KMANPUB | AI and Tech in Behavioral and Social Sciences Vol. 2 No. 4 (2024): 54-65

Article history:
Received 04 June 2024
Revised 03 August 2024
Accepted 13 August 2024
Published online 01 October 2024

A Review of Cognitive UAVs: AI-Driven Situation Awareness for Enhanced Operations

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Article Info

Article type:
Review Article

How to cite this article:
Dehghan, M., & Khosravian, E. (2024). A Review of Cognitive UAVs: AI-Driven Situation Awareness for Enhanced Operations. *AI and Tech in Behavioral and Social Sciences*, *2*(4), 54-65.
https://doi.org/10.61838/kman.aitech.2.4.6

ABSTRACT

The integration of artificial intelligence (AI) into unmanned aerial vehicles (UAVs) has substantially advanced these platforms' capabilities, particularly in enhancing situational awareness. This paper presents a comprehensive survey and review of AI-driven techniques aimed at improving situational awareness in UAVs. We begin by defining situational awareness and its essential components—perception, comprehension, and projection—within the context of UAV operations. Subsequently, we explore various AI methodologies, including machine learning, deep learning, computer vision, natural language processing, and data fusion, that are employed to augment UAVs' capabilities to perceive and interpret their environments. The paper examines diverse AI-enhanced UAV situational awareness applications across military, civilian, and commercial domains. Critical applications include advanced surveillance, target acquisition, search and rescue missions, environmental monitoring, traffic and crowd monitoring, infrastructure inspection, and delivery services. Additionally, we discuss the technical and operational challenges associated with implementing AI in UAVs, such as data quality, real-time processing, environmental impacts, and scalability. Ethical and legal considerations are also addressed, including privacy concerns and regulatory issues. In addition to a thorough review of the current literature, we provide detailed case studies highlighting successful AI implementations in UAVs, offering practical insights and lessons learned. We also identify emerging technologies and future research opportunities with the potential to advance the field, such as innovations in sensor technology and AI algorithms. Our findings underscore the transformative potential of AI in enhancing the situational awareness of UAVs, paving the way for more intelligent, autonomous, and effective aerial systems. This survey serves as a valuable resource for researchers, practitioners, and policymakers interested in understanding and leveraging the intersection of AI and UAV technology for various applications.

Keywords: *Artificial Intelligence, Unmanned Aerial Vehicle, Situational Awareness*

1. Introduction

Unmanned Aerial Vehicles (UAVs), commonly referred to as drones, have become essential tools across various sectors, including military, civilian, and commercial applications. Their capability to operate in hazardous or inaccessible environments, combined with their versatility and cost-effectiveness, has led to their widespread adoption. In the military domain, UAVs are crucial for surveillance, reconnaissance, and tactical operations, providing real-time intelligence and situational awareness, thereby reducing risks to human operators and enhancing mission effectiveness. Civilian applications are equally diverse, encompassing disaster response, environmental monitoring, agriculture, infrastructure inspection, and delivery services. In search and rescue operations, UAVs can rapidly cover large areas and access rugged terrains, significantly improving the likelihood of locating and assisting victims (Arjomandi et al., 2006).

Situational awareness is critical in UAV operations, enabling the vehicle to understand and interpret its environment to make informed decisions. It comprises three key components: perception, comprehension, and projection. Perception involves recognizing and identifying objects and events in the environment. Comprehension pertains to understanding the significance of these elements and their interrelationships. Projection involves predicting future states and potential developments based on the current understanding. Effective situational awareness ensures that UAVs can navigate complex environments, avoid obstacles, and achieve their operational objectives safely and efficiently (Endsley, 1995, 1999).

The dynamic and often unpredictable nature of the environments in which UAVs operate necessitates advanced capabilities for real-time data processing and decision-making (Endsley, 1995). Traditional methods struggle to manage the sheer volume and complexity of data. This is where artificial intelligence (AI) becomes crucial. AI technologies, such as machine learning, deep learning, and computer vision, offer powerful tools for enhancing situational awareness. They enable UAVs to autonomously perceive and interpret their surroundings, recognize patterns, adapt to new situations, and make decisions with minimal human intervention. The integration of AI into UAV systems not only enhances their operational efficiency and effectiveness but also expands the scope of their applications (Endsley, 1995).

This paper aims to survey and review the current state of AI-driven techniques for enhancing situational awareness in UAVs. By exploring various AI methodologies and their applications, we seek to comprehensively understand how AI can transform UAV operations, addressing both the opportunities and challenges associated with this integration.

The scope of this survey encompasses a broad range of AI methodologies, including machine learning, deep learning, computer vision, natural language processing, and data fusion, as they pertain to UAV situational awareness. The review covers various UAV applications across military, civilian, and commercial domains, highlighting how AI technologies are employed to improve UAVs' ability to perceive, comprehend, and project environmental information.

The primary objectives of this survey are:

- To present an overview of the fundamental concepts of situational awareness and its importance in UAV operations.
- To explore and categorize the AI techniques used to enhance situational awareness in UAVs.
- To examine the diverse applications of AI-driven situational awareness in various fields.
- To identify and discuss the technical, operational, ethical, and legal challenges associated with integrating AI into UAV systems.
- To identify emerging technologies and future research opportunities in this field.

The paper is organized as follows: The next section outlines the methodology and criteria for paper selection and review. Section three covers the fundamentals of situational awareness, UAVs, and artificial intelligence methods. We then examine papers proposing AI models to enhance situational awareness in UAV applications. Lastly, we discuss future initiatives for applying AI and new technologies to further improve situational awareness in UAVs.

2. Methods and Materials

This paper systematically reviews existing literature on AI-controlled UAVs to assess their impact on situational awareness. The selection criteria focus on relevance to AI technology, application to UAV systems, and contributions to understanding situational awareness enhancement. Sources from peer-reviewed journals, conference proceedings, and reputable technical reports were meticulously chosen to ensure currency and relevance. Each study is evaluated based on its methodology, results, and influence in the field, particularly regarding the effectiveness of AI applications in various operational contexts. The review organizes the literature into thematic categories, including machine learning, deep learning, computer vision, and data fusion, which helps identify trends, challenges, and research gaps. Collectively, these insights offer a structured overview of advancements in AI for UAVs and pinpoint critical areas for further

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investigation. The review also addresses practical implications for UAV operations and outlines future research directions, providing a comprehensive assessment of how AI-controlled UAVs can enhance situational awareness and identifying opportunities for further technological developments and applications.

