ENHANCEMENT OF TRANSPORTATION SAFETY BY REMOTE SENSING DEVICES

Ivashov, Sergey I., *Bauman Moscow State Technical University, Moscow, Russia.*
Bugaev, Alexander S., *Moscow Institute of Physics and Technology, Moscow, Russia.*
Tataraidze, Alexander B., *Bauman Moscow State Technical University, Moscow, Russia.*
Skrebkov, Alexey V., *Russian University of Transport, Moscow, Russia.*

ABSTRACT

Improving safety of rail transportation in the face of increasing speeds and traffic intensity and the presence of a terrorist threat requires introduction of new technical means of surveillance and control. A particular task is development of measures to prevent accidents and catastrophes, as well as to eliminate their consequences. The use of Earth remote sensing means, which allow to receive information from large areas and with a sufficiently high resolution, can significantly help in implementation of these tasks. The article deals with variants of satellites and remotely piloted aircrafts systems receiving information in various ranges of the electromagnetic spectrum. Their advantages and disadvantages, opportunities of joint use are analyzed.

Keywords: rail transportation safety, remote sensing of the Earth, satellites, remotely-piloted aircraft, aerial photography, radar sounding, image processing.

Background. *In scientific publications of recent years [1–7], the possible applications of remotely piloted aircrafts (RPA) and other remote sensing facilities, including ground survey satellites, in order to ensure rail transportation safety, are shown in sufficient detail.*

Earth remote sensing (ERS) is a method of obtaining information about an object or phenomenon without direct physical contact with the object itself, for example, from air or space vehicles. Such information can be obtained in different ranges of electromagnetic waves, but other types of emissions and parameters can be recorded as well: radiation, gravity, terrain measurements, etc. Sounding methods are divided into passive methods (naturally reflected or secondary thermal emissions of objects on the Earth's surface due to solar activity is used) and active methods (using stimulated emission of objects initiated by an artificial source of directional action, for example, by radar or laser). Depending on the problem to be solved, one or another type of equipment carrier and its composition should be used.

Objective. *The objective of the authors is to consider provision of transportation safety by means of remote sensing.*

The article is devoted to the study of the possibility of combined use of various data sources.

Methods. *The authors use engineering methods, comparative analysis, physics, geodesic, attelite navigation, IT and mathematical methods.*

Results.

Advantages and disadvantages of RPA

If RPA were used previously exclusively for military purposes, it is now their civilian application that is becoming increasingly relevant. The initial interest of the military, which arose in the late 1960s, was dictated by the desire to avoid life risks for crews while performing reconnaissance flights, as well as strikes at explored targets. The drawback of those aircrafts was the need to return to their territory after completing the mission to develop films with captured images and to interpret obtained materials. This reduced the immediacy of obtaining information.

Further, the most successful development of RPA took place in Israel (tactical and operational-tactical devices and the USA (operational-tactical and strategic RPA). Progress in development of their new generation is primarily associated with the advent of digital devices, including cameras operating in different wavelength ranges, satellite navigation aids and satellite communications. This significantly improved the characteristics of the on-board equipment, primarily mass dimensional features, and allowed to improve the flying qualities of RPA.

Modern civilian RPA are characterized by a lower operating cost and no need to use stationary aerodromes (as a rule, they are launched from mobile catapults or directly from the operator's hand). Particular progress was made in development of multi-rotor helicopter-type devices with electric traction. They are of simple design and cheap. This is due to the lack of such an integral element for conventional helicopters, as the blades' swashplate, and the use of asynchronous control of traction of electric motors, which makes it possible to control movement of the apparatus in flight. The six-rotor RPA, shown in Pic. 1, was used to obtain images of the infrastructure of the VNIIZhT experimental ring in Shcherbinka. Another advantage of this type of RPA is the fact that their use in the railway right of way and

a)

b)

Pic. 1. General view of helicopter-type RPA: a) in flight with a camera installed in a gimbal suspension; b) an operator with a control panel.

● **WORLD OF TRANSPORT AND TRANSPORTATION, Vol. 16, Iss. 4, pp. 180–192 (2018)**

Ivashov, Sergey I., Bugaev, Alexander S., Tataraidze, Alexander B., Skrebkov, Alexey V. Enhancement of Transportation Safety by Remote Sensing Devices

at altitudes less than 100 m does not require special permits for flights.

