INTERDISCIPLINARY CHALLENGES OF ANTI-DRONE EFFORTS

INTERDYSCYPLINARNE WYZWANIA ZWALCZANIA DRONÓW

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Abstract. The steps against the careless and deliberately malignant use of unmanned aircraft vehicle involve the evidence needed for the support of detection, drone avoidance and legal consequences. Detection is made more difficult by the small size as well as stealth operations. Avoidance shall be solved such lawful means that cause no unjustifiable or disproportionate harm to third parties. The complexity of the challenge can be handled with close collaboration among different various disciplines. The aim of this research is to give a brief introduction including interdisciplinary collaboration, hoping for uniting the resources can lead to the realization of the realistic constraints of the mischievous use of unmanned aircraft vehicles.

Abstrakt. Działania przeciwko nierozważnemu i celowo złośliwemu oblatywaniu bezzałogowych statków powietrznych jest koniecznym działaniem wymagającymi wsparcia, z zaznaczeniem ochrony przed dronami i związanych z prawnymi konsekwencjami ich użycia. Ze względu na małe rozmiary umożliwiają one tajne działania. Ochrona przed nimi musi jednak uwzględniać rozwiązania zgodne z prawem i nie może być przyczyną nieproporcjonalnego przeciwdziałania ze szkodą dla osób trzecich. To wymaga interdyscyplinarnego podejścia różnych dyscyplin. Celem tych badań jest krótkie wprowadzenie i analiza możliwości współpracy różnych dziedzin, w ramach rozszerzania zasobów i metod działania. Takie podejście umożliwi realizację realistycznych ograniczeń statków bezzałogowych i pojazdów powietrznych.

Keywords: drone law, drone surveillance, drone counter measures
Słowa kluczowe: prawo dotyczące dronów, nadzór nad dronami, środki przeciwdziałania dronom

Introduction

Hannibal ante portas! And unmanned aircraft vehicles[1] are floating, literally, outside the door. It is not known yet if it is due to either the ordered product, the paparazzi, peeping[2] or something else (Orban, 2019, p. 224-230). In the vision of smart cities, runways for drones[3] are designed on the roofs of houses like in case of

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1 According to Eu regulatory wording, the unmanned aircraft (UA) means the unmanned aircraft system (UAS) involving the remote operation system.

2 Overseas, so in several US states and Canada, 'Peeping Tom' laws have already been introduced.

3 Unmanned Aircraft, UA, and Unmanned Aircraft System, UAS phases and abbreviations are in use according to the definitions of the now in force Article 3 of Regulation 2019/945/EU, par.1. The definitions of Remotely Piloted Aircraft, RPA, Remotely Piloted Aircraft System, RPAS, Unmanned Aircraft Systems, UAS; Unmanned Aircraft Vehicle, or Unmanned Airborne Vehicle UAV are also frequently used. Despite all these, ther term 'drone' is used both in colloquial language and in most professional articles.

current hospitals which reckon with the runway of helicopters providing emergency care. Foreseeing the future, at a press conference Edward Teller already claimed in 1981 that "the unmanned vehicle today is a technology akin to the importance of radar and computers in 1935" (Shane, 2016, p.71) Showing an annual 17% increase, the regulation is trying to follow the huge growth pace down and down behind in one of the most dramatically developing industry of the unmanned aircraft system nowadays. The European Union authorised (1139/2019/EU, art. 5) EASA[4] by the Regulation No. 1139/2019/EU to formulate that regulation having been realised primarily in the Regulation 945/2019/EU and the Implementing Regulation 947/2019/EU in 2019. The regulation should require Member States to direct enforcement and to formulate articles requiring further elaboration until 2020. The appearance makes things easier for authorities and law-abiding users. The light of development has brought along the shadow of the unlawful and specifically malicious application. Information (Yedroudj, 2019) about near miss catastrophes frequently appears in the news. A greater challenge is that it has been already used for smuggling, detecting security holes, drug home delivery (Levesque, 2018), transporting prohibited goods to correctional institutes[5] in criminal circles all over Europe.

