict the correct output for new, unseen data.

2 **Unsupervised Learning**
In unsupervised learning, the model is provided with data that has no labeled outputs. The goal is to identify hidden patterns, structures, or relationships within the data. These models try to group or represent the data in meaningful ways, without explicit guidance on what the output should be.

3 **Semi-Supervised Learning**
Semi-supervised learning is a middle ground between supervised and unsupervised learning. In this approach, the model is trained on a dataset that is partially labeled, with only a small portion of the data containing labels, while the rest is unlabeled. This can be useful when labeled data is expensive or time-consuming to acquire.

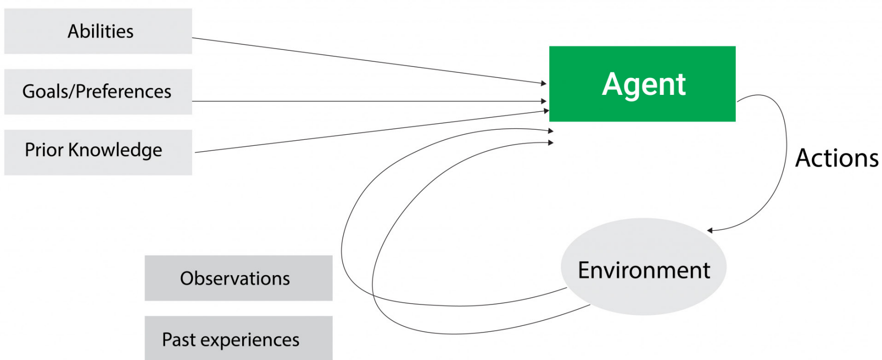
4 **Reinforcement Learning**
Reinforcement learning (RL) is an approach inspired by behavioral psychology. In RL, an agent learns to make decisions by interacting with an environment, receiving rewards or penalties based on its actions, and trying to maximize cumulative rewards over time. It doesn't require labeled data but learns from feedback in the form of rewards.

5 **Recommender Systems**
Recommender systems are another important type of machine learning technique, often falling under unsupervised learning or semi-supervised learning, depending on how they are implemented. While they're not one of the core types of machine learning like supervised, unsupervised, or reinforcement learning, they are a popular and specialized category of algorithms used to make personalized recommendations based on past behaviors, preferences, or interactions.[2]

Once trained, the algorithms are integrated into applications where they continue to learn and adapt based on new data inputs.

One compelling application of AI is the creation of AI agents - autonomous entities designed to interact with their surroundings, make decisions, and complete tasks aimed at specific objectives (Figure 2). While AI provides the theoretical and technological basis, AI agents bring this intelligence to life in functional applications. They utilize AI methods, such as ML and DL, to learn from experience, adjust to evolving environments, and operate independently. In doing so, AI agents illustrate how AI can not only interpret information but also take action, making AI's potential both visible and impactful in practical settings.

Figure 2 - What is an AI agent?



Source: https://walkingtree.tech/how-ai-agents-empower-industries-with-efficiency-and-insight/

There are a lot of ways to separate different types of AI, but there are three fundamental categories:

1. Capability-Based AI – Based on how they learn and how far they can apply their knowledge.

a. Narrow AI: Also called artificial narrow intelligence (ANI) or weak AI, refers to AI systems created to perform specific tasks or follow particular commands such as image recognition software, industrial robots, and virtual assistants.

b. AGI – Artificial General Intelligence: Also known as general AI or strong AI, refers to AI systems capable of learning, reasoning, and performing a broad array of tasks in a way that mirrors human intelligence.

c. Artificial Superintelligence: Or super AI, is a concept rooted in science fiction. The theory suggests that once AI achieves general intelligence, it could rapidly advance its learning and capabilities, eventually surpassing human intelligence and abilities.

2. Functionality-Based AI - Functionality concerns how an AI applies its learning capabilities to process data, respond to stimuli and interact with its environment.

a. Reactive Machine AI: This category of AI is response-driven. This means it can handle immediate tasks and requests but lacks the ability to store memory, learn from past interactions, or enhance its performance over time. Machines integrating this capability can only react to a specific set of inputs and represent the most basic form of AI.

b. Limited Memory AI: Limited memory AI can retain past data and use it to make predictions, building a temporary knowledge base that it relies on to perform tasks.

c. Theory of Mind AI: Borrowed from psychology, this term describes the human ability to understand others' emotions and anticipate actions based on that insight. While AI with theory of mind capabilities hasn't been fully developed, it represents a major goal in AI's advancement.

d. Self-Aware AI: Often called the AI singularity, this stage goes beyond theory of mind and represents one of the ultimate ambitions in AI development. At this level, AI systems would not only recognize the emotions of others but would also possess a sense of self. It's believed that once AI reaches self-awareness, it may become difficult to control, as it would act with its own understanding of identity and purpose.

3. Technique-Based Types of AI – Based on techniques used in the training of AI models

a. ML – a system that learns from data and improves over time without explicit programming for each task.

b. DL – a subset of ML that uses neural networks with many layers (deep networks) to model complex patterns in large amounts of data.

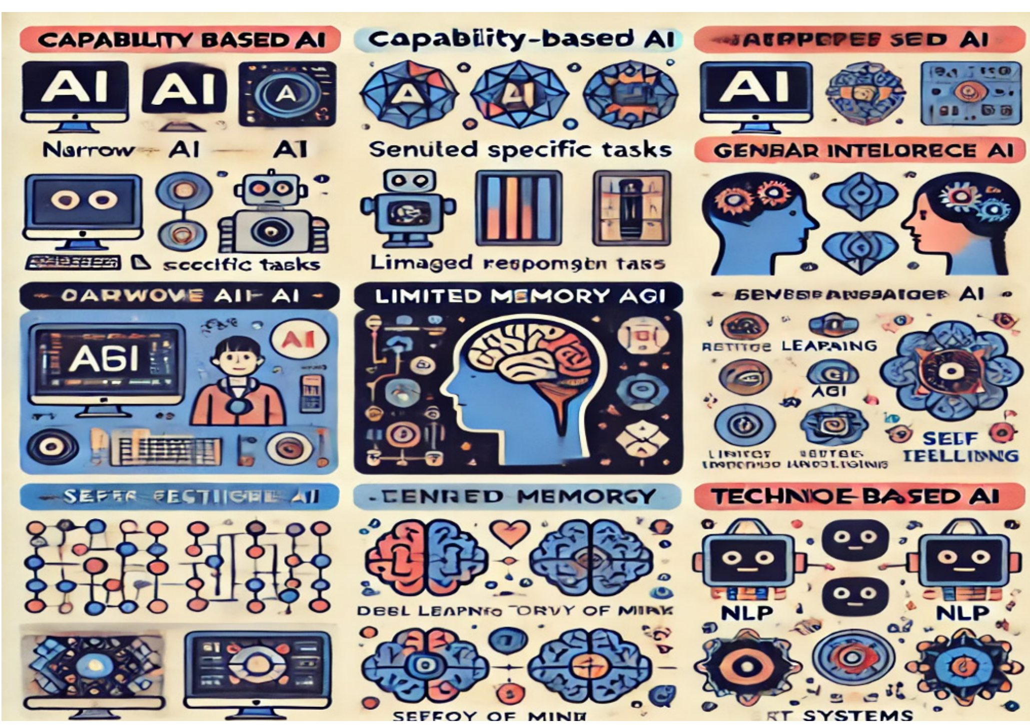
- o **Convolutional Neural Networks (CNNs):** primarily used for image processing and computer visions tasks.
- o **Recurrent Neural Networks (RNNs):** Designed for sequential data, such as time series analysis or natural language processing.
- o **Generative Adversarial Networks (GANs):** Used to generate new data similar to a given dataset.

