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COMPLEX STRUCTURE OF UAVs DETECTION AND IDENTIFICATION

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Abstract**—***Possible radiation fields of UAV-like object were analyzed by optical and, particularly, IR-systems. Structure of multi-functional integrated complex of detection and identification of unmanned aerial vehicles has been presented.*

Index Terms—Unmanned aerial vehicle; detection and identification system; multifunctional integrated complex.

I. INTRODUCTION

Fundamentally new technology creation is the most important area of scientific and technical progress. This task can be connected with the development of aircraft, including unmanned aerial vehicles (UAVs), which has a strong influence on the acceleration rate of technological progress in general. UAVs are not just a new class of aerial vehicles (AV), but also a new, higher level of military as well as civil aviation.

Over the last years the popularity of small UAVs has boomed and is expected to increase even further. Both in the military domain and in the civil domain mini-UAVs are more widely used e.g. to obtain television footage of main events or to support first responders in dangerous areas.

The high efficiency of UAVs used for military purposes forces the defending side to develop detection and identification means.

When considering mini-UAVs as a potential threat, suitable counteractions need to be developed. The first step in counteracting this threat is timely detection of incoming mini-UAVs. Small UAVs are however difficult to detect since they fly relatively slow and at low altitude (LSS-target). Moreover, flying birds may lead to (many) false alarms.

Detection and classification of mini-UAVs can be performed with different types of sensors such as acoustic sensors, high-resolution infrared sensors and radar. In general detection by acoustic sensors is not very robust because mini-UAVs are relatively quiet and in the urban environment ambient noise levels may be high.

High-resolution infrared sensors are capable of detecting mini-UAVs at practical distances and, after detection, they can zoom in on the target to obtain detailed imagery supporting classification. A drawback of infrared sensors is that they cannot provide speed and range of the target, and they are incapability to operate at fog and bad weather conditions, i.e. their possibilities are limited.

At the moment, the most promising way of solving the problem of detection and identification is considered to be the use of radar in combining with infrared optoelectronic devices when it is possible.

II. ANALYSIS OF POSSIBLE RADIATION FIELDS

The main thermal radiation source of the UAV is the engine.

The UAV engine is a source of energy and ensures its movement. The UAV’s flight characteristics as well as the possibility of its detection by optoelectronic means depend to a large extent on engine performance, its characteristics, dimensions and contours.

Reconnaissance UAVs’ structure analysis shows that the most widely used types of engines are internal combustion engines (ICE), and turbojet engines (turbojets), because they have excess capacity and long uptime. This feature allows the UAV to carry out the flight mission and return to the desired location for a perfect landing. Furthermore, they work on non-toxic fuel, which improves their operability.

Modern reconnaissance UAVs with medium and long flight time usually have piston or rotary piston engines. This is due to the advantage of the internal combustion engine noise characteristics and specific fuel consumption over turbojets. Micro and mini UAVs (with take-off weight up to 30 kg and flight range of up to 20 km) can have electric motors mounted.

Since the driving force for the UAV with a piston engine and the electric motor is the propeller, then the best location of the propulsion system is in the bow of the UAV (tractor propeller engine) or in the back of the (pusher propeller engine). This allows you to completely (pusher propeller UAVs) or partially (tractor propeller UAVs) eliminate the effect on the wing and tail turbulized air flow from the propeller.

Usage of two engines worsens the following UAV characteristics: aerodynamic (increased drag), energy efficiency (increased fuel consumption), cost, reliability and manufacturability.

However, usage of dual-engine UAV scheme with engines thrust difference control allows performing stabilization and yaw-controlling without using the rudder.

The task of detecting and tracking the UAV, especially at night, can be handled by infrared (IR) optical-electronic devices (OED).

By the nature of tasks existing IR OEDs can be divided into two classes. First one includes thermal imaging devices, whose main task is the detection and recognition of different heat-radiating objects by their images. This class of devices makes possible to solve the problem of maintenance. They are called infrared imagers. The image sizes of objects in such devices are comparable to the size of the focal plane (or the size of the recording matrix radiation receiver (MRR)). Increasing the range of these devices involves the use of high-luminosity and narrow-field lenses and high-quality matrix IR devices.

Second class contains detection devices. They are called surveillance OEDs (thermal direction finders). TDFs have an optical system with a wide field of view (> 25°), short focal distance of about 50 mm and the matrix IR receiver. The angular size of the observed pointobject in them is less than or equal to an elementary angular field of matrix infrared (IR) receivers [2]. The main task of these devices is the detection of point thermal objects against the atmospheric background which came in sight of the optical system, at maximum range. The point object (target) refers to small-sized thermal object (SSTO), which the picture fits in an elementary field of view (image pixel) of the direction finder or simultaneously falls into several neighboring pixels (vertically or horizontally) [2].

Such TDFs currently use point thermal objects detection method on the background target image (BTI), which is based on the visual separation of point marks brightness of the thermal point object and the fluctuations of atmospheric background. Getting BTI on the monitor of the picture monitor is conducted in accordance with the video signal from the output of MRR. Each pixel of the BTI is assigned to a limited number of discrete brightness levels – quantum which are proportional to radiance of intrinsic emission of the atmosphere and target. The more quantization levels are there, the better image quality is.

