Jurnal TRANSFORMATIKA
Vol. 23, No.2, Januari 2026, pp. 238 - 246
P-ISSN: 1693-3656, E-ISSN: 2460-6731
https://journals.usm.ac.id/index.php/transformatika/

LITERATURE REVIEW ON ANTI-DRONE TECHNOLOGY AND DEFENSE SYSTEMS

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ARTICLE INFO

History of the article :
Received 30 December 2010
Received in revised form 30 April 2011
Accepted 26 September 2012
Available online 8 October 2012

Keywords:

anti-drone technology, air defense systems, artificial intelligence, drone detection, technological challenges

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ABSTRACT

Research on anti-drone technology and modern air defense systems is growing as the use of drones in military and civilian contexts increases. Major trends in development include the use of radar, optical sensors, microwave technology, and the integration of artificial intelligence (AI) to improve detection speed and accuracy. Recent studies show that combining several technologies can improve drone identification accuracy. The research methods used are diverse, such as computer simulations, field tests, and cost-benefit analyses. The results of the research reveal that there are still challenges, including detection errors, slow responses, and limited range. In addition, ethical and legal aspects are also important considerations. Overall, this review provides a comprehensive overview of the latest developments and challenges in the implementation of anti-drone technology.

1. INTRODUCTION

In modern air defence systems, a vital element within the framework of national security strategies for various countries around the world, the increasing complexity of threats arising from technological advancements—including direct air attacks, missiles, and the use of drones—has made research in this field increasingly important. These diverse and sophisticated threats demand a defence system that is not only adaptive but also well-integrated within complex operational environments. Moreover, the significant challenges currently faced by air defence systems include interoperability among systems, which often struggle to function synergistically, as well as emerging threats from high-tech innovations such as cyber weapons and autonomous drones (Wilson & Brown, 2021; Miller, 2022). Given the substantial investment required for the development and maintenance of effective air defence systems, many countries encounter difficulties in allocating adequate resources (Lee & Thompson, 2023).

This research aims to explore the issues present in modern air defence systems, including existing gaps in relevant research, and to articulate the importance of this topic within the context of national security policy. By identifying and analysing these aspects, it is hoped that innovative and strategic solutions can be offered for the development of more effective defence systems in the future. In this regard, this literature review is intended to provide a deeper understanding of the challenges and opportunities present in the management of modern air defence systems. With this rationale, further in-depth research on this issue is expected to contribute significantly to enhancing the effectiveness and sovereignty of a country's defence system in the modern era (Kumar, 2021; Adams, 2023). Thus, this introduction aims to provide important background regarding the issues faced in modern air defence systems and the significance of this research in enhancing national security effectiveness.

2. RESEARCH METHODS

The research methodology employs a Systematic Literature Review (SLR) approach. Steps of the Systematic Literature Review (SLR) In applying the Systematic Literature Review (SLR) method, there are several key steps that must be followed :

a) Formulating the Research Question

The first step in SLR is to articulate a clear and specific research question. This question should provide precise guidance throughout the literature search process.

b) Inclusion and Exclusion Criteria

Once the research question is established, the inclusion and exclusion criteria for the selection of articles must be defined. These criteria will serve as a guide in choosing relevant, high-quality studies based on relevance, language, publication year, and study type.

c) Literature Search

The search is conducted using variations of relevant keywords. Search sources may include academic databases such as PubMed, Scopus, Web of Science, and Google Scholar. Documenting search results is crucial to ensure transparency.

d) Study Selection

After collecting articles from the literature search, the next stage is to review and evaluate the studies found based on the established inclusion and exclusion criteria. Two or more independent reviewers may be employed to minimise bias during this process.

e) Data Extraction

Data from the selected studies is then extracted. Important information to note includes the authors' names, publication year, methodology used, key findings, and study limitations. This process should be conducted systematically using a consistent extraction form.

f) Data Analysis and Synthesis

The extracted data is then analysed and synthesised. The analysis methods may involve qualitative or quantitative analysis, depending on the type of data obtained. The aim is to identify patterns or themes emerging from the reviewed studies.

g) Reporting and Presenting Results

The results of the SLR should be reported clearly and systematically. Presenting data in the form of tables or diagrams can aid in visualising the results and supporting the arguments made. Validity and Reliability of SLR When conducting an SLR, it is important to consider the aspects of validity and reliability of the research. Several ways to enhance validity and reliability include :

1) Using Strict Selection Criteria

   By ensuring that only high-quality studies are included, the results of the SLR can be more trustworthy.