c. Natural Language Processing (NLP): AI techniques that allow machines to understand, interpret, and generate human language (text, speech, and language processing).

d. Expert Systems: AI designed to mimic the decision-making ability of a human expert in a specific field

- o **Rule-based systems:** Systems that use predefined rules and logic to solve problems.
- o **Knowledge-based systems:** Systems that use a database of knowledge and inference rules to provide solutions.

Image 1 - Image created using Open AI's GPT 4.0 after pasting the whole part of this article about types of AI and asking it to create an image on it. It connected the content of the image with the text, but it still lacks the ability to generate text in the image that makes sense. There is also restrictions for reproducing certain text and graphics due to copyright law.



Source: https://www.copyright.gov/help/faq/faq-general.html

Brief history and quick look on evolution of an AI

The concept of AI dates back centuries, with the earliest mentions appearing in myths and stories of machines brought to life. However, the formal journey of AI began in the 20th century. Let's go over some important dates:

1940s-1950s: Foundations of AI

The groundwork for AI was laid during the 1940s and 1950s, with pioneers like Alan Turing, who proposed the idea that machines could potentially simulate human thinking. Turing introduced the Turing Test in 1950, a benchmark for determining a machine's ability to exhibit intelligent behavior indistinguishable from that of a human.[5]

1956: The Birth of AI as a Field

In 1956, at the Dartmouth Conference, AI was officially named, and it was recognized as a distinct academic discipline. Researchers aimed to develop machines that could "think," marking a period of high optimism, with bold predictions about AI's capabilities.

1960s-1970s: The Rise of Rule-Based Systems

During this era, AI research focused heavily on symbolic AI and rule-based systems. In the 60s, perceptron algorithm, also known as the basis of modern NNs, was first introduced. Also, expert systems were developed to mimic the decision-making of human experts in fields like medicine and engineering. However, the limitations of these early systems became evident as they struggled with complex, real-world applications.

1980s: Introduction of ML

The 1980s saw a shift from rule-based AI to data-driven approaches, leading to the emergence of ML. Instead of programming explicit rules, ML allowed systems to "learn" from data, enabling more dynamic responses and adaptability. This period also saw increased computational power, supporting more sophisticated AI experiments.

1990s-2000s: Advances in AI and the Rise of Big Data

With the advent of the internet, vast amounts of data became available, fueling further development in AI and ML. Furthermore, cost-effective computing systems supported the processing of that data. Parallel processors and powerful servers enabled high performance local processing that allowed developers to push the boundaries for ML and AI. Breakthroughs in fields like natural language processing (NLP) and computer vision laid the foundation for AI applications we see today. In 1997, IBM's Deep Blue defeated world chess champion Garry Kasparov, showcasing the power of AI (Figure 3).

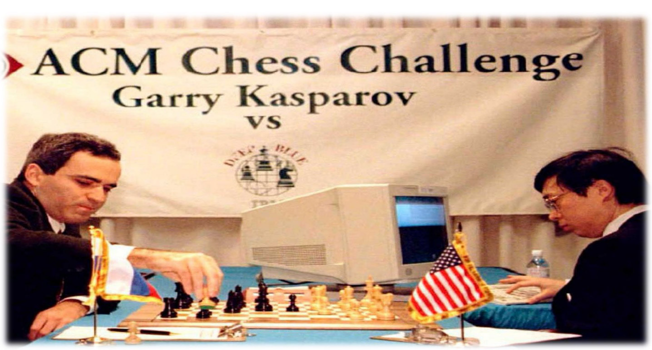


Figure 3 - World chess champion Garry Kasparov (left) playing against IBM's supercomputer Deep Blue in 1996 during the ACM Chess Challenge in Philadelphia.

Source: https://spectrum.ieee.org/how-ibms-deep-blue-beat-world-champion-chess-player-garry-kasparov

2010s: The Deep Learning Revolution
The 2010s witnessed the rapid growth of DL. Techniques like convolutional neural networks (CNNs) and recurrent neural networks (RNNs) enabled AI to surpass human performance in specific tasks such as image recognition and language translation. This era also marked the rise of generative models, including Generative Adversarial Networks (GANs), transforming fields like art and media.

2020s: AI in Everyday Life and Ethical Challenges
Today, AI permeates daily life through applications like virtual assistants, recommendation algorithms, and autonomous systems. However, with its growing influence, ethical concerns and regulatory challenges have also emerged. AI safety, privacy, and transparency have become crucial topics as researchers and policymakers work to balance innovation with societal well-being.