In social media several video-documented incidents can be found as well. Attacks against essential infrastructure buildings, in particular nuclear power plants (Solodov, 2016), reservoirs, communication infrastructures, chemical factories and establishments producing food might just as well result in the political and economic disruption of the target. All these give a sufficient reason to the detect supporting defence, estimate vehicle intentions, prevent attacks and to the demand for acquiring evidence supporting the punishment of acts. Due to its small size and great mobility, only one instrument is not sufficient for the defence (Shi, 2018, p. 68-74). The aim of the study is to provide a brief overview to this, on the whole, complex challenge.

Prerequisites of the technology history of small sized unmanned aircraft vehicles

In order to detect and obviate unmanned aircraft vehicles, it is advisable to review the technological historical interdisciplinary prerequisites of the development of the device. The joint review is essential in order to find the weak points and to the possible solutions based on it.

The first military trials of remotely piloted unmanned aircraft vehicles had already been performed during WWII. For a long time, this kind of device seemed

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4 European Safety Agency, az Európai Unió Repülésbiztonsági Ügynöksége.

5 Drone's heroin delivery to Ohio prison yard prompts fight among inmates. The Guardian, 2015. 08.04. https://www.theguardian.com/us-news/2015/aug/04/drone-drug-delivery-ohio-prison-fight-heroin-marijuana-tobacco.

not to exit from military applications. RC air models were flown by enthusiastic amateurs in well-regulated and demarcated areas. At the beginning of the 21th century, scientific and technological developments showed a turbulent developmental phenomenon in several fields. There is no doubt that one of its main driving forces, beside space technology, is undeniably the widespread use and competition of cell phones and it currently remains. In order to make the bag size device shrink to watch size, new energy supply, miniaturization, microwave aerial, chip technology and material technology developments were essential. Lithium-ion batteries ensure the possibilities of specific energy density, high current capacity, and quick charges. In case of the miniaturization of integrated circuits, in addition to the huge increase in complexity degrees, the current 5 nm technology resulted not only in the reduction in the physical size, but in the power consumption. Developers could get to the miniaturization of electromechanical devices through the development of new magnetic materials. The resolution of optical sensors starting from the light sensors of the huge photocells' principle had exceeded the value of 100 megapixels in the most up-to-date cell phones by August, 2019.

Artificial intelligence and its further development 'deep learning' meant the new dimensions of automatic self-learning. All these together were necessary for the development of airborne small size unmanned aircraft vehicles. Previous principles used in the development of aircrafts had to be overcome. Reliable miniaturization of internal combustion engines showed no dramatic improvement; however, the specific energy density of fossil fuels is still significantly better than of electrical energy. Consequently, mass production civil drones operate on battery-powered electric motors apart from some specific uses. Rejecting the change direction principle of buoyancy achieved through the rotor blade adjustment of conventional rotorcrafts, fixed numbers of rotors and numerous engines are used. Synchronised control of the engines of 4-6-8-12-16-engined drones cannot be technically solved by the human brain due to the rapid and complex challenges of the task. The basic condition of drone flying is the engine control based on artificial intelligence which ensures a stable floating state despite outer wind forces, uneven weight distribution. During the flight, the operator determines only the vector deflection, the direction and speed needed for carrying out the task. It is easy to understand that in case of previously known mission-driven tasks; human intervention can be dispensed during flights. In such cases, the accurate knowledge of their own position and the basic knowledge of terrain obstacles and air conditions are essential. The dedicated dual board camera is the prerequisite for the optical positioning while the satellite GNSS[6] is for the radiofrequency one. The dual camera is essential for three-dimensional object recognition which is suitable for identifying smaller ground and air objects that cannot be positioned by GNNS.

6 Global Navigation Satellite Systems.

Drones do not contain a collision avoidance system based on the evaluation of active air situation pictures similar to the proven TCAS in the civil aviation system[7].