DOI : https://doi.org/ 10.26623/transformatika.v23i2.13113

2) Involving Multiple Reviewers
3) Engaging more than one reviewer in the selection and extraction process can minimise bias, thereby increasing the reliability of the results.

h) Applying Appropriate Analysis Methods

Choosing suitable and transparent analysis methods will help improve the accuracy of data interpretation. By following the steps outlined above and prioritising validity and reliability, SLR can serve as an effective tool for summarising existing knowledge and providing new insights within a specific research field.

3. RESULTS

The research appears to be predominantly focused on the themes of national defence and security, followed by the use of drones for counter-terrorism and the integration of innovative technologies and systems.

Table 1. Summary of Research Themes and Key Findings

No	Theme / Category	Number Of Studies	Key Findings	Implications
1	Drone Technology for National Defense and Security	9 studies	Drones are effective in enhancing surveillance, precision strikes, and territorial monitoring; UAV integration strengthens national air defense	Strategic national policies are needed for the integration of military and anti-drone systems, personnel training, and modernization of national radar systems
2	The Use of Drones in Counterterrorism and Public Security	5 studies	Drones are used by both military and terrorist groups; AI and RF sensors improve early detection of autonomous drone attacks.	AI-based security systems and interagency collaboration are required to detect and neutralize drone terrorism threats
3	Regulation and Policy on Drone Usage in Indonesia	3 studies	National regulations (Ministerial Decrees No. 37/2020, 90/2015) exist but implementation is weak due to lack of socialization and supervision.	The government needs to strengthen policy frameworks, operator licensing, and control mechanisms for civilian drones
4	Technological Innovation and System Integration (AI, HAPS, LoRa, GIS)	5 studies	Integrating drones with AI, LoRa, HAPS, and ArcGIS improves detection, communication, and spatial mapping efficiency	Hybrid technology implementation can support military and disaster management systems; strengthening of digital defense infrastructure is required
5	Utilization of Civilian Drones and Reserve Components	2 studies	Civilian drone pilots have potential to become part of national defense	Training and certification for civilian drone operators need

			components; drones support territorial surveys and the One Map Policy	improvement to support non-combat military operations and national development.
6	Strategy and Doctrine of National Air Defense	4 studies	Air defense must adapt to drone, AI, and electronic warfare threats	Modernization of air defense systems is needed through UAV, radar, and strategic human resource integration.
7	Development of Drones for Non-Military Environmental, Social	2 studies	Drones are effective in detecting crowds and forest fires using AI algorithms (FCN, YOLOv4).	mitigation and real-time public monitoring

