Multiple robots (robotic centers) and systems. Remote sensing and non-destructive testing

Роботизированные комплексы и системы. Технологии дистанционного зондирования неразрушающего контроля

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RESEARCH ARTICLE

Identification system for detecting and suppressing unmanned aerial vehicles based on video interception for use in combat conditions

Alexey A. Konik [1],
Roman E. Afonin [1],
Ivan M. Klimov [2],
Dmitry S. Zinchenko [2, @]

[1] *I.D. Putilin Belgorod Law Institute of the Ministry of Internal Affairs of Russia, Belgorod, 308024 Russia*
[2] *FKU NGO "STiS", Ministry of Internal Affairs of Russia, Moscow, 111024 Russia*
[@] *Corresponding author, e-mail: dmitriy.zinchenko.1998@mail.ru*

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Abstract

Objectives. In the context of military operations, states face the threats of attacks by unmanned aerial vehicles (UAVs) on vulnerable assets, in particular, those pertaining to law enforcement agencies. Currently, there is no uniform or—more importantly—effective approach to detecting and suppressing certain types of UAVs, in particular, first person view (FPV) drones. The aim of the work is to develop modernized systems for the detection and suppression of enemy unmanned aerial vehicles and to justify their full-scale implementation in the service activities of law enforcement agencies.

Methods. The work used system-structural, comparative-legal, and measurement research methods along with analysis, observation, and field modeling. In addition, the research refers to generalized and systematized experience of using UAVs in combat conditions.

Results. The structure, basic tactical and technical characteristics are described according to the principle of operation of the identification complex for detecting and suppressing UAVs, having the ability to intercept analog radio signals carrying video information, which makes it possible to effectively detect and counteract enemy UAVs at a considerable distance. An algorithm of actions to be taken by law enforcement officers when using this complex is also developed and described. Proposals for creating a hardware and software system based on the complex with the possibility of spoofing a video stream are outlined.

Conclusions. The results of the study indicate the need to supply law enforcement agencies with an identification system for detecting and suppressing UAVs having the ability to intercept an analog radio signal carrying video information. The use of such a system across a wide area subject to UAV attacks will significantly improve the effectiveness of alerting all categories of employees and civilians, as well as contributing to the establishment of airspace control and improving the effectiveness of the fight against UAVs.

Keywords: identification system, analog radio signal, video information, unmanned aerial vehicle, antenna, descrambling, video stream

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НАУЧНАЯ СТАТЬЯ

Идентификационный комплекс обнаружения и подавления беспилотных воздушных судов на основе видеоперехвата для использования в условиях боевых действий

А.А. Коник [1],
Р.Е. Афонин [1],
И.М. Климов [2],
Д.С. Зинченко [2, @]

[1] *Белгородский юридический институт МВД России имени И.Д. Путилина, Белгород, 308024 Россия*
[2] *ФКУ НПО «СТиС» МВД России, Москва, 111024 Россия*
[@] *Автор для переписки, e-mail: dmitriy.zinchenko.1998@mail.ru*

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Резюме

Цели. В условиях проведения боевых действий государства столкнулись с угрозами атак беспилотных воздушных судов (БВС) на различные объекты, в частности, объекты силовых структур. В настоящее время нет единого, а самое главное, эффективного подхода по обнаружению и подавлению различных видов БВС, а именно, FPV-дронов. Целью работы является создание модернизированных комплексов обнаружения и подавления БВС противника и обоснование полномасштабного внедрения этих комплексов в служебную деятельность силовых структур.

Методы. В работе использовались системно-структурный, сравнительно-правовой, измерительный методы исследования, анализ, наблюдение и натурное моделирование, а также обобщение и систематизация опыта применения БВС в условиях боевых действий.

Результаты. Описаны структура, основные тактико-технические характеристики и принцип работы идентификационного комплекса обнаружения и подавления БВС с возможностью перехвата аналогового радиосигнала, несущего видеоинформацию, позволяющего эффективно обнаруживать и противодействовать БВС противника на значительном расстоянии. Разработан и описан алгоритм действий сотрудников силовых структур при работе с данным комплексом, изложены предложения по созданию на базе комплекса аппаратно-программных систем с возможностью подмены видеопотока.