3. Fundamentals of Situational Awareness, UAVs, and AI

3.1. Situational Awareness

Situational awareness is a cognitive process that involves perceiving and comprehending the current situation and projecting near-future events. Based on this awareness, plans can be formulated, decisions made, and actions executed (Dehghan et al., 2022). Several definitions of situational awareness exist, with one of the most widely recognized provided by Mica Endsley in 1995 (Endsley, 2018): "Situational awareness or situation awareness (SA) is the perception of environmental elements and events with respect to time or space, the comprehension of their meaning, and the projection of their future status." This definition distinguishes between three levels of situational awareness: perception (including observation), comprehension, and projection (including prediction). The lowest level involves observation and perception, while the highest level involves the projection of the current situation into the future to predict the evolution of the tactical situation. The highest level in Endsley's situational awareness model, termed projection, involves predicting the status of environmental elements in the near future (Dehghan et al., 2022).

Figure 1

Model of Situational Awareness in Dynamic Decision-Making (Endsley, 1995).

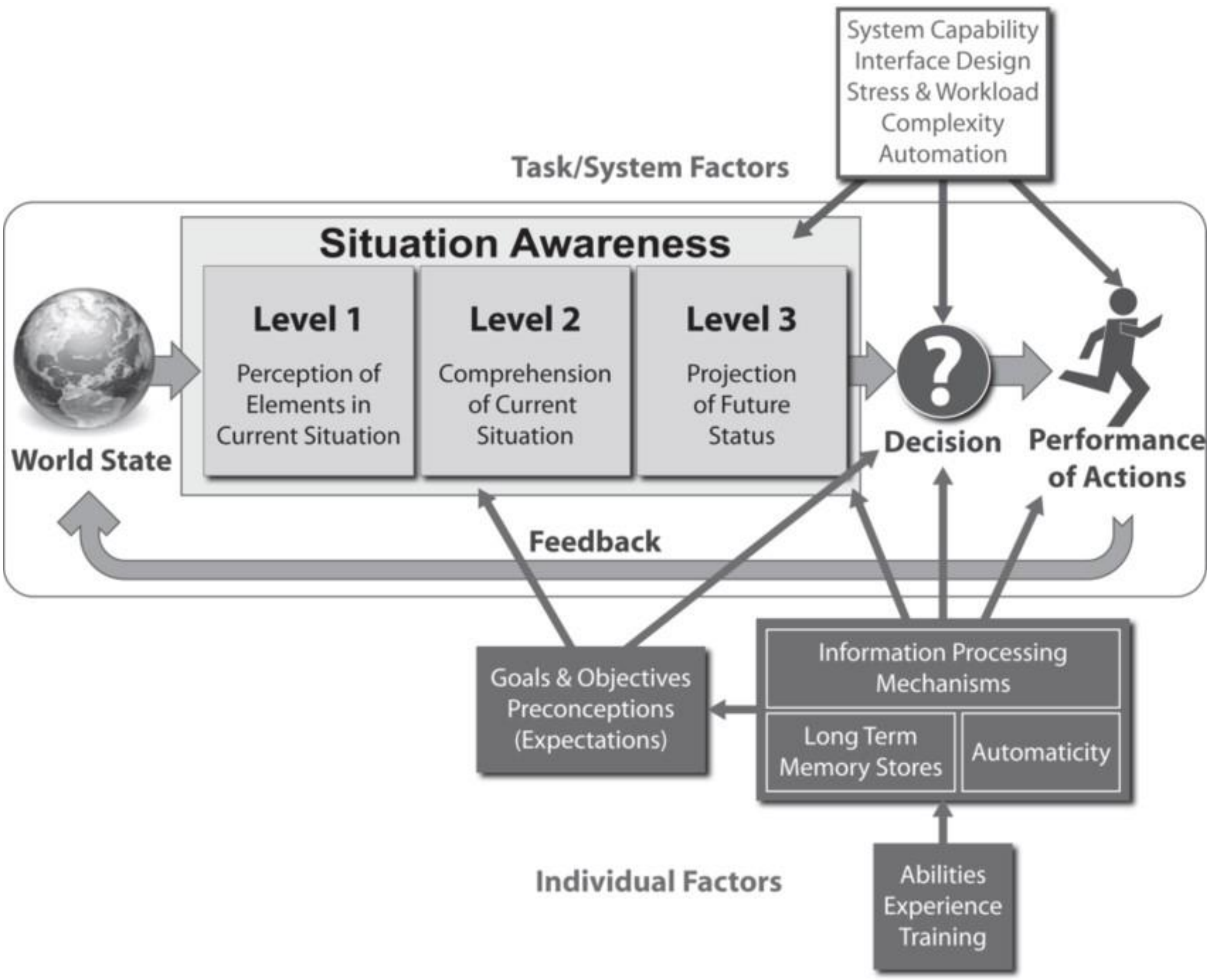

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Figure 1 illustrates the role of situational awareness (SA) in the decision-making process. According to the model, an individual's perception of relevant environmental elements—derived from system representations or direct sensations—forms the basis of their SA. Action selection and execution emerge as distinct phases from SA. Several factors influence this process, starting with individual variations in the ability to achieve SA from the same data input, which depends on information processing mechanisms, innate abilities, experience, and training. Additionally, biases and goals can shape how individuals filter and interpret their environment. System design also impacts SA by determining how effectively it provides necessary information and its alignment with human information processing capabilities. Furthermore, characteristics of the work environment, such as workload, stress, and complexity, may affect SA. The influence of these individual and system factors on SA has been discussed (Endsley, 1995).