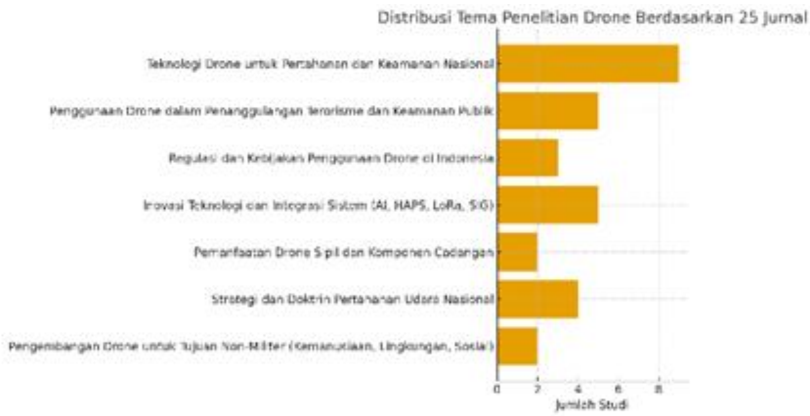

Figure 1. Visual Summary of Research Themes and Key Implications

4. DISCUSSION

Drone Technology for National Defense and Security

The majority of studies (9 out of 25) concentrate on the strategic functions of drones in national defence. Drones are seen as capable of enhancing reconnaissance systems, territorial monitoring, and precision military operations. Research by Afirus Nurul Fuadi et al. (2018) and Muhammad Syaroni Rofii (2025) asserts that drones play a vital role in bolstering air defence capabilities, particularly in modern conflicts such as the Ukraine-Russia and Azerbaijan-Armenia wars. However, the studies also highlight that such capabilities must be complemented by policies and human resource readiness. Raihan Muhammad Rifqi (2024) emphasises the need for improved training for operators and the integration of anti-drone technology within the Indonesian National Armed Forces (TNI). Overall, this theme indicates that Indonesia is moving towards a technology-based modernisation strategy in defence, yet still requires a cross-service surveillance and coordination system to address asymmetric air threats.

The development of drones for national defense shows a significant transformation from basic ISR platforms to integrated systems with artificial intelligence, precision strike capabilities, and swarm operations. Post-2020 trends emphasize network-centric warfare, where drones function as sensor nodes in real-time data-based command and control (C2) systems. Additionally, the development of loitering munitions and first-person-view (FPV) attack drones is changing the nature of warfare to be more asymmetric due to their low cost and high destructive power. A study by Castrillo et al. (2022) states that the successful use of drones in modern conflicts has prompted countries to develop layered air defense systems to counter the threat of small UAVs that are difficult to detect with traditional radar (Castrillo et al., 2022).

Meanwhile, recent research concludes that the effectiveness of conventional air defenses (SAM, long-range radar) is insufficient in countering micro and tactical drone threats. Therefore, multi-sensor integration is required: micro-doppler radar, RF detection, electro-optical/infrared (EO/IR) sensors, and AI algorithms for target classification. Modern anti-UAS (Counter-UAS) systems combine soft-kill (jamming, spoofing, hacking command links) and hard-kill (lasers, smart bullets, interceptor drones) capabilities. This is reinforced by a ResearchGate review titled Counter Drone Technology: A Review, which emphasizes the need for layered response capabilities against small drone threats (Awan & Sarwar, 2024).

The Use of Drones in Counterterrorism and Public Security

Five studies discuss drones in the context of counter-terrorism and security. Mihaiela Bușe (2019) and Fahad Alsifiany (2023) describe how terrorist groups are now employing drones for autonomous attacks, while nations are striving to combat this with AI, RF sensors, and jamming systems. Research by Muhammad Zaenuddin Firmansyah (2021) and Sigit Yudha Pratama (2025) demonstrates that inter-agency collaboration (TNI, police, BIN) is crucial in developing anti-drone security systems. Thus, current counter-drone efforts are not solely focused on technological aspects but also on institutional coordination and responsive national policies.

Drones have become an important tool in counterterrorism operations, whether for monitoring high-risk areas, intelligence operations, or apprehending perpetrators. A study by OHCHR (2023) shows that drones facilitate surveillance without endangering personnel, provide high-precision aerial perspectives, and enable real-time data-driven operations. However, challenges arise in relation to ethics, proportionality, and the risk of misidentifying targets. Computer vision-based AI technology helps recognize suspicious movement patterns and objects, but is affected by weather conditions, light, and adversarial attacks. International studies recommend the implementation of human-in-the-loop for high-risk operations (OHCHR, 2023).

In addition, other studies explain how terrorist groups use inexpensive commercial drones for improvised attacks using throwable bombs or FPV. This phenomenon requires security forces to improve early detection, protect vital objects, and enforce counter-drone technology in public areas and at borders. The Wall Street Journal reports a global trend of increased drone use by non-state groups in conflict zones, prompting changes in state counter-terrorism strategies (Watson, 2024).