The disadvantage of multi-rotary RPA is a relatively short flight time (usually less than 1 hour) and, consequently, the associated limitations on range and altitude of the flight. However, the type of aircraft is extremely convenient when the operator controlling their flight is directly at or near the site of the event. In this case, information on what is happening on the ground can be obtained in real time, which is necessary, for example, in the aftermath of a railway catastrophe. The increase in flight time can be achieved due to replaceable batteries during intermediate landings, although the limitation on the radius of action remains, and it is significant.

Analysis of satellite resources

While in the 1960s and 1970s the main consumers of satellite information (photo and radar reconnaissance) were military, and the information itself was of a secret nature, in recent decades a significant segment of consumers is a very lucrative civil sector. First of all, the tasks to be solved by the ERS satellites include:

• research of natural resources and rational nature management;

• prediction, flow analysis, monitoring of emergencies and elimination of their consequences;

• exploration;

• weather forecast;

• control over the environment and sources of its pollution;

• agriculture;

• forestry;

• construction and many other industries.

During remote sensing satellites record emissions from the Earth's surface in various ranges of electromagnetic waves. As a rule, multispectral photography and side-scan radars are used. In some cases, for geodetic surveying, laser emission is used to measure the surface relief. The remote sensing data received from a spacecraft equipped with a visible range photo equipment is characterized by a high degree of dependence on transparency of the atmosphere and time of day. Therefore, to remove these limitations, the Earth remote sensing satellites equipped with side-scan radars were developed. Radar images have a worse resolution than optical images, but they make it possible to obtain images regardless of weather and time of day, which is of fundamental importance, for example, for piloting along the Northern Sea Route during the polar night.

At present, ERS satellites together with communication and navigation satellites make up a significant segment of the commercial services offered by the space industry. Often, ERS satellites are created by organizations associated with the military-industrial complex of their countries, which makes it possible to reduce the costs of their development through the continuity of design solutions with military satellites.

Usually, ERS satellites are launched into a so-called solar synchronous orbit (sometimes referred to as a heliosynchronous orbit), which has such parameters that a satellite located on it passes over any point of the Earth's surface in approximately the same local solar time. Thus, the angle of illumination of the Earth's surface will be approximately the same at all satellite passages. Constant lighting conditions are very well suited for receiving by satellites of optical images of the Earth's surface (including satellites for remote sensing of the Earth, meteorological satellites). The parameters of the solar-synchronous orbits lie in the ranges: the altitude above the Earth's surface is 600–800 km, the period of revolution is 96–100 min, and the orbit inclination is about 98°.

The main advantage of optical ERS satellites is the possibility of obtaining high-resolution images, which can reach 0,3 m. At the same time, these satellites are not all-weather, i. e. they cannot receive an image at night or of a terrain covered by clouds. If the first drawback can still be potentially eliminated, for example, using infrared optics, cloudiness, which in the middle latitudes in winter can conceal the Earth for weeks, and sometimes even months, makes it impossible to use optical satellites. All-weather satellites are areas radar reconnaissance satelites, although they have a worse resolution. In this case, radar provides additional possibilities, for example, obtaining images in different polarizations.

Databases of satellite information

The results of satellite imagery are widely spread thanks to the general availability and ease of operation, for example, through the Internet network. Satellite imagery and maps based on them are used even for solving everyday tasks, including for personal car navigation or taxi calling.

Free space information services, although they have a sufficiently high resolution, do not allow receiving rapid information, it is updated very rarely there. Photo images for the websites are usually obtained from the results of shooting in the warm season, in the absence of snow cover. Such images can be used for some types of analytical work, but do not allow to receive up-to-date information about an interesting event or object. For this, one must turn to specialized organizations selling satellite information. This service is payable, but it gives the opportunity to have data taking into account the customer's wishes: time, place and conditions of shooting, resolution of pictures and other parameters. The information can be either up-to-date, i. e. received recently, or obtained from their databases, accumulated in previous years. The latter is important for the information used for environmental studies, where it is necessary to compare the change in the landscape over a long period.

Comparison of information from different carriers

To perform the work on obtaining images of the transport infrastructure of the railways, an experimental ring (ER) of VNIIZhT was chosen. The choice of this object was due to the following circumstances. Firstly, it is well studied and is located close to Moscow. Secondly, because of its experimental status, there was no difficulty with the RPA permission to fly over its territory. Pic. 2 shows the ER image taken from the GoogleMaps database. The center of the ring is marked with a marker, its coordinates are: 55.521373, 37.550190 (northern latitude and east longitude in degrees, respectively). Inside the ring there is a holiday village. The ER itself consists of two double-track rings: external and internal. The outer has the shape of a regular circle, and the inner one contains a rectilinear segment.

