Optical Information And Measurement System for Polygon Testing of Small-Dimensional Aircraft

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Оптична Інформаційно-Вимірювальна Система для Полігонних Випробувань Малорозмірних Літальних Апаратів

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***Abstract*—The work is devoted to the development of recommendations for the construction of an optical information and measurement system that provides the detection and support of small-sized aircraft in their field testing**

***Анотація*—Робота присвячена розробці рекомендацій, щодо побудови оптичної інформаційно-вимірювальної системи, яка забезпечує виявлення і супровід малорозмірних літальних апаратів при їх полігонних випробуваннях**

Keywords—optical-electronic station of trajectory measurements; field testing; small-sized aircraft

Ключові слова—оптико-електронна станція траєкторних вимірювань; польові випробування; малогабаритні літаки

I. Introduction

In the context of the intensive development of modern samples of small-sized aircraft (SSA) of special purpose, to test their characteristics at the landfill, there is a need for the development of a modern model of the optical-electronic station of trajectory measurements (OESTM).

OESTM provides detection of air targets in the visible and infrared spectrum range, tracking and issuing coordinates in real time.

Homes can be used for various flight experiments, attestation of flight characteristics of the air target.

OESTM provides information on the trajectory and video information to control the characteristics of small-sized aircraft, with further analysis of their technical characteristics.

For measurements of external trajectory flight parameters of test objects in the whole range of heights and speeds of their flight, registration, processing, transmission of results of trajectory measurements and video images of objects or their operation in real time, maintenance of test objects in any time of the day it is necessary to combine several OESTM into a single information and measuring system (IMS) of the landfill [1, 2].

The authors carried out a patent search and analysis of the existing developments of the IMS [3, 4] and separately considered over 200 designs of USA, France, Britain, Israel, Canada, Russia, Belarus, and others. On this basis, it is concluded that at this time the possibilities of the known analogues of the IMS do not allow to provide growing requirements:

- to the accuracy of the measurement of external trajectory parameters of the flight SSA;
- to the conditions of maintenance of objects of testing throughout the range of heights and speeds of their flight at any time of day;
- before registration, processing and transfer of results of trajectory measurements and video objects of objects during their real-time operation.

Thus, there is a problem regarding the insolvency of the testing ground to provide testing of modern samples of specially designed SSA. To solve this problem, a new solution is proposed for the methodology of constructing the IMS, its components and working algorithms are new and consistent with the world level.

II. JUSTIFICATION OF THE RELEVANCE OF RESEARCH

The main objective of the testing ground is to measure the external-flight parameters of the flight of objects (coordinates, velocity vector, angular position in space, etc.). The values of these parameters assess the quality of the operation of objects and identify the reasons for the emergence of abnormal situations. OESTM are used to measure these parameters. However, despite the large assortment of OESTM offered by the modern market, such systems are not suitable for field testing of modern SSA.

This is due to the following reasons:

1. Large mass and dimensions of the considered measuring systems do not allow to speak about their mobility in the conditions of the testing ground. The disadvantage of transportation and the complexity of service (in many respects as a consequence of large masses and dimensions) in field conditions during field trials makes it impractical, and sometimes impossible, to use them in principle.

2. Dependence on the conditions of illumination and on weather, as well as the limited range of maintenance of SSA.

Consequently, the use of existing optical measuring equipment is not possible, therefore, for the measurement of foreign-trajectory parameters of the SSA movement, the development of specialized OESTM should be developed and their integration into a single testing center of the testing ground.

Thus, the task for solving this study is relevant.

III. THE PURPOSE AND TASKS FOR WHICH THE RESEARCH WAS DIRECTED

Object of study. Processes of the functioning of the IMS during external-dimensional measurements of the parameters of the SSA movement during field-testing.

Subject of study. The analysis of the limitations of the IMS based on OESTM for the detection and high-precision maintenance of SSA.

The purpose of the work is to develop recommendations for the construction of an automated optical IMS, which provides support for SSA.

In order to achieve this goal a solution of the following scientific and technical tasks is necessary:

1. Determination of the limitations of OESTM in detecting and providing high-precision SSA support.

2. Determination of the error of trajectory measurements of SSA.

3. Comparison of trajectory measurements of SSA using the angle-distance-finding method or the direction finding method.

IV. COMPOSITION OF OPTOELECTRONIC STATION OF TRAJECTORY MEASUREMENTS

In the course of research, an experimental sample of OESTM will be used. The structure of which includes:

- high-precision support-turning device;
- a thermal imager;
- a television camera;
- rangefinder.