Regulation and Policy on Drone Usage in Indonesia

Three studies (Sri Gita et al., 2021; Eko, 2022) highlight the weak implementation of policies related to Ministerial Regulation No. 37/2020 and 90/2015. Socialisation and law enforcement remain limited, particularly regarding the use of civil drones without permits. The lack of education and public awareness poses a significant barrier, resulting in existing regulations not effectively curbing potential drone misuse (such as privacy violations and aviation security issues). This situation indicates the need for policy synchronisation between the defence, transportation, and cybersecurity sectors so that drone regulations are cross-functional. In Indonesia, drone operations are regulated by Ministry of Transportation Regulation No. 37 of 2020, which governs flight area classification, altitude restrictions, operator certification, reporting requirements, and flight restrictions in strategic areas such as vital objects and military zones. This regulation is necessary to improve flight safety given the growth in commercial and recreational drone use. National studies show that the implementation of regulations still faces obstacles, such as low user awareness, weak low airspace surveillance, and the suboptimal integration of the national UTM (Unmanned Traffic Management) system. The Ministry of Transportation also highlights the importance of synchronization between civil regulations and defense needs (Indonesian Ministry of Transportation, 2020).

At the global level, literature states that countries that have successfully integrated drones safely have UTM systems based on real-time data, ground sensors, mini radars, and IoT-based tracking networks. Indonesia is still in the early stages of development, so harmonization of policies across ministries (Transportation, Defense, National Police, BNPP, BNPB) is needed. Studies on Southeast Asian airspace policy indicate that drone regulations must be adaptive to rapid technological developments because the potential security threats from commercial UAVs are very high (Maniadaki et al., 2022).

Technological Innovation and System Integration (AI, HAPS, LoRa, GIS)

Five studies (such as Devina Chandra Dewi, 2020; Januar Arief Martharaharja, 2025) reveal a trend towards the convergence of drone technology with other systems such as AI, HAPS, LoRa, and SIG. This integration not only extends the operational range of military activities but also enhances the effectiveness of territorial mapping and data communication. Fahad Alsifiany (2023) demonstrates that the combination of AI, Computer Vision, and LiDAR can improve the real-time detection accuracy of dangerous drones. This signifies that the future of air defence will rely on hybrid autonomous platforms capable of rapidly adapting to dynamic threats.

AI improves object identification capabilities, navigation autonomy, and threat prediction. Deep learning is used in EO/IR systems to detect enemy drones, vehicles, or suspicious activities. However, the presence of adversarial noise can reduce accuracy, so research is focused on improving robustness. AI is also used in swarm drones that are capable of automatic coordination in reconnaissance or logistics operations. The study by Castrillo et al. (2022) notes a significant improvement in AI in threat detection systems.

HAPS is an aerial platform at an altitude of 20 km that functions as a high-performance communications relay and sensor. HAPS enables long-range drone operations without line-of-sight limitations. Its integration into the defense ecosystem provides advantages for maritime and border surveillance missions. A recent study by the United Nations Telecommunications Programme found that HAPS improves the range and stability of C2 communications for drone systems (UN ICT, 2023).

LoRa offers low-power long-range communication, suitable for environmental monitoring missions, forest fire detection, and agricultural drones. Research by Khor et al. (2025) proves that LoRa can be used for drone-to-drone communication, although the small bandwidth limits real-time video transmission. LoRa is suitable as a backup control link for emergency operations.

Drones combined with GIS enable precision mapping: topography, land cover, and disaster damage analysis. A study by Christofi et al. (2025) confirms that the integration of UAV-GIS-AI improves the accuracy of coastal line modeling, abrasion mitigation, and coastal management. In the security sector, GIS is used for risk modeling and border area surveillance.

Utilization of Civilian Drones and Reserve Components

Research by Bakti Dasasasi Pananggungan (2025) indicates the significant potential of civil drone pilots as backup components for national defence. Civil drones used in agriculture and mapping can also be integrated into passive defence systems. However, there remains a need for national training standardisation and certification for drone operators to effectively contribute to the defence system when required.

DOI : https://doi.org/ 10.26623/transformatika.v23i2.13113

The use of civilian drones is growing rapidly: medical logistics, infrastructure mapping, precision agriculture, disaster mitigation, and environmental monitoring. However, dependence on imported components such as flight controllers, GPS modules, Pixhawk autopilots, and EO/IR sensors poses strategic risks. Industry studies indicate that more than 80% of commercial UAV components come from Chinese supply chains, so the country needs to strengthen its stockpile of critical components and local manufacturing industry. Awan & Sarwar (2024) emphasize the importance of technological independence as part of national resilience.