Выводы. Полученные результаты исследования указывают на необходимость внедрения в служебную деятельность силовых структур идентификационного комплекса обнаружения и подавления БВС с возможностью перехвата аналогового радиосигнала, несущего видеоинформацию, применение которого на широком участке местности, подверженном атакам БВС, позволит существенно улучшить эффективность оповещения всех категорий служащих и гражданского населения, а также будет способствовать установлению контроля над воздушным пространством и повышению эффективности борьбы с БВС.

Ключевые слова: идентификационный комплекс; аналоговый радиосигнал, видеоинформация, беспилотное воздушное судно, антенна, дескремблирование, видеопоток

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INTRODUCTION

The capabilities of modern unmanned aerial vehicles (UAVs) have been demonstrated in combat operations. UAV attacks carried out by copter-type UAVs equipped with a "drop" system and first person view (FPV) drone-type UAVs [1] pose a threat not only to civilian and industrial buildings and structures, but also to critical infrastructure facilities and facilities belonging to law enforcement agencies, as well as their personnel [2].

During military operations, the territories of many states are often subjected to indiscriminate and sometimes chaotic attacks by UAVs equipped with various munitions and explosive devices (PG-7V[1] (VL[2], VR[3], VM[4]), RKG-3[5], etc.) [3], especially improvised explosive devices (Fig. 1).

Fig. 1. Improvised explosive devices used in an UAV attack

In addition, recently developed "drop" systems for FPV drones are already in widespread use. These are capable of carrying out multiple attacks using different types of modernized munitions [4]: for example, FPV drones can remotely mine terrain by dropping munitions of different types: "butterfly," "bell," etc.

The above factors, together with the analysis of statistical data, indicate that FPV drones are the most dangerous to the civil population, law enforcement personnel, and facilities. They can attack at high speeds (over 100km/h), carry a significant payload in the form of an explosive charge, and penetrate deep into territory to a distance of 15–20 km, and in certain cases, up to 30 km [5]. Moreover, combat experience has shown that contemporary FPV drones use non-standard, permanently shifted frequencies for control [6], significantly increasing their resistance to electronic reconnaissance and electronic warfare (EW) detection.

In view of the increasingly challenging situation and the intensified use of FPV drones, it is necessary to introduce additional measures to increase the effectiveness of countering the enemy in this context, as well as to inform the civilian population of the threat of UAV attacks in a timely manner. The actual direction is the development of improved complexes for detection and suppression of UAVs. In particular, the creation and introduction of an identification complex for detection and suppression of UAVs with the ability to intercept analog radio signals carrying video information [7].

IDENTIFICATION COMPLEX FOR UAV DETECTION AND SUPPRESSION, CAPABLE OF INTERCEPTING ANALOG RADIO SIGNALS CARRYING VIDEO INFORMATION

Based on the above considerations, as well as electronic reconnaissance combat operations data confirming it to be a key EW approach and effective circuit of destroying enemy UAVs [8], researchers from the Belgorod oblast of the Russian Federation have developed an identification complex for detecting and suppressing UAV (hereinafter "the complex"). The complex can be used to detect and identify an enemy UAV in the airspace with a high degree of probability. The complex is based on the interception of the analog radio signal carrying video information from enemy UAVs.

[1] A shot with an anti-tank grenade.
[2] A shot with an anti-tank grenade "Luch."
[3] A shot with an anti-tank grenade "Resume."
[4] A modernized anti-tank grenade shot.
[5] A handheld shaped-charge grenade.

Fig. 2. "EFIR" UAV detector

It should be noted that similar products are currently being developed for this purpose, such as the "EFIR" and "Umbrella" detectors (Fig. 2). The basic operating principle of such complexes is based on scanning the air and recording the carrier frequency with detecting and recording the video stream.

However, from an analysis and evaluation of the tactical and technical characteristics of such products, it appears that they do not allow the simultaneous detection of UAV signals in a wide range of frequencies (the products include a minimum number of frequency bands, for example 2.4 and 5.8 GHz) and at long distances (the declared maximum detection distance ranges from 500 m to 5 km) [9].