In the lower left corner there is a depot. One of the areas of flights the resuts of which are used in our article, is marked with a square. The asterisk in the square is located on the site of the water tower, which served as a reference point for flights. An enlarged image of the tower obtained from the satellite is shown in Pic. 3.

Pic. 2. The image of ER VNIIZHT from the database Google Maps.
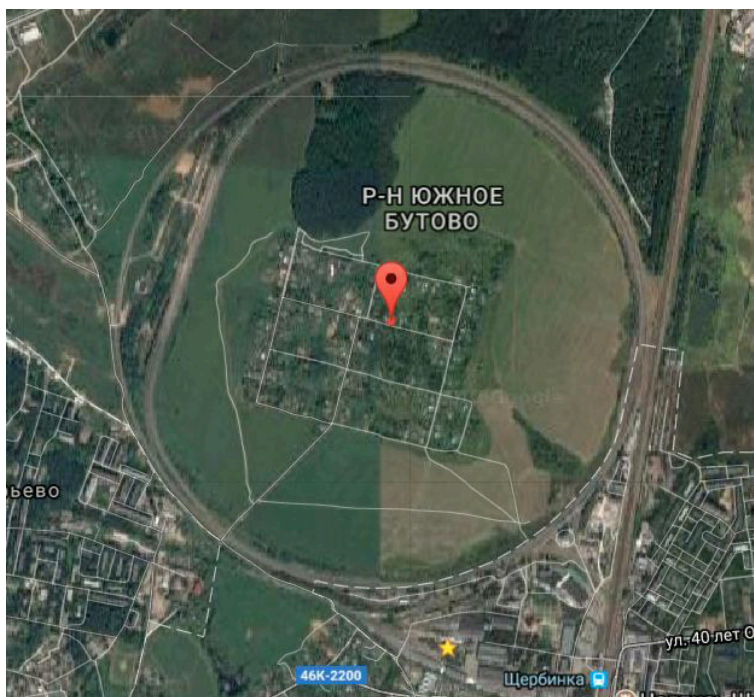
The roof of the tower has a conical shape and is covered with galvanized iron. Individual sheets of iron are joined together in the form of vertical ribs. The ribbed shape of the roof can be clearly seen even on a satellite image. The same area near the water tower was photographed from RPA, equipped with a camera on the gimbal suspension from a height of about 70 m, the result of the shooting is in Pic. 4.

Both pictures differ in location of rolling stock on tracks, since they are made at different times of the year. They also differ in both size and direction of the shadow cast by local objects, because images were taken at different positions of the sun in the celestial sphere. This circumstance underscores the importance of solar synchronous orbits, which were mentioned earlier and are usually intended for ERS satellites. Another advantage of the sun-synchronous orbits is the ability to determine the length of the shadow cast on the images obtained at different turns of the satellite's rotation, whether the object is being built or not and at what speed. Usually, this method is used to decode images of reconnaissance satellites, but it can be used in cadastral surveys, when it is necessary to reveal illegally constructed buildings on a large array of images. Here it is enough to subtract two images, obtained with a difference of several weeks or months, to fix newly constructed buildings and their height.

If we compare the resolution of both photographs, then it becomes obvious that images made with RPA have a much better resolution than satellite images. This is understandable, since the height of the orbits of ERS satellites is 400–600 km. The RPA have one more advantage over satellites: they are less dependent on weather conditions. In the presence of cloudiness, it is impossible to shoot in the visible spectrum from satellites. While RPA can fly below the cloud boundary and get the information they need.

Radar survey is all weather. Pic. 5 shows two large-scale images of the vicinity of the experimental ring, obtained from the GooleMaps resource data and the Sentinel-1 radar satellite database [8].

In the lower part of both pictures you can see Ostafyevo airport (on the left in the picture) and ER VNIIZhT (right). Both images have approximately the same scale, but the visible image contains more details than the radar picture. The scale of the above pictures can be easily estimated, given that the outer
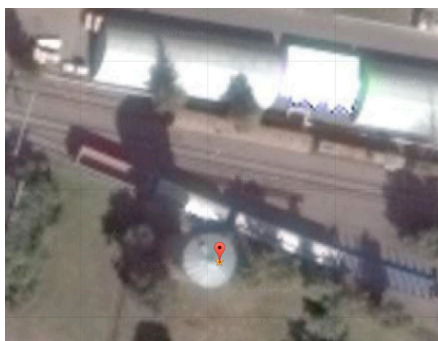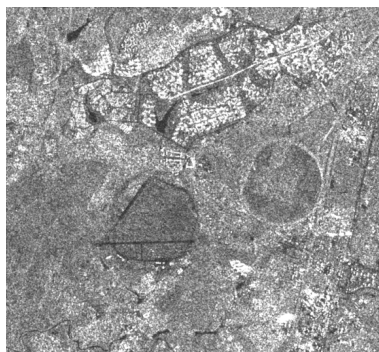

Pic. 3. Large-scale satellite image of the water tower area on the ER.