3.2. Unmanned Aerial Vehicles

Unmanned aerial vehicles (UAVs), commonly known as drones, operate without the need for an onboard human pilot. UAVs are categorized into several types: fixed-wing UAVs, designed for extended flight durations and long-distance missions; rotary-wing UAVs, such as quadcopters, which offer vertical takeoff and landing capabilities as well as high maneuverability; and hybrid UAVs, which combine features of both fixed-wing and rotary-wing designs. These UAVs are equipped with a variety of sensors and payloads, including high-resolution cameras, LiDAR, radar, and GPS, enabling them to perform tasks such as surveillance, mapping, inspection, and environmental monitoring. The data collected by these sensors in real-time enhances situational awareness, supporting a wide range of applications across military, civilian, and commercial sectors. This capability allows UAVs to navigate complex environments, avoid obstacles, and effectively execute their missions (Ahmed et al., 2022).

3.3. Artificial Intelligence

Artificial intelligence (AI) is a broad scientific discipline that enables computer systems to solve problems by emulating complex biological processes, such as learning, reasoning, and self-correction. AI systems and entities can perform operations analogous to human cognitive processes, with particular emphasis on learning and decision-making. AI applications, such as virtual personal assistants, intelligent vehicles, purchase prediction, speech recognition, and smart home devices, are becoming increasingly pervasive, transforming daily life by enhancing human productivity, safety, and even entertainment and communication (Ertel, 2018).

Artificial intelligence encompasses a variety of methods. Based on studies focused on applying AI to enhance situational awareness in UAVs, the key methods identified in this area include:

Machine Learning: This includes supervised learning (e.g., object detection, terrain classification, anomaly detection), unsupervised learning (e.g., clustering, dimensionality reduction, feature extraction), and reinforcement learning (e.g., navigation, autonomous decision-making, multi-UAV coordination).

Deep Learning: This involves the use of neural networks, with a specific emphasis on Convolutional Neural Networks (CNNs) for image recognition and Recurrent Neural Networks (RNNs) for processing time-series data.

Computer Vision: Techniques in this domain include object detection and recognition, as well as scene understanding, all of which are critical for interpreting visual data.

Augmented Reality (AR): AR provides a real-time direct or indirect view of a physical, real-world environment enhanced by adding virtual computer-generated information.

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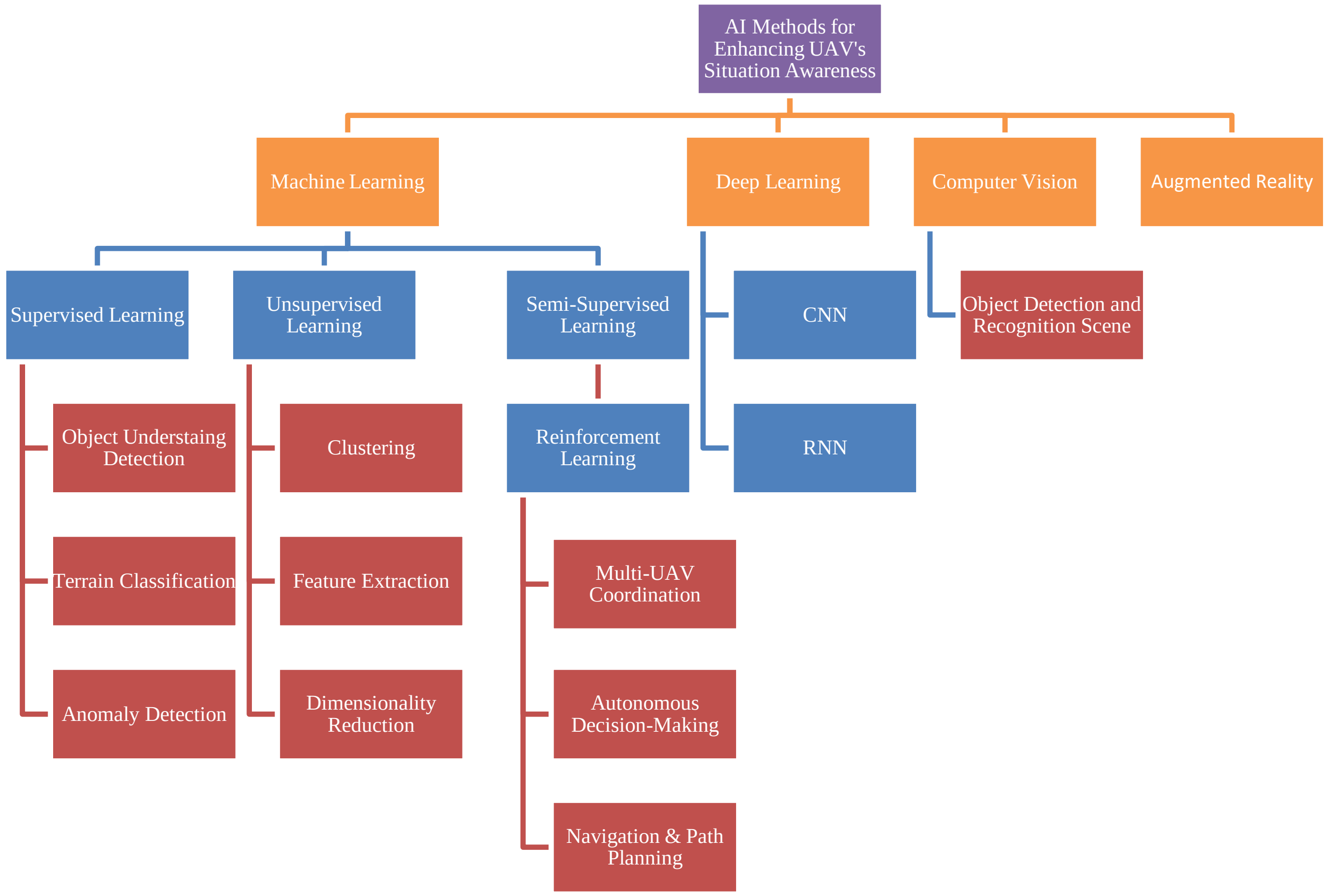
Figure 2

Classification of AI Methods for Enhancing UAV's Situation Awareness



4. Literature Review

This section reviews research on the application of AI in enhancing UAV situational awareness.