A feature of optoelectronic devices with a wide field of view working in the range of 8–13 microns are high brightness jumps of simultaneously observed image patches. For example, radiation contrast of a heap cloud against the clear sky in the daytime, as well as at night, can reach 60 K [2]. A similar situation arises while viewing the target near the horizon, when angular field of view contains part of celestial hemisphere and ground terrain, which is usually “warmer” than sky. When the sensitivity of the matrix is less than 0.1 K and there exist white level limitations in the output video signal, MRR signals compression is performed. This in turn leads to a target signal decrease at the input of picture monitor [2].

Vision problems are caused by potentially low BTI contrast and low visibility of targets. In addition to these factors, a significant role in reducing the detectability performance are playing noise components of the signal, which are formed because of the characteristics of the sensors and non-ideal data transmission channel. Having the improvement of image quality as the main objective and analyzing the causes of its deterioration, different ways of two-dimensional image digital filtering and processing have been created. Image processing is performed in real time, without resampling down the pixel video data stream and without dropping frames. It contains: digital irregularities correction algorithms, noise smoothing, contrast increasing, underlining borders, high-frequency correction, defective pixel correction, and so on, being implemented in the software of video processor of TDF. But these methods of image processing are implicitly improving TDF characteristics due to better visual perception of the operator. The final assessment of the video quality improvement effectiveness should be subjectively estimated image quality, since the final consumer of image is a human operator. Spotting opportunities are different for different operators, and uneven image cloud atmospheric background is difficult to distinguish the point mark of the thermal object. More difficult task is to discriminate several marks, so using visual detection increases the possibility making-decision errors.

Medium and large UAVs nicely “fit” in the capacity of many existing ground-to-air missiles.

Small systems operating at low speeds and altitudes are easier to knock down, but by nature they have smaller effective reflection surface (ERS), infrared and acoustic signatures, and therefore are harder to detect and harder to hit.

Thin-walled shells are widely used in UAV designs. In order to build the UAV detection systems the problem of determining the temperature field of its design due to internal heat sources at rest and in flight must be solved.

This problem reduces to the study of the temperature field of arbitrary thin-walled shell when heated by a plane-parallel radiant heat flux from an infinitely distant source. Convective heat transfer occurs between the shell and the environment by Newton's law.

The solution to this problem is based on the conversion of the above non-linear mathematical model to a linear equation, schematization of considered UAV as a compound of separate beams and constructing numerical schemes based on the use of finite element method.

Complex including reconnaissance search station (RSS), optical-electronic reconnaissance station and radar station is presented in [3]. The effective reflection surface detects and locates control and information reset channels, the GPS navigation system (even in the case of "closing" a public GPS signal, UAVs will still show up, since there is the signal itself) of small class UAV. Effective reflection surface takes the bearings of target, transfers targeting for bearing to the radar station, and then optical-electronic system is connected with this information to obtain the exact coordinates of UAVs.

III. System of Detection and Identification of Unmanned Aerial Vehicles Design

The main sources of heat radiation are the engines, however, note that electric motors have little means of heat.

Due to the fact that the UAV by virtue of its task is flying with insignificant speed (less than 100 km / h), the aerodynamic heating of the body of the UAV is small, so it is possible to detect thermal heating in the area of running engines.

Solution of UAV detection and recognition problem in accordance with the above materials is a great challenge because of the large variety of used UAVs, a wide range of changes in their speed and height, changing the angles on the radar screen, noise caused by precipitation, time of day, and so on. It is known that modern UAVs can be either with a metal frame or completely made of plastic and composite materials. Therefore, their equivalent radar cross-section size, defined by the metallic elements (control board, the engine mount optical lens, antenna) can vary by tens and more times. It is especially difficult to detect the UAV, if its construction and equipment contains little amount metal parts and their sizes are small. In this case, the reflection of electromagnetic waves can be detected by radar receiver only at certain angles and in terms of resonant reflection occurrence. And since the true cross sectional dimensions of the reflecting element of the UAV are unknown, it is necessary to search for resonance by a smooth or a step change in sensing frequency with increments of no more than tens of MHz. Therefore, the only solution option is to develop a multi-functional integrated complex of detection and identification of UAVs based on the use of radar for slow-moving low-flying targets (that is, with low Doppler signature) and the optoelectronic system.

The radar analyzes the signature and the kinematics of the UAV for the purpose of its classification and identification, and signals to the optoelectronic/infrared system (OIS) for more accurate identification. OIS also provides high-precision target's azimuth and elevation data. Target identification system is also assisted by the avionics software system, which is based on the "unique radio-frequency radiation" of UAV.

Scanning of whole frequency range (searching through all wave lengths, which are proportional to size of the design elements) and detection accuracy increase is provided.

The advantage of proposed multi-functional integrated complex of detection and identification of UAVs is the ability to detect single point heat objects in different points, even in the case of existing marks of local items in the processed array. Contrast images of thermal objects obtained on the screen allow defining their angular position, the quantitative composition and other characteristics without pretreatment of the human operator, which leads to an increase in information capacity and ease of the complex operation.