The developed identification complex includes the following components:

- directional receiving antennas for specific frequency ranges (circular antennas can be used, but in this case the detection distance is much shorter);
- receiver for analog radio signal carrying video information;
- video signal transmission cable with RCA connectors (the length of the cable depends on the installation configuration of the equipment, and it should be noted that the quality of data transmission decreases with increasing cable length);
- monitor with VGA or HDMI connector;
- AV RCA-VGA or AV RCA-HDMI monitor connection converter (depending on the monitor used);
- VGA-VGA or HDMI-HDMI cable;
- 2 USB, 5V/2.1A power supplies.

The complex operating principle consists in the use of a circular antenna (when the direction of the likely UAV take-off is unknown) or a directional antenna to continuously monitor the surrounding space within a radius of 1.5 to 3 km (when using a circular antenna) and up to 30 km (when using a directional antenna). These distances depend on a number of factors such as the transmitting power of the FPV drone, the gain of the receiving antenna, the terrain, and so on. When the UAV with analog video signal transmission channel appears, the complex automatically intercepts and transmits (duplicates) to the monitor a video with an illustration of the terrain over which the UAV is flying and flight data, which is observed on the monitor screen or in the FPV drone goggles by the operator who is controlling it.

The developed complex is capable of operating across a wide range of temperatures, under strong vibrations, and in various other extreme conditions. An important aspect of the complex's operation is its passivity, meaning that it does not emit any signals of its own that could be detected by devices that scan radio waves.

A special feature of the complex is its ability not only to detect UAVs by receiving an analog video signal (displayed on the monitor), but also to descramble encrypted "X-signals." This allows for the prior identification of illegal flights of UAVs, with the possibility of determining their speed and altitude, predicting their trajectories, and identifying possible targets. The detection range of enemy UAVs (up to 30 km) allows time for security and countermeasures to be put into place.

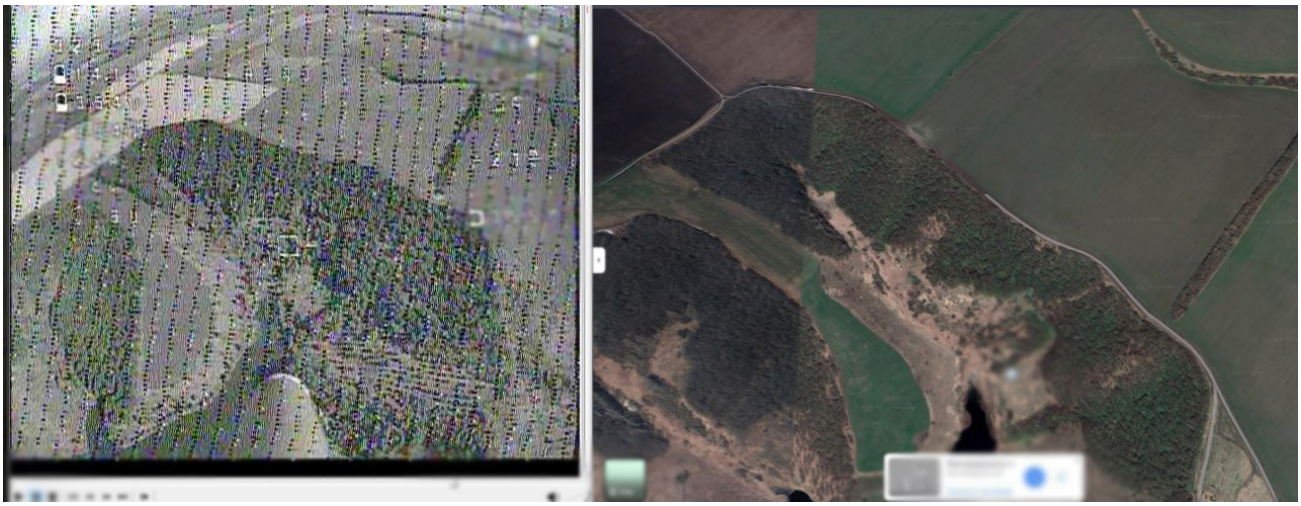

Fig. 3. Identifying UAV flight directions by collating complex data on terrain maps

Fig. 4. Capturing UAV analog video and linking the flight path to a terrain map

It should also be noted that in addition to the above characteristics, the complex offers unique capabilities and potential for use in combat operations. However, for reasons of confidentiality, the circuitry and more detailed tactical and technical characteristics of the complex cannot be disclosed.

