

Systematic Review

Drone Imaging and Sensors for Situational Awareness in Hazardous Environments: A Systematic Review

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Abstract

Situation awareness is essential for ensuring safety in hazardous environments, where timely and accurate information is critical for decision-making. Unmanned Aerial Vehicles (UAVs) have emerged as valuable tools in enhancing situation awareness by providing real-time data and monitoring capabilities in high-risk areas. This study explores the integration of advanced technologies, focusing on imaging and sensor technologies such as thermal, spectral, and multispectral cameras, deployed in critical zones. By merging these technologies into UAV platforms, responders gain access to essential real-time information while reducing human exposure to hazardous conditions. This study presents case studies and practical applications, highlighting the effectiveness of these technologies in a range of hazardous situations.

Keywords: UAV; drones; imaging technology; sensor technology; situation awareness; hazardous environments



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1. Introduction

Unmanned Aerial Vehicles (UAVs), commonly referred to as drones, have become an essential tool in various industries due to their adaptability and advanced capabilities. The emergence of drone technology has transformed the way hazardous environments are approached and managed. By providing flexible and efficient means of accessing challenging or unsafe areas for humans, drones play critical roles in disaster response, environmental monitoring, high-risk construction sites, military operations, and homeland security [1]. Equipped with advanced imaging and sensor technologies, they serve as vital tools for real-time data collection, enhanced situational awareness, improved decision-making, and minimized danger to personnel [2].

Drones equipped with these technologies can operate effectively across diverse environmental conditions and varying lighting levels [3]. For instance, in search and rescue (SAR) efforts, thermal sensors and imaging technologies are a significant improvement, allowing UAVs to locate survivors in environments where traditional visual detection is difficult, whether it be survivors trapped under debris from natural disasters or border security issues [4]. Spectral imaging can be highly beneficial in conflict areas, aiding in the detection and identification of targets, even when they are camouflaged in remote

areas such as deserts, mountains, or forests, causing targets to stand out from the natural background [5]. Light Detection and Ranging (LiDAR) technology is another significant advancement, providing accurate depth information necessary for comprehending the three-dimensional structures of the surroundings. LiDAR's capacity to deliver comprehensive 3D spatial data makes it an essential sensor technology, especially in fields such as airspace monitoring and security [5,6], rendering it a crucial tool in challenging and high-risk environments. Furthermore, sensors are integral to UAV functionality, facilitating thorough environmental assessment and threat identification, for instance, with infrared, gas, acoustic, and chemical detectors, as dynamic measurement systems, operating independently or in conjunction with other unmanned systems under diverse conditions. These sensing technologies are essential for maintaining UAV safety, security, and overall performance [7,8].

The main aims and the contributions of this study are as follows:

- This study aims, first and foremost, to investigate the integration and synergy of advanced imaging and sensor technologies in drone operations, with a focus on enhancing situational awareness in hazardous environments that pose significant risks to human health, safety, and operations. These include dangerous environments with extreme conditions, restricted zones with controlled access, and high-risk areas prone to natural disasters or industrial accidents. Critical zones and threat-sensitive regions require heightened surveillance due to security concerns. In contrast, unsafe environments, such as contaminated zones and hostile territories, can contain hazardous pollutants or present security threats, necessitating remote sensing for situational awareness.
- Secondly, by examining the integration of these technologies, this research aims to assess the effectiveness of UAVs in detecting hazards; enhancing real-time decision-making, and ensuring safer operations in complex and challenging conditions.
- Moreover, this research will emphasize the role of UAVs in disaster response, where rapid situational awareness is vital for emergency management, as well as military and security operations, where UAVs enhance reconnaissance, surveillance, and threat detection [2,9,10].
- Lastly, the review will assess their effectiveness in identifying and managing hazardous materials, thereby contributing to enhanced safety measures and improved risk mitigation strategies in hazardous environments.

As a technology-based literature review, the scope of this analysis is not intended to critically evaluate the effectiveness of individual or specific technologies directly, but to review the effectiveness of UAV systems across different situations and domains based on available academic literature. The rest of the article is organized as follows: The paper begins by providing a background of the research in Section 2. Section 3 examines the methodology of the systematic review. A discussion of the key application areas of the study (disaster and emergency management, military operations, and HAZMAT) is given in Section 4. Section 5 concludes the paper. We also present some commonly used AI solutions in UAV-SAR as an extended discussion topic.

2. Background of the Research

The growing use of UAVs has significantly improved data collection and operational effectiveness in remote, challenging, and hazardous environments, establishing UAV systems as essential assets in various industries [1,11,12]. By providing real-time data, advanced surveillance, and comprehensive situational awareness, these technologies enable faster, more informed decision-making, ultimately improving operational efficiency, safety, and strategic planning.

The integration of advanced imaging systems and sensor technologies, such as high-resolution optical cameras, thermal imaging, LiDAR, and multispectral sensors, has significantly enhanced UAV capabilities to operate effectively in hazardous environments, providing real-time data for better situational awareness, safer decision-making, and mission execution in areas too dangerous for human intervention [13–17]. This research focuses on the role of UAV-based imaging and sensor technologies in three critical domains: disaster and emergency management, military operations, and hazardous material (HAZMAT) incidents. The selection of these three domains is based on their inherent high-risk profiles, the critical requirement for precise and time-sensitive data acquisition, and the demonstrable influence of enhanced situational awareness on the efficacy of safety protocols, security measures, and hazard mitigation strategies [18–20].

2.1. UAVs in Disaster and Emergency Management

In disaster and emergency management, UAVs play a crucial role in damage assessment, search and rescue missions, and coordination of disaster response efforts [21,22]. Li and Hu [21] show that an integral component of China's comprehensive emergency response system is aerial emergency rescue. The 5-year plan for the development of the national emergency response system in China has identified UAVs as critical rescue tools due to cost-effectiveness, rapidity, adaptability, and ergonomics, which make them ideal for on-site emergency response [21]. Following the devastating 2015 Nepal earthquake, one of the most catastrophic natural disasters in the region, swarms of UAVs with high-resolution cameras and LiDAR systematically surveyed affected areas, identifying collapsed buildings and potential survivor locations [23]. During time-critical rescue operations following the 2017 Mexico earthquake, UAVs with thermal imaging technology were instrumental in locating survivors beneath collapsed structures, significantly expediting and enhancing rescue efforts [24]. These examples of UAVs and thermal sensors stand in stark comparison to pre-UAV technological SAR methods, such as the 1985 Mexico City earthquake, where rescue efforts were hindered by limited real-time data and access challenges, resulting in massive destruction and loss of life.

Experts believe that modern UAVs with thermal imaging could have significantly improved operations by quickly locating survivors, mapping damage, and guiding rescue teams efficiently [4]. Through the integration of technologies such as high-resolution cameras, spectral, hyperspectral, and thermal imaging sensors, as well as other suitable sensors, UAVs enable emergency responders to gain a comprehensive visual understanding of affected areas, allowing for continuous monitoring of environmental conditions while strategically prioritizing resource allocation, as shown in Figure 1. By providing real-time data and actionable insights, UAVs significantly enhance disaster response efforts, reducing delays in assessment, improving coordination, and ensuring a more efficient, data-driven approach to emergency management.

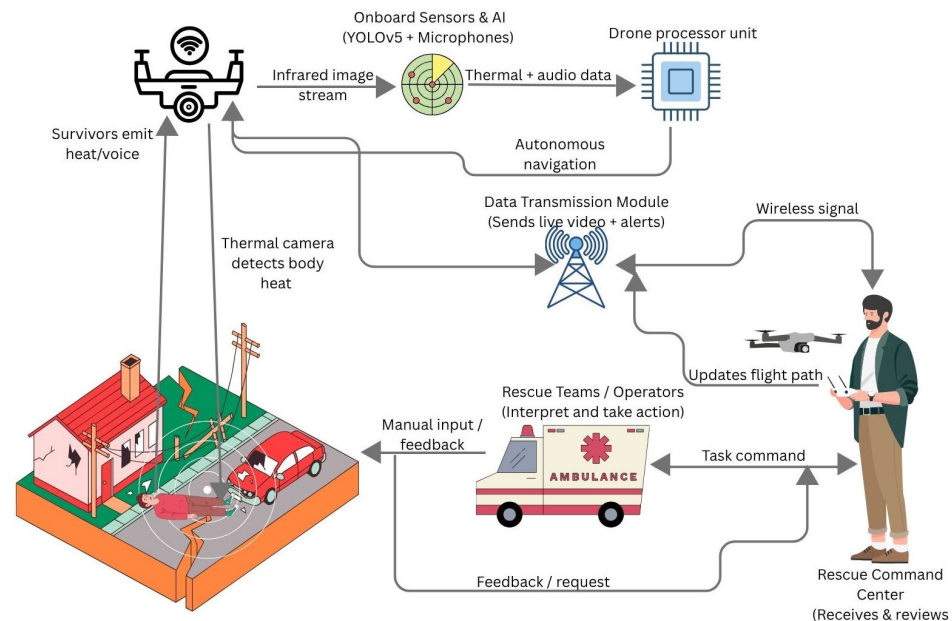


Figure 1. The diagram demonstrates how a drone’s real-time data transmission assists first responders in locating survivors during disaster management.

2.2. UAVs in Military Operations

UAVs have significantly advanced Intelligence, Surveillance, and Reconnaissance (ISR) capabilities within military operations, lowering personnel exposure while improving real-time situational awareness in high-risk and combative environments [25–29]. Imaging and sensor technologies integrated into UAVs enable the acquisition of high-resolution imagery for battlefield operational awareness. The absence of UAVs in combat operations can lead to protracted execution times and diminished precision. Conversely, the deployment of UAVs significantly reduces operational risk and enhances lethality.

In military applications, standard UAV sensor configurations commonly feature high-resolution and IR cameras. Tactical UAV platforms, designed for more complex missions, can integrate additional sensors such as GPS/INS, RADAR, meteorological sensors, and Nuclear, Biological, and Chemical (NBC) detectors [30]. Threat detection and identification can be achieved through a variety of technologies, encompassing visual and thermal imaging, radar, acoustic, magnetic, and radio frequency (RF) signal sensors, as shown in Figure 2. The performance of these technologies varies, depending upon the UAV platform’s design and intended detection capabilities [31].

By utilizing advanced imaging and sensor technologies, UAVs can conduct nocturnal surveillance of enemy forces and detect thermally distinct subsurface threats [9]. In the current Ukrainian conflict, UAVs equipped with high-resolution cameras and synthetic aperture radar (SAR) have proven strategically vital for target identification, artillery support, and battlefield mapping, highlighting their importance in modern warfare [32–34]. Additionally, multispectral and hyperspectral imaging (MSI, HSI) technologies provide imagery intelligence capable of delivering precise, detailed information regarding the location and physical properties of both threats and the surrounding environment, enabling the effective circumvention of camouflage while aiding accurate discrimination between targets and decoys in combat scenarios [35]. It is evident that, due to these advancements, UAVs have undeniably become a transformative force within modern warfare, leading to the alteration of traditional combat strategies through automated surveillance and precision targeting technologies.

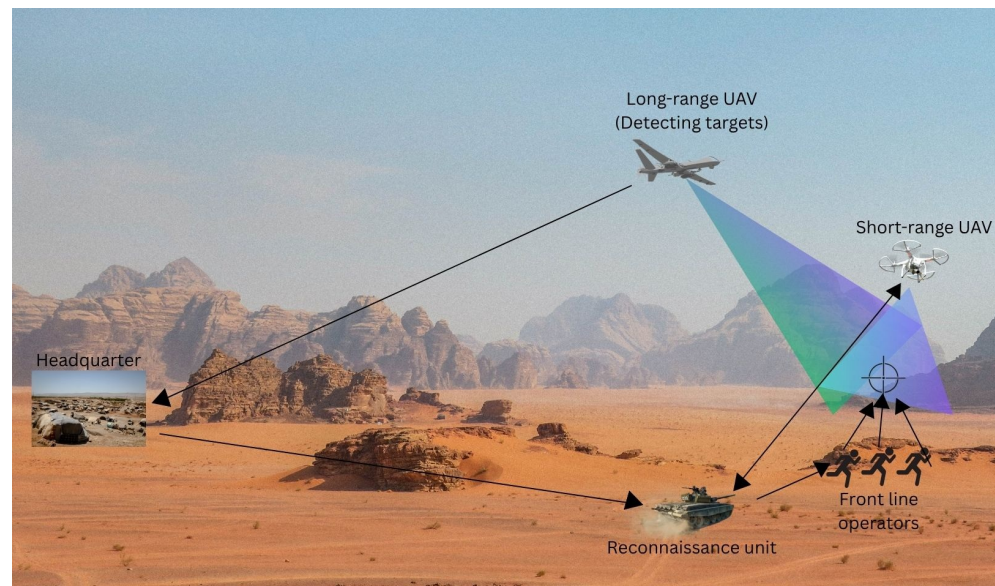


Figure 2. An example of drone reconnaissance employing thermal and/or hyperspectral imaging to detect concealed threat targets within camouflaged areas.