Some important radar techniques to classify airborne targets are High Range Resolution Profiling (HRRP), Inverse Synthetic Aperture Radar (ISAR) and analysis of micro-Doppler (m-D) signatures. The Jet Engine Modulation is a modulation of the radar echo signal from flying objects by rotating propellers of engines or compressor and turbine blades of jet engines [4]. Classification on the basis of HRRP and ISAR relies on high resolution. To capture the spatial structure of mini-UAVs centimetre resolution is required.

Consequently wide signal bandwidths are mandatory and in case of ISAR also long observation times with associated comprehensive motion compensation. HRRP and ISAR are demanding radar modes suitable for sophisticated radar systems (in terms of RF hardware and processing). With respect to analysis of micro-Doppler signatures, there is no need for high resolution or complex signal processing. Detection can be performed using moderate range resolution, i.e. of the order of decimeters, and afterwards detailed Doppler information can be obtained by operating the radar in Continuous Wave mode.

The micro-Doppler properties of a target are determined by moving and rotating parts in addition to the main body motion. The moving parts induce frequency and amplitude modulations on the backscattered radar wave. These modulations are unique for different types of targets since they depend on the specific configuration and rate of motion of the target's moving parts.

Once the signal from radar is sampled, it passes through the m-D signature estimation, filtering, alignment, feature extraction and classifier blocks, then the final decision (with confidence score) is made.

The micro-Doppler signature of the moving target is estimated as the magnitude of the spectrogram of the Doppler signal.

The noise together with clutter could be removed from the observation by the "spectral subtraction" noise reduction procedure [5]. The main idea of this approach is subtraction of an estimate of the average noise spectrum from the noisy signal spectrum.

In order to extract behavior of micro-Doppler features the motion of the target must be compensated. This can be done by tracking the change of velocity of the target's body.

The features are based on extraction of bases of the micro-Doppler signature. These bases are orthogonal to each other and contain essential information about the rotating parts of the target. After the alignment we assume that the spectrogram can be viewed as a low rank matrix.

First we need to compute the correlation between different frequency components. Second step is to estimate eigen pairs (eigenvector and correspond eigen value) of correlation matrix.

Next, the Fourier transform of the eigenvectors is computed to obtain features with strong "energy compaction" property, i.e. the features where most of the signal information is concentrated.

As a classifier it is used neuron networks.

Testing UAV detection and detection algorithms is performed as a result of the simulation of the UAV motion dynamics at various approach angles of it for each of the systems that make up the complex and the whole complex.

IV CONCLUSION

The analysis of possible radiation fields (optical, thermal) and identification of the UAV-like objects by optical and, in particular, infrared systems was performed. It is shown that the development of UAV detection and identification systems based on the analysis of the optical and thermal fields is relevant. A review of existing systems of this type was performed.

Reasoning of UAV and evaluation of its geometrical parameters for further work on the creation of optoelectronic UAV detection and identification complexhas been performed. It is shown thatthe only solutionoptionis to develop a multi-functional integrated complex of detection and identification of UAVs based on the use of radar for slow-moving low-flying targets (that is, with low Doppler signature) and the optoelectronic system.

REFERENCES

[1] V. M. Sineglazov and A. V. Brykalov, *Computer-aided design of unmanned aerial vehicles*: monograph, Kyiv, OOO "NVP "Interservis", 2012. 268 p.

[2] V. M. Sineglazov, A. G. Protasov and A. A. Ketkovich, *Active thermal introscopy*, Kyiv, Technika, 1993. 168 p.

[3] P. Molchanov, R. I. A. Harmanny, J. J. M. de Wit, K. Egiazarian and J. Astola, "Classification of small UAVs and birds by micro-Doppler signatures". *Military & aerospace electronics magazine,* http://www.militaryaerospace.com/topics/uav.htm

[4] M. Skolnik, *Introduction to Radar Systems.* McGraw-Hill, 1962.

[5] S. V. Vaseghi, *Advanced Digital Signal Processing and Noise Reduction.* John Wiley & Sons, 2006.

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В. М. Синєглазов. Структура комплексу виявлення та ідентифікації БПЛА

Проаналізовано можливі поля випромінювання об'єкта БПЛА за допомогою оптичних і, зокрема, ІЧ-систем. Представлено структуру комплексу виявлення та ідентифікації безпілотних літальних апаратів.

Ключові слова: безпілотний літальний апарат; виявлення та ідентифікація систем; багатофункціональний інтегрований комплекс.

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Напрям наукової діяльності: аеронавігація, управління повітряним рухом, ідентифікація складних систем, вітроенергетичні установки.
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В. М. Синеглазов. Структура комплекса обнаружения и идентификации БПЛА

Проанализированы возможные поля излучения объекта БПЛА с помощью оптических и, в частности, ИК-систем. Представлена структура комплекса обнаружения и идентификации беспилотных летательных аппаратов.

Ключевые слова: беспилотный летательный аппарат; обнаружение и идентификация систем; многофункциональный интегрированный комплекс.

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