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IDENTIFICATION AND NEUTRALISATION OF UNMANNED AIRCRAFT

IDENTYFIKACJA I NEUTRALIZACJA BEZZAŁOGOWYCH STATKÓW POWIETRZNYCH

Abstract

Unmanned aerial vehicles have revolutionized the conduct of battles and wars since the 19th century. The following years brought a very dynamic development of unmanned aerial vehicles not only in military operations, but also in the commercial and civilian spheres. The use of modern technology is mainly associated with introducing new opportunities into everyday life. However, many of these advantages can be used inappropriately, thus leading to the exposure of the machines' shortcomings. Easy access and loopholes in the law have contributed to the use of drones in criminal and even terrorist activities.

Keywords: unmanned aerial vehicle, identification, neutralisation, types of UAV

Streszczenie

Bezzałogowe aparaty latające już od XIX wieku zrewolucjonizowały prowadzenie walk i wojen. Kolejne lata przyniosły bardzo dynamiczny rozwój bezzałogowych statków powietrznych nie tylko w działaniach wojsk, ale także w sektorze komercyjnym i cywilnym. Zastosowanie nowoczesnych technologii kojarzone jest głównie z wprowadzeniem nowych możliwości do życia codziennego. Jednakże wiele z tych zalet może być przez człowieka wykorzystane w sposób nieodpowiedni, prowadząc tym samym do ujawnienia niedoskonałości maszyn. Łatwy dostęp oraz luki w prawie przyczyniły się do wykorzystywania bezzałogowych statków powietrznych w działalnościach przestępczych, a nawet terrorystycznych.

Słowa kluczowe: bezzałogowy statek powietrzny, identyfikacja, neutralizacja, rodzaje BSP

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1. INTRODUCTION

Unmanned aerial vehicles (UAVs), have become increasingly popular in recent years due to their autonomy, flexibility and variety of applications[1]. The use of UAVs spans a variety of civilian applications, such as real-time monitoring, providing wireless coverage, remote sensing, search and rescue operations, delivery services, security and surveillance, precision agriculture and civil infrastructure inspection[2]. Researchers are focusing on improving methods for detecting and measuring the coordinates of covert UAVs using small radar networks[3]. In addition, research has focused on optimizing wing design for Global Hawk composite UAVs, emphasizing maneuverability, flexibility, safety and reliability[4].

In the field of photogrammetry, UAV technology remains an attractive research topic, particularly in determining elements of exterior orientation through aerial triangulation processing[5]. The deployment of multiple UAVs with directional antennas acting as wireless base stations for optimal wireless coverage has been studied, highlighting the efficiency of such configurations[6]. Moreover, the impact of human factors on UAV operations has been systematically analyzed and classified, shedding light on the importance of considering human elements in UAV design and deployment[7].

The potential of UAVs in wireless communications has been highlighted, considering their advantages in terms of strong channels in sight, high mobility and flexible deployment[8]. Trajectory design for UAV-enabled multicasting systems was investigated to minimize the completion time of information dissemination to ground terminals, demonstrating the performance of UAV-enabled communication systems[9]. In addition, the use of UAV technology as a mobile wireless sensor network (WSN) sink node was investigated, demonstrating the versatility of UAVs in various fields such as national defense security, agriculture, forestry and logistics[10].

In the context of aviation security, the challenges and risks posed by UAVs were analyzed, highlighting the need for safe development directions to take advantage of the

1 M. Mozaffari et al., A Tutorial on UAVs for Wireless Networks: Applications, Challenges, and Open Problems.
2 H. Shakhatreh et al., Unmanned Aerial Vehicles (UAVs): A Survey on Civil Applications and Key Research Challenges.
3 H. Khudov, Improving a Method for Detecting and Measuring Coordinates of a Stealth Aerial Vehicle by a Network of Two Small-Sized Radars.
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8 Z. Yuan et al., Interference Coordination and Throughput Maximisation in an Unmanned Aerial Vehicle-Assisted Cellular.
9 T. Zeng et al., Wireless-Enabled Asynchronous Federated Fourier Neural Network for Turbulence Prediction in Urban Air Mobility (UAM).
10 H. Cao, Z. Yang, and Y.Q. Li, A Mobile WSN Sink Node Using Unmanned Aerial Vehicles.