AI has evolved from speculative theory to a transformative force, shaping industries and lifestyles. As AI continues to advance, its potential to impact future generations only grows, with ongoing research focusing on achieving Artificial General Intelligence (AGI) and exploring the ethical implications of increasingly autonomous systems.[7]

Introduction to Generative AI

Generative AI (GenAI) is a form of AI that independently creates content, including text, images, audio, and video. These engines are trained on vast datasets and generate content by predicting the next word, pixel, or sound element to form a coherent output. Most popular GenAI models today are in a form of chat bots:

- **ChatGPT, Claude, Gemini:** Written content
- **Dalle-E, Midjourney:** Images (Used to generate Image 1 above)
- **AIVA:** Music generator

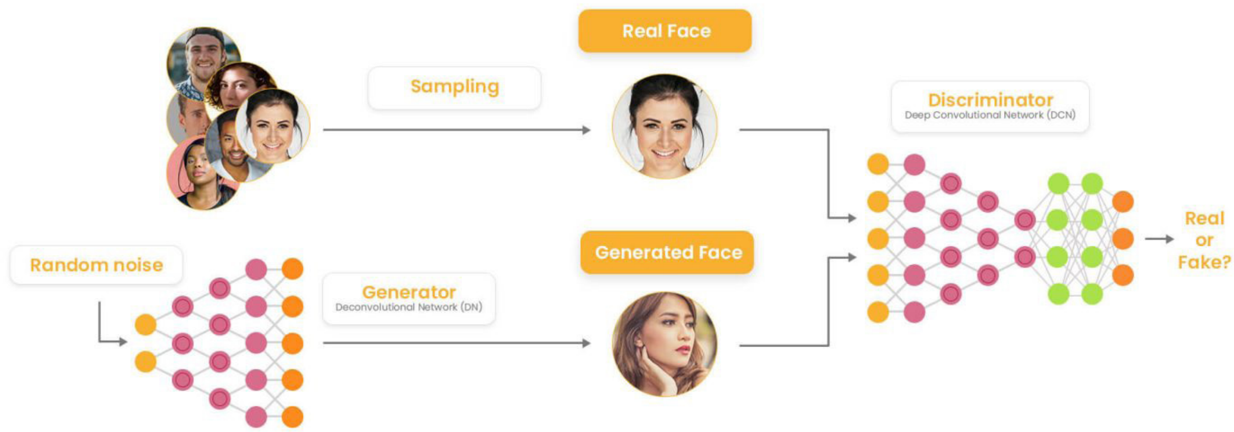
There are many options, but these are among the most popular. While innovations like ChatGPT and DALL-E have thrust generative AI into the spotlight, the roots of AI-generated content go back to the 1960s with ELIZA, a basic chatbot developed by MIT professor Joseph Weizenbaum. ELIZA simulated conversation by using pattern matching and substitution methodologies, creating the illusion of understanding. One of its most famous implementations was the DOCTOR script, which mimicked a Rogerian psychotherapist, captivating users by reflecting their statements as questions. Despite its simplicity, ELIZA laid the groundwork for modern conversational agents, sparking both fascination and ethical debates about the relationships humans might form with machines.[8]

Most generative AI tools available today are built on OpenAI's GPT engine and act as specialized interfaces that focus on specific areas, like marketing, or offer added functionalities by combining multiple features, such as text and image generation, in one platform. The way GenAI tools work is straight-forward, at least from the outside. There is a text input, that varies in maximum length from provider to provider, and there is an output that is produced by the model after analyzing the input. To general audience might seem like a magic, but in the background, it is just a lot of math (linear algebra, statistics, data manipulation, etc.).

As its backbone, GenAI includes **Generative Adversarial Networks (GANs), transformers, and Large Language Models (LLMs)**. GenAI, as we know it today, wasn't possible until the mid-2010s. The development of GANs in 2014 by Ian Goodfellow was a major breakthrough, allowing machines to generate realistic images, text, and other forms of content by training on data and creating new examples that mimicked that data.

GANs are machine learning models that consist of two neural networks working in competition to improve their accuracy. One network generates fake outputs (Generator) resembling real data, while the other tries to distinguish between these artificial outputs and genuine data (Discriminator) as you are able to see in Figure 4. Through this dynamic, both networks enhance their methods using deep learning techniques. Without GANs, AI-generated images, videos, and audio would not have reached their current level of realism.

Figure 4 - Simple GAN display



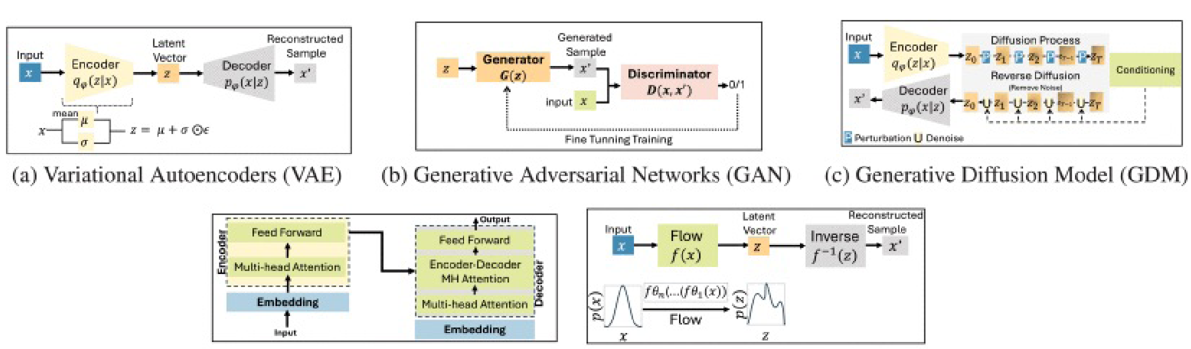
Source: https://www.clickworker.com/ai-glossary/generative-adversarial-networks/

Transformers are a ML model that enables AI to process and interpret natural language effectively. They allow AI models to identify subtle connections across billions of pages of text, leading to more accurate and nuanced outputs. Without transformers, models like OpenAI's Generative Pre-Trained Transformer (GPT), Bing's chat feature, or Google's Gemini chatbot would not be possible.

Large Language Models (LLMs) are a crucial component of generative AI, containing billions or even trillions of parameters. These models enable AI to produce fluent, grammatically accurate text, making them one of the most successful applications of transformer technology.

(Apart from GANs, Transformers, and LLMs there are other notable technologies that make AI seem like "a magic", and all of them have their one use cases) Beyond GANs, Transformers, and LLMs, several other remarkable technologies contribute to the perception of AI as 'magic,' each excelling in its specific use cases. Some of those include Variational Autoencoders (VAEs), Generative Diffusion Models (GDMs), and Normalizing Flow Models (NFMs) (Figure 5).

Figure 5 - GenAI techniques



(a) Variational Autoencoders (VAE) (b) Generative Adversarial Networks (GAN) (c) Generative Diffusion Model (GDM)

(d) Transformers (e) Normalizing Flow Model (NFM)

Source: https://ieeexplore.ieee.org/document/10623653

VAEs are neural networks that encode input data into a compressed latent representation and then decode it back, allowing for structured data generation.