The development of civilian drones is also necessary to support the National Reserve Component (Komcad) program, in which the use of non-military drones can be taught to the public for mapping, SAR, and disaster monitoring. This strategy strengthens universal defense. A study by Sanz-Martos et al. (2022) shows that drones are effective in supporting emergency operations and medical transportation.

Strategy and Doctrine of National Air Defense

Four studies (Tahan Samual Lumban Toruan, 2023; Hendra Roza, 2024) examine that Indonesia's air defence strategy needs to adapt to cyber threats, autonomous drones, and electronic warfare. Enhancing radar capabilities, integrated command systems, and mastery of electromagnetic technology are top priorities. Research by Enggal Leksono (2022) emphasises that the Indonesian Air Force (TNI AU) must strengthen its electronic warfare (EW) organisation and supporting electromagnetic spectrum infrastructure to confront modern warfare.

Modern air defense doctrine must recognize the threat of drones as a permanent element in the landscape of warfare. Watson's study (2024) shows that the conflict in Ukraine has changed the global paradigm: inexpensive FPV drones can destroy armored vehicles, while mini swarms can disrupt radar and air defenses. Air defense doctrine must include: multi-layer detection systems, the use of AI for rapid identification, the integration of cyber units as part of counter-UAS, and the formulation of clear rules of engagement for the use of jammers and other disruptive tools. Countries also need to develop a joint doctrine between the Army, Navy, Air Force, Police, and civil authorities in dealing with the threat of drones.

Development of Drones for Non-Military Environmental, Social

Two studies (Rikki Afrizal, 2022; Muhammad Fatih, 2021) illustrate the use of drones in civil contexts, forest fire detection and public crowd monitoring. With YOLOv4 algorithms and Fully Convolutional Networks (FCN), drones have proven efficient in accurately detecting fires and crowds. These findings reinforce the position of drones as a multidimensional technology relevant not only for military purposes but also for disaster mitigation and environmental governance.

Drones play an important role in environmental monitoring, such as water quality, forest inventory, fire detection, and disaster mitigation. Srivastava et al. (2022) studied the use of multispectral drones for forest inventory and detecting tree health decline. In the social and humanitarian sectors, drones are used to deliver medicine to remote areas, assess post-disaster damage, and search for missing victims. Disaster response drone systems in Europe show that integrating UAVs into national contingency plans increases the speed of evacuation and the efficiency of risk assessment (Maniadaki et al., 2022).

In the Indonesian context, drones are used for forest fire monitoring, coastal mapping, and flood assessment. The integration of UAVs with GIS and AI improves the accuracy of modeling and decision-making by agencies such as BNPB. Research by Yucesoy et al. (2024) shows that the use of drones in disaster response is highly effective for search operations and damage assessment.

5. CONCLUSIONS AND RECOMMENDATIONS

Drones have become a strategic national element in defence, security, and civil development. The integration of AI, SIG, and HAPS technologies is making drones increasingly autonomous and adaptive to various functions. The threat posed by autonomous drones highlights the urgency for anti-drone policies and cross-agency cooperation. Regulations and operator education remain significant weaknesses in the management of Indonesia's airspace. Moving forward, Indonesia needs to strengthen its national drone ecosystem, encompassing innovation, research, certification, and civil-military collaboration.

National Drone Policy Framework The government needs to establish a national policy that regulates the use of military, civilian, and commercial drones under a single regulatory umbrella. Establishment of the Indonesian Drone Research and Innovation Centre (PRIDI) Focus on the development of AI-based autonomous drones and anti-drone defence systems. National Drone Operator Certification Collaboration between the Ministry of Defence, the Ministry of Transportation, and BRIN to create standards for licensing and training drone operators. Modernisation of the Integrated Air Defence System Integrate radar, UAVs, and Electronic Warfare (EW) into a centralised command system based on real-time data. International Collaboration and Technology Transfer Indonesia should partner with countries that are advanced in UAV technology to accelerate the mastery of air defence technology.

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