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benefits of UAV deployment while ensuring the safety of air transportation[11]. The study also proposed intelligent learning diversity mechanisms for UAV applications to mitigate safety risks associated with increased UAV use[12]. Moreover, a study of UAV flight capabilities in civil and military aviation safety has highlighted the importance of automated flight control systems in minimizing threats to both sectors[13].

Concluding, the literature on UAVs covers a wide range of topics, from their applications in wireless networks, civil domains and surveillance, to their optimization in design, trajectory planning and impact on aviation safety. Researchers continue to explore innovative ways to enhance UAV capabilities, deal with challenges and maximize their potential in various sectors, highlighting the dynamic and evolving nature of UAV research and development.

2. CLASSIFICATION OF UAV

Unmanned aerial vehicles can be classified in many ways[14], and one of the key criteria is their weight. The mass of a UAV directly affects its application, range, flight duration and operational capabilities. Below are the main categories of UAVs by weight[15]:

- Super Heavy UAV: Weight exceeds 2,000 kg. These drones are most often used for military tasks, where large payloads and advanced systems are required. Examples include large combat drones that can carry heavy payloads, including armaments.
- Heavy UAV: Weight in the range of 200 kg to 2,000 kg. These drones are used for both military missions and civilian tasks, such as long-term surveillance missions, border patrolling and environmental monitoring.
- Medium UAV: Weight from 50 kg to 200 kg. Medium-sized drones are versatile and can be used for a variety of tasks, including infrastructure inspection, search and rescue, as well as commercial purposes such as cargo delivery.
- Light UAV: Weights from 5 kg to 50 kg. These drones are commonly used for commercial and recreational purposes. They can be used for filming, photography, inspecting buildings or delivering small shipments.
- Micro UAVs: Weighing up to 5 kg. Micro drones are used for precision operations in confined spaces. They can be used for spy and scientific tasks, as well as in the entertainment industry.

Each of these categories has its own specific uses and limitations. Very heavy and heavy UAVs require specialized takeoff and landing infrastructure and more

[11] G. Nowacki and K. Bolz, Challenges and Threats of Unmanned Aerial Vehicles for Aviation Transport Safety.

[12] A. Periola and E. Obayiuwana, Intelligent Learning Diversity Mechanism for Unmanned Aerial Vehicles Applications.

[13] W. Paterek et al., Study of Unmanned Aerial Vehicle Flight Capabilities in the Aspect of Civil and Military Aviation Safety.

[14] A. Michalska, Introduction to Reliability Tests of Unmanned Aircraft Used in the Armed Forces of the Republic of Poland.

[15] https://theprint.in/defence/nano-micro-small-the-different-drone-types-in-india-if-jammu-like-strike-can-be-averted/686158/.

sophisticated flight control and management systems. Medium and lightweight UAVs are more mobile and easier to operate, making them ideal for a wide range of applications. Micro drones, on the other hand, can perform tasks in places inaccessible to larger aircraft due to their light weight and size.

Dividing UAVs by weight is crucial to understanding their potential applications and operational capabilities. This allows drone technology to be better tailored to specific needs and to more effectively manage their use in different sectors.

3. RISKS ASSOCIATED WITH USAGE OF UAVS

3.1. CIVILIAN APPLICATIONS OF UNMANNED AERIAL VEHICLES

Unmanned aerial vehicles have become a permanent part of people's lives these days, finding wide application in various fields. UAVs are used in photography and filming, especially during family celebrations like weddings and birthday parties, enabling spectacular aerial shots. They also serve professional photographers and videographers, providing high-quality footage for cinema premieres, TV series and online videos.