The framework proposed by Han, Wang, and Wang (2023) enhances situational awareness in UAV swarms, particularly for search and rescue operations. A multi-layer perceptron (MLP) neural network identifies swarm behavior formations and provides insights into their dynamics. A fuzzy inference system assesses the swarm's current situation and intentions, while a long short-term memory (LSTM) neural network predicts future conditions, enabling proactive decision-making. Additionally, a benefit assessment function facilitates quantitative analysis of the swarm's effectiveness in search and rescue, optimizing mission outcomes. Overall, the framework improves decision-making and operational efficiency in UAV swarm operations, highlighting its potential for critical missions (Han et al., 2023).

Song et al. (2023) explore UAV cluster situational awareness technology, crucial for executing autonomous tasks. Situational awareness aims to provide a comprehensive understanding and forecast of threats in complex environments by leveraging information fusion and AI. The authors introduce cluster situational awareness technology and examine its applications in domestic and international projects. They also address the technical challenges of implementing this technology and discuss the framework and critical technologies involved. Finally, they outline future development directions for enhancing situational awareness in UAV clusters, offering valuable insights for future research in the field (Song et al., 2023).

Gao and Lv (2023) emphasize the significance of cooperative UAV swarm operations in future warfare, highlighting their disruptive potential. They introduce two novel cooperative situational awareness (SA) models specifically designed for UAV swarms, incorporating classical models alongside the swarms' unique traits. The first model enhances Endsley's three-level SA framework

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by replacing conventional mental models with an intelligent individual-level human-machine model. The second model distinguishes between homogeneous and heterogeneous UAV swarms, creating distinct cooperative SA models based on the extended team SA model and the distributed SA model (DSA). They compare multi-UAV operations with UAV swarm operations, highlighting the differences in cooperative SA. Additionally, a scenario analysis demonstrates the functioning of swarm cooperative SA in combat situations, providing practical insights for military applications (Gao & Lv, 2023).

Ren et al. (2021) examine the transformative impact of AI on warfare, emphasizing the shift toward intelligent, unmanned, and networked combat systems in modern operations. Their focus is on machine learning, a crucial aspect of AI that has proven useful in fields like computer vision and natural language processing. The paper investigates potential UAV applications in combat missions, particularly how machine learning can enhance UAV situational awareness and autonomous decision-making. Detailed analysis underscores the importance of machine learning in processing large amounts of battlefield data, enabling UAVs to extract critical information and facilitate faster decision-making in combat. The authors argue that integrating machine learning into UAV operations will improve battlefield responsiveness and effectiveness, representing a key area for future research and exploration (Ren et al., 2021).

Igonin, Kolganov, and Tiumentsev (2021) highlight the importance of situational awareness in effectively controlling UAV behavior, providing essential information aligned with UAV objectives and tasks. UAVs are categorized as controlled dynamic systems, and their position within this hierarchy is discussed. The authors present concepts of UAV behavior and activity, detailing algorithm requirements for behavior management. They propose a framework for understanding situational awareness in highly autonomous UAVs (HA-UAVs), analyzing its various levels and types. The paper emphasizes the distinct aspects of situational awareness formation for UAVs compared to manned aircraft and remotely piloted UAVs, focusing on predicting the behavior of nearby objects and processing visual information. Additionally, it explores machine learning applications to address situational awareness challenges, such as tracking maneuvering aircraft and semantic segmentation for landing site selection. Finally, the authors outline several unresolved issues in the field of situational awareness for HA-UAVs (Igonin et al., 2021b).

Igonin, Kolganov, and Tiumentsev (2021) also address the challenges of situational awareness in controlling UAVs. Situational awareness involves gathering information about the UAV's operating environment, which is essential for effective decision-making. A critical component is understanding surrounding objects, their movement trajectories, and predicting their future motion. The authors focus on predicting the trajectories of dynamic objects around the UAV. To address this, they created a dataset using the FlightGear flight simulator, divided into training, validation, and test sets for developing a neural network model. The model utilizes recurrent neural networks, which are suitable for predicting the motion of tracked objects (Igonin et al., 2021a).

Anjum, Sadhu, and Pompili (2020) discuss advancements in neural networks (NNs) for tasks like image classification and gaming, highlighting their high computational demands and limited real-time applicability. They propose integrating low-resource mobile devices, such as drones, with approximate distributed computing techniques. The goal is to enable NN technology on resource-constrained devices while maintaining real-time situational awareness, particularly in rapidly understanding critical elements of new environments. The article illustrates how drones can detect suspects and weapons in real-time using local resources and addresses suspect identification during emergencies, showcasing a practical application of the proposed methods. Validation is conducted using the Microsoft AirSim simulator, which combines simulation and hardware-in-the-loop emulation to demonstrate effectiveness (Anjum et al., 2020).

Zak, Parmet, and Oron-Gilad (2020) discuss the importance of situational awareness for UAV operators in their operational areas, particularly in relation to Command and Control (C2) maps, which often lack relevant data. Operators need timely and relevant information to make effective decisions, as current filtering methods for C2 maps are insufficient and layer-based. The authors propose a new solution that automatically filters C2 map information based on environmental and mission context, utilizing a three-tier AI algorithm called GiCo-MAF. The GiCo-MAF algorithm integrates machine learning (ML) models to enhance UAV mission support, developed through data collection from simulated runs with professional UAS operators. Various ML models have been tested and incorporated into the algorithm, accurately reflecting human preferences and areas of interest. This approach also addresses time-critical spatiotemporal challenges in UAV missions (Zak et al., 2020).