The support-turning device (STD) is intended for installation of an opto-electronic module (OEM), which includes television and thermal imaging channels, as well as a laser rangefinder. The mean square error of the angular coordinates of the STD is 10 angle sec.

Optoelectronic module:

1. Television channel. FCB-EV7520 Modular, integrated with lens camera, 2.13 MP.

ТАБЛИЦЯ II. THE MAIN CHARACTERISTICS OF THE TELEVISION CHANNEL

Sensor size (optical)	1/2.8"
The ratio of S / N	50 dB
Total pixels (H × V)	1920×1080 pixel
Sensitivity	0,01 Lk
Zuma	4.3 mm – 129.0 mm
Focus, f	F1,6 – F4,7
Horizontal field of view	63.7° – 2.3°

2. Thermal imaging channel.

ТАБЛИЦЯ III. THE MAIN CHARACTERISTICS OF THE THERMAL IMAGING CHANNEL

Detector type	FPA, 640x480 pixel
Pixel size	17 microns
Temperature sensitivity	65 K

3. Laser range finder.

ТАБЛИЦЯ IV. THE MAIN CHARACTERISTICS OF THE LASER RANGE FINDER

Detector type	0.5±0.2 mrad
Pixel size	~8-10 mJ
Temperature sensitivity	~15±4 ns
Range measuring	20.000 meters

V. ERROR OF TRAJECTORY MEASUREMENTS

The OEM television channel includes: TVS – TV sensor; MB – measuring block; IRD – indication and registration device; CSG – control signal generator; AA – actuator (servo drive STD). Television sensor TVS has in its composition a lens O, photomatrix FM, electronic module EM (video amplifier, clock generator, etc.). The television sensor forms an image of the SSA located in the field of view of the lens and transmits it as an electrical signal to the measuring unit. The measuring block serves to preprocess the image. An executive device, based on signals from the control signal generator, changes one or more parameters of the television sensor (for example, the direction of the optical axis, the exposure time, the degree of opening of the lens aperture) so as to optimize the monitoring conditions of the SSA.

According to the functional scheme of the OEM TV channel, you can determine the contribution of the blocks to the overall error. All without exception, the blocks are sources of errors in the measuring system. One of the main sources of errors is a pair of lenses – a photographic matrix.

The error introduced by a pair of lens/photodetector, in angle, is evaluated as:

$$\otimes\langle\, T\varsigma\Sigma = 2\alpha\rho\chi\tau\alpha\nu\ [\lambda\pi\iota\chi/2\phi], \qquad (1)$$

where: *lpic* is the geometric size of the pixel; *f* is focal length of the lens.

The angle error of the TVS in accordance with the parameters of cameras and lenses used in OESTM is given in Table 4.

ТАБЛИЦЯ V. ERROR TVS

Channel	$\Delta\alpha_{TVS}$, angle sec
Long-focal TV channel	0.756
Heat-visional channel	2.813

Errors occurring in MB and CSG affecting the measurement result are largely determined by the methodology and mathematical algorithms chosen for their work. The calculation of the position of a point object on each video frame occurs at an accuracy of not less than 1 pixel. However, in case of a short-term disruption of escort due to overlapping of the target with other objects (tree, cloud, etc.), in conditions of obstacles (meteorological conditions, solar glare) the error will increase.

In video systems installed on mobile platforms, taking into account the error of the AA (angle sensors, servo drives) is an extremely important task, since at the present level of the development of the element base, the errors of the rotary platform, as a rule, dominate the errors of the optoelectronic component of the measuring system. AA error for OESTM is equal to 5 angular seconds.

The following factors contribute to the additional error in the measurement of OESTM:

1. Errors due to discrepancy between the centers of the rotary platform and elements of the optical system. With any deviation of the constructive placement of the optical system on the platform from the idealized true angle α, the direction to the target will be different from that actually fixed by the photomatrix of the optical system of the angle ά. The error Δα = α–ά depends on ΔD, the distance between the centers of rotation and the fixing point of the video system, and D, the distance to the SSA.

2. Errors due to the choice of the design of the STD and the placement of the platform for the OEM. Errors of this kind are connected with the accuracy of the installation of the platform plane for fixing the optical system relative to the axes of rotation of the STD and with the possibilities of its alignment. When qualitatively aligned, they can be reduced to zero. They are evaluated only in an experienced way, in the so-called calibration of the zero point of the measuring system.