2.3. UAVs for Hazardous Material Incidents

For hazardous material (HAZMAT) incidents, UAVs serve as vital tools for detecting, monitoring, and assessing chemical, biological, radiological, and nuclear (CBRN) threats. Equipped with advanced imaging and sensor technologies, these UAVs can collect real-time data on hazardous substances, measure contamination levels, and identify potential exposure risks without endangering human responders [36–38]. A UAV equipped with visual and thermal cameras was used to assess an unidentified chemical leak, providing scene imagery, obstacle detection, and remote temperature measurement of potential tank damage [36] as shown in Figure 3. UAV technology has proven effective in mitigating COVID-19 risks, and Australia has utilised this technology in its pandemic response. Australian healthcare has implemented UAVs for remote patient monitoring, employing integrated sensors to detect abnormalities in respiratory rate, heart rate, body temperature, and other vital signs indicative of viral infections [39–41].

Furthermore, to enhance safety and improve operational and environmental monitoring, the nuclear industry is increasingly utilizing UAVs, which can perform physical, chemical, and radiochemical measurements in environments inaccessible to humans [42]. Effective surveillance of nuclear power plants is achieved through UAVs equipped with radiation detectors, cameras, and thermal imaging, enabling the detection of radiation levels and leaks, and resulting in a thorough environmental assessment [43]. The implementation of UAV-based imaging and sensor technologies in HAZMAT scenarios enables a reduction in direct human exposure to toxic environments, resulting in substantial improvements in both response efficiency and personnel safety.

The critical need for improved situational awareness in complex and unsafe environments, coupled with the ability of UAV technology to enhance decision-making and operational efficiency, makes disaster and emergency management, military operations, and HAZMAT incidents key application areas. The capacity for drones to achieve swift deployment, acquire high-resolution visual data, and conduct real-time data analysis establishes their significance within high-risk operational environments. Consequently, the research presented herein aims to explore the evolving landscape of UAV imaging and sensor technologies, recognizing their potential to enhance situational awareness in hazardous environments significantly and ultimately revolutionize risk management and emergency response protocols.



Figure 3. Equipped with specialised sensors to monitor hazardous environments, drones can detect odourless and colourless toxic gases.

3. Research Methodology

A comprehensive scoping review was undertaken to systematically collect, evaluate, and synthesize evidence derived from a diverse range of study designs. The primary objective of this review was to provide a thorough examination of existing research and to elucidate and clarify key concepts and trends in the literature. Where previous reviews have focused on a deeper understanding of specifics [44–46], the innovation of this systematic review is built upon a more exhaustive analysis of currently available academic research that seeks to contribute to a broader understanding of the efficacy of, and developing trends in, imaging and sensor technologies within the emergent field of UAV technology.

3.1. Research Method

This study adopts a qualitative research design within the framework of a systematic literature review to investigate the current state and application of imaging and sensor technologies in environmental monitoring. The focus is specifically on advanced imaging modalities—including MSI, HSI, spectral, infrared, and thermal imaging; with environmental sensors measuring parameters such as temperature, humidity, carbon dioxide (CO₂), and particulate matter (PM_{2.5}).

The systematic review methodology was selected to ensure a transparent, reproducible process of identifying, evaluating, and synthesising relevant academic literature. A qualitative approach was deemed appropriate given the exploratory nature of the research objectives, which aim to interpret and categorize existing findings rather than quantify relationships. The review process involves the development of well-defined inclusion and exclusion criteria, as well as the systematic searching of academic databases and the thematic analysis of selected studies. Data collection was conducted independently by the researcher, with collaborative discussions held with a supervisor to ensure consistency and alignment in the thematic direction of the review. Data were extracted from the top 100 search results obtained via Publish or Perish software, based on publicly available bibliometric information. A flowchart was developed to identify eligible studies in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, ensuring clarity and traceability in the selection process, as shown in Figure 4. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-

Analyses) method was utilized for searching and selecting papers related to the scope of the study. The Checklist is illustrated in Supplementary Materials.

This design facilitates the extraction of nuanced insights into technological capabilities, implementation challenges, and emerging trends in the use of imaging and sensor technologies for environmental data acquisition. Furthermore, it enables the identification of research gaps and potential directions for future investigation. As this review focused on metadata analysis, details such as participants, interventions, or funding sources were not applicable. Missing or unclear data were left blank without assumptions to maintain data integrity.

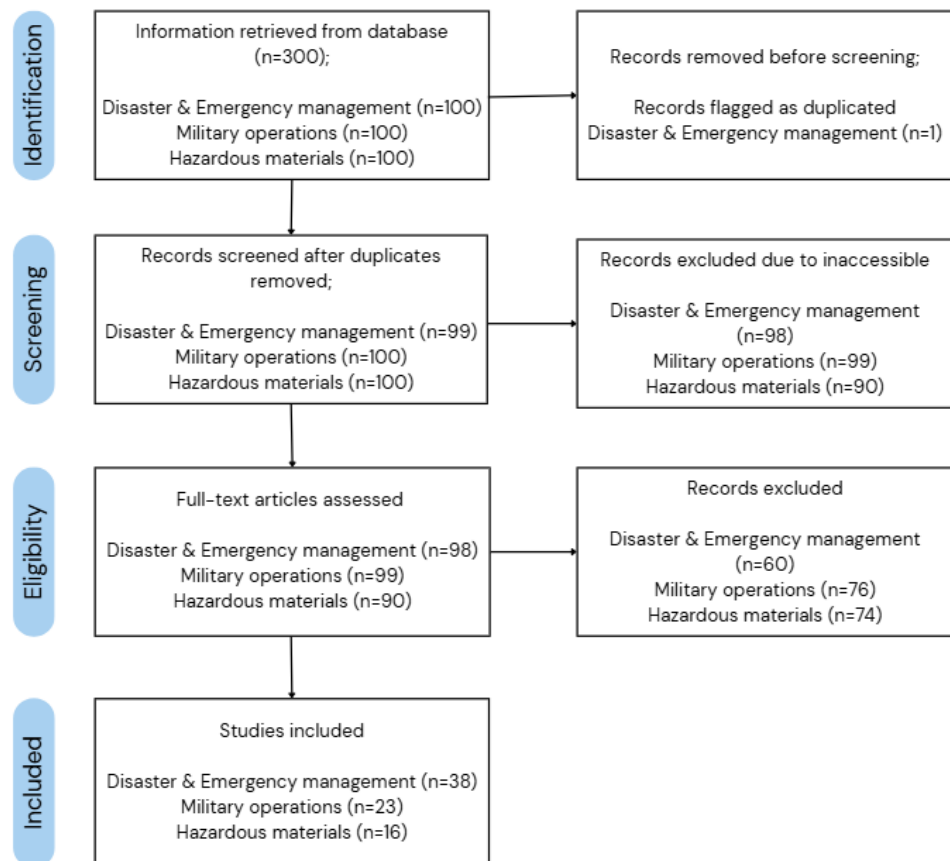


Figure 4. PRISMA flow diagram of study selection process.

3.2. Search Criteria

The literature search was conducted in March 2025 using the Publish or Perish database, a software program that retrieves and analyzes academic citations. The overall research and data analysis were completed by June 30, 2025. This tool extracts raw citation data from sources such as Google Scholar and Microsoft Academic Search between 2015 and 2025, subsequently processing and presenting the information through various bibliometric indicators [47]. The data were extracted from the top 100 search results in each category and included the number of citations, year of publication, author affiliations, journal sources, and keywords or thematic focus. These outcomes were used to identify research trends, influential studies, and topic distributions. All available bibliometric information from each selected entry was collected without filtering by time points, measurement types, or analytical methods. To perform the bibliometric search using Publish or Perish, the following query was employed: UAV OR “Unmanned Aerial Vehicle” OR Drone AND “Situation awareness” OR “Real-time monitoring” AND “Keyword for that area” AND “Imaging technologies” AND “Sensor technologies” OR Payload OR Sensor. with Boolean

operators applied—using “|” to denote “OR” and spaces to indicate “AND”—to refine and enhance the search results. The search results for each category were limited to a maximum of 100 papers. Full-text articles were then reviewed to assess their eligibility for inclusion in the study, following the process, as illustrated in Figure 5.

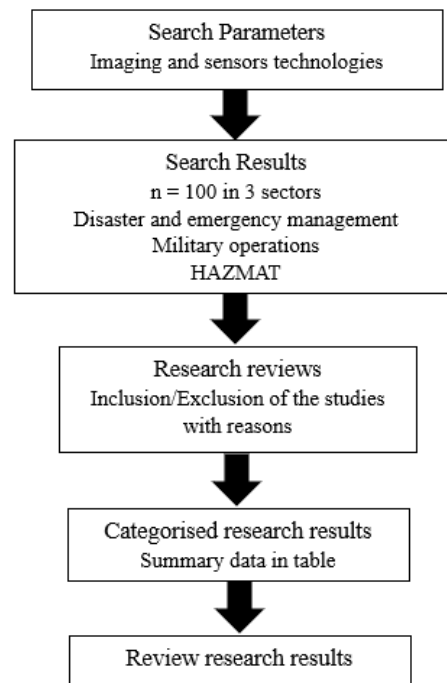


Figure 5. Research methodology.

3.2.1. Search Query for Disaster and Emergency Management

The query for disaster and emergency management for searching was: UAV OR “Unmanned Aerial Vehicle” OR Drone AND “Situation awareness” OR “Real-time monitoring” AND “Disaster management” OR “Disaster response” OR Emergency OR “Hazardous Environment” OR Dangerous OR Danger OR High-risk AND “Imaging technologies” OR “Sensor technologies” OR “Payload” OR Sensor. This comprehensive query aimed to capture a wide range of relevant studies focusing on situational awareness, monitoring, and sensing in high-risk environments.

3.2.2. Searching Query for Military Operations

Search term for military operations was: UAV OR “Unmanned Aerial Vehicle” OR Drone AND “Situation awareness” OR “Real-time monitoring” AND “Military operation” OR Military OR ISR OR Battlefield OR Military OR Surveillance OR Reconnaissance OR Defence AND “Imaging technologies” OR “Sensor technologies” OR “Payload” OR Sensor. This comprehensive search query was designed to capture a wide range of the relevant literature addressing the use of unmanned aerial systems and sensing technologies in military contexts, with a focus on real-time information gathering, situational awareness, and strategic defence applications.

3.2.3. Searching Query for Hazardous Material (HAZMAT) Incidents

Imaging and sensor technologies used with drone in HAZMAT were explored using the search term: UAV OR “Unmanned Aerial Vehicle” OR Drone AND “Situation awareness” OR “Real-time monitoring” AND “Hazardous material” OR HAZMAT OR Chemical OR “Chemical spill” OR “Chemical leak” OR CBRN OR “CBRN threats” OR “Industrial safety” AND “Imaging technologies” OR “Sensor technologies” OR Payload OR Sensor.

This search aimed to identify studies involving UAV-based imaging and sensing systems relevant to hazardous environments, particularly in HAZMAT and CBRN scenarios.

3.3. Inclusion and Exclusion Criteria of Sampling

This article aims to conduct a comprehensive literature review on imaging and sensor technologies employed in unmanned aerial vehicle (UAV) operations, with a particular emphasis on imaging modalities, including the infrared, thermal, spectral, MSI, and HSI cameras. Additionally, the review encompasses a wide range of sensors used to measure environmental, motion, and imaging-related parameters.

Papers most relevant to the review were selected based on predefined inclusion and exclusion criteria. Subsequently, the publication type was assessed to ensure that only original research articles published in English were considered for inclusion. Publications such as editorials, review articles, conference abstracts, and book chapters were excluded from the analysis.

Furthermore, studies that primarily focused on (1) emerging digital technologies, including wireless sensor networks, the Internet of Things, big data, and artificial intelligence (AI); (2) not published in English; (3) did not explicitly address the role or operation of imaging and sensor technologies in relation to unmanned aerial vehicle (UAV) operations; therefore excluding papers that merely mentioned or briefly touched upon these technologies without substantive discussion; (4) were duplicates; or (5) had inaccessible full texts during the review process.