Fan et al. (2020) examine the use of UAVs for surveillance and observation, specifically their role as edge servers for real-time data collection and processing. Maintaining situational awareness is challenging because UAVs must frequently shift between detection areas. Continuous flight and data processing can quickly deplete UAV batteries, necessitating energy-efficient trajectory planning and data offloading strategies. The authors introduce a freshness function based on the concept of information age to assess situational awareness freshness. They present a multi-agent deep reinforcement learning (DRL) algorithm for the cooperative control of multiple UAVs, utilizing global and local rewards. Simulation results demonstrate that this algorithm significantly reduces energy consumption while preserving high situational awareness in rapidly changing environments (Fan et al., 2020).

Maltezos et al. (2020) explore the increasing use of UAVs to enhance situational awareness across various sectors. UAVs provide operational managers with real-time information, facilitating informed decision-making during events. The authors propose a preliminary design for a multipurpose UAV situational awareness platform that leverages advanced on-board processing, including computer vision, image processing, and machine learning techniques, to improve effectiveness. The design integrates aerial and terrestrial surveillance assets, ensuring rapid and reliable information delivery during emergencies, which is essential for effective area monitoring. Experimental results from RGB and thermal video datasets illustrate innovative object detection and tracking algorithms, highlighting the proposed UAV's potential and utility. Lastly, the authors suggest future directions for enhancing and optimizing the multipurpose UAV situational awareness system, indicating ongoing research and development (Maltezos et al., 2020).

Avanzini, De Luca, and Pascarelli (2020) explore the use of UAVs in sensitive areas such as civil airports, emphasizing the need for operator situational awareness to ensure safe operations. The authors argue that operators require real-time, relevant information to make timely emergency decisions. They suggest augmented reality (AR) as a tool to overlay vital information onto the real-world view, enhancing situational awareness. The paper presents an architecture for integrating drone operations into airspace, allowing UAVs to coexist safely with manned aircraft. It also describes the design of an AR application aimed at improving pilots' awareness and response in critical situations (Avanzini et al., 2020).

You (2020) presents a multi-layered framework for autonomous perception and data fusion in UAV swarms to enhance mission performance. This framework integrates various perception techniques to boost situational awareness. A critical approach involves advanced algorithms for real-time data processing, enabling UAVs to make swift decisions based on environmental information. The authors also implement collaborative strategies among UAVs, facilitating effective data sharing and insights. This collaboration is essential for optimizing resource allocation and improving mission outcomes. Furthermore, the paper addresses challenges such as communication delays and environmental uncertainties by incorporating adaptive mechanisms that adjust UAV operations based on real-time conditions. The outlined methods aim to create a robust system capable of operating efficiently in dynamic, unpredictable environments, enhancing the effectiveness of UAV swarms for applications such as surveillance and search and rescue missions (You, 2020).

Gao et al. (2020) discuss the challenges UAVs encounter in battlefield scenarios, particularly electromagnetic interference that can result in loss of ground control. The authors propose a method for UAV electromagnetic jamming security situation awareness through semantic analysis. This analysis is based on subtle changes in UAV state parameters during electromagnetic interference. The method features a tracing comparison technique to detect abnormal UAV behaviors and employs fuzzy logic reasoning for analyzing link jamming and intrusion scenarios. Lastly, it includes a semantic evaluation of the link situation to enhance UAV active defense capabilities. Simulation results show that this approach effectively assesses security situations using limited and diverse state parameters, thereby improving the operational resilience of battlefield UAVs (Gao et al., 2020).

Liu et al. (2020) address the challenges of automated situational awareness (ASA) in complex, dynamic environments, where accurately perceiving elements and events is crucial for mission success. Target detection is essential for ASA, but identifying distant targets is often hampered by factors such as size, complex backgrounds, and poor lighting. The authors recommend multimodal imaging techniques that combine visible and thermal images to enhance situational awareness and improve

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detection capabilities. They present a deep learning framework for Deep Multimodal Image Fusion (DIF), utilizing a deep convolutional neural network (CNN) to integrate complementary information from different modalities to enhance target detection. Validation of the DIF framework, conducted using the Military Sensing Information Analysis Center dataset, shows that it outperforms traditional methods in detection accuracy and computational efficiency (Liu et al., 2020).

Geraldes et al. (2019) highlight the significance of situational awareness in using UAVs for surveillance, search and rescue, and disaster response. They outline three key challenges: limited bandwidth that restricts access to live video feeds, prolonged video monitoring that is tedious for operators, and the impracticality of locating individuals via cell phones. To address these issues, the authors developed the Person-Action-Locator (PAL) system, which utilizes a supercomputer-on-a-module to analyze video feeds onboard the UAV. The PAL system employs deep learning models to detect people and recognize their actions in near real-time, aiding human operators. Additionally, a Pixel2GPS converter estimates individuals' locations from the video feed, displaying detected people and their actions on a map interface. The paper reports successful lab tests of the deep learning models and field tests of the fully integrated PAL system, demonstrating its effectiveness in real-world applications (Geraldes et al., 2019).

Das et al. (2018) present a framework for managing diverse teams of unmanned systems and human agents in unpredictable environments to enhance situational awareness for mission-critical operations. The framework minimizes cognitive load for human agents while ensuring effective team communication and control by integrating five key components: control, communication, artificial intelligence (AI), platform, and visualization. Control is categorized into agent-level and mission-level, enabling structured task management. The Robot Operating System (ROS) facilitates communication, ensuring consensus among unmanned systems. These platforms feature advanced AI/ML capabilities that boost performance and improve human-robot interaction (HRI). A mixed reality (MR) visualization scheme alleviates cognitive burden by offering a hybrid mapping approach that combines 2D and 3D elements. This framework has been tested with a diverse group of UAVs collaborating with a human operator (Das et al., 2018).

Ruano et al. (2017) explore the challenges UAV operators face as they transition from traditional piloting to Ground Control Station (GCS) operations. Standard GCSs typically feature separate displays: one screen shows the video feed, while another presents mission plans and sensor data. The authors propose an augmented reality (AR) tool designed to alleviate the challenge of synthesizing information from these screens. Designed for Medium-Altitude Long-Endurance (MALE) UAVs, the AR system offers two essential functions: route orientation and target identification. Route orientation helps operators visualize upcoming waypoints and the UAV's trajectory, while target identification enables rapid localization, even when obstacles obstruct the view. The AR tool adheres to North Atlantic Treaty Organization (NATO) standards, ensuring compatibility with various GCSs. Experiments demonstrate that the AR tool significantly enhances UAV operators' situational awareness (Ruano et al., 2017).