In order to avoid the complications of radiofrequency licensing and making use of the instruments already developed, unlicensed, SRD[8] frequency bands are used for communication between unmanned aircraft vehicles and remote pilots. In the simplest case, WIFI[9] bands are used, which can result in failures of communication in a mass WIFI device environment. Such cases are mass events where many cell phones have WIFI connection working. That is why, in case of more sophisticated civil drones, controlling is done by other SRD bands[10].

In favour of the energy efficiency of drones, it is aimed to minimise their own weight; therefore, the application of glass or carbon fibre reinforced plastic mechanical structures is considered to be almost exclusive. This way the own weight can be decreased, and the size of the payload can be increased. The sum of the two gives the maximum take-off mass (MTOM).

Rate risk

The investigation of UA air events, i.e., the findings of near miss approaches encounter obstacles. In many cases civil aircraft pilots do not even detect events, i.e., emergencies. The radio-frequently effective reflective surface of the UAS is small, hard to be detected, so in case of notifications no recorded and probative radar shootings can be found. According to the assessment made by the US Academy Model Aeronautics (AMA) in March, 2016 based on data from FAA, only 3,3% of the UA detections could be considered dangerous. AMA welcomes it for being so low. However, viewed from the perspective of the threat, each number greater than zero is unacceptable. In particular, as UAS and passenger aircrafts should use completely segregated airspace.

On March 31, 2016, at the airport of Phoenix, Arizona, the AAL A319 civil aircraft and the shadow C130 military aircraft detected the presence of UA one after another[11]. The number of detection failures is presumed to be lower than that of non-detected threats. That is why, the development of UA notifications by FAA can be considered as having an indicative value. Between January 1, 2015 and December 31, 2018 more than 15,000 cases of UA presence were detected and notified by pilots. AMA claim is true that in opposition to the exponential growth of the number of UA, the number of notifications only increases linearly with the passing years. At the same time, it cannot be considered positive in spite of the growing number of events, enlightening lectures, informative meetings in professional communities.

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7 Traffic Collision Avoidance System.

8 Short Range Device.

9 2400-2483,5 MHz and 5200-5900 MHz range.

10 In 433-435 MHz and 863-870 MHz ranges.

11 https://www.faa.gov/uas/resources/public_records/uas_sightings_report.

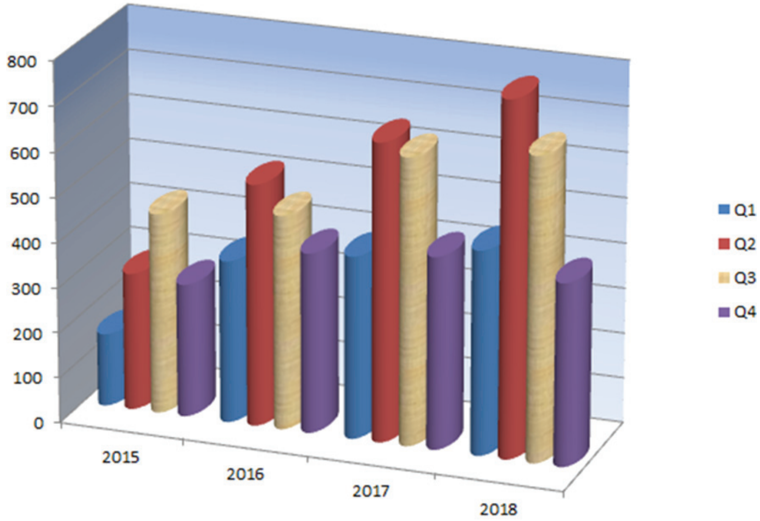

Diagram 1: Drone detection in USA airspace between 2015-2018.
FAA recorded notifications by pilots[12]

Defence against unmanned aircraft vehicles

Defence involves detection, identification, will estimate and countermeasures. All these for phases are embraced by enforcement. In case of detection and identification, purpose limitation principle is essential. While in case of will estimation, the value of undesired false positive results is necessary to keep as low as possible, since prevention, which can result in the destruction of the device and the prosecution of the remote pilot in case of ultima ratio, can lead to miscarriage of justice. While making countermeasures, the principle of proportionality should be followed.