3.4. Review of Relevant Literature

After applying the inclusion and exclusion criteria, a final selection of relevant studies on imaging and sensor technologies in drones was made. The results were synthesized using a descriptive bibliometric approach, focusing on trends and patterns in publication counts, citation metrics, keyword analysis, and thematic categorization. This approach was chosen because the review aimed to map the research landscape rather than quantify effect sizes or conduct statistical comparisons. No formal sensitivity analyses were performed due to the descriptive nature of the bibliometric synthesis. From the top 100 search results in each sector using Publish or Perish, 38 studies were identified in disaster and emergency management, 23 in the military sector, and 16 in HAZMAT-related applications. These articles were assessed for eligibility and are presented in Tables 1–3.

Table 1. Breakdown of results from relevant Publish or Perish studies in relation to disaster and emergency management.

Study Title	Study Design	Goal	Imaging Technology Used	Sensor Technology Used
An innovative system to enhance situational awareness in disaster response [48]	Experimental study	Develop a user-friendly system for responder situational awareness	Infrared camera	Radiation, gas sensors
From Sensors to Safety: Internet of Emergency Services (IoES) [49]	Observational study	Examine IoES role in disaster management and real-time coordination	N/A	Environmental, motion, gas sensors
AI-Based drone-assisted human rescue [50]	Observational study	Explore UAV-based survivor detection using imaging, acoustics, and signals	Infrared thermal, RGB depth camera	3D depth, time-of-flight, optical, infrared sensors
Sensors on IoT systems for urban disaster management [51]	Observational study	Review IoT sensors for urban disaster response	LWIR, visual range, omnidirectional cameras	Water level/pressure, soil moisture, UV, pressure, temperature, rainfall, ultrasonic, thermal, infrared sensors

Table 1. Cont.

Study Title	Study Design	Goal	Imaging Technology Used	Sensor Technology Used
Visual servoing and deep learning methods for disaster management [52]	Observational study	Improve UAV precision with deep learning and visual servoing	Infrared, CMOS, thermal, multispectral, hyperspectral cameras	LiDAR, hyperspectral sensors
Integrating remote sensing for disaster management [53]	Conceptual study	Propose DSS integrating remote sensing and modeling	Thermal, satellite, radar imagery; multispectral fusion	Remote, airborne, thermal infrared, spatiotemporal sensors
Wildfire detection using UAS and sensor fusion [54]	Experimental study	Integrate UAS and sensor fusion with 5G for wildfire detection	RGB, thermal cameras	Sensor fusion technology
GIS, remote sensing and drones for disaster risk management [55]	Observational study	Explore GIS, remote sensing, UAVs in risk management	Multispectral, SPOT, IRS images; hyperspectral, SAR	Hyperspectral, chemical sensors
ResponDrone - A situation awareness platform for first responders [56]	Experimental study	Improve disaster response via UAV real-time data sharing	Electro-optical, infrared cameras	N/A
Drones application scenarios in a nuclear or radiological emergency [57]	Observational study	Highlight UAV applications in nuclear/radiological events	Compton, optical cameras; 3D-LiDAR	Gamma-ray, altitude sensors
Advanced first aid UAV system [58]	Experimental study	Detect falls and deliver UAV-based first aid	N/A	Heartbeat, ECG, LiDAR, temperature, humidity, BP, ultrasonic sensors
UAV sensing for power system inspection [59]	Observational study	Review UAV-based power system monitoring	Infrared thermal, IR thermography, UV imagers	Ultraviolet, acoustic, vibration, thermal, gas, magnetic, piezoelectric sensors
Drone vision for disaster impact response [60]	Experimental study	UAV-based emergency response system	Thermal map	Infrared, LiDAR sensors
UAV remote sensing applications in marine monitoring: Knowledge visualization and review [15]	Observational study	Review UAV sensing for marine disaster monitoring	Thermal, infrared, multispectral cameras	Multispectral, near/shortwave infrared, hyperspectral, thermal, fluorescence, radar
Big data and emergency management [61]	Experimental study	Enhance UAV inspections for real-time crisis detection	RGB, depth cameras	Dual-light, IR, LiDAR, ultrasonic radar
Integrated WSN/UAV/crowdsensing monitoring [62]	Observational study	Review integrated monitoring approaches and prospects	Thermal, optical, multispectral, hyperspectral, infrared cameras	Chemical, thermal, biological; temperature, pressure, turbidity, radiation; LiDAR, optical RGB, infrared, UV, hyperspectral
Disasters and emergency management in chemical plants [63]	Experimental study	Develop drone-based training for situational awareness in industrial disasters	N/A	Air contamination, biomedical sensors
UAVs for search and rescue: A survey [64]	Observational study	Review UAV roles and improvements in SAR operations	Thermal, RGB, depth cameras	Thermal, infrared, optical, PIR, ultrasonic, LiDAR
Optimized UAV surveillance strategies [65]	Observational study	Review UAV optimisation strategies for diverse surveillance tasks	Near-infrared, multispectral, hyperspectral	Laser scanning, LiDAR sensors
IoT for disaster management: State-of-the-Art and Prospects [66]	Observational study	Survey IoT disaster applications, challenges, and trends	N/A	Temperature, humidity, gas, tilt, pressure, moisture, strain gauge, acoustic sensors
A proposed drone-enabled platform for holistic disaster management [67]	Conceptual study	Propose a drone platform for disaster data, logistics, and communication	Electro-optical, infrared cameras	Gas, gamma radiation, chemical sensors
Enhancing vehicle navigation safety [68]	Experimental study	UAV safety with real-time pothole detection and trajectory planning	2D/3D LiDAR	GPS, vision sensors

Table 1. *Cont.*

Study Title	Study Design	Goal	Imaging Technology Used	Sensor Technology Used
Optimizing emergency response with UAV-integrated fire safety for real-time prediction and decision-making [69]	Experimental study	Evaluate UAV-cloud and ML for real-time fire prediction and response	Thermal cameras, high-resolution infrared imagery	LiDAR, thermal, infrared sensors
Towards the respond-a initiative: Next-generation equipment tools and mission-critical strategies for first responders [70]	Experimental study	Develop 5G/AR/IoT/UAV platform to support first responders	Thermal, infrared, AR cameras	Biometric, environmental, personnel location, health sensors
A logical remote sensing based disaster management and alert system using AI-assisted IoT technology [71]	Experimental study	Develop a neural network system for early disaster prediction	N/A	Seismic, temperature, humidity, pressure, thermistor, infrared, thermal, LiDAR
Factors in UAS use for aviation accidents [72]	Observational study	Identify factors influencing UAS use in aviation emergencies	N/A	Infrared, near-infrared sensors
UAV-IoT warehouse monitoring system [73]	Experimental study	Design a UAV-IoT system for real-time monitoring in dangerous goods warehouses	N/A	Temperature, humidity, gas, dust sensors
Extended reality for flood management [74]	Experimental study	Develop an XR platform for decision-making in floods and media planning	Multispectral image	Water level, ECG, respiration sensors
Drone imaging with vehicle telemetry [75]	Observational study	Enhance smart mobility with UAV imaging and telemetry	Thermal, optical cameras	LiDAR, multispectral sensors
UAV-based fire prediction in tank farms [76]	Experimental study	Develop a UAV system for real-time fire prediction and assessment	Infrared thermal camera/imaging	Thermocouple sensor
Flood monitoring sensor technologies [77]	Observational study	Review flood sensors and AI integration for monitoring and response	Optical, infrared, multispectral, hyperspectral cameras	Hyperspectral, ultrasonic, radar, infrared sensors
Eins3d project for 3D SAR mapping [78]	Experimental study	Develop a UAV system for real-time 3D SAR mapping	Thermal camera/mapping, 3D LiDAR	Attitude, laser, GPS sensors
DROPEX autonomous drone swarm [79]	Experimental study	Propose a drone swarm for faster, safer SAR operations	Thermal imaging	Infrared, LiDAR sensors
UAV for air pollutant monitoring [80]	Experimental study	Develop a UAV system for real-time air pollution monitoring	N/A	CO ₂ , PM2.5, temperature, humidity sensors
Drone tech for surveillance [3]	Observational study	Review UAV surveillance advancements for safety	Thermal, infrared cameras	Multispectral, infrared, LiDAR sensors
RPAS feasibility for major incidents [81]	Experimental study	Assess the feasibility of RPAS for incident management	Thermal, infrared cameras	N/A
UAV video systems for emergencies [82]	Observational study	Assess UAV video transmission range for emergency response	Multispectral, infrared, thermal cameras	N/A

Table 2. Breakdown of results from relevant Publish or Perish studies in relation to military operations.

Study Title	Study Design	Goal	Imaging Technology Used	Sensor Technology Used
A Review of cognitive UAVs: AI-Driven situation awareness for enhanced operations [83]	Observational study	Review AI's role in improving UAV situational awareness	Visible, thermal images; RGB video	Environmental sensors
Handheld combat support tools utilizing IoT technologies and data fusion algorithms as reconnaissance and surveillance platforms [84]	Experimental study	Develop mobile IoT tools for reconnaissance and decision support	N/A	Infrared motion, electromagnetic radar, fibre optic, microwave sensors

Table 2. Cont.

Study Title	Study Design	Goal	Imaging Technology Used	Sensor Technology Used
Situation awareness via Internet of Things and in-network data processing [85]	Experimental study	Enhance situational awareness via IoT and edge-processed data fusion	N/A	Passive infrared (PIR), sound sensor
Survey in adaptive hybrid wireless sensor network for military operations [86]	Observational study	Review adaptive hybrid WSNs for military situational awareness	Thermal imager	Seismic, acoustic, magnetic, electro-optical, radar, RF, PIR sensors
From battlefield to border: The evolving use of drones in surveillance operations [87]	Observational study	Analyze UAV surveillance applications, benefits, and challenges	High-resolution cameras	Thermal sensors
Surveillance and protection of critical infrastructure with unmanned aerial vehicles [88]	Observational study	Assess UAV and AI use in critical infrastructure security	Thermal, high-resolution cameras	LiDAR
Using heterogeneous multilevel swarms of UAVs and high-level data fusion to support situation management in surveillance scenarios [89]	Experimental study	Use UAV swarms and fusion for improved surveillance and detection	Electro-optical, infrared cameras	Long-range radar, infrared sensors
The Impact of the IoT on military operations [90]	Observational study	Examine IoT applications, challenges, and prospects in military ops	N/A	Smartwatches, health sensors
Conceptualization of the military's common operation picture [91]	Experimental study	Develop a COP system with geospatial data and unmanned vehicles	N/A	Mine-detection sensor
Who is watching whom? Military and civilian drone: Vision intelligence investigation and recommendations [92]	Observational study	Survey UAV cyber threats, vulnerabilities, and countermeasures	Infrared, thermal cameras	Radar, infrared, optical, motion, acoustic sensors
Preliminary approach for UAV-based multi-sensor platforms [93]	Experimental study	Design an efficient UAV sensor platform with edge computing	Multispectral, thermal, infrared cameras	Multispectral, thermal, image sensors
Visualization analysis of research on unmanned-platform based battlefield situation awareness [94]	Observational study	Analyze battlefield situational awareness research trends	N/A	Photoelectric, infrared, LiDAR sensors
Heterogeneous wireless sensor networks for armed forces in urban environments [95]	Conceptual study	Improve urban situational awareness with autonomous WSNs	N/A	Optical, infrared, radar sensors
Situation awareness in AI-based technologies and multimodal systems [96]	Observational study	Apply AI and multimodal fusion to improve system awareness	Visible, infrared images	N/A
Development of a surveillance tool using UAV's [97]	Experimental study	Build a UAV-based surveillance tool for urban police	Thermal, NIR, high-resolution cameras	Imaging sensors
Additive manufacturing of sensors for military monitoring applications [98]	Experimental study	Advance 3D-printed sensors for troop monitoring	N/A	Strain, chemical, biological sensors
System-of-Systems for remote situational awareness [99]	Experimental study	Integrate ground sensors with UAV for real-time awareness	N/A	Stereo, tracking, RGB-D, imaging sensors
Real-time anomalous command detection in UAV operations [100]	Experimental study	Detect abnormal UAV commands via operator-UAV monitoring	N/A	Wearable, ECG sensors
Introduction to drone detection radar with ATR technology [101]	Experimental study	Improve small drone detection with ATR-enhanced radar	Optical camera	Electro-optical, infrared sensors
Overview of research on intelligent swarm munitions [102]	Observational study	Review advances in collaborative swarm munitions	Infrared images	N/A
Detecting and localizing objects on a UAS with mobile integration [103]	Experimental study	Develop autonomous UAS for target localization in GPS-denied areas	N/A	LiDAR, vision, acoustic/laser, RGB-D sensors

Table 2. *Cont.*

Study Title	Study Design	Goal	Imaging Technology Used	Sensor Technology Used
Interoperability of unmanned systems in military maritime operations [104]	Experimental study	Develop interoperable unmanned maritime systems and UAV controller	N/A	Infrared markers, optical sensor
Real-time monitoring and battery life enhancement of surveillance drones [105]	Experimental study	Improve drone endurance and real-time processing with edge AI	Microphone	N/A

Table 3. Breakdown of results from relevant Publish or Perish studies in relation to HAZMAT.