Agriculture is another field where UAVs have found their use. Drones are used for material handling, spreading and spraying pesticides and fertilizers, making farmers' work much more efficient. UAVs are also used in surveying and mapping, construction, emergency medical services, transportation, forestry and the film industry. They can deliver equipment and medicines to hard-to-reach places, making them indispensable in emergency situations.

However, because of their accessibility and ability to be easily converted, UAVs can pose risks when used improperly. Ignorance, ignorance of regulations or disregard for restrictions can lead to accidents and other incidents in the civilian environment. Examples include disruption of air traffic, smuggling of illegal substances, and privacy violations.

UAVs are also used by criminals to smuggle drugs, cigarettes and other illegal substances. Smugglers appreciate the small size of drones and their ability to move over any terrain, making them difficult for services to detect. UAVs have also become a tool for smuggling goods into prisons, such as drugs, cigarettes and cell phones.

3.2. MILITARY APPLICATIONS OF UNMANNED AERIAL VEHICLES

In military applications, UAVs play a key role in modern combat operations. UAVs are used for battlefield surveillance, strategic reconnaissance and direct combat operations. With advanced optical and navigation systems, military drones can monitor enemy movements and carry out precision attacks on ground targets with high accuracy, increasing the effectiveness and safety of military operations.

UAVs are often equipped with a variety of weapons, including guided missiles, glide bombs and explosive charges. An example is the MQ-1 Predator, capable of carrying

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AGM-114 Hellfire and AIM-92 Stinger missiles. UAVs can be used for precision attacks on military targets, destruction of enemy infrastructure and elimination of strategic facilities.

Terrorists also use UAVs for their purposes. UAVs are used for carrying and dropping explosives, chemical attacks and conducting reconnaissance flights. An example is the 2021 attack on Irbil airport, where drones armed with bombs attacked an international airport that was a base for a coalition of countries fighting jihadists.

UAVs can also serve as a tool for cybercrime. An example is the Snoopy drone, which pretends to be a WiFi router and allows hackers to steal data from mobile devices. Similarly, the Aerial Assault drone detects and attacks poorly secured WiFi networks.

The use of UAVs in the military and by terrorist groups shows the importance of these machines in modern conflicts. High-end drones such as the Bayraktar TB-2 can precisely destroy military and civilian targets, making them one of the most dangerous tools of modern warfare. Unmanned aerial vehicles, thanks to their remote control capability and long range, are revolutionizing military strategies and are becoming an increasingly integral part of modern armies.

4. WAYS TO IDENTIFY UAVS

Identification of unmanned aerial vehicles is based on unambiguous identification of the type, size, identity or other characteristics of an object by means of acquired information and data, which are then analyzed[16]. In order to locate and identify a UAV, it is necessary to obtain adequate coverage and radar coverage. The identification process begins with the UAV being detected by a sensor system, which then identifies, locates and tracks the drone. Secondary sensors, such as cameras or electronic identification elements, can confirm that the detected object is indeed a drone and provide additional information about the UAV.

4.1. RADAR AND ACOUSTIC TECHNOLOGIES

Radar technologies are widely used in both military and civilian aerial surveillance. Radars such as monostatic pulse radar, frequency modulated continuous wave (FMCW) radar, high-frequency radar and micro-Doppler feedback radar offer various benefits and challenges. These radars can detect UAVs over long distances, separate drones from birds, and operate in harsh weather conditions. However, some materials do not reflect radar signals, making identification difficult, and high-powered radars can emit unhealthy radiation.

FMCW radar sends and listens simultaneously, eliminating the internal blind spot, while monostatic pulse radar has an internal blind spot resulting from switching between sending and receiving signals. Micro-Doppler return radar is particularly effective at detecting small drones, but generates huge streams of data to process.

[16] D. Michalski, A. Michalska, Protection against drone activity, 'Security_Forum', 1/2017, DOI: https:/doi.org/10.26410/SF 1/17/8.

Sound sensors, which use microphones to detect a UAV's specific sound signature, can be effective at distances of up to several hundred meters. However, their range is limited, and performance can be degraded by background sounds and weather conditions.