PRACTICAL APPLICATION OF THE DEVELOPED IDENTIFICATION COMPLEX FOR UAV DETECTION AND SUPPRESSION

After deploying the developed complex at a site, its successfully tactical and technical characteristics were confirmed by detecting more than 500 UAVs over the course of several months of operation. For example, in just one day, the complex enabled the detection of 20 FPV drones, 9 of which were successfully suppressed[6].

The complex was used to identify UAV flight directions by analyzing topographic maps, including offline electronic maps (Figs. 3 and 4). In addition, under certain conditions, it is possible to determine UAV launch points. Furthermore, the integration of the complex into the mobile version is being actively pursued in order to use the complex on mobile objects.

In addition to military applications, the complex has been successfully used by law enforcement officers. Over a short period of time, it has been used to significantly increase the efficiency of detection and suppression of UAVs in the controlled area (18 FPV drones destroyed). The practical use of the complex has demonstrated that an integral part of its successful application is the maintenance of appropriate documentation (log, statement, etc.), which must necessarily reflect the information received (location of the UAV detected with reference to a settlement or exact coordinates, the nature of the UAV behavior, the measures taken, and the result obtained, etc.). To this end, researchers from the FKU NPO "STiS"[7] of the Ministry of Internal Affairs of Russia and the I.D. Putilin Belgorod Law Institute of the Ministry of Internal Affairs of the Russian Federation[8] have developed an optimal template for the logbook of data on the detection of illegal UAVs.

[6] Statistical data (materials) are provided by the initiative group, the developers of the complex.

[7] https://стис.мвд.рф (in Russ.). Accessed March 20, 2025.

[8] https://белюи.мвд.рф (in Russ.). Accessed March 20, 2025.

Therefore, for the timely detection and effective suppression of hostile UAVs, it is proposed to introduce this complex into the official activities of law enforcement officers and create a network of strongholds equipped with the complex alongside EW and other means of suppression of UAVs on the basis of established roadblocks, checkpoints, and dislocations, as well as at temporary bases of law enforcement agencies with further alerting of the authorities through closed communication channels and the civilian population through open ones (e.g., in messenger groups etc.).

It is also necessary to define the algorithm of actions for law enforcement officers [10] when using the complex:

- identifying the threat;
- alerting personnel, operations duty officer, countermeasures group, and civilians through prepared communication channels;
- taking measures to suppress the enemy UAV by all possible means (EW, physical elimination including the use of firearms [11], etc.);
- taking measures to eliminate the consequences of UAV suppression or detonation and documenting the incident.

Personnel should be alerted simultaneously with civilians. The message should be brief but informative: UAV direction, expected type, required action.

UAVs can be suppressed either directly in the vicinity of the observation station, or using the tactics of mobile ambush groups armed with additional electronic reconnaissance equipment and various UAV suppression equipment (EW systems, smoothbore weapons, etc.) to intercept and suppress drones away from civilian areas and critical assets.

It should be borne in mind that the use of EW means in the immediate vicinity of the complex may be the cause of interference and equipment malfunction. Therefore, it is necessary to switch off the various EW complexes and other means of UAV suppression in the immediate vicinity of the complex during its use. Since EW cannot guarantee UAV suppression [12], it is also necessary to be prepared to use firearms to defeat the drone. At low altitudes (up to 40 m), UAVs can be effectively suppressed with smoothbore weapons loaded with shotgun cartridges #3 and #5. Alternatively, an effective "density" of fire can be created with 3–5 automatic weapons [13].

Once the UAV has been disposed of, first aid should be administered to any casualties and the scene cordoned off from unauthorized persons, taking care to ensure that no further mined parts remain on the surviving parts of the UAV. Taking all necessary safety precautions, the surviving parts of the UAV should then be reassembled for examination. If the status of the UAV is in doubt, or if it has been destroyed without an explosive device detonating, it is strictly forbidden to approach it until the object has been examined by experts. This is because the explosive device may be remotely triggered or rigged to detonate after a certain period of time.