Study Title	Study Design	Goal	Imaging Technology Used	Sensor Technology Used
Cyber-physical systems to counter CBRN threats [106]	Observational study	Develop a UAV platform for real-time HAZMAT monitoring	NIR, VNIR hyperspectral imaging	Hyperspectral, LiDAR, EO/IR sensors
A novel UAV driven real-time situation awareness for fire accidents [76]	Experimental study	Create a UAV system for real-time fire detection and prediction	Infrared thermal, infrared cameras	Thermocouple sensors
Disasters and emergency management in chemical plants [63]	Observational study	Enhance UAV pilot training via 3D simulation for emergencies	N/A	Air contamination, biomedical sensors
Industrial floor monitoring system drone with hazardous gas detection [107]	Experimental study	Develop an autonomous drone to detect hazardous gas and smoke	N/A	Gas, smoke sensors
Aerial platforms for hydrogen leak detection [108]	Observational study	Detect hydrogen leaks in real-time with UAV systems	Thermal, multispectral, hyperspectral, infrared cameras	Catalytic bed, MOX sensors
Toward integrated large-scale environmental monitoring using WSN/UAV/Crowdsensing [62]	Observational study	Advance large-scale monitoring via UAVs, WSNs, crowdsensing	Thermal, multispectral, hyperspectral, optical cameras	Physical, chemical environmental sensors
Determining water toxicity after oil spills using UAV [109]	Experimental study	Monitor water toxicity post-oil spill via UAV sensors	N/A	Turbidity sensor
Drone-based aerial surveillance and hazardous gas leakage detection [110]	Experimental study	Develop a low-cost UAV system for air quality and gas leak monitoring	N/A	Gas, CO, temperature/humidity sensors
Evaluation of landfill leachate biodegradability using IoT drone surveying [111]	Experimental study	Monitor toxic waste and leachate with IoT drones	Thermal cameras	Hyperspectral, electromagnetic, inductive sensors
UAV platform with low-power components for air pollutant monitoring [112]	Experimental study	Develop a UAV system for real-time air pollution monitoring	N/A	Electrochemical gas sensors
Detection of natural gas leakage using UAV with ML [113]	Experimental study	Detect gas leaks via UAV and machine learning	N/A	Gas sensors, LiDAR
Low-cost wireless sensor network for water quality monitoring [114]	Conceptual study	Monitor water quality in real-time using solar-powered IoT sensors	N/A	Hydrogen, turbidity, ammonia sensors
UAV for inspection of environmental emissions [115]	Conceptual study	Monitor hazardous emissions in real-time with UAV	N/A	Electrochemical gas sensors
Aerial mapping of odorous gases in wastewater treatment plants [116]	Conceptual study	Map hazardous gas emissions with UAVs	N/A	Electrochemical, MOX sensors
AirQuality Lab-on-a-Drone for H ₂ S monitoring [117]	Observational study	Monitor H ₂ S gas in real-time using UAV IoT system	N/A	MOX sensors
Solar-powered automated drone for industrial safety [118]	Experimental study	Deploy solar-powered UAVs for autonomous inspections in HAZMAT sites	N/A	Ultrasonic sensors

4. Discussion

Tables 1–3 outline the findings from the included papers, which focus on imaging technologies such as thermal, multispectral, and hyperspectral cameras, as well as a range of onboard sensors. The table consists of the study title, type of study, goal of the study, imaging technology, and sensor technology integrated with drones, as defined in the papers. The review papers shown in Tables 1–3 are consequently summarised below.

4.1. Imaging and Sensor Technologies Used in Disaster and Emergency Management

- Imaging and sensor technologies integrated with drones not only play a critical role in managing natural disasters and hazardous situations, but also contribute supplementary functions to a range of high-risk scenarios. These include supporting the delivery of first aid, detecting falls among elderly individuals, enhancing situational awareness for first responders to improve decision-making under duress, and monitoring the storage conditions of dangerous goods to prevent potentially fatal incidents for personnel working in such environments.
- Most imaging and sensor technologies in drones are not stand-alone systems; they could provide greater benefits when integrated with wireless networks, big data, and AI. This combination enables real-time data processing, enhancing the accuracy and effectiveness of disaster response operations.
- Most research in disaster and emergency management aims to support frontline personnel by enhancing situational awareness, reducing unnecessary workload, and facilitating more effective decision-making. These improvements contribute not only to the safety of emergency responders but also to the timely assistance and potential survival of individuals in critical need during emergencies.
- Crowdsensing platforms have attracted growing research interest, mainly due to the increased accessibility of smartphones, wearable devices, and intelligent systems integrated into modern vehicles. These platforms enable the collection of large-scale, real-time data from numerous individuals, offering valuable insights for disaster and emergency management. However, concerns regarding data privacy and user security remain critical and must be carefully addressed in both the design and implementation of such systems.
- A significant proportion of the excluded papers—representing 62 out of 100—primarily focus on data transmission between sensors and the integration of technologies such as AI, big data, and wireless communication. This trend aligns with the earlier observation that imaging and sensor technologies are no longer stand-alone systems. Their integration within intelligent networks enhances both the speed and accuracy of results. Consequently, there is a notable shift in research interest toward system-level integration and data processing, rather than solely examining how cameras detect objects or individuals, or how sensors function in isolation.
- The findings indicate that the majority of studies prioritise enhancing situational awareness and decision-making for first responders, highlighting the central role of UAVs in real-time disaster management. A clear distinction emerges between experimental studies, which focus on developing and testing UAV prototypes, and observational or conceptual studies, which emphasize frameworks, systematic reviews, and integration strategies.
- Thermal and infrared imaging technologies remain the most dominant tools across applications, while multispectral, hyperspectral, and LiDAR systems are increasingly adopted to provide high-resolution environmental monitoring and mapping. The integration of multi-sensor platforms, spanning environmental (temperature, humidity, gas, radiation), biomedical (ECG, respiration, blood pressure), and safety-critical

(seismic, motion, pressure) domains, demonstrates the expanding scope of UAV-based disaster monitoring.

- Several studies underscore the role of AI, deep learning, and 5G connectivity in improving automation, predictive analytics, and coordination efficiency in emergency response operations. The emergence of extended reality (XR) and augmented reality (AR) applications suggests growing attention to training, decision support, and situational awareness in disaster risk reduction.

4.2. *Imaging and Sensor Technologies Used in Military Operations*

- Some research works were excluded from the results in the military context because the technologies were primarily applied in geological, environmental, and marine surveillance, overlapped with disaster and emergency management studies, or utilized for tracking, delivery services, and general surveillance applications. This suggests that the search query included the term ‘surveillance,’ which is broadly used across various non-military industries.
- In addition to excluding works that are not directly related to the military context, several other studies were also omitted from consideration. This exclusion was primarily due to these studies focusing predominantly on areas such as the Internet of Things (IoT), wireless sensor networks, and data extraction and collection processes. While these topics are important, they do not emphasize imaging and sensor technologies, which are the central focus of this paper.
- The studies presented in Table 2 predominantly explore the application of drone technologies integrated with advanced sensor systems to enhance military operations. These include the use of sensors for real-time threat detection, integration with wireless sensor networks for improved communication and data sharing, and monitoring systems for tracking the health and activity of military personnel. Collectively, these technologies play a crucial role in strengthening situational awareness, supporting tactical decision-making processes for soldiers and commanders, and improving the effectiveness of Intelligence, Surveillance, and Reconnaissance (ISR) missions.
- The body of research indicates that imaging and sensor technologies developed for military drones are increasingly applicable to civilian domains. Although drone technology originally emerged from military contexts, contemporary advancements have facilitated significant improvements in various civilian sectors. Consequently, this crossover is evident in the research findings, where the reviewed technologies are shown to be shared and adapted across both military and civilian industries.
- UAVs have become increasingly central to military operations, with research emphasizing improvements in situational awareness, reconnaissance, surveillance, and decision-making support across diverse operational contexts. Experimental studies typically focus on developing and validating UAV prototypes, multi-sensor platforms, and AI-driven systems, whereas observational studies emphasize frameworks, reviews, and integration strategies for operational deployment.
- Imaging technologies commonly employed include thermal and infrared cameras, high-resolution optical cameras, multispectral and hyperspectral cameras, and visible light imaging. Sensor technologies encompass environmental (temperature, pressure, seismic, chemical, biological, and radiation), motion (PIR, acoustic, and radar), biomedical (ECG and wearable), and LiDAR or laser-based systems. Integration of these multi-modal sensors facilitates autonomous or semi-autonomous UAV operations in complex and high-risk environments. AI, machine learning, and data fusion enhance predictive capabilities, automate threat detection, identify anomalies, and improve operational decision-making.

- Key challenges in military UAV applications include operational reliability in GPS-denied or communication-limited environments, complex integration of emerging technologies (e.g., swarm UAVs, 5G connectivity, additive manufacturing of sensors), and cybersecurity concerns such as secure data transmission, operator and UAV monitoring, and mitigation of potential misuse.
- Emerging solutions aim to enhance UAV operational efficiency and effectiveness, including the deployment of edge computing, AI, and data fusion to optimize situational awareness and reduce reliance on centralized command; swarm UAV frameworks and autonomous coordination algorithms to improve coverage, responsiveness, and mission success; and multi-sensor UAV platforms combining optical, infrared, LiDAR, and chemical/biological sensors for comprehensive battlefield intelligence.

4.3. *Imaging and Sensor Technologies Used in HAZMAT*

- Although the reviewed studies do not explicitly state drone use in HAZMAT or CBRN scenarios, several show potential for such applications. The research aligns broadly with disaster and emergency management, with cases like hazardous environment monitoring, toxic gas detection, and industrial safety inspections suggesting relevance to HAZMAT. Thus, while not all studies directly target HAZMAT or CBRN, some drone systems exhibit characteristics that make them suitable for high-risk deployments.
- The excluded studies primarily concentrate on environmental monitoring applications that are not directly relevant to HAZMAT or CBRN scenarios. These include areas such as water quality assessment, detection of algal blooms or other forms of water contamination, crop health monitoring, and precision agriculture. While necessary for sustainability and resource management, these applications fall outside the scope of hazardous material detection and emergency response.
- Interestingly, the majority of the reviewed studies place greater emphasis on sensor technologies rather than imaging systems. Most of the included research utilised metal-oxide (MOX) sensors and electrochemical sensors, highlighting a focus on gas detection and chemical analysis over visual data capture.
- Most of the studies included under the HAZMAT category predominantly address scenarios involving chemical spills and the detection of hazardous gases. These works often emphasize the use of real-time monitoring and early warning systems, utilizing sensor-equipped drones to detect toxic substances in industrial environments. Comparatively fewer studies have explored other types of hazardous materials, such as radiological or biological agents, indicating a research focus on chemical-related threats.
- UAVs are increasingly employed in hazardous materials (HAZMAT) operations to improve real-time situational awareness, emergency response, and industrial safety. Applications span chemical plants, waste management, oil spill response, and environmental pollution monitoring. Both experimental and observational studies highlight UAVs as practical tools to reduce human exposure to high-risk environments while enhancing detection, monitoring, and decision-making processes.
- Sensor technologies utilized in HAZMAT UAV applications are diverse, encompassing gas and smoke sensors, electrochemical sensors, MOX sensors, turbidity sensors, LiDAR, thermocouples, and biomedical or environmental sensors. The integration of multiple sensors allows UAVs to simultaneously monitor complex chemical, biological, radiological, and environmental parameters.
- Key challenges in deploying UAVs for HAZMAT operations include operational reliability in hazardous, dynamic, or toxic environments, accurate real-time detection of multiple hazardous agents under varying environmental conditions (e.g., airflow,

temperature fluctuations, chemical interactions), limitations in UAV endurance and power supply for extended monitoring or large-area coverage, difficulties in integrating heterogeneous sensor data for timely situational awareness, and the high costs and technical complexity of implementing robust multi-sensor platforms.