Rattadilok and Petrovski (2014) propose an adaptive inferential measurement framework for control and automation systems, tested on simulated traffic surveillance data. This framework enables the inference of anomalies in the data through statistical, computational, and clustering analysis. Additionally, a computational intelligence technique can dynamically optimize its ensemble performance. Experimental results show that the framework is applicable across various domains, achieving reasonable inferential accuracy. Computational intelligence also effectively identifies critical features in detecting anomalies within the surveillance data. The authors use statistical, computational, and clustering analysis, along with computational intelligence techniques, for dynamic tuning of ensembles (Rattadilok & Petrovski, 2014).

Table 1 demonstrates an overview of previous research in this area.

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Table 1

A review on previous studies

Source	AI method	Contribution
(Han et al., 2023)	MLP, Fuzzy inference, and LSTM neural networks.	Perception, Comprehension, and projection of UAV swarm situation.
(Song et al., 2023)	Information Fusion	Proposal of cluster situation awareness technology
(Gao & Lv, 2023)	Deep Neural Network, Inverse reinforcement learning, transfer learning	Improved Endsley three level SA model with human- machine intelligent model.
		Homogeneous and heterogeneous swarm cooperative SA models based on team and DSA.
(Ren et al., 2021)	LSTM-RNN and variant GRU methods	Focus on understanding root causes of attacks in enterprises
(Igonin et al., 2021a)	LSTM- RNN, Image Segmentation using Deep Learning	Formulation of requirements for controlling UAV behavior algorithms.
		Analysis of SA levels and types for HA-UAVs.
(Gao et al., 2020)	Deep learning, fuzzy logic reasoning	UAV security situation awareness based on semantic analysis.
		Improved active defense capacity of battlefield UAVs.
(Igonin et al., 2021b)	RNN- based deep learning	Formation of a neural network to predict object trajectories.
		Use of FlightGear simulator to prepare datasets.
(Anjum et al., 2020)	Distributed and approximate computing techniques, and neural networks	Deploying Neural Network techniques on resource-constrained drones for SA.
		Real time suspect/ weapon detection and identification in emergency situations
(Zak et al., 2020)	Lasso Regression, Neural Network, Random Forest, XGBoost	A new approach to automatically filter information on C2 maps.
		Developed a three level AI algorithm (GiCo-MAF) using machine learning
(Fan et al., 2020)	Multi-agent deep reinforcement learning	Energy efficient trajectory planning for UAV.
		Freshness function based on Age of Information for situation awareness
(Maltezos et al., 2020)	Computer vision, image processing, and machine learning techniques	Design of multipurpose UAV situational awareness platform.
		Utilization of advanced computer vision and machine learning techniques
(Avanzini et al., 2020)	Augmented Reality	AR-based visual aids for sUAS operations in security sensitive areas.
		Design and discussion of augmented reality application for pilot's situation awareness.
(You, 2020)	Information fusion based on UAV swarm	Mission- driven autonomous perception and fusion. based on UAV swarm technology
(Liu et al., 2020)	CNN- based deep learning, and multimodal imaging and fusion techniques	Deep multimodal image fusion framework proposed for target detection enhancement.
		Demonstrated effectiveness and superiority in detection accuracy and computational efficiency.
(Geraldes et al., 2019)	Deep Learning models	Developed PAL system for UAV-based situational awareness.
		Created Deep Learning models for person detection and action recognition
(Das et al., 2018)	Robot Operating System	Rapid SA development framework for MUM-T.
		Leveraging cutting-edge technologies like distributed neuro- adaptive control.
(Ruano et al., 2017)	Augmented Reality	AR tool for route orientation and target identification.
		Improved situational awareness of UAV operators demonstrated in experiments.
(Rattadilok & Petrovski, 2014)	Computational Intelligence techniques, clustering and statistical techniques	Inferential measurement framework for UAV control systems with heterogeneous inputs.
		Highlighting potential anomalies in real-time surveillance data for autonomous control.

5. Discussion

In military applications, AI-driven UAVs are crucial for surveillance and reconnaissance missions. AI enhances these operations by employing computer vision and machine learning techniques, which enable the identification and tracking of targets, such as vehicles and personnel. By analyzing vast volumes of sensor data, AI can detect anomalies and provide early warnings of potential threats. Furthermore, AI analyzes terrain data to optimize flight routes and identify strategic locations, thereby improving the accuracy and efficiency of target acquisition through predictive analytics. Machine learning models, leveraging historical and real-time data, forecast

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target movements to enhance tracking effectiveness. Deep learning techniques, such as Convolutional Neural Networks (CNNs), assist in differentiating between targets and non-targets, thereby reducing false positives. AI systems also facilitate quicker goal prioritization and decision-making in real-time tactical operations.

In search and rescue (SAR) missions, AI significantly enhances UAV capabilities through automatic object detection, path optimization, and real-time data fusion. AI-controlled UAVs utilize advanced imagery and sensor analytics to locate missing persons and objects in challenging environments. Simultaneously, machine learning algorithms optimize search patterns and flight routes to ensure efficient area coverage. Integrating data from various sensors, such as thermal cameras and LiDAR, aids in detecting heat signatures and movement in difficult terrains.

AI-controlled UAVs also play a critical role in environmental monitoring, including pollution detection, wildlife tracking, and disaster assessment. AI algorithms analyze sensor data to quantify air, water, and soil contaminants, supporting environmental protection efforts. These UAVs monitor wildlife populations and habitats, contributing to conservation initiatives. After natural disasters, AI-enabled UAVs assess damage using imagery and sensor data, assisting in the planning and coordination of relief efforts.

In urban environments, AI-enabled UAVs contribute to traffic and crowd monitoring by analyzing traffic flow, crowd behavior, and detecting incidents. Computer vision algorithms process real-time video feeds to monitor traffic, detect congestion, and identify incidents. AI systems track crowd movements, providing insights for event management, public safety, and emergency response. Machine learning models also help detect accidents and fires, enabling faster response times and better resource allocation.