- **Application:** Used for generating images, denoising, and anomaly detection by learning data distributions.

GDMs model data by iteratively adding and removing noise, which allows for high-quality generative tasks by reversing this noise process.

- **Application:** Applied in high-resolution image generation, text-to-image synthesis (like DALL-E), and sound generation.

NFMs are a type of generative model that transforms a simple distribution into a complex one by applying invertible transformations.

- **Application:** Used in density estimation, anomaly detection, and data generation for structured data distributions.

Use cases, Benefits, Limitations, and Concerns surrounding GenAI

Use cases:

Generative AI has a wide range of applications, enabling the creation of nearly any type of content. Advances such as GPT have made this technology more accessible and adaptable, allowing it to be fine-tuned for diverse tasks. Generative AI can power chatbots for customer service and technical support, create realistic deepfakes to mimic individuals, and improve dubbing for movies and educational content in various languages. It also finds use in generating written content, such as email responses, dating profiles, resumes, and academic papers, as well as in producing photorealistic artwork in specific styles. Beyond content creation, generative AI is being applied to enhance product demonstration videos, suggest new drug compounds, design physical products and architectural structures, optimize chip designs, and even compose music in targeted styles or tones (Figure 6). In the uncrewed industry, generative AI holds particular promise for autonomous vehicle design, mission planning, and simulation, which will be covered later in the paper.

Figure 6 - Some GenAI Use Cases

Source: https://www.solulab.com/ai-use-cases-and-applications/

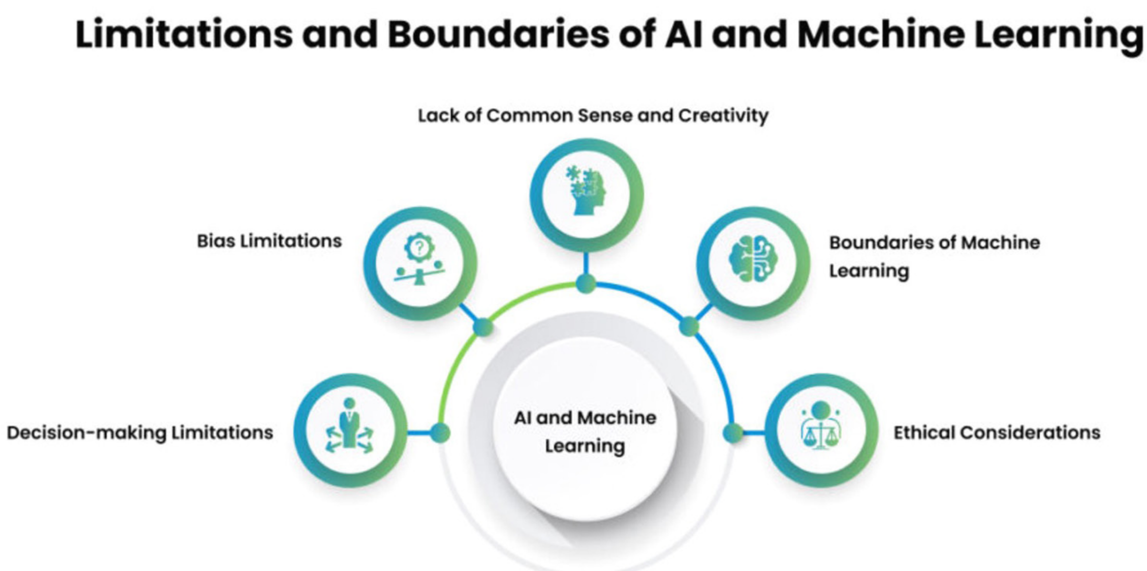
Benefits:

Generative AI brings transformative potential to businesses by revolutionizing how content is interpreted and produced. It streamlines workflows by automating the generation of new material and improving the comprehension of existing information. Key applications include simplifying email responses, crafting tailored content for specific needs, summarizing complex data into clear narratives, generating realistic digital human models, and creating content in specialized styles. These capabilities not only save time but also enhance precision and creativity in various domains.

Limitations:

Generative AI, while powerful, has notable limitations that are evident in its early implementations. Many of these challenges arise from the methods used to generate content for specific applications. For instance, while a generative AI model might provide a simplified summary of a complex topic, this often sacrifices the transparency of source material, making it difficult for users to verify the information's origins. Key limitations to consider when using or developing generative AI applications include the lack of source attribution, difficulty in identifying the bias of original sources, the risk of realistic-sounding but inaccurate information, challenges in adapting models to new contexts, and a tendency to overlook issues like bias, prejudice, and harmful content.

Figure 7 - GenAI limitations



Source: https://copperdigital.com/blog/the-limitations-of-ai-and-machine-learning/

Concerns:

Generative AI's rapid rise has sparked various concerns regarding the quality of its outputs, the potential for misuse, and its impact on existing business models. Specific challenges with generative AI include its tendency to produce inaccurate or misleading information, the difficulty of verifying content without clear sources, and the risk of enabling new forms of plagiarism that disregard the rights of original creators. Additionally, generative AI may disrupt business models built around search engine optimization and advertising, facilitate the spread of fake news, and create plausible deniability for genuine photographic evidence by labeling it as AI-generated. There's also the threat of AI being used for social engineering attacks by impersonating individuals. Given the novelty and rapid adoption of generative AI, businesses should anticipate a "trough of disillusionment" typical of emerging technologies and establish responsible AI practices and sound engineering principles to address these concerns.

Generative AI and Uncrewed Systems: Technical

The integration of Generative AI into uncrewed systems represents a significant step forward in the field of autonomous technology, with applications spanning defense, commercial, and industrial sectors. This integration is made possible through advancements in ML algorithms, data processing, and model architectures, which enable uncrewed systems to operate with greater autonomy, adaptability, and intelligence. Generative AI, encompassing models like Generative Adversarial Networks (GANs), Variational Autoencoders (VAEs), and Large Language Models (LLMs), enhances the capabilities of these systems, from decision-making and predictive modeling to cybersecurity and real-time environmental adaptation. By enabling autonomous vehicles and drones to better interpret and respond to complex, dynamic environments, Generative AI is transforming how uncrewed systems interact with their surroundings, making them more reliable and resilient in a range of challenging applications. By enabling autonomous vehicles and drones to better interpret and respond to complex, dynamic environments, Generative AI is transforming how uncrewed systems interact with their surroundings, making them more reliable and resilient in a range of challenging applications. However, this capability remains to be implemented across many autonomous platforms.