- Emerging strategies to address these challenges involve the deployment of multi-sensor UAV platforms combining thermal, infrared, hyperspectral imaging with environmental sensors (gas, electrochemical, MOX, LiDAR) to improve hazard detection accuracy, the development of solar-powered or low-power UAVs to enhance endurance and autonomy, and the integration of crowdsensing and wireless sensor networks (WSNs) to enable large-scale environmental monitoring and remote HAZMAT incident assessment.

4.4. Systematic Insights into Drone Imaging and Sensor Technologies Across Key Sectors

The summary results of the top 100 papers from Publish and Perish in these three categories demonstrate that imaging technology, focusing on infrared, thermal, spectral, and MSI cameras, and sensor technology-equipped drones, produced the highest occurrence of relevant papers in disaster and emergency management, followed by military operations and HAZMAT environments. These research works indicate that imaging and sensor technologies do not stand alone in drone applications; with the integration of AI, cloud systems, IoT, and big data, they add significant scope to the widespread interest in this field.

Moreover, the parameters of search queries play a significant role in the search results on Publish and Perish. For example, in the instance where a focus on ‘Imaging technology’ includes the infrared, thermal, spectral, and multi-spectral cameras/imagers parameters, the search returns present many results that include various technological modalities irrelevant to this paper’s targeted research. Furthermore, there are limited characters on search queries on Publish and Perish, which affects the ability to cover the target research area comprehensively.

Recent studies indicate significant advancements in drone technology. A key focus of current development is the integration of real-time data processing with emerging technologies such as Artificial Intelligence (AI), Big Data, and the Internet of Things (IoT). These interconnected systems, when networked with drones, enhance operational capabilities—enabling rapid analysis, situational awareness, and decision-making in critical scenarios. This technological convergence not only improves the detection and response efficiency in disaster zones but also supports civilian applications, such as monitoring high-risk individuals like the elderly who may be prone to falls or indoor accidents. Drones, which were initially developed for applications beyond disaster response and humanitarian rescue, are now increasingly adapted for civilian-focused operations. Technological advancements have enabled unmanned aerial systems (UAS) to autonomously deliver critical supplies such as medical kits, vaccines, potable water, and emergency rations to remote or inaccessible areas—significantly enhancing the reach and efficiency of relief efforts. Furthermore, with the integration of emerging technologies including artificial intelligence, machine learning, and real-time sensor networks, drones are evolving towards fully autonomous search and rescue capabilities, enabling them to detect, locate, and assist victims without the need for direct human control.

Military drone technology has advanced significantly beyond traditional applications in Search and Rescue (SAR) and Intelligence, Surveillance, and Reconnaissance (ISR). Drones have become indispensable tools for reducing human casualties, lowering operational costs, and supporting strategic planning. A variety of drone types have been developed to enhance specific mission capabilities. Modern warfare has shifted away from

conventional ground combat involving large numbers of soldiers; instead, unmanned aerial systems are increasingly used to detect camouflaged targets, identify explosive devices, and, in some cases, carry out precision strikes by deploying munitions without direct human presence. The deployment of multiple drone types within a single mission further improves operational efficiency and mission effectiveness. Given these technological advancements, future warfare may see a significant decline in direct human-to-human combat. Swarm technology, in particular, will enable hundreds of drones to operate as a single, coordinated unit—dynamically adapting to threats or mission changes in real time, thereby reducing the risk of human casualties. Additionally, the integration of advanced AI will enable drones to self-learn and autonomously respond to battlefield conditions, eliminating the need for constant human commands and thereby enhancing both efficiency and responsiveness in combat operations.

Historically, the detection of HAZMAT and CBRN threats has relied on a combination of ground-based detection instruments, mobile response units, and trained personnel equipped with specialised tools to identify hazardous substances. While these personnel typically operate in full protective suits, prolonged exposure during extended operations still poses a significant health risk. The integration of drones into these operations offers a safer and more efficient alternative, as drones can be equipped with advanced sensors capable of detecting odorless and colorless toxic gases that are invisible to the human eye. Moreover, drones enable the transmission of real-time data, thereby overcoming the limitations associated with human vision and handheld detection devices. There is a strong possibility that, in the future, drones will not only detect hazardous materials but will also autonomously collect samples from affected areas and transport them to laboratories for further analysis. This advancement would enable experts to investigate threats in detail and determine appropriate preventive measures, all while minimizing human exposure to dangerous environments.

Drones are no longer confined to specific applications; their integration with emerging technologies has enabled their deployment across a wide range of sectors. Furthermore, individuals who initially engage with drones as a hobby can develop expertise in the field over time. Although certain advanced technologies remain restricted from public access, it is anticipated that such technologies will become increasingly accessible in the future.

4.5. Limitations and Challenges of Drone Operations

Drone research and applications have been rapidly developing across a wide range of industries, from disaster response to military operations and hazardous materials (HAZMAT) management. While the benefits of drones are significant, it is equally important to recognize their disadvantages and limitations. One of the most critical challenges is battery life. Drones typically have limited endurance, which poses a major drawback during operations that require continuous monitoring, such as in disaster management. This limitation becomes more serious in harsh environments, where drones are susceptible to water, strong winds, and heavy rain—conditions that are often present in natural disasters [119]. Most drone research, however, is conducted under normal weather conditions [44], which may not fully capture the operational challenges faced during extreme events. In addition, effective deployment requires operators to undergo specialized training to ensure safe and efficient usage.

In military operations, drones face distinct weaknesses. Unlike manned aircraft designed with advanced stealth technology, drones have limited stealth capability [120], making them more detectable and therefore more vulnerable in high-threat combat zones. This makes them easy targets for adversaries equipped with radar or anti-drone defense systems. Furthermore, the maintenance and operational costs of military-grade drones are

substantially higher compared to drones used in civilian sectors [120]. Ethical concerns also arise, particularly regarding the potential violation of civilian privacy and the broader implications of remote warfare, which can risk dehumanizing conflict.

When applied to HAZMAT scenarios, drones present both opportunities and risks. Their use requires operators to be specially trained for safety, since operating in contaminated zones may endanger human health and wildlife. In many cases, deploying drones in such environments may involve compliance with strict safety regulations. Moreover, navigating confined or obstructed spaces often requires highly specialized drones designed for the task [121,122]. Different types of sensors may also be needed to detect harmful chemicals, meaning that a single drone model may not be sufficient for all HAZMAT situations.

Beyond these technical and operational limitations, drones also raise broader ethical and societal issues. While drones offer advantages in areas such as surveillance, delivery, and scientific research, they may also infringe upon individual privacy, disrupt animal habitats, or contribute to the dehumanization of warfare. Therefore, it is essential to strike a balance between the benefits of drone technology and the risks it poses to privacy, safety, and ethics. Operating drones not only affects civilians but also requires careful consideration of their impact on the environment and wildlife.

4.6. AI Technologies for Drones

This subsection provides a more technical extension of the previous discussion, focusing on AI solutions applied in UAV applications, particularly in disaster management, search and rescue operations, military operations, and hazardous materials response.

4.6.1. AI Technical Solutions Commonly Used in Disaster Management and Emergency Response

UAVs play a crucial role in damage assessment, environmental monitoring, and post-disaster rescue coordination. Equipped with optical cameras, LiDAR, and thermal sensors, UAVs can provide real-time data to identify hazardous areas, optimize resource allocation, and interface with AI-enabled ground control stations (GCS) to support on-site command operations.

In disaster management, the rapid collection, analysis, and dissemination of data are vital. Integrated Helicopter-Balloon/UAV systems, when combined with AI, enable automated analysis of imagery and sensor data to assess damage, detect hazards, and support efficient resource deployment. A key challenge, however, is that post-disaster environments often feature visual noise, such as dust, smoke, rain, and debris, which complicates computer vision tasks.

To overcome this, AI-based damage assessment solutions have been developed using CNNs, ResNet, or EfficientNet models, which are trained on satellite and UAV imagery collected both before and after disasters. Multi-temporal imagery processing enables comparisons between pre- and post-disaster conditions to detect collapsed buildings, damaged bridges, and disrupted roadways. Semantic segmentation models (e.g., DeepLab, U-Net) are also used to classify affected zones by severity (e.g., mild, moderate, or severe damage).

AI further enhances real-time UAV video analysis through object tracking algorithms such as SORT, DeepSORT, and ByteTrack, which help monitor evacuees and prevent overcrowding or loss. In many cases, Edge-AI systems are deployed directly on UAVs or nearby ground stations, reducing latency compared to cloud-based systems. Another important technique is sensor fusion, where data from optical imagery, thermal cameras, radar, and LiDAR is combined. This fusion is further enhanced by deep learning approaches such as Multimodal Deep Learning (e.g., late-fusion or cross-attention), improving the reliability of disaster monitoring and response.

4.6.2. AI Technical Solutions Commonly Used in UAV-SAR

In search and rescue (SAR) operations, the application of AI for small object detection is critically important. While traditional imaging systems, including RGB, thermal, and multispectral imaging (MSI), have proven valuable, their effectiveness diminishes significantly when detecting small targets such as life jackets, debris, or individual victims from high-altitude UAVs.

To address this challenge, modern object detection architectures such as YOLOv, UAV-YOLO, and slice-based techniques like Slicing Aided Hyper Inference (SAHI) are increasingly adopted. These approaches improve the accuracy of bounding boxes and recall rates for essential SAR targets, particularly when used alongside high-resolution sensors and robust preprocessing techniques (e.g., glare reduction on water surfaces, contextual feature enhancement).

In real-world UAV-SAR scenarios, the targets often occupy less than 2% of the input image size—for example, individuals wearing life vests, lifebuoys, or floating debris. Victims partially submerged in water appear even smaller. The high observation angle and water-surface reflections often cause conventional models to miss these targets, thereby delaying rescue efforts.

4.6.3. AI Technical Solutions Commonly Used in Military Operations

Various UAV platforms featuring stealth capabilities and extended flight duration enhance intelligence, surveillance, and reconnaissance (ISR) operations. Multispectral, hyperspectral, radar, and infrared sensors enable detection of camouflaged targets, nighttime surveillance, and support for precision strikes. Case studies from recent conflicts, such as in Ukraine, underscore the strategic importance of UAVs for surveillance and fire coordination.

In military applications, these UAV systems not only gather information but also serve as platforms for AI-powered ISR. Adversaries often use camouflage, radar jamming, or smoke and heat decoys, necessitating AI algorithms that can distinguish between genuine targets and deception.

Key technologies include camouflage detection using hyperspectral and multispectral imaging, paired with transformer-based attention models (e.g., Swin Transformer, ViT) to detect subtle anomalies in natural environments. Generative Adversarial Networks (GANs) are also used to create synthetic battlefield datasets, improving detection performance when real training data is scarce.

For nighttime operations, AI leverages infrared and Synthetic Aperture Radar (SAR) data. Temporal analysis of imagery via 3D CNNs and RNNs (e.g., LSTM, GRU) enables detection of troop movements. Additionally, AI-based acoustic classification can differentiate between tank engines, vehicles, and artillery, even when obscured.

A promising area of research is the deployment of AI in UAV swarms, where multiple UAVs collaborate using reinforcement learning (RL). These swarms can share real-time data, execute coordinated encirclement tactics, and adapt dynamically. AI also enhances anti-jamming and anti-spoofing capabilities, using machine learning to detect and counter electronic warfare threats.

Through these advancements, integrated UAV systems not only improve surveillance but also push modern warfare toward greater automation and data-driven decision-making.

4.6.4. AI Technical Solutions Commonly Used in Hazardous Materials Incident Response (HAZMAT/CBRN)

In chemical, biological, radiological, and nuclear (CBRN) emergencies, integrated Helicopter-Balloon/UAV platforms are deployed to detect leaks, assess contamination, and

evaluate risk without exposing human personnel to danger. These systems have also been used in public health applications, for instance, during the COVID-19 pandemic to monitor patient conditions using biosensors remotely.

AI, when combined with UAV platforms, plays a critical role in minimizing human exposure in HAZMAT/CBRN scenarios. One major challenge is that many hazards, such as toxic gases, radiation, or pathogens, are invisible to the human eye.

The integrated UAV platform can carry diverse sensors, including infrared, hyperspectral, chemical, radiation, and acoustic sensors. AI algorithms process this data in real time to identify potential threats. For example, machine learning models such as Support Vector Machines (SVM) and Random Forests classify chemical compounds based on sensor input. In contrast, deep learning models process hyperspectral imagery to map contamination zones or radiation leaks.