Pic. 4. Photo of the area of the water tower on the ER, received from RPA.
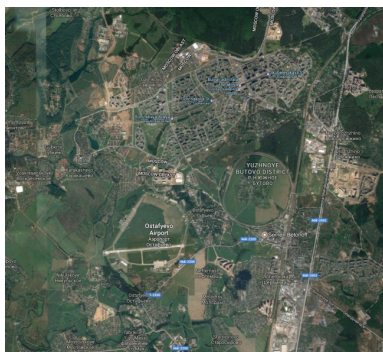
Pic. 5. Satellite images of the vicinity of the experimental ring:
a) an image of the visible spectrum from the resource GoogleMaps;
b) radar image from the European satellite Sentinel-1.

ring of the polygon has the shape of a regular circle with a diameter of 1912 m.

The advantage of radar, as indicated, is all-weather and round the clock operation. In some cases, radar images may be the only source of information. In this regard, we can conclude that to solve its tasks, it is important for Russian Railways to have access to a variety of remote sensing facilities.

Building 3D images

Modern image processing tools help to synthesize three-dimensional images of objects on the surface of the Earth on the basis of individual images obtained from RPA. This allows us to view objects from different angles and from different heights. Such technology can find its application in the design of compound infrastructure objects (bridges, tunnels, etc.), and also solve some problems of ensuring their safety.

As initial data for constructing a three-dimensional model of the surface of a piece of land with the railway infrastructure facilities located on it, 176 photographs were taken, collected during the flight of a helicopter-type RPA with six lifting rotors and a Canon EOS 5D Mark II camera with a gimbal suspension and Canon EF-S 17–55 f / 2.8 IS USM lens, Pic. 1. Examples of some initial photographs are shown in Pic. 6.

To synthesize a three-dimensional image, the problem of finding a correspondence between key points on different images is solved, it is performed by searching for points with minimally different descriptors – vectors of parameters describing the point. Thus, the SIFT algorithm describes each key point with a vector with 128 parameters, determined on the basis of local gradients in the vicinity of the point.

One of the most effective algorithms for filtering falsely defined correspondences of key points is RANSAC (Random Sample Consensus) [9]. The essence of the method consists in iteratively searching

for a better transformation matrix (fundamental matrix) between randomly selected N key points in one image and the corresponding points in the second one. As a result, points whose deviation as a result of applying the found conversion from the corresponding points on the other image exceeds a predetermined threshold, are removed from a set of key points.

To build a 3D surface model, it is necessary to set internal (focal length, coordinates of the principal point, distortion coefficients) and external parameters of the camera (position and orientation). The internal parameters are independent of external conditions and do not change from the picture to the picture. As a rule, internal parameters are calculated by shooting calibration objects, the geometry of which is known in advance, but can also be calculated without using them, provided there is a large number of pictures with common points [10]. External calibration is performed by triangulation of key points common to two or more frames.

The resulting three-dimensional model of the surface under different angles of observation and from different heights is shown in Pic. 7.

A more complete idea on the model obtained can be got from the video presented in [11]. Some features of the data used to build the model shoul be noted:

• a relatively small number of pictures;
• non-optimal flight trajectory of RPA;
• small overlap between images;
• lack of information about orientation of RPA and the camera, as well as of data on GPS/GLONASS coordinates.

Despite these features, the model obtained accurately reflects the nature of the terrain where the survey was conducted. The model was constructed using the mathematical support of Pix4DMapper [12].
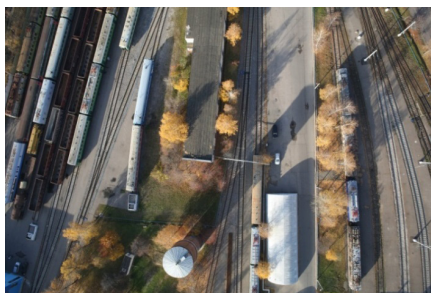