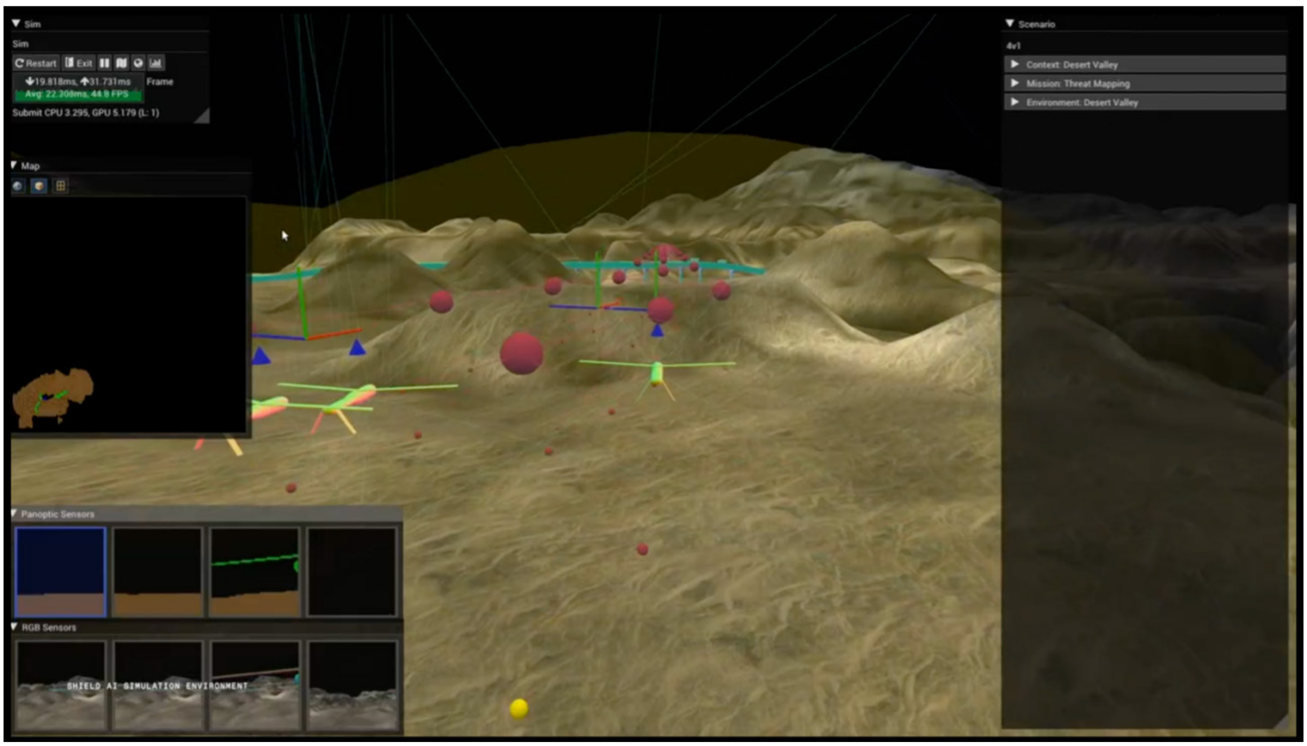
Image 2 - This is how Open AI's image creation model sees the future with autonomous vehicles.

In the development of this article, we were fortunate to have the opportunity to interview some key players in the AI industry and gain their unique perspectives on these rapidly advancing solutions, especially as they pertain to uncrewed systems. In our discussion with Sterling McHale, Director of Government Relations at Shield AI, he provided invaluable insights into the practical and conceptual challenges of integrating generative AI into defense operations and policy. Shield AI, known for developing cutting-edge autonomous software and it's MQ-35 V-BAT – a group 3 VTOL UAS, both actively deployed by the Department of Defense (DOD), represents the forefront of innovation in defense applications. Sterling provided insights into the critical role these technologies play in modernizing operations while addressing the unique demands of the defense sector, where precision, predictability, and interpretability are paramount.

Generative AI has transformative potential in mission planning and simulation. Shield AI's autonomy stack Hivemind AI (Figure 8), trains agents in low and high-fidelity virtual environments. These environments allow autonomous systems and human operators to train extensively, preparing for unpredictable scenarios such as sudden enemy movements or adverse environmental conditions. These simulations refine the agent decision-making processes and enhance the resilience of systems operating in high-stakes environments. However, the non-deterministic nature of generative AI presents challenges for its use in defense applications. It's important to achieve explainability, as defense policies often require detailed justifications for every AI-driven decision, particularly in missions where lives and strategic objectives are on the line. This need for transparency sets defense operations apart from commercial industries, where performance and efficiency often take precedence.

Generative AI's ability to synthesize data is another area of focus. By incorporating synthetic sensor data and environmental variables, Shield AI's autonomy software can prepare for edge cases they might not otherwise encounter. These advancements help bridge gaps in real-world data and improve operational readiness in environments where real-world testing may be limited or risky.

Figure 8 - Hivemind: Shield's proprietary AI pilot



Source: https://shield.ai/hivemind/

While autonomous UAS may demonstrate significant capabilities in real-time decision-making, the limitations of generative AI are apparent. For instance, while generative AI excels at creating realistic training environments or synthesizing data for algorithm improvement, its unpredictability presents challenges in actual combat scenarios where decision-making must be flawless and easily interpretable. This interpretability becomes a sticking point as defense policies and officials often necessitate detailed explanations for every AI-driven action, especially in missions where lives and strategic objectives are at stake.

Despite these challenges, generative AI holds potential for defense operations, particularly in mission planning and simulation. Shield AI's ability to create high-fidelity, realistic environments allows operators and systems to train extensively in virtual settings that mimic real-world combat scenarios. These simulations refine decision-making capabilities and enhance the readiness of human operators. For example, Shield AI's drones navigate highly dynamic combat environments in simulations, adapting to sudden changes such as unpredictable enemy movements or environmental hazards.

Generative AI also has the potential to revolutionize data synthesis within defense systems. By generating synthetic sensor data or environmental variables, it can bridge gaps in real-world data, enabling autonomous systems to prepare for edge cases they might not otherwise encounter. Shield AI's work in augmenting real-world data with synthetic inputs has proven invaluable in improving system resilience and adaptability. Furthermore, these techniques allow for extensive testing without the logistical and financial constraints of traditional field exercises.