A crucial application is AI-based plume modeling, which predicts the spatial and temporal dispersion of toxic substances, enabling the generation of real-time contamination maps to inform evacuation and containment efforts. Anomaly detection techniques, such as autoencoders and isolation forests, are employed to identify irregular sensor patterns and issue early warnings.

During the COVID-19 pandemic, Helicopter-Balloon/UAV systems equipped with AI and biosensors (e.g., thermal cameras, remote heart/respiration monitors) facilitated contactless health surveillance in communities. These technologies are now being extended to nuclear safety applications, where AI monitors radiation levels to detect minor leaks before they become critical. When integrated with Edge-AI, UAVs can perform on-site data processing, ensuring rapid, accurate responses essential for effective CBRN management.

4.7. Convergence and Integration of Technologies

Our methodology attempted to exclude studies that did not have a primary focus on imaging or sensor hardware. Yet our analysis of the selected literature reveals a clear trend towards integrating these hardware systems with advanced AI and IoT frameworks. The large number of papers excluded for focusing solely on these software integrations further underscores the dominance of this multidisciplinary approach in the broader field.

5. Conclusions

To garner a broader understanding of technological trends regarding the applications of imaging and sensor technologies in UAVs, this study collected and analysed data from Publish or Perish across three key domains: disaster management, military operations, and HAZMAT.

The findings reveal several limitations in relying solely upon Publish or Perish. The search engine imposes restrictions on the length of search queries, which may limit the comprehensiveness of retrieved results. Moreover, within the top 100 ranked papers, several studies were found to be only loosely related or irrelevant to the intended scope, despite being highlighted as relevant by the software. Therefore, it is advisable to utilize additional search engines in parallel to enhance the accuracy, precision, and completeness of literature searches within specific research areas.

Although the systematic study addressed UAV imaging and sensor technologies, most provided only superficial descriptions of their roles and applications. Detailed explanations regarding their operational mechanisms, hardware specifications, comparative effectiveness, or rationale for choosing one technology over another were rarely presented. This lack of depth may be due to the confidential nature of technical specifications or proprietary data that companies do not publicly disclose. As a result, comparisons of technical performance often depend on the discretion and preferences of end-users rather than standardised evaluations.

Furthermore, the majority of research placed greater emphasis on the integration of imaging and sensor technologies with complementary systems such as AI, WSNs, and cloud computing. This reflects a growing trend in research toward leveraging drones within larger, more complex ecosystems, particularly when targeting large-scale civilian or industrial applications that require precision, efficiency, and rapid responsiveness. The ever-growing application of innovative and wireless systems within UAV systems will no doubt continue to develop in sophistication as changing situations and environments require more nuanced understandings of data.

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Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial Intelligence
CBRN	Chemical, Biological, Radiological, and Nuclear
CO ₂	Carbon Dioxide
ECG	Electrocardiograph
EO	Electro-optical
GPS	Global Positioning System
HAZMAT	Hazardous Materials
HSI	Hyperspectral Imaging
IMINT	Imagery Intelligence
INS	Inertial Navigation System
IoT	Internet of Things
IR	Infrared
ISR	Intelligence, Surveillance, and Reconnaissance
LiDAR	Light Detection and Ranging
MOX	Metal-Oxide Semiconductor
MSI	Multispectral
NBC	Nuclear, Biological, and Chemical
NIR	Near Infrared
PIR	Passive infrared detectors
PM	Particulate Matter
RADAR	Radio Detection and Ranging
RGB	Red, Green, Blue
SAR	Search and Rescue
VNIR	Very Near Infrared
WSN	Wireless Sensor Network

References

1. Mohsan, S.A.H.; Othman, N.Q.H.; Li, Y.; Alsharif, M.H.; Khan, M.A. Unmanned aerial vehicles (UAVs): Practical aspects, applications, open challenges, security issues, and future trends. *Intell. Serv. Robot.* **2023**, *16*, 109–137. [CrossRef]
2. Emimi, M.; Khaleel, M.; Alkrash, A. The current opportunities and challenges in drone technology. *Int. J. Electr. Eng. Sustain.* **2023**, *1*, 74–89.
3. Dokoro, H.A.; Hassan, I.; Yada, M.Y.; Umar, M. Exploring the Technological Advancement in Drone Technology for Surveillance. *Gombe State Polytech. Bajoga, J. Sci. Technol.* **2024**, *1*, 78–85.
4. Velasco, J.A.H.; Guevara, H.S.D. Development of uavs/drones equipped with thermal sensors for the search of individuals lost under rubble due to earthquake collapses or any eventuality requiring such capabilities. In Proceedings of the 34th International Council of the Aeronautical Sciences (ICAS) Congress, Florence, Italy, 9–13 September 2024.
5. Yuen, P.W.; Richardson, M. An introduction to hyperspectral imaging and its application for security, surveillance and target acquisition. *Imaging Sci. J.* **2010**, *58*, 241–253. [CrossRef]
6. Seidaliyeva, U.; Ilipbayeva, L.; Utebayeva, D.; Smailov, N.; Matson, E.T. LiDAR Technology for UAV Detection: From Fundamentals and Operational Principles to Advanced Detection and Classification Techniques. *Sensors* **2025**, *25*, 2757. [CrossRef]
7. Balestrieri, E.; Daponte, P.; De Vito, L.; Picariello, F.; Tudosa, I. Sensors and measurements for UAV safety: An overview. *Sensors* **2021**, *21*, 8253. [CrossRef] [PubMed]
8. Balestrieri, E.; Daponte, P.; De Vito, L.; Lamonaca, F. Sensors and measurements for unmanned systems: An overview. *Sensors* **2021**, *21*, 1518. [CrossRef]
9. Kunertova, D. Drones have boots: Learning from Russia's war in Ukraine. *Contemp. Secur. Policy* **2023**, *44*, 576–591. [CrossRef]
10. Kunertova, D. The war in Ukraine shows the game-changing effect of drones depends on the game. *Bull. At. Sci.* **2023**, *79*, 95–102. [CrossRef]
11. Rejeb, A.; Rejeb, K.; Simske, S.; Treiblmaier, H. Humanitarian drones: A review and research agenda. *Internet Things* **2021**, *16*, 100434. [CrossRef]
12. Maghazei, O.; Netland, T. Drones in manufacturing: Exploring opportunities for research and practice. *J. Manuf. Technol. Manag.* **2020**, *31*, 1237–1259. [CrossRef]
13. Mohsan, S.A.H.; Khan, M.A.; Noor, F.; Ullah, I.; Alsharif, M.H. Towards the unmanned aerial vehicles (UAVs): A comprehensive review. *Drones* **2022**, *6*, 147. [CrossRef]
14. Hildmann, H.; Kovacs, E. Using unmanned aerial vehicles (UAVs) as mobile sensing platforms (MSPs) for disaster response, civil security and public safety. *Drones* **2019**, *3*, 59. [CrossRef]
15. Yang, Z.; Yu, X.; Dedman, S.; Rosso, M.; Zhu, J.; Yang, J.; Xia, Y.; Tian, Y.; Zhang, G.; Wang, J. UAV remote sensing applications in marine monitoring: Knowledge visualization and review. *Sci. Total Environ.* **2022**, *838*, 155939. [CrossRef] [PubMed]
16. Shakhathreh, H.; Sawalmeh, A.H.; Al-Fuqaha, A.; Dou, Z.; Almaita, E.; Khalil, I.; Othman, N.S.; Khreishah, A.; Guizani, M. Unmanned aerial vehicles (UAVs): A survey on civil applications and key research challenges. *IEEE Access* **2019**, *7*, 48572–48634. [CrossRef]
17. Telli, K.; Kraa, O.; Himeur, Y.; Ouamane, A.; Boumehraz, M.; Atalla, S.; Mansoor, W. A comprehensive review of recent research trends on unmanned aerial vehicles (uavs). *Systems* **2023**, *11*, 400. [CrossRef]
18. U.S. Department of Homeland Security. *National Incident Management System: Emergency Operations Center How-to Quick Reference Guide*; U.S. Department of Homeland Security: Washington, DC, USA, 2022. Available online: <https://www.fema.gov> (accessed on 22 March 2025).
19. Kedia, T.; Ratcliff, J.; O'Connor, M.; Oluic, S.; Rose, M.; Freeman, J.; Rainwater-Lovett, K. Technologies enabling situational awareness during disaster response: A systematic review. *Disaster Med. Public Health Prep.* **2022**, *16*, 341–359. [CrossRef] [PubMed]
20. U.S. Department of Health and Human Services. *Department of Health and Human Services All-Hazards Plan*. Administration for Strategic Preparedness & Response. 2024. Available online: <https://aspr.hhs.gov/legal/Documents/AHP-final-2024-508.pdf> (accessed on 20 March 2025).
21. Li, T.; Hu, H. Development of the use of unmanned aerial vehicles (UAVs) in emergency rescue in China. *Risk Manag. Healthc. Policy* **2021**, *14*, 4293–4299. [CrossRef]
22. Restas, A. Drone applications for supporting disaster management. *World J. Eng. Technol.* **2015**, *3*, 316–321. [CrossRef]
23. Abuali, T.M.; Ahmed, A.A. Innovative Applications of Swarm Drones in Disaster Management and Rescue Operations. *Open Eur. J. Eng. Sci. Res. OEJESR* **2025**, *1*, 23–31.
24. Eshtaiwi, A.; Ahmed, A.A. Emergency response and disaster management leveraging drones for rapid assessment and relief operations. *Afr. J. Adv. Pure Appl. Sci. AJAPAS* **2024**, *3*, 35–50.
25. Udeanu, G.; Dobrescu, A.; Oltean, M. Unmanned aerial vehicle in military operations. *Sci. Res. Educ. Air Force* **2016**, *18*, 199–206. [CrossRef]
26. Fowler, M. The strategy of drone warfare. *J. Strateg. Secur.* **2014**, *7*, 108–119. [CrossRef]
27. Mahadevan, P. The military utility of drones. *CSS Anal. Secur. Policy* **2010**, *78*, 1–3.