In addition, regular briefings are required to develop the knowledge and skills of the personnel in the algorithm of actions to be taken upon detection of a UAV.

STRATEGIC TASKS SOLVED BY THE DEVELOPED IDENTIFICATION COMPLEX FOR DETECTING AND SUPPRESSING UAVS

One of the strategic goals of using the complex consists in the collection of information, followed by its mandatory analysis and use in the official activities of law enforcement officers, including special forces.

When used on a regular basis, the system also solves the following tasks:

- UAV direction detection and tracking. This allows UAV flight paths to be tracked and, in some cases, the launching point and the most dangerous directions to be determined and recorded in surveillance logs and terrain maps, including the use of various services. The data thus obtained can be used to reinforce the EW systems in certain directions and to carry out ambush operations;
- identification of UAV models and types [14]. The nature of the drones behavior in the air (flight speed and altitude, stability, etc.) allows UAV models and types to be identified with a high degree of accuracy, making it possible to predict further operator actions and prepare for a potential threat;
- detection of enemy groups (with UAV identity or unit call sign information) conducting terrorist activities in the vicinity (in a specific area). This information is often displayed on screen when an analog radio signal carrying video information is intercepted. After the attack, this data could potentially be passed on to the investigating authorities for analysis. In addition, this approach allows a more accurate determination of the number and size of enemy UAV groups in a given area;
- identification of criminals (traitors). At present, there are known cases of launching UAVs by hostile sabotage-reconnaissance groups and criminals (traitors) from various territories. Since these facts are difficult to detect without special equipment, such groups may operate for a long time, causing selective damage to vital infrastructure and civilian population. With a high-quality functional arrangement of the complex, the UAV take-off position can be captured by a video signal (when entering the antenna coverage area), thus enabling

measures to be taken to liquidate and eliminate such groups;
- documentation of UAV suppression (elimination) or the result of using it. In this case, it is a matter of documenting both the disposal of the UAV and the further collection of its fragments, including in the case of its suppression without disposal, for further investigation. There are also known cases of drones being found by civilians and injured by a detonation of the explosive device. In the event of UAV attacks and injuries, the complex enables rapid response and dispatch of the necessary services to the designated location to provide assistance;
- determination of UAV technical abilities [15]. Using the complex with the ability to intercept the analog radio signal carrying video information, it is possible to determine the flight range and limit distances. It is also possible to monitor new techniques used by the enemy (e.g., the use of special software makes it possible to record the frequency values of the UAV used during the flight), including any increase in battery power. The complex can also be used to determine the resistance of UAVs to the EW systems used to counter them and make adjustments to its operation.

CONCLUSIONS

The use of an identification complex for the detection and suppression of UAVs having the ability to intercept analog radio signals carrying video information, along with the possibility to protect a large area of terrain vulnerable to UAV attack, significantly improves the effectiveness of alerting all categories of officials and the civilian population. It also contributes to the establishment of airspace control to increase the effectiveness of the fight against UAVs. In turn, the collection and analysis of data obtained using the complex and recorded in the logbook can be used to supply accurate forecasts of the situation in a given area.

On the basis of the characteristics identified by scientific analysis and practical application of the developed complex, the following innovative features that determine its potential in conditions of special military operation can be distinguished:
- wide frequency range (more than 4 frequencies);
- UAV detection range up to 30 km;
- the ability to descramble encrypted “X” signals;
- resistance to extreme conditions and a wide operating temperature range: from −25 to +40°C.

Thus, the results of the study determine the possibility of creating hardware-software systems with the possibility of spoofing the video stream, which implies interference in the form of transmitting an extraneous video to the UAV operator, as well as permitting various modifications of the complex: stationary, automotive, etc.

Authors’ contributions

A.A. Konik—creation of the research concept and methodology, preparation of the initial version of the manuscript, literature review, editing of the manuscript text.

R.E. Afonin—development of methodology, preparation of the initial version of the manuscript, collection and systematization of information on the practice of using the complex, literature review.