In the realm of infrastructure inspection, AI enhances the efficiency and accuracy of UAV operations through automated defect detection, predictive maintenance, and high-resolution imaging. Deep learning algorithms identify cracks, corrosion, and other defects in structures such as bridges, pipelines, and buildings. By analyzing historical inspection data, AI models predict potential failures, enabling proactive maintenance and minimizing downtime. UAVs equipped with high-resolution cameras and AI-driven image analysis can conduct detailed inspections of hard-to-reach areas.

In delivery services, AI improves UAV capabilities through route optimization, autonomous navigation, and package handling. Machine learning algorithms optimize delivery routes based on factors such as weather, traffic, and urgency, ensuring timely deliveries. AI systems enable UAVs to navigate autonomously, avoiding obstacles and adapting to changing environments. AI-driven robotic systems enhance the precision and reliability of package handling, from loading to delivery.

By leveraging AI technologies, UAVs can perform complex tasks across various applications with greater autonomy, accuracy, and efficiency, significantly increasing their utility and impact in military, civilian, and commercial sectors.

6. Challenges and Limitations

The deployment of AI-driven UAVs presents several technical challenges that impact their effectiveness and reliability. Key issues include data quality and availability; sensor limitations, noise, and the lack of labeled training data can undermine AI model accuracy. Real-time processing is another significant constraint, as the high computational demands of AI algorithms may overwhelm onboard systems, leading to delays and increased power consumption. Overcoming these technical barriers is crucial for enabling UAVs to process and respond to information swiftly and accurately.

Operationally, UAVs must contend with environmental factors such as adverse weather, complex terrains, and signal interference, which can disrupt performance and navigation. Ensuring scalability and robustness is challenging, as integrating AI with existing systems and adapting to various operational contexts requires substantial effort. Furthermore, ethical and legal considerations are paramount; privacy concerns arise from potential surveillance, while regulatory issues involve compliance with airspace regulations and data protection laws. Addressing these ethical and legal challenges effectively is essential for the responsible deployment of AI-driven UAVs.

7. Future Directions and Research Opportunities

The future of AI-driven UAVs stands to benefit from emerging technologies and advancements that promise to enhance their capabilities and applications. Advancements in AI, such as more sophisticated machine learning algorithms, neural network architectures, and real-time data

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processing techniques, are expected to improve UAV performance in complex and dynamic environments. Innovations in sensor technology, including higher-resolution cameras, more sensitive LiDAR systems, and advanced environmental sensors, will provide UAVs with richer and more accurate data, further enhancing their situational awareness and operational effectiveness.

Despite these advancements, several research gaps require further investigation. Key areas for exploration include improving the robustness and adaptability of AI algorithms to handle diverse and unpredictable conditions, enhancing the integration and fusion of data from multiple sensor types, and addressing privacy and regulatory compliance challenges. The potential future applications of AI in UAVs are vast and speculative, with possibilities including fully autonomous disaster response units, advanced aerial logistics networks, and intelligent swarm technologies for complex missions. Continued research and innovation in these areas will drive the next generation of AI-driven UAVs, expanding their capabilities and applications across various domains.

8. Conclusion

This survey has explored the integration of AI in enhancing situational awareness for UAVs, highlighting several key points. AI techniques, including machine learning, deep learning, computer vision, and data fusion, significantly enhance UAV capabilities in various domains, such as military surveillance, civilian search and rescue, environmental monitoring, and commercial infrastructure inspection. Despite these advancements, challenges such as data quality, real-time processing constraints, environmental factors, and ethical concerns remain critical. The review identifies research gaps in improving algorithm robustness, sensor integration, and regulatory compliance while pointing to future innovation and application opportunities.

The practical implications for UAV operations include more effective and autonomous decision-making, improved monitoring and inspection task efficiency, and enhanced real-time response capabilities in complex scenarios. For AI research, these findings underscore the need for continued development in robust AI models, advanced sensor technologies, and solutions to privacy and regulatory issues. In conclusion, the future of AI-driven UAVs holds promise for further transforming situational awareness capabilities, potentially leading to more autonomous, intelligent, and versatile UAV systems that can operate efficiently across various applications and environments.

Authors' Contributions

M.D. and E.K. collaborated on the research, analysis, and writing of the review paper on AI-driven situational awareness in UAVs. M.D. was primarily responsible for conducting the literature review and drafting the sections on AI methodologies and their applications in UAV operations. E.K. focused on the technical challenges, ethical considerations, and future research opportunities, as well as ensuring the comprehensive integration of case studies into the manuscript. Both authors contributed to the final manuscript revision, and E.K. provided overall supervision and guidance throughout the project.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

Acknowledgments

We would like to express our gratitude to all individuals helped us to do the project.

Declaration of Interest

The authors report no conflict of interest.

Funding

According to the authors, this article has no financial support.

Ethics Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

References

Ahmed, F., Mohanta, J. C., Keshari, A., & Yadav, P. S. (2022). Recent advances in unmanned aerial vehicles: A review. *Arabian Journal for Science and Engineering*, *47*(7), 7963-7984. https://doi.org/10.1007/s13369-022-06738-0

AITBSS AI and Tech in Behavioral and Social Sciences
E-ISSN: 3041-9433

Anjum, K., Sadhu, V., & Pompili, D. (2020). *Multi-UAV situational awareness via distributed and approximate computing techniques* 2020 IEEE 17th International Conference on Mobile Ad Hoc and Sensor Systems (MASS), https://ieeexplore.ieee.org/abstract/document/9356011/

Arjomandi, M., Agostino, S., Mammone, M., Nelson, M., & Zhou, T. (2006). *Classification of unmanned aerial vehicles*. https://www.academia.edu/download/29666442/group9.pdf