28. Wallace, D.; Costello, J. Eye in the sky: Understanding the mental health of unmanned aerial vehicle operators. *J. Mil. Veterans Health* **2017**, *25*, 36–41.
29. Gargalakos, M. The role of unmanned aerial vehicles in military communications: Application scenarios, current trends, and beyond. *J. Def. Model. Simul.* **2024**, *21*, 313–321. [\[CrossRef\]](#)
30. Jeler, G.E. Military and civilian applications of UAV systems. In *Proceedings of the International Scientific Conference Strategies XXI. The Complex and Dynamic Nature of the Security Environment-Volume 1*; Carol I National Defence University Publishing House: Bucharest, Romania, 2019; pp. 379–386.
31. Brust, M.R.; Danoy, G.; Stolfi, D.H.; Bouvry, P. Swarm-based counter UAV defense system. *Discov. Internet Things* **2021**, *1*, 1–19. [\[CrossRef\]](#)
32. Molloy, D.O. Drones in Modern Warfare: Lessons Learnt from the War in Ukraine. *Aust. Army Res. Cent.* **2024**. [\[CrossRef\]](#)
33. Kunertova, D. *Learning from the Ukrainian Battlefield: Tomorrow's Drone Warfare, Today's Innovation Challenge*; Technical report; ETH Zurich: Zurich, Switzerland, 2024.
34. Kostenko, I.; Hurova, A. Connection of Private Remote Sensing Market with Military Contracts—the Case of Ukraine. *Adv. Space Law* **2024**, *13*. [\[CrossRef\]](#)
35. Victor-Luca, I. Multispectral, Hyperspectral imaging and their military applications. *Commun. Across Cult.* **2024**, *29*.
36. Rabajczyk, A.; Zboina, J.; Zielecka, M.; Fellner, R. Monitoring of selected CBRN threats in the air in industrial areas with the use of unmanned aerial vehicles. *Atmosphere* **2020**, *11*, 1373. [\[CrossRef\]](#)
37. Aiello, G.; Hopps, F.; Santisi, D.; Venticinque, M. The employment of unmanned aerial vehicles for analyzing and mitigating disaster risks in industrial sites. *IEEE Trans. Eng. Manag.* **2020**, *67*, 519–530. [\[CrossRef\]](#)
38. Safie, S.; Khairil, R. Regulatory, technical, and safety considerations for UAV-based inspection in chemical process plants: A systematic review of current practice and future directions. *Transp. Res. Interdiscip. Perspect.* **2025**, *30*, 101343. [\[CrossRef\]](#)
39. Tarr, A.A.; Perera, A.G.; Chahl, J.; Chell, C.; Ogunwa, T.; Paynter, K. Drones—Healthcare, humanitarian efforts and recreational use. In *Drone Law and Policy*; Routledge: Abingdon, UK, 2021; pp. 35–54.
40. Khanam, F.T.Z.; Chahl, L.A.; Chahl, J.S.; Al-Naji, A.; Perera, A.G.; Wang, D.; Lee, Y.; Ogunwa, T.T.; Teague, S.; Nguyen, T.X.B.; et al. Noncontact sensing of contagion. *J. Imaging* **2021**, *7*, 28. [\[CrossRef\]](#)
41. Mohsan, S.A.H.; Zahra, Q.u.A.; Khan, M.A.; Alsharif, M.H.; Elhaty, I.A.; Jahid, A. Role of drone technology helping in alleviating the COVID-19 pandemic. *Micromachines* **2022**, *13*, 1593. [\[CrossRef\]](#)
42. Solodov, A.; Williams, A.; Al Hanaei, S.; Goddard, B. Analyzing the threat of unmanned aerial vehicles (UAV) to nuclear facilities. *Secur. J.* **2018**, *31*, 305–324. [\[CrossRef\]](#)
43. Ardiny, H.; Beigzadeh, A.; Mahani, H. Applications of unmanned aerial vehicles in radiological monitoring: A review. *Nucl. Eng. Des.* **2024**, *422*, 113110. [\[CrossRef\]](#)
44. Daud, S.M.S.M.; Yusof, M.Y.P.M.; Heo, C.C.; Khoo, L.S.; Singh, M.K.C.; Mahmood, M.S.; Nawawi, H. Applications of drone in disaster management: A scoping review. *Sci. Justice* **2022**, *62*, 30–42. [\[CrossRef\]](#) [\[PubMed\]](#)
45. AL-Dosari, K.; Hunaiti, Z.; Balachandran, W. Systematic review on civilian drones in safety and security applications. *Drones* **2023**, *7*, 210. [\[CrossRef\]](#)
46. Yucesoy, E.; Balcik, B.; Coban, E. The role of drones in disaster response: A literature review of operations research applications. *Int. Trans. Oper. Res.* **2025**, *32*, 545–589. [\[CrossRef\]](#)
47. Harzing, A.W. Publish or Perish. 2007. Available online: <https://www.harzing.com/resources/publish-or-perish> (accessed on 14 May 2025)
48. Mohsin, B.; Steinhäusler, F.; Madl, P.; Kiefel, M. An innovative system to enhance situational awareness in disaster response. *J. Homel. Secur. Emerg. Manag.* **2016**, *13*, 301–327. [\[CrossRef\]](#)
49. Damaševičius, R.; Bacanin, N.; Misra, S. From sensors to safety: Internet of Emergency Services (IoES) for emergency response and disaster management. *J. Sens. Actuator Netw.* **2023**, *12*, 41. [\[CrossRef\]](#)
50. Pappan, N.; Kulhandjian, M.; Kulhandjian, H.; Aslanyan, L. AI-based drone assisted human rescue in disaster environments: Challenges and opportunities. *Pattern Recognit. Image Anal.* **2024**, *34*, 169–186. [\[CrossRef\]](#)
51. Zeng, F.; Pang, C.; Tang, H. Sensors on the internet of things systems for urban disaster management: A systematic literature review. *Sensors* **2023**, *23*, 7475. [\[CrossRef\]](#)
52. Jagatheesaperumal, S.K.; Hassan, M.M.; Hassan, M.R.; Fortino, G. The duo of visual servoing and deep learning-based methods for situation-aware disaster management: A comprehensive review. *Cogn. Comput.* **2024**, *16*, 2756–2778. [\[CrossRef\]](#)
53. Balamurugan, M.; Sathesh, M.; Ramakrishnan, K.; Raja, M.; Kalaiarasi, K. Integrating Remote Sensing Technologies for Real-Time Disaster Management, Mitigation, and Decision Support Systems. In *Proceedings of the 2024 International Conference on Recent Advances in Science and Engineering Technology (ICRASET)*, Mandya, India, 21–22 November 2024; pp. 1–5.
54. Kanand, T.; Kemper, G.; König, R.; Kemper, H. Wildfire detection and disaster monitoring system using UAS and sensor fusion technologies. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2020**, *43*, 1671–1675. [\[CrossRef\]](#)

55. Gunturu, V.R. GIS, remote sensing and drones for disaster risk management. In *5th World Congress on Disaster Management: Volume I*; Routledge: Abingdon, UK, 2022; pp. 182–194.
56. Friedrich, M.; Lieb, T.J.; Temme, A.; Almeida, E.N.; Coelho, A.; Fontes, H. Respondrone—a situation awareness platform for first responders. In *Proceedings of the 2022 IEEE/AIAA 41st Digital Avionics Systems Conference (DASC)*, Portsmouth, VA, USA, 18–22 September 2022; pp. 1–7.
57. Hussain, M.; Mehboob, K.; Ilyas, S.Z.; Shaheen, S.; Abdulsalam, A. Drones application scenarios in a nuclear or radiological emergency. *Kerntechnik* **2022**, *87*, 260–270. [[CrossRef](#)]
58. Fakhruddin, S.S.; Gharghan, S.K.; Al-Naji, A.; Chahl, J. An advanced first aid system based on an unmanned aerial vehicles and a wireless body area sensor network for elderly persons in outdoor environments. *Sensors* **2019**, *19*, 2955. [[CrossRef](#)] [[PubMed](#)]
59. He, Y.; Liu, Z.; Guo, Y.; Zhu, Q.; Fang, Y.; Yin, Y.; Wang, Y.; Zhang, B.; Liu, Z. UAV based sensing and imaging technologies for power system detection, monitoring and inspection: A review. *Nondestruct. Test. Eval.* **2024**, 1–68. [[CrossRef](#)]
60. Yang, S. Natural Disaster Impact and Emergency Response System Design Under Drone Vision. 2024. Available online: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4710030 (accessed on 20 March 2025). [[CrossRef](#)]
61. Li, Q.; Xu, Y. Intelligent Early Warning Method Based on Drone Inspection. *J. Uncertain Syst.* **2021**, *15*, 137–146. [[CrossRef](#)]
62. Fascista, A. Toward integrated large-scale environmental monitoring using WSN/UAV/Crowdsensing: A review of applications, signal processing, and future perspectives. *Sensors* **2022**, *22*, 1824. [[CrossRef](#)]
63. Bruzzone, A.; Longo, F.; Massei, M.; Nicoletti, L.; Agresta, M.; Di Matteo, R.; Maglione, G.L.; Murino, G.; Padovano, A. Disasters and emergency management in chemical and industrial plants: Drones simulation for education and training. In *Proceedings of the International Workshop on Modelling and Simulation for Autonomous Systems*, Rome, Italy, 15–16 June 2016; pp. 301–308.
64. Lyu, M.; Zhao, Y.; Huang, C.; Huang, H. Unmanned aerial vehicles for search and rescue: A survey. *Remote Sens.* **2023**, *15*, 3266. [[CrossRef](#)]
65. Fang, Z.; Savkin, A.V. Strategies for optimized uav surveillance in various tasks and scenarios: A review. *Drones* **2024**, *8*, 193. [[CrossRef](#)]
66. Ray, P.P.; Mukherjee, M.; Shu, L. Internet of things for disaster management: State-of-the-art and prospects. *IEEE Access* **2017**, *5*, 18818–18835. [[CrossRef](#)]
67. Aretoulaki, E.; Ponis, S.T.; Plakas, G.; Tzanetou, D.; Kitsantas, A. A proposed drone-enabled platform for holistic disaster management. In *Proceedings of the IADIS International Conference Applied Computing*, Madeira Island, Portugal, 21–23 October 2023; pp. 239–244.
68. Mavi, T.; Priya, D.; Grih Dhawaj Singh, R.; Singh, A.; Singh, D.; Upadhyay, P.; Singh, R.; Katyal, A. Enhancing unmanned vehicle navigation safety: Real-time visual mapping with CNNs with optimized Bezier trajectory smoothing. *Robot. Intell. Autom.* **2025**, *45*, 28–69. [[CrossRef](#)]
69. Majumdar, S.; Kirkley, S.; Srivastava, M. Optimizing Emergency Response with UAV-Integrated Fire Safety for Real-Time Prediction and Decision-Making: A Performance Evaluation. In *Proceedings of the 2024 IEEE Long Island Systems, Applications and Technology Conference (LISAT)*, Holtsville, NY, USA, 15 November 2024; pp. 1–7.
70. Grigoriou, E.; Fountoulakis, M.; Kafetzakis, E.; Giannoulakis, I.; Fountoukidis, E.; Karypidis, P.A.; Margounakis, D.; Mikelidou, C.V.; Sennekis, I.; Boustras, G. Towards the RESPOND-A initiative: Next-generation equipment tools and mission-critical strategies for First Responders. In *Proceedings of the 2022 IEEE International Conference on Omni-layer Intelligent Systems (COINS)*, Barcelona, Spain, 1–3 August 2022; pp. 1–5.
71. Nagaiah, K.; Kalaivani, K.; Palamalai, R.; Suresh, K.; Sethuraman, V.; Karuppiyah, V. A Logical Remote Sensing Based Disaster Management and Alert System Using AI-Assisted Internet of Things Technology. *Remote Sens. Earth Syst. Sci.* **2024**, *7*, 457–471. [[CrossRef](#)]
72. Terwilliger, B.; Vincenzi, D.; Ison, D.; Witcher, K.; Thirtyacre, D.; Khalid, A. Influencing factors for use of unmanned aerial systems in support of aviation accident and emergency response. *J. Autom. Control Eng.* **2015**, *3*, 246. [[CrossRef](#)]
73. Yao, J.; Gao, X.; Liu, H. Design of UAV-Based Information Acquisition and Environmental Monitoring System for Dangerous Goods Warehouse. In *Proceedings of the International Conference on Traffic and Transportation Studies*; Springer: Singapore, 2024; pp. 435–443.
74. Symeonidis, S.; Samaras, S.; Stentoumis, C.; Plaum, A.; Pacelli, M.; Grivolla, J.; Shekhawat, Y.; Ferri, M.; Diplaris, S.; Vrochidis, S. An extended reality system for situation awareness in flood management and media production planning. *Electronics* **2023**, *12*, 2569. [[CrossRef](#)]
75. Gurung, P. Drone-Assisted Imaging and Vehicle Telemetry Integration for Enhanced Smart Mobility Applications. *Rev. Internet Things IoT Cyber-Phys. Syst. Appl.* **2025**, *10*, 26–38.
76. Sheng, H.; Chen, G.; Li, X.; Men, J.; Xu, Q.; Zhou, L.; Zhao, J. A novel unmanned aerial vehicle driven real-time situation awareness for fire accidents in chemical tank farms. *J. Loss Prev. Process Ind.* **2024**, *91*, 105357. [[CrossRef](#)]
77. Tao, Y.; Tian, B.; Adhikari, B.R.; Zuo, Q.; Luo, X.; Di, B. A Review of Cutting-Edge Sensor Technologies for Improved Flood Monitoring and Damage Assessment. *Sensors* **2024**, *24*, 7090. [[CrossRef](#)]