4.2. OPTICAL AND RADIO SYSTEMS

Optical systems, such as electro-optical (EO) sensors and digital cameras, are used to identify UAVs through optical zoom, high-resolution sensors and image stabilization. These technologies offer long detection ranges and target classification capabilities. However, the performance of these systems is limited in poor weather conditions, and lenses must remain clear to maintain functionality.

Radio signal detection (WLAN/RF) systems monitor data transmissions from UAVs, which typically use 2.4 or 5 GHz frequency bands. These technologies do not require signal transmission, which can involve simple construction and operation. The ability to detect the UAV operator is also a major advantage. However, these systems can have difficulty detecting rogue drones and can be disrupted by heavy traffic in the frequency bands.

4.3. INTEGRATED RADAR SYSTEMS

The GIRAFFE 1X system is an example of an integrated mobile radar system that provides early warning and the ability to detect and track multiple targets simultaneously. GIRAFFE 1X offers long range, military-grade ruggedness and the ability to automatically warn of incoming threats. It is a lightweight and small system that can be transported on various platforms but may have limited mobility in some applications and require high power consumption.

Table 1. Summary of advantages and disadvantages of identification technologies

Technology	Advantages	Disadvantages
FMCW Radar	No internal deadband, low peak power	Limited range due to signal leakage
Monostatic pulse radar	Long range	Internal blind spot, distance limitation
Micro-Doppler return radar	High detail, separation of drones from birds	Generating large data streams, difficulties with small objects
Czujniki dźwięku	Ability to detect through obstacles, low price	Limited range, sensitivity to weather conditions
EO sensors (digital cameras)	Long range, classification capability, night vision	Poor performance in poor weather conditions, need for lens cleanliness
WLAN/RF detection	Simple design, ability to locate operator	Difficulty in detecting rogue drones, interference in frequency bands
GIRAFFE 1X	Long range, military strength, automatic warning	High energy consumption, limited mobility

Source: own work.

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4.4. WAYS TO NEUTRALIZE UNMANNED AERIAL VEHICLES

With the growing popularity of unmanned aerial vehicles, both companies and individuals have been forced to develop various devices to neutralize unwanted drones. Police and military troops often had to use regular weapons, which proved ineffective due to the high level of precision required. Therefore, specialized technologies have been developed to neutralize UAVs, which are mainly based on signal jamming and interception techniques.

4.5. SIGNAL JAMMING

RF jamming involves disrupting the radio link between a drone and its operator by generating strong RF (Radio Frequency) interference. These systems can detect and interfere with up to 200 targets simultaneously by sending signals at the appropriate frequency that break the radio link, forcing the drone to land or return home. An example is Australia's DroneGun Tactical handheld neutralization kit.

GNSS (Global Navigation Satellite System) jamming involves interfering with navigation signals, such as GPS or GLONASS, making it impossible for a drone to determine its position. Small transmitting devices can emit higher-powered signals, interfering with a drone's satellite communications. Drones that lose satellite connectivity typically hover, land or fly home.

Spoofing is a technique that involves emitting false navigation or communication signals that take control of a drone, directing it to another target. For spoofing to be effective, the power of the false signals must exceed that of the original signals.

4.6. INTERCEPTION TECHNIQUES

Blinding involves using a high-intensity light beam or laser to "blind" a drone's camera, preventing it from continuing its mission. The laser can also destroy vital segments of the drone, causing it to fall. An example is Israel's Drone Dome system, which successfully neutralized drones during Gatwick Airport security in 2018.

The nets are used to entangle the drone and its rotors, quickly rendering the machine inoperable. The SkyWall 100 system, developed by OpenWorks Engineering, fires a net that entangles the drone, bringing it to the ground. Another example is the system used by police in Tokyo, where drones with mounted nets neutralize unwanted UAVs.

Missiles are a solution that uses specially designed ammunition to destroy drones. The Polish UAV neutralizing system combines a rapid-firing 12.7 mm caliber WKLM multi-barrel machine gun with an optoelectronic warhead, capable of detecting drones at distances of up to 15 km.