Avanzini, G., De Luca, V., & Pascarelli, C. (2020). AR-based visual aids for sUAS operations in security sensitive areas. In *Augmented Reality, Virtual Reality, and Computer Graphics: 7th International Conference, AVR 2020, Lecce, Italy, September 7–10, 2020, Proceedings, Part I* (pp. 289-298). Springer International Publishing. https://doi.org/10.1007/978-3-030-58465-8_20

Das, A., Kol, P., Lundberg, C., Doelling, K., Sevil, H. E., & Lewis, F. (2018). *A rapid situational awareness development framework for heterogeneous manned-unmanned teams* NAECON 2018-IEEE National Aerospace and Electronics Conference, https://ieeexplore.ieee.org/abstract/document/8556769/

Dehghan, M., Sadeghiyan, B., Khosravian, E., Moghaddam, A. S., & Nooshi, F. (2022). Proapt: Projection of apt threats with deep reinforcement learning. In: arXiv preprint arXiv:2209.07215.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors*, *37*(1), 32-64. https://journals.sagepub.com/doi/abs/10.1518/001872095779049543

Endsley, M. R. (1999). Situation awareness in aviation systems. In *Handbook of aviation human factors* (pp. 257-276). CRC Press. http://www.pacdeff.com/pdfs/Situation%20Awareness%20in%20Aviation%20Endsley%201999.pdf

Endsley, M. R. (2018). Automation and situation awareness. In *Automation and human performance* (pp. 163-181). CRC Press. https://www.taylorfrancis.com/chapters/edit/10.1201/9781315137957-8/automation-situation-awareness-mica-endsley

Ertel, W. (2018). *Introduction to artificial intelligence*. Springer. https://doi.org/10.1007/978-3-319-58487-4

Fan, W., Luo, K., Yu, S., Zhou, Z., & Chen, X. (2020). *AoI-driven fresh situation awareness by UAV swarm: Collaborative DRL-based energy-efficient trajectory control and data processing* 2020 IEEE/CIC International Conference on Communications in China (ICCC), https://doi.org/10.1109/ICCC49849.2020.9238897

Gao, X., Jia, H., Chen, Z., Yuan, G., & Yang, S. (2020). *UAV security situation awareness method based on semantic analysis* 2020 IEEE International Conference on Power, Intelligent Computing and Systems (ICPICS), https://doi.org/10.1109/ICPICS50287.2020.9201954

Gao, Y., & Lv, N. (2023). *UAV Swarm Cooperative Situation Awareness Theory Model Construction and Scenario Analysis* Journal of Physics: Conference Series, https://doi.org/10.1088/1742-6596/2504/1/012013

Geraldes, R., Goncalves, A., Lai, T., Villerabel, M., Deng, W., Salta, A., & Prendinger, H. (2019). UAV-based situational awareness system using deep learning. *IEEE Access*, *7*, 122583-122594. https://doi.org/10.1109/ACCESS.2019.2938249

Han, W., Wang, Y., & Wang, J. (2023). A framework for UAV swarm situation awareness. In *International Conference on Cognitive Computation and Systems* (pp. 233-246). Springer Nature Singapore. https://doi.org/10.1007/978-981-97-0885-7_20

Igonin, D. M., Kolganov, P. A., & Tiumentsev, Y. V. (2021a). Providing situational awareness in the control of unmanned vehicles. In *Advances in Neural Computation, Machine Learning, and Cognitive Research IV: Selected Papers from the XXII International Conference on Neuroinformatics* (pp. 125-134). Springer International Publishing. https://doi.org/10.1007/978-3-030-60577-3_14

Igonin, D. M., Kolganov, P. A., & Tiumentsev, Y. V. (2021b). Situational awareness and problems of its formation in the tasks of UAV behavior control. *Applied Sciences*, *11*(24), 11611. https://doi.org/10.3390/app112411611

Liu, S., Liu, H., John, V., Liu, Z., & Blasch, E. (2020). Enhanced situation awareness through CNN-based deep multimodal image fusion. *Optical Engineering*, *59*(5), 053103. https://doi.org/10.1117/1.OE.59.5.053103

Maltezos, E., Karagiannidis, L., Douklias, T., Dadoukis, A., Amditis, A., & Sdongos, E. (2020). *Preliminary design of a multipurpose UAV situational awareness platform based on novel computer vision and machine learning techniques* 2020 5th South-East Europe Design Automation, Computer Engineering, Computer Networks and Social Media Conference (SEEDA-CECNSM), https://doi.org/10.1109/SEEDA-CECNSM49515.2020.9221786

Rattadilok, P., & Petrovski, A. (2014). *Automated inferential measurement system for traffic surveillance: Enhancing situation awareness of UAVs by computational intelligence* 2014 IEEE Symposium on Computational Intelligence in Control and Automation (CICA), https://doi.org/10.1109/CICA.2014.7013256

Ren, Y., Cao, X. Q., Guo, Y. N., Peng, K. C., Xiao, C. H., & Tian, W. L. (2021). Application of machine learning in UAV combat. In *International Conference on Autonomous Unmanned Systems* (pp. 2963-2969). Springer Singapore. https://doi.org/10.1007/978-981-16-9492-9_290

Ruano, S., Cuevas, C., Gallego, G., & García, N. (2017). Augmented reality tool for the situational awareness improvement of UAV operators. *Sensors*, *17*(2), 297. https://doi.org/10.3390/s17020297

Song, C., Zhang, H., Xu, H., & Hao, M. (2023). A review of situation awareness techniques for unmanned aerial vehicle clusters. In *International Conference on Autonomous Unmanned Systems* (pp. 1609-1622). Springer Singapore. https://doi.org/10.1007/978-981-99-0479-2_149

You, H. E. (2020). Mission-driven autonomous perception and fusion based on UAV swarm. *Chinese Journal of Aeronautics*, *33*(11), 2831-2834. https://doi.org/10.1016/j.cja.2020.02.027

Zak, Y., Parmet, Y., & Oron-Gilad, T. (2020). *An artificial intelligence algorithm to automate situation management for operators of unmanned aerial vehicles* 2020 IEEE Conference on Cognitive and Computational Aspects of Situation Management (CogSIMA),