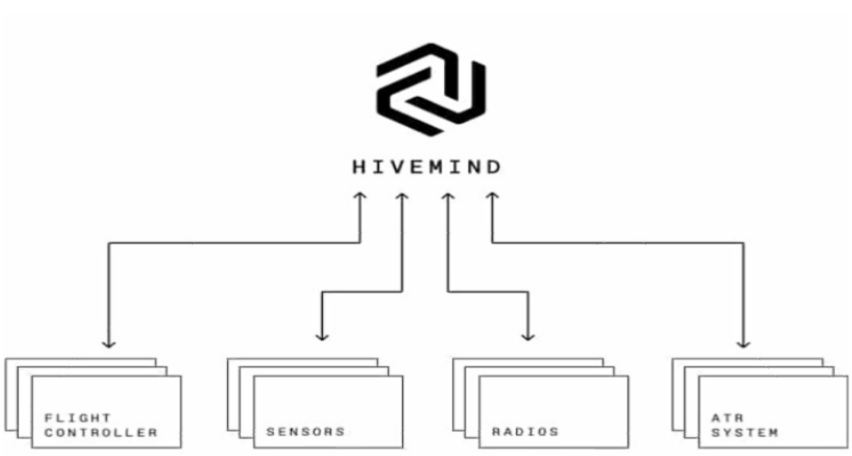
Another intriguing application of generative AI lies in enhancing human-machine collaboration. Ongoing research explores how AI can translate complex mission objectives into actionable strategies for autonomous systems, effectively acting as a bridge between human commanders and uncrewed units. This capability could significantly reduce the cognitive load on human operators, enabling them to focus on broader strategic decisions while AI handles tactical execution.

In sum, Shield AI's advancements highlight the dual nature of generative AI in defense: a tool with immense potential but one that requires careful adaptation to meet the vital requirements and ethics of military applications. While generative AI is not yet fully integrated into deployed systems, it already plays a pivotal role in simulation, data augmentation, and mission planning. These developments set the stage for more extensive applications as the technology matures, underscoring its transformative potential for enhancing system resilience, operational readiness, and decision-making within defense-related uncrewed systems.

In recent news[14], another defense contractor, Anduril Industries announced a strategic partnership with OpenAI to advance the application of generative AI in uncrewed defense systems. By integrating OpenAI's cutting-edge AI models with Anduril's advanced Lattice software platform, the collaboration focuses on enhancing counter-uncrewed aircraft systems (CUAS) capabilities. Leveraging generative AI for tasks like real-time threat detection, data synthesis, and situational awareness, this partnership aims to address the evolving challenges posed by uncrewed aerial threats while reducing reliance on human operators. These efforts demonstrate the growing role of generative AI in streamlining complex operations and augmenting decision-making processes in defense missions.

This partnership also highlights the transformative potential of generative AI in shaping next-generation uncrewed technologies. By using synthetic data to simulate various threat scenarios and improving AI-driven autonomy in CUAS, Anduril and OpenAI are addressing critical operational gaps. These advancements complement ongoing innovations in the uncrewed systems industry, emphasizing the importance of generative AI in building resilient, adaptable, and ethically governed defense technologies. Together, these efforts pave the way for safer and more efficient applications of uncrewed systems in modern defense strategies.

Figure 9 - Hivemind diagram



Source: *https://shield.ai/hivemind/*

In contrast, our conversation with Vlad Voroninski, CEO of Helm.ai, delved into the transformative role of generative AI in autonomous driving systems, especially within the realm of commercial applications. Vlad provided a comprehensive overview of how Helm.ai leverages generative AI to address some of the most pressing challenges in autonomous vehicle development, including real-time decision-making, predictive modeling, and system simulation.

Vlad emphasized the importance of generative AI in processing the continuous influx of sensory data from sources such as LiDAR, cameras, and radar. This data forms the backbone of an autonomous system's perception stack, which is responsible for interpreting the environment and identifying potential obstacles or hazards. According to Vlad, generative AI excels in creating predictive models capable of simulating the behavior of objects within complex driving environments. These simulations enable autonomous systems to anticipate the movement of pedestrians, vehicles, and other dynamic entities, allowing for safer and more informed decision-making. "The ability to predict potential outcomes based on current observations," Vlad noted, "is critical for navigating the unpredictability of real-world scenarios."

Helm.ai's use of generative AI extends beyond real-time operations to include the development of high-fidelity simulations that mimic challenging driving conditions. Vlad shared insights into how these simulations are crafted to address rare or complex edge cases, such as navigating unexpected road obstacles or responding to erratic behavior from other drivers. By generating synthetic datasets through generative AI models, Helm.ai can expose its systems to a wider variety of scenarios than would be possible with real-world data alone. This approach not only accelerates the training process but also enhances the robustness of autonomous systems in handling unforeseen events.

One of the most intriguing aspects of the discussion centered on Helm.ai's innovations in scaling generative AI for real-time applications. Vlad highlighted how Helm.ai combines generative AI with proprietary unsupervised learning techniques to optimize computational efficiency without sacrificing accuracy. This method, known as "deep teaching," enables the company to develop scalable solutions that can operate effectively within the computational constraints of commercial vehicles. Vlad noted that this capability is particularly crucial for ensuring that generative AI can be seamlessly integrated into real-world systems, where latency and reliability are paramount.

Figure 10 - Helm.ai's VidGen 2 model for generating ultra realistic driving videos.
Image is AI generated and not a real-world photo

Source: https://www.businesswire.com/news/home/20241001089771/en/Helm.ai-Introduces-VidGen-2-Generative-AI-for-Higher-Resolution-and-Enhanced-Realism-Multi-Camera-Video-for-Autonomous-Driving%20

The conversation also touched on the ethical and interpretability challenges inherent in deploying generative AI for autonomous driving. Vlad acknowledged that achieving transparency in AI decision-making remains a critical focus for Helm.ai, especially given the safety-critical nature of the automotive industry. He discussed the company's efforts to address these challenges through modular system designs and advanced interpretability techniques, ensuring that each decision made by the AI can be traced and validated. This emphasis on accountability underscores Helm.ai's commitment to creating systems that not only perform reliably but also inspire trust among regulators and consumers alike.