3. Mistakes related to the non-synchronization of frame registration moments with the corresponding registration of the angular position of the rotary platform. This situation occurs when the fixation of the angular position occurs at the signal of opening the electronic shutter of the optical system or, conversely, when the optical system shutter opens when the corresponding signal from the platform arrives when its position is known. It should be borne in mind that the passage of such signals takes some time, because on their way there are logical elements with a certain speed. Typically, the total delay they make does not exceed hundreds of nanoseconds, so this kind of error can be neglected.

4. Errors caused by the physical state of the atmosphere. Atmospheric Earth Refraction can greatly distort the measurement of the angles of the place (ε_m) performed by the OESTM in the surface air layers. In addition to the effect on the magnitude of the total error, the atmosphere causes a weakening of the intensity of the electromagnetic (light) wave, which leads to a decrease in the range of optical measuring instruments. Corrections for refraction to the value of the angles of the place are taken into account by the expression:

$$\sum_{\delta} = \sum_{\mu} \pm \otimes\sum, \qquad (2)$$

where ε_d is the real angle of the place of the SSA; $\Delta\varepsilon$ is depends on the temperature, humidity and pressure of the atmosphere, as well as on the angle of the place and the distance of the SSA from OESTM.

Fluctuations in the SSA image due to the turbulence of the atmosphere do not cause a systematic error in the measurements of vertical angles, but random errors increase to 40...45" and more and can only be evaluated qualitatively.

5. Methodical regular error, which is caused by the chosen method of trajectory measurements. Static treatment, based on the use of structural and temporal redundancy when using three (two) OESTM simultaneously, can increase the accuracy of the results of trajectory measurements in comparison with the one-point method.

6. Instrumental random errors of measuring instruments. In order to assess the accuracy of the measuring instruments at the measuring point and the measuring line, they undergo periodic metrological certification (certification).

7. Square-to-right deviations of a single time service (STS) 1 microsecond;

8. Geodetic binding of the points of installation. The geodetic coordinates (latitude, longitude, height) of the points of its standing, as well as the orientation of the measuring axes in relation to "their" local meridians and the horizon, should be determined for the OESTM. The geodetic binding of the points of the OESTM facility is carried out with errors not exceeding 30 cm.

Measurement errors in angle (at an angle of azimuth or at the angle of a place) for one $\Delta\alpha 1$ according to the structural scheme can be represented as:

$$\otimes\langle_1 = \otimes\langle_{T\varsigma\Sigma} + \otimes\langle_{MB,\ X\Sigma\Gamma} + \otimes\langle_{AA}, \qquad (3)$$

where $\Delta\alpha_{TVS}$ is the error of the TVS, $\Delta\alpha_{MB,\ CSG}$ is the errors of MB and CSG, $\Delta\alpha_{AA}$ is the errors of blocks AA.

Error of measurement of range Δr is determined by tactical technical characteristics laser range finder.

Thus, the total error of measurement of the coordinates of a point goal using one OESTM, depending on the channel involved, is given in Table 5.

ТАБЛИЦЯ VI. ERROR OF ONE OESTM

Channel	**$\Delta\alpha_1$, angle sec**	**$\Delta R(\Delta\alpha 1)$, m at distances to the object 5 km**	**$\Delta R(\Delta\alpha 1)$, m at a distance of 20 km**	**Δr, m**
Long-focal TV channel	6.513	0.158	0.632	2
Heat-visional channel	10.626	0.258	1.03	2

In addition to the errors inherent in each OESTM separately, with sequential arrangement of video systems along the route of the SSA flight there are specific errors. In the general case, the moments of the exposure time of the frames of the first video system do not coincide with the moments of exposure of the frames second, and sometimes the video recording frequency may be different. To compensate for time mismatch, a linear interpolation method is used. Since the time interval between the moments of exposure is small enough, we can assume that the angular change in this segment is linear in time.

The total error of measurement in the use of two OESTM can be expressed in the form:

$$\otimes\langle = \otimes\langle_1 + \otimes\langle_{1.2}, \qquad (4)$$

$$\otimes® = \otimes®_1 + \otimes®_{1.2}, \qquad (5)$$

where $\Delta\alpha_{1.2}$, $\Delta\beta_{1.2}$ – respectively error azimuth and angle of the target's with the joint processing of information from two stations.

When properly positioned OESTM on the road on the route SSA can minimize the measurement error of coordinates. To do this, it is necessary to be able to estimate the potentially achievable measurement accuracy in each particular case of equipment placement at the landfill.

VI. CONDUCTING TRAJECTORY MEASUREMENTS USING AN ANGLE-DISTANCE DETECTION METHOD

Conducting trajectory measurements using an angle-distance detection method.