4.7. INTEGRATED COUNTERMEASURE SYSTEMS

Combined countermeasures use a combination of different neutralization methods to increase the effectiveness and likelihood of successful intervention. Jamming systems often combine RF and GNSS jamming and use electronic systems as the first line of defense and kinetic systems as backup means. Depending on the situation, a drone may need to be isolated and recovered, especially if it is potentially armed. In that case, a sapper team is called in to assess and neutralize the threat. Even unarmed drones must be handled with care to avoid injury from rotors or risk of battery fire. Forensic analysis performed on a captured device must ensure that the system is disconnected from the operator and that potentially valuable data is secured.

Table 2. Summary of advantages and disadvantages of neutralized technologies

Method	Advantages	Disadvantages
RF jamming	Effective over long distances, quickly immobilize the drone	May interfere with other RF systems, limited effectiveness with autonomous drones
GNSS jamming	Disruption of drone navigation, ease of implementation	Requires high interference power, drones can hover or land
Spoofing	Taking control of the drone, changing its route	High difficulty of implementation, requires high signal power
Blinding	Immediate immobilization of the drone, destruction of segments	Requires precise aiming, possible risk of eye injury
Networks	Effectively immobilize the drone, quickly bring it to the ground	Short range, risk of being spotted by drone operator
Bullets	Destruction of drone, remote operation	Requires precision, risk of collateral damage
Counteracting combined	Increased efficiency, comprehensive neutralization	High cost of implementation, complex operation

Source: own work.

4.8. NEW TECHNOLOGIES

Counter-Unmanned Aerial Vehicle technology has evolved significantly to address the growing challenge of drone threats. Key advancements in this field include AI-enabled detection systems, which allow for more precise detection and identification of UAVs. By leveraging machine learning models, these systems can differentiate between various drone types and behaviors, leading to improved response times and accuracy in threat assessment. Another crucial technology is Radio Frequency (RF) detection, which scans the communication frequencies used by drones, enabling early detection and identification of threats before they approach critical areas.

High-performance optical sensors and cameras play a significant role in this ecosystem, providing enhanced surveillance capabilities that allow operators to visually track UAVs. These sensors can be integrated with other detection technologies, creating a more comprehensive and layered defense network. Additionally, integrated autonomous solutions, like those developed by Sentrycs, bring together detection, tracking, and mitigation functions into a single system. This integration simplifies operations and ensures faster response times to neutralize potential threats.

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Directed energy weapons (DEWs) have emerged as a cutting-edge solution within counter-UAV strategies. Utilizing high-powered lasers, these systems can disable or destroy drones by targeting their critical components, such as sensors or propulsion systems. Unlike traditional kinetic methods, directed energy weapons offer precision and a rapid engagement capability, minimizing collateral damage and providing an effective countermeasure against a wide range of UAV threats. The combination of these technologies ensures a robust and adaptive defense against the evolving challenges posed by unmanned aerial threats[17].

5. CONCLUSION

Identifying and neutralizing UAVs is a key aspect of ensuring security in an era of growing drone popularity. The proper use of detection and countermeasure technologies, combined with appropriate regulations, can significantly reduce the risks associated with unauthorized drone use. Education of operators and continued development of detection and neutralization technologies are essential to effectively manage this new challenge.

Looking ahead, the counter-UAV sector is likely to see a greater emphasis on autonomous systems that can seamlessly integrate multiple detection and response capabilities. AI-driven analytics will play an even larger role, enabling real-time analysis of drone threats and reducing human intervention. Directed energy weapons are expected to become more common, especially in military and high-security environments, where the need for precise and immediate neutralization is critical. Furthermore, we can anticipate developments in swarm countermeasures to address the increasing threat of drone swarms. Overall, the integration of AI, autonomous systems, and directed energy technology will drive the next phase of innovation in counter-UAV solutions, making these systems more adaptive, responsive, and capable of handling evolving aerial threats.

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