Additionally, Vlad shared Helm.ai's approach to balancing fleet data collection with generative AI-driven simulations. While Tesla has gained prominence for its extensive fleet data collection, Helm.ai differentiates itself by combining real-world data with high-fidelity synthetic simulations. This hybrid approach allows the company to train its systems on a diverse array of scenarios while minimizing the reliance on costly and time-intensive field data collection. Vlad explained how this strategy enhances the scalability of autonomous driving solutions, enabling Helm.ai to compete effectively in a rapidly evolving industry.

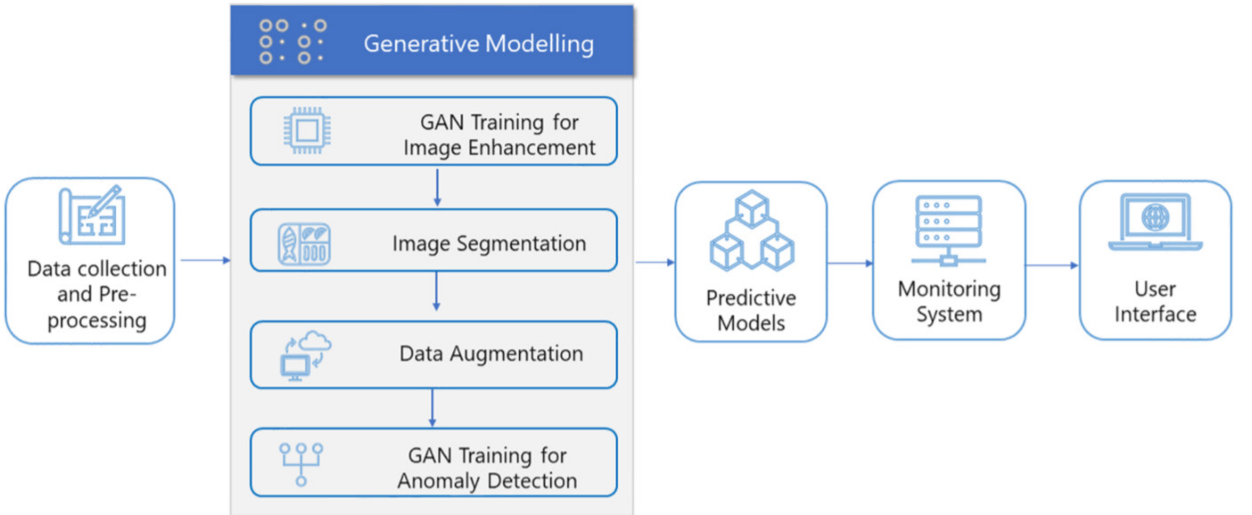
The discussion concluded with an exploration of Helm.ai's vision for the future of autonomous systems. Vlad outlined the potential for generative AI to expand beyond driving applications into other sectors, such as mining and robotics. By leveraging generative AI to create adaptable and resilient systems, Helm.ai aims to set new benchmarks for innovation across multiple domains. This forward-looking perspective underscores the transformative potential of generative AI not only in autonomous driving but also in shaping the broader uncrewed systems industry, where adaptability, safety, and efficiency are increasingly critical.

Generative AI and Uncrewed Systems: Industry Integration and Technical Challenges

The uncrewed systems industry, spanning drones, autonomous vehicles, and robotics, is leveraging generative AI to address critical challenges related to decision-making, resilience, and adaptability in dynamic environments. However, the integration of generative AI into these systems is not without its obstacles. Data scarcity, adaptability to changing conditions, cybersecurity, and network connectivity are among the most pressing challenges. Generative AI models, such as GANs and VAEs, allow these systems to augment datasets by generating synthetic data, which is particularly useful in environments where obtaining real-world data is either too costly or unsafe. For instance, synthetic data generated by GANs can simulate edge cases in autonomous vehicle operation, such as navigating through severe weather conditions or responding to unexpected obstacles. By training on this synthetic data, autonomous systems can develop robust predictive models that improve their response to real-world scenarios.

In addition, generative AI has been instrumental in enhancing the cybersecurity and resilience of uncrewed systems. Autonomous systems, especially those used in critical infrastructure and defense, are susceptible to cyber threats that could compromise their functionality or safety. Generative AI strengthens these systems' security by enabling advanced intrusion detection, anomaly detection, and fault tolerance. For example, VAEs are utilized to monitor operational data in real-time, enabling early detection of unusual patterns that may indicate system faults or cybersecurity breaches. This capability is essential for autonomous systems operating in sensitive environments, where the risk of cyber-attacks is high. Through predictive maintenance, generative models can identify early signs of wear or malfunction in system components, thereby preventing unexpected failures that could jeopardize missions or operations (Figure 11).

Figure 11 - Equations Work GenAI predictive maintenance implementation diagram for Wind Turbines



Source: https://eqw.ai/learn-how-we-applied-gan-for-predictive-maintenance-of-wind-turbines/

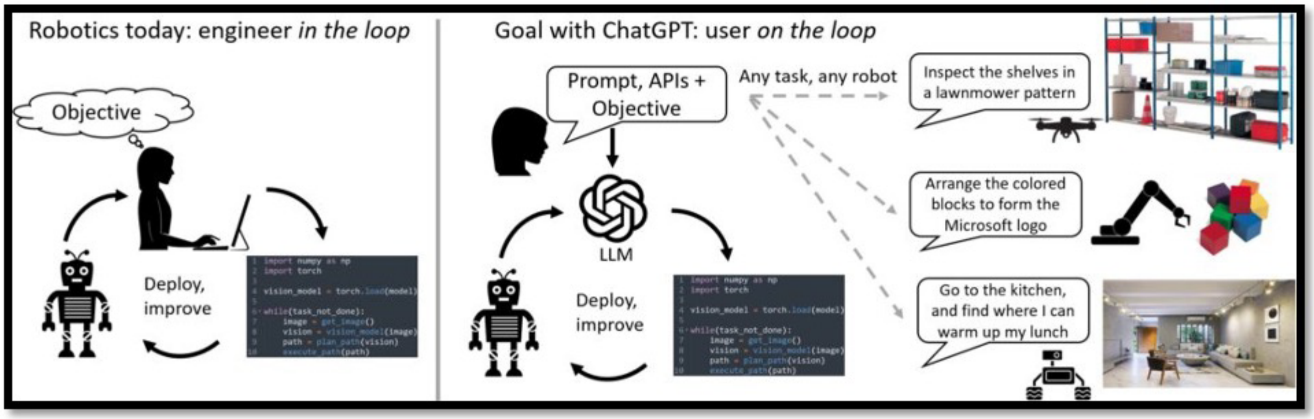
The dual role of Large Language Models (LLMs) in cybersecurity further showcases the adaptability of Generative AI in uncrewed systems. LLMs, while widely recognized for their language processing capabilities, are increasingly being used in security functions like malware detection, phishing detection, and threat intelligence. In autonomous systems, LLMs can help monitor network security by analyzing communication logs for anomalies or potential vulnerabilities. However, LLMs also present new challenges, as they can be exploited in adversarial attacks aimed at extracting model parameters or generating malicious content. Ensuring the safe deployment of LLMs within uncrewed systems requires ongoing research into model extraction attacks, parameter tuning, and secure data handling practices.