Unmanned aircraft detection

The detection of unmanned aircrafts can be possible on the basis of either their physical characteristics or the traces left in their environment. Based on these, several detection methods are known, and their development is continuous. Generally, speaking, despite all technical difficulties, the radar and RF detections can be considered as primary detection tools. The other detection methods are mostly for conformation and classification.

12 Author's quaterly evaluation based on FAA data (Q1-Q4).

Radar detection

Classic airspace detection is based on the time lag of RF impulses reflected from the metal surface of the aircraft and the direction of the detection antenna. In civil aviation, typically, 80% probability detection (PD) is considered for 1 m^2 Radar Cross Section (RCS) in comparative literature[13]. The European expectations for the entire detection area are determined in 90% minimum average by EUROCONTROL. Hereby, it has to be taken into consideration that the aim of the devices is air control, not the detection of the entire airspace. In cases of drones not having anti-detection protection, RCS rate is less than 0,02 m^2. It shows that, however, it is a civil device, the detection of drones requires military challenges. Another problem is that drones typically flying under radar coverage, so they mean a hardly discoverable goal for radars. For detecting civil drones, generally, X-band (9,5 GHz) radars are used. Due to high resolution and the detection of close points, FMCW transmission mode is nearly exclusive. As the range is just few kilometres, many instruments have to be installed in the safety net that increases the computer hardware demand needed for data fusion.

Radio direction measurement and ICT detection

The observation of the communication between the remote pilot and the drone and RF direction measurement can be beneficial (Abeywickrama, 2018) Analysing the communication between the aircraft and the remote pilot, the identification data of the device can be determined. As in this case, the observed is active, while the observer is passive, the drone or the remote pilot do not realize that their acts are being detected and recorded. The position of the drone can be determined by a triangular system based on the detection of more direction measurement devices. It shows the susceptibility of the method that it can be detected preferably before the drone takes off. Based on RF signals, modern mathematical methods are capable of fingerprint-like identification (Yang, 2019). The detection of non-radiocommunication devices performing tasks autonomously cannot be performed this way.

Optical detection

The visible light, either on the infrared PTZ camera or in case of laser-based methods, is necessary for detecting the device. The camera system rather serves the identification of the detected target and the estimation of its aim than the detection.

[13] In compariasion, the RCS values relavant to detection are as follows: B-52 bomber – 100 m^2, MÍG-21 – 15 m^2, F117 – 0,003 m^2. Souce: https://www.globalsecurity.org/military/world/stealth-aircraft-rcs.htm.

From the photo taken of the drone, the category can be recognised with the help of artificial intelligence (AI).

Acoustic detection

Copter type aircrafts for buoyancy development reason make acoustically detected noise. The target position can be determined from the intensity and direction of the noise. The noise made by rotors is significantly lower than by internal combustion engines; therefore, voice detection is not a reliable solution, either.

Other detection methods

Significant current pulses flowing through cables ensuring the energy supply of engines leave a unique footprint in the form of electromagnetic noise. The notification of high-energy electromagnetic pulses appearing in space has arisen as a theoretical detection possibility. The possibility to detect the device is decreased by magnetic shading or by suppressing interference. Engines ensuring the buoyancy of the drone move large amounts of air. The volume of the air pulled is several orders of magnitude larger than the vehicle itself. During polluted air flights RF radar detection can produce results, while during clean air flights the detection made by lidar using laser can do the same.

Estimating the aim of unmanned aircraft vehicles and remote pilots and alarms

The remote pilot or the system operator announcing the drone flight plan to the competent authority also declares his intention of law-abiding[14]. Flights to registered devices support this basis intent as well. The device involves the geographical boundaries restricting its flights, so it will not fly beyond the limited borders despite the false instructions of the remote pilot. Estimating drone intention increases the efficiency of countermeasures and of risk mitigation measures, and also decreases the probability of false alarms. One of the intention estimation methods is trajectory that can foreshadow the drone flight direction. The reliability of the route estimate from trajectory seems to be refuted by the high mobility of the drone; however, at the same time, the short flight time makes the remote pilot strive to seek the shortest route.