For conducting trajectory measurements on the territory of a polygon, it is necessary to create a network of geographically dispersed OESTM, forming a single IMS. Each OESTM in its area of responsibility is programmed to support the target in the predicted trajectory. The programming process is automated and carried out simultaneously for all OESTM. For the purpose of issuing a target for each OESTM, it is proposed to use the technology of the sensory infocommunication network [6-13]. It is suggested to use

IEEE 1588 Precision Time Protocol (PTP) to synchronize OESTM. The number of simultaneously involved OESTM depends on the type of target (aircraft, helicopter, quadcopter), the length of the trajectory, which requires the registration of its flight coordinates, meteorological conditions and permissible error of construction of the trajectory. If the listed conditions of trajectory measurements can be carried out using the angle-distance-finding method, one or more of the OESTM located along the target's path are working. In this case, OESTM are arranged so that, during trajectory measurements, the range from OESTM to the target does not exceed the range allowed by the laser range finder for the given data, and the minimum distance to the target is limited to the permissible angular velocity of the target maintenance for the STD and the flight altitude of the target.

For unambiguous determination of the position of a goal in a three-dimensional space, the OESTM must be measured:

- the range of *Dt*;
- the angle of the place of the target ε and its azimuth β;
- the radial velocity of the target *Vr*.

The values of the measured coordinates *Dt*, ε, β essentially form a three-dimensional spherical coordinate system, tied to the horizon and northward to the center at the point of standstill.

To obtain information about the trajectories of the target movement, it is necessary to measure the values of the coordinates of the target repeatedly in time, and then link the resulting points to a single line.

The accuracy of measurements of OESTM is characterized by median error of measurable quantities: azimuth β, angle ε, inclined range of *Dt*, angular rate, velocity *Vr*.

VII. Conducting trajectory measurements using the direction detection method

If the application of the angle-distance detection method does not allow conditions or it does not provide the necessary parameters of trajectory measurements, then the direction detection method is used. Two (or three) OESTM simultaneously track the movement of one object and determine its coordinates in the function of time. The work of all OESTM synchronizes the service of a single time.

Typically, the IMS consists of three OESTM. One of them performs an auxiliary function and can be used to control the determination of the coordinates of the object. In addition, the simultaneous tracking of three OESTM allows to exclude random errors of measurements when accompanied by the object under sharp angles, as well as in the case when the sun falls in the field of view of one of the OESTM.

When placing OESTM for measurements by directional method, the following considerations should be followed:

1. The location of all OESTM should provide direct visibility within the entire area of the trajectory measurements of the flight of the airspace.
2. Overlap of measuring zones with neighboring OESTM for obtaining continuous measurements of the SSA trajectory.
3. OESTM are placed on both sides of the airplane's flight trajectory (preferably on even distances) in order to reduce methodological errors. The methodological error of trajectory measurements depends on the choice of flight directions for a pair of geographically dispersed OESTM. It is recommended to choose the direction of flight perpendicular to the measuring base closer to its middle.
4. The angular velocity of movement of SSA for OESTM should not exceed the permissible angular tracking speeds for these measuring instruments.
5. In order to achieve high accuracy of trajectory measurements, the length of the measuring base must be in the appropriate relation to the airship's height, the line of sighting by its measuring instruments must intersect at right angles. Reducing this angle increases the methodological error.
6. Arrangement of OESTM should take into account the position of the sun (against the sun, measurements are not carried out) in the hours when it is necessary to use them.

To determine the location of the target in the space by a triangulation algorithm, three independent measurements (or two azimuths and a point of the space, or azimuth, and two angles of the place) must be carried out, which requires two OESTM. Then, the position of the target will be defined as the point of intersection of the three planes specified by these angles.

The accuracy of the measurements by the triangulation algorithm is characterized by median error of the measured values: azimuth, angle of the place.

The accuracy of determining the coordinates of a target is usually estimated with the following assumptions:

- systematic errors are detected and eliminated;
- the random error has a normal distribution law;
- the curvature of the earth's surface is not taken into account;
- the inaccuracy of the time-bound binding of the measurement results of two measuring points to the STS does not exceed $2 \cdot 10^{-6}$ s;
- the measurement errors of the primary parameters are independent.

VIII. Main results

- the general requirements for the IMS are substantiated, as well as the specific requirements that are presented to individual OESTM during foreign-sector measurements of the parameters of the SSA movement during landfill tests;
- the errors of trajectory measurements of SSA are determined for the experimental sample of OESTM;
- for a network of geographically dispersed OESTM, forming a single IMS, a comparison of the trajectory characteristics of SSA with the use of the angle-distance detection method and the direction detection method.

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