78. Lauterbach, H.A.; Koch, C.B.; Hess, R.; Eck, D.; Schilling, K.; Nüchter, A. The Eins3D project—Instantaneous UAV-based 3D mapping for Search and Rescue applications. In Proceedings of the 2019 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR), Würzburg, Germany, 2–4 September 2019; pp. 1–6.
79. Kannan, K.; Awati, A.N.; Rao, S.S.; Malagi, V.P. DROPEX: Disaster Rescue Operations and Probing using EXpert drones. In Proceedings of the 2024 8th International Conference on Computational System and Information Technology for Sustainable Solutions (CSITSS), Bengaluru, India, 7–9 November 2024; pp. 1–5.
80. Singh, S.S.; Themvinah, A.; Sharma, T.S.; Tarao, D.K.; Shougaijam, B.; Singh, T.C.; Singh, R.B. Real-Time Monitoring of Atmospheric Air Pollutants using Sensor Integrated UAV. In Proceedings of the 2024 International Conference on Electrical Electronics and Computing Technologies (ICEECT), Greater Noida, India, 29–31 August 2024; Volume 1, pp. 1–6.
81. Abrahamsen, H.B. A remotely piloted aircraft system in major incident management: Concept and pilot, feasibility study. *BMC Emerg. Med.* **2015**, *15*, 12. [\[CrossRef\]](#)
82. Maladyka, I.; Stas, S.; Pustovit, M.; Dzhulay, O. Application of UAV Video Communication Systems During Investigation of Emergency Situations. *Adv. Sci. Technol.* **2022**, *114*, 27–39. [\[CrossRef\]](#)
83. Dehghan, M.; Khosravian, E. A review of cognitive UAVs: AI-driven situation awareness for enhanced operations. *AI Tech Behav. Soc. Sci.* **2024**, *2*, 54–65. [\[CrossRef\]](#)
84. Chmielewski, M.; Kukielka, M.; Gutowski, T.; Pieczonka, P. Handheld combat support tools utilising IoT technologies and data fusion algorithms as reconnaissance and surveillance platforms. In Proceedings of the 2019 IEEE 5th World Forum on Internet of Things (WF-IoT), Limerick, Ireland, 15–18 April 2019; pp. 219–224.
85. Ehala, J.; Kaugerand, J.; Pahtma, R.; Astapov, S.; Riid, A.; Tomson, T.; Preden, J.S.; Motus, L. Situation awareness via Internet of things and in-network data processing. *Int. J. Distrib. Sens. Netw.* **2017**, *13*, 1550147716686578. [\[CrossRef\]](#)
86. Wichai, P. A Survey in Adaptive Hybrid Wireless Sensor Network for Military Operations. In Proceedings of the IEEE Second Asian Conference on Defence Technology (ACDT), Chiang Mai, Thailand, 21–23 January 2016.
87. Hua, Z. From Battlefield to Border: The Evolving Use of Drones in Surveillance Operations. *ITEJ Inf. Technol. Eng. J.* **2024**, *9*, 44–52. [\[CrossRef\]](#)
88. Marut, A.; Wojciechowski, P.; Wojtowicz, K.; Djabin, J.; Kochan, J.; Kurenda, M. Surveillance and protection of critical infrastructure with Unmanned Aerial Vehicles. In Proceedings of the 2024 IEEE International Workshop on Technologies for Defense and Security (TechDefense), Naples, Italy, 11–13 November 2024; pp. 312–317.
89. Bouvry, P.; Chaumette, S.; Danoy, G.; Guerrini, G.; Jurquet, G.; Kuwertz, A.; Muller, W.; Rosalie, M.; Sander, J. Using heterogeneous multilevel swarms of UAVs and high-level data fusion to support situation management in surveillance scenarios. In Proceedings of the 2016 IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI), Baden-Baden, Germany, 19–21 September 2016; pp. 424–429.
90. Rajora, R.; Rajora, A.; Sharma, B.; Aggarwal, P.; Thapliyal, S. The Impact of the IoT on Military Operations: A Study of Challenges, Applications, and Future Prospects. In Proceedings of the 2024 4th International Conference on Innovative Practices in Technology and Management (ICIPTM), Noida, India, 21–23 February 2024; pp. 1–5.
91. Kumsap, C.; Mungkung, V.; Amatacheewa, I.; Thanasomboon, T. Conceptualization of military's common operation picture for the enhancement of disaster preparedness and response during emergency and communication blackout. *Procedia Eng.* **2018**, *212*, 1241–1248. [\[CrossRef\]](#)
92. Adel, A.; Alani, N.H.; Whiteside, S.T.; Jan, T. Who is Watching Whom? Military and Civilian Drone: Vision Intelligence Investigation and Recommendations. *IEEE Access* **2024**, *12*, 177236–177276. [\[CrossRef\]](#)
93. Amezcua, N.; Gonzalez, S.; Teran, M.; Salazar, C.; Corredor, J.; Corzo, G. Preliminary approach for UAV-based multi-sensor platforms for reconnaissance and surveillance applications. *Ingeniería* **2023**, *28*. [\[CrossRef\]](#)
94. Yang, H.; Yang, J.; Zhang, B.; Wang, C. Visualization analysis of research on unmanned-platform based battlefield situation awareness. In Proceedings of the 2021 IEEE International Conference on Artificial Intelligence and Computer Applications (ICAICA), Dalian, China, 28–30 June 2021; pp. 334–338.
95. Kaniewski, P.; Romanik, J.; Zubel, K.; Golan, E.; R-Moreno, M.D.; Skokowski, P.; Kelner, J.M.; Malon, K.; Maślanka, K.; Guszczynski, E.; et al. Heterogeneous wireless sensor networks enabled situational awareness enhancement for armed forces operating in an urban environment. In Proceedings of the 2023 Communication and Information Technologies (KIT), Vysoke Tatry, Slovakia, 11–13 October 2023; pp. 1–8.
96. Chen, J.; Seng, K.P.; Smith, J.; Ang, L.M. Situation awareness in ai-based technologies and multimodal systems: Architectures, challenges and applications. *IEEE Access* **2024**, *12*, 88779–88818. [\[CrossRef\]](#)
97. Rangel, R.K.; Terra, A.C. Development of a Surveillance tool using UAV's. In Proceedings of the 2018 IEEE Aerospace Conference, Big Sky, MT, USA, 3–10 March 2018; pp. 1–11.
98. Bird, D.T.; Ravindra, N.M. Additive manufacturing of sensors for military monitoring applications. *Polymers* **2021**, *13*, 1455. [\[CrossRef\]](#)

99. Kim, J.; Gregory, T.; Freeman, J.; Korpela, C.M. System-of-systems for remote situational awareness: Integrating unattended ground sensor systems with autonomous unmanned aerial system and android team awareness kit. In Proceedings of the 2022 International Conference on Unmanned Aircraft Systems (ICUAS), Dubrovnik, Croatia, 21–24 June 2022; pp. 1418–1423.
100. Elia, R.; Theocharides, T. Real-Time and On-Board Anomalous Command Detection in UAV Operations via Simultaneous UAV-Operator Monitoring. In Proceedings of the 2024 International Conference on Unmanned Aircraft Systems (ICUAS), Chania-Crete, Greece, 4–7 June 2024; pp. 248–255.
101. Gong, J.; Yan, J.; Kong, D.; Li, D. Introduction to drone detection radar with emphasis on automatic target recognition (ATR) technology. *arXiv* **2023**, arXiv:2307.10326. [[CrossRef](#)]
102. Chang, G.; Fu, W.; Zhao, J.; Li, J.; Miao, H.; Zhang, X.; Dong, P. Overview of research on intelligent swarm munitions. *Def. Technol.* **2024**, *in Press*. [[CrossRef](#)]
103. Kim, J.; Lin, K.; Nogar, S.M.; Larkin, D.; Korpela, C.M. Detecting and localizing objects on an unmanned aerial system (uas) integrated with a mobile device. In Proceedings of the 2021 International Conference on Unmanned Aircraft Systems (ICUAS), Athens, Greece, 15–18 June 2021; pp. 738–743.
104. Carapau, R.S.; Rodrigues, A.V.; Marques, M.M.; Lobo, V.; Coito, F. Interoperability of Unmanned Systems in Military Maritime Operations: Developing a controller for unmanned aerial systems operating in maritime environments. In Proceedings of the OCEANS 2017-Aberdeen, Aberdeen, UK, 19–22 June 2017; pp. 1–7.
105. Kumari, P.; Gosula, H.S.; Lokhande, N. Real-Time Monitoring and Battery Life Enhancement of Surveillance Drones. In *Intelligent Methods in Electrical Power Systems*; Springer: Berlin/Heidelberg, Germany, 2024; pp. 151–171.
106. Vaseashta, A.; Kudaverdyan, S.; Tsaturyan, S.; Bölgen, N. Cyber-physical systems to counter CBRN threats—sensing payload capabilities in aerial platforms for real-time monitoring and analysis. In *Nanoscience and Nanotechnology in Security and Protection Against CBRN Threats*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 3–20.
107. Hassan, C.A.Z.C.; Yaacob, M.S.Z.; Razif, M.R.M.; Zaik, M.A.; Bostaman, N.S. An Industrial Floor Monitoring System Drone with Hazardous Gas and Smoke Detection. *Prog. Eng. Appl. Technol.* **2024**, *5*, 1–2.
108. Vitale, M.; Barresi, A.; Demichela, M. The Use of Aerial Platforms for Identification of Loss of Containment. *Chem. Eng. Trans.* **2024**, *111*, 73–78.
109. Nagarajapandian, M.; Gopu, G.; Anitha, T.; Raksha, G.; Sabarisri, S.; Sarmitha, S. Determining the Toxicity of Water After Oilspill using UAV. In Proceedings of the 2024 9th International Conference on Communication and Electronics Systems (ICCES), Coimbatore, India, 16–18 December 2024; pp. 36–40.
110. Ramesh, K.B.; Saran, S. Drone-Based Aerial Surveillance and Real-Time Hazardous Gas Leakage Detection System with Power BI Dashboard Integration for Enhanced Environmental Safety. In Proceedings of the 2025 6th International Conference on Mobile Computing and Sustainable Informatics (ICMCSI), Goathgaun, Nepal, 7–8 January 2025; pp. 541–547.
111. Gopikumar, S. Evaluation of landfill leachate biodegradability using IOT through geotracking sensor based drone surveying. *Environ. Res.* **2023**, *236*, 116883. [[CrossRef](#)]
112. Caragnano, G.; Ciccica, S.; Bertone, F.; Varavallo, G.; Terzo, O.; Capello, D.; Brajon, A. Unmanned aerial vehicle platform based on low-power components and environmental sensors: Technical description and data analysis on real-time monitoring of air pollutants. In Proceedings of the 2020 IEEE 7th International Workshop on Metrology for AeroSpace (MetroAeroSpace), Pisa, Italy, 22–24 June 2020; pp. 550–554.
113. Sonkar, S.K.; Kumar, P.; George, R.C.; Philip, D.; Ghosh, A.K. Detection and estimation of natural gas leakage using UAV by machine learning algorithms. *IEEE Sens. J.* **2022**, *22*, 8041–8049. [[CrossRef](#)]
114. Menon, G.S.; Ramesh, M.V.; Divya, P. A low cost wireless sensor network for water quality monitoring in natural water bodies. In Proceedings of the 2017 IEEE Global Humanitarian Technology Conference (GHTC), San Jose, CA, USA, 19–22 October 2017; pp. 1–8.
115. Ciccica, S.; Bertone, F.; Caragnano, G.; Giordanengo, G.; Scionti, A.; Terzo, O. Unmanned Aerial Vehicle for the Inspection of Environmental Emissions. In *Proceedings of the Conference on Complex, Intelligent, and Software Intensive Systems*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 869–875.
116. Burgués, J.; Esclapez, M.D.; Doñate, S.; Pastor, L.; Marco Colás, S. Aerial mapping of odorous gases in a wastewater treatment plant using a small drone. *Remote Sens.* **2021**, *13*, 1757. [[CrossRef](#)]
117. Leal, V.G.; Silva-Neto, H.A.; da Silva, S.G.; Coltro, W.K.T.; Petrucci, J.F.d.S. AirQuality lab-on-a-drone: A low-cost 3D-printed analytical IoT platform for vertical monitoring of gaseous H₂S. *Anal. Chem.* **2023**, *95*, 14350–14356. [[CrossRef](#)]
118. Omar, T.M.; Alshehhi, H.M.; Alnauimi, M.M.; Alblooshi, S.A.; El Moutaouakil, A. Solar-Powered Automated Drone for Industrial Safety and Anomaly Detection. In Proceedings of the 2024 IEEE 18th International Conference on Application of Information and Communication Technologies (AICT), Turin, Italy, 25–27 September 2024; pp. 1–6.
119. Visser, H.; Petersen, A.C.; Ligtvoet, W. On the relation between weather-related disaster impacts, vulnerability and climate change. *Clim. Change* **2014**, *125*, 461–477. [[CrossRef](#)]

120. Gilli, A.; Gilli, M. The diffusion of drone warfare? Industrial, organizational, and infrastructural constraints. *Secur. Stud.* **2016**, *25*, 50–84. [[CrossRef](#)]
121. Alsayed, A.; Yunusa-Kaltungo, A.; Quinn, M.K.; Arvin, F.; Nabawy, M.R. Drone-assisted confined space inspection and stockpile volume estimation. *Remote Sens.* **2021**, *13*, 3356. [[CrossRef](#)]
122. Fabris, A.; Kirchgeorg, S.; Mintchev, S. A soft drone with multi-modal mobility for the exploration of confined spaces. In Proceedings of the 2021 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR), New York, NY, USA, 25–27 October 2021; pp. 48–54.
123. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ* **2021**, *372*, n71. [[CrossRef](#)]

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