[14] In Hungary HungaroControl responsible for air traffici control is developing such an application that support for mobile phones recording drone flight needs online and after evaluaiting the necessary conditions, it informs the person submitting the aplication about the assessment result in email. Simon, A.: Drón stratégia a HungaroControl szemszögéből.

Anti-drone methods

A great number of anti-drone systems (C-UAS) can be found on market. According to the Holland Michel's Study published in 2018, 233 products were made by 155 manufacturers in 33 countries (Holland, 2018). In the absence of standardisation, their reliability and efficiency can show differences. Some of them are used either for only detection or only defence. The table of Holland Michel's data supplemented with EU application contains the Hungarian audit results as well. The devices in the first six rows of the Table 1 are included in the EU weapon list, so their manufacturing, possessing and usage are subject to individual authorization[15]. RF jamming means the impossibility of drone control and satellite navigation. GNSS jamming, however, affects not only drones, but any device operating in the jamming environment. Looking forward, it can cause particular risk in the environment of driverless cars, IoT devices and instruments using satellite temporal reference.

Table 1. C-UAS Interdiction methods and test results

Method	Nr.	Weapon licence required in EU	Tested in Hungary	Verification result
Jamming (RF, GNSS, or Both)	96	yes	yes	positive
Net	18	yes	yes	positive
Spoofing	12	yes	yes	positive
Laser	12	yes	-	-
Machine gun	3	yes	-	-
Electromagnetic Pulse	2	yes	-	-
Water Projector	1	no	yes	negative
Sacrificial Collision Drone	1	no	yes	positive
Other	6	depends	yes	positive

Source: the author's test validation based on the paper of Holland Michel, A.: Counter-Drone Systems

Destructive radiator sources, laser, and electromagnetic impulse, as well as machine guns can cause damage to other objects or creatures beyond intentions. No experimental results are known that what size of the environment is where the use of an EP weapon can disable a pacemaker, or the electronical system of vehicles, mainly aircraft vehicles.

[15] The tests on devices classified as weapon were made by trained Hungarian Army officers.

The defensive option with a water jet was demonstrated with a fire hosepipe. Even such little results reached during experiments can be hardly considered effective. Self- sacrificing drone deployment is successful, it raises fewer legal obstacles. The literature of drone clearing done by birds of prey is large (Nikolic, 2017), however, its industrial applications are less possible. Among other clearance procedures, the influence of the operation of the microelectromechanical systems (MEMS), placed on the board of the drone, can be mentioned. According to Pan, the connection between the chip and the environment is interrupted with appropriate soundwave combinations, and due to the lack of equilibrium feedback, the drone losing its coordination falls down[16].

The summary of the legal obstacles of anti-drone efforts

After a long wait, there was a change in the field of European drone regulations. At the same time, civil (and in several non-civil applications) drone avoidance has still been made impossible by the complete prohibition of avoidance systems. The regulation of military applications does not provide sufficient opportunities, as in all European countries, such a great number of establishments need defence that can be solved by only military instruments. In order to prevent the increase of vulnerability, the import of the instruments must be strictly limited. The arsenal of the above listed illegal goods can be purchased from several Asian manufacturers through channels.

Drone diversion and drone spoofing type of defence are currently against the law. Even if the non-military status guard service does it for the defence of a critical infrastructure, ad absurdum, a nuclear power plant. According to Hungarian legislations, the offender covers the legal definition of prohibited data acquisition[17] or the penetration of IT systems. Shooting a whole fleet of drones can result in 1-5 years of imprisonment according to the law[18]. The struggles against illegal drones bring those absurd old facts images back when people rushing to help victims were sentenced instead of the offender. And finally, there is an urgent need for an unambiguous re-regulation of RF jamming policy in the entire EU for the sake of drone safe airspace.

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16 https://www.foxnews.com/tech/sonic-weapon-knocks-drones-right-out-of-the-sky.

17 Act C of 2012 on the Criminal Code. 322. §. d).

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