I.M. Klimov—analysis of existing solutions, providing recommendations on problem formulation and development of the complex, conducting an expert assessment of the results obtained.

D.S. Zinchenko—methodology development, preparation of the initial version of the manuscript, interpretation and generalization of the results, general guidance, preparation of the article for publication.

All the authors made a common equivalent contribution, read and agreed on the published version of the manuscript.

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About the Authors

Alexey A. Konik, Cand. Sci. (Ped.), Associate Professor, Deputy Head of the Department of Tactical and Special Training, I.D. Putilin Belgorod Law Institute of the Ministry of Internal Affairs of Russia (71, Gor'kogo ul., Belgorod, 308024 Russia). E-mail: 89205666067@mail.ru. RSCI SPIN-code 9074-3701, https://orcid.org/0000-0003-4563-3509

Roman E. Afonin, Senior Lecturer, Department of Physical Training, I.D. Putilin Belgorod Law Institute of the Ministry of Internal Affairs of Russia (71, Gor'kogo ul., Belgorod, 308024 Russia). E-mail: afonin.roman@mail.ru. RSCI SPIN-code 4015-0302, https://orcid.org/0009-0000-6383-3913

Ivan M. Klimov, Head of the Department for the Development of Means to Counter the Functioning of Unmanned Vehicles, Scientific and Production Association "Special Equipment and Communications," Ministry of Internal Affairs of the Russian Federation (2, Prud Klyuchiki ul., Moscow, 111024 Russia). E-mail: klimov.ivan700@gmail.com. https://orcid.org/0009-0006-9824-8224

Dmitry S. Zinchenko, Senior Researcher, Department for the Development of Means to Counter the Functioning of Unmanned Vehicles, Scientific and Production Association "Special Equipment and Communications," Ministry of Internal Affairs of the Russian Federation (2, Prud Klyuchiki ul., Moscow, 111024 Russia). E-mail: dmitriy.zinchenko.1998@mail.ru. RSCI SPIN-code 9816-4245, https://orcid.org/0009-0001-0948-8239

Об авторах

Коник Алексей Алексеевич, к.пед.н., доцент, заместитель начальника кафедры тактико-специальной подготовки, ФГКОУ ВО «Белгородский юридический институт Министерства внутренних дел Российской Федерации имени И.Д. Путилина» (308024, Россия, Белгород, ул. Горького, д. 71). E-mail: 89205666067@mail.ru. SPIN-код РИНЦ 9074-3701, https://orcid.org/0000-0003-4563-3509

Афонин Роман Евгеньевич, старший преподаватель, кафедра физической подготовки, ФГКОУ ВО «Белгородский юридический институт Министерства внутренних дел Российской Федерации имени И.Д. Путилина» (308024, Россия, Белгород, ул. Горького, д. 71). E-mail: afonin.roman@mail.ru. SPIN-код РИНЦ 4015-0302, https://orcid.org/0009-0000-6383-3913

Климов Иван Михайлович, начальник отдела развития средств противодействия функционированию беспилотных аппаратов, Центр развития беспилотных аппаратов и средств противодействия их функционированию, Научного-исследовательский институт специальной техники, ФКУ «Научно-производственное объединение «Специальная техника и связь», Министерство внутренних дел Российской Федерации» (ЦРБАиСПиФ НИИСТ ФКУ НПО «СТиС» МВД России) (111024, Россия, Москва, ул. Пруд Ключики, д. 2). E-mail: klimov.ivan700@gmail.com. https://orcid.org/0009-0006-9824-8224

Зинченко Дмитрий Сергеевич, старший научный сотрудник, отдел развития средств противодействия функционированию беспилотных аппаратов, Центр развития беспилотных аппаратов и средств противодействия их функционированию, Научного-исследовательский институт специальной техники, ФКУ «Научно-производственное объединение «Специальная техника и связь», Министерство внутренних дел Российской Федерации» (ЦРБАиСПиФ НИИСТ ФКУ НПО «СТиС» МВД России) (111024, Россия, Москва, ул. Пруд Ключики, д. 2). E-mail: dmitriy.zinchenko.1998@mail.ru. SPIN-код РИНЦ 9816-4245, https://orcid.org/0009-0001-0948-8239

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