Impact on Specific Applications in the Uncrewed Industry

Generative AI's impact on specific applications within the uncrewed industry extends across security, autonomy, adaptability, predictive maintenance, and fleet coordination. In the realm of security, Generative AI plays a crucial role in anomaly detection for drone swarms and autonomous vehicles. VAEs, for instance, are adept at identifying irregular patterns in sensor data, enabling systems to detect faults or potential security breaches before they escalate into critical issues. Enhanced by generative AI models like GANs, these systems can simulate a wide range of operational scenarios, including rare failure modes, to build resilience and improve the reliability of fault-detection mechanisms. This capability is particularly valuable for mission-critical applications where system failure is not an option, such as military or disaster response operations.

Autonomy is another area where generative AI has a profound impact on uncrewed systems. Generative models allow autonomous vehicles and drones to navigate complex environments by creating predictive models that anticipate potential obstacles or changes in their surroundings. Large Language Models (LLMs) like those utilized in DriveLLM enable uncrewed systems to characterize and adapt to new environments, facilitating improved decision-making and reasoning. Fugure.AI, for example, is the first-of-its-kind AI robotics company bringing a general purpose humanoid to life. With this, they are working on solving ongoing issues, primarily, labor shortages and reducing the number of workers in unsafe jobs[18]. On the other hand, Microsoft's research into combining LLMs with robotics exemplifies this, demonstrating how models such as ChatGPT can interact with uncrewed systems in a human-like manner, interpreting natural language commands to execute tasks. This interaction is particularly beneficial in settings where human oversight is required, as it allows uncrewed systems to respond more intuitively to dynamic, unpredictable situations (Figure 12).

Figure 12 - ChatGPT for robotics by Microsoft



Source: https://www.microsoft.com/en-us/research/publication/chatgpt-for-robotics-design-principles-and-model-abilities/%20

"Autonomy" is a complex concept that means many things to different people. Kyle Snyder, the Founder of Flyabout Strategies LLC, has over two decades of experience developing and deploying autonomous systems. "I'm excited to see the advancements in Generative AI to improve the interface between human-machine communications. Using LLMs as a method to improve explainability for AI decision-making will help with certification and trust of autonomous systems. By combining GenAI with ML, knowledge-based systems, and other AI-derivatives, complex autonomy capabilities such as dynamic mission replanning, intent inferencing, and system-of-systems management are closer to becoming a reality. At Flyabout Strategies, we are excited to see how GenAI is advancing our expectations for robot independence, while demonstrating the criticality of infrastructure to provide data and processing that enables higher levels of autonomy."

Adaptability is a key advantage of generative AI in uncrewed systems, as these systems must often function in diverse and changing conditions. For instance, the RTX robotic control LLM can translate control policies across different robotic arms, enabling efficient cross-platform adaptability. This adaptability allows uncrewed systems to operate reliably in various environments, from urban areas to remote or hazardous locations. Furthermore, generative AI models are capable of creating synthetic data to improve model robustness, which is especially useful in scenarios where environmental factors vary significantly, such as weather changes or obstacle-laden terrain. This capability makes uncrewed systems more resilient and versatile, enabling them to handle a wider range of missions and environments.

Predictive maintenance is another significant application of generative AI in the uncrewed industry. By analyzing sensor and operational data, generative models like GANs and VAEs can detect early signs of component wear and predict potential failures before they occur. This predictive capability is vital for maintaining the operational integrity of autonomous systems, particularly in sectors where regular maintenance may be challenging, such as military drones or underwater exploration vehicles. Models like GAN-FP have been developed specifically to generate synthetic training data for failure prediction, which enhances the effectiveness of machine learning algorithms in diagnosing faults. This proactive approach to maintenance reduces downtime and extends the lifespan of uncrewed systems, making them more reliable for extended missions.

In **fleet operations**, generative AI enhances the coordination, communication, and resilience of autonomous systems working in unison, such as drone swarms or autonomous vehicle fleets (Figure 13). Techniques like Generative Knowledge-Supported Transformers (GKST) enable drones to process and interpret complex sensory data, which is crucial for tasks that require real-time situational awareness and data fusion across multiple units. Coordination models like CLIPSwarm leverage generative AI to dynamically adjust drone formations based on mission requirements, facilitating more efficient and responsive operations. Additionally, blockchain technologies, including Delegated Proof of Stake (DPoS) and Practical Byzantine Fault Tolerance (PBFT), enhance the resilience of communication networks within autonomous fleets by securing node interactions against cyber threats.

Figure 13 - Swarm of drones

Source: https://sdi.ai/blog/military-drone-swarm-intelligence-explained/

Future of Generative AI

Generative AI is having a significant impact on robotics and autonomous vehicles. For example, Boston Dynamics has integrated advanced AI in robots like Spot and Atlas, which are tailored for industrial tasks such as inspections and warehouse operations, as well as disaster response.[24] These innovations demonstrate the dynamic versatility generative AI brings to robotics, enabling them to tackle complex challenges in industrial and domestic settings. This adaptability also facilitates collaborative learning across networks of autonomous vehicles and robots, allowing systems to share data and optimize behaviors in real time. Such advancements improve operational efficiency, safety, and reliability, particularly in high-stakes environments like logistics, defense, and disaster recovery.

In conclusion, the evolution of generative AI in uncrewed systems presents transformative possibilities for daily life and business. While progress is rapid, ethical considerations, such as transparency, bias reduction, and regulatory compliance, must guide its deployment. Balancing innovation with responsibility will be key to ensuring generative AI aligns with societal values and achieves its full potential in advancing both industry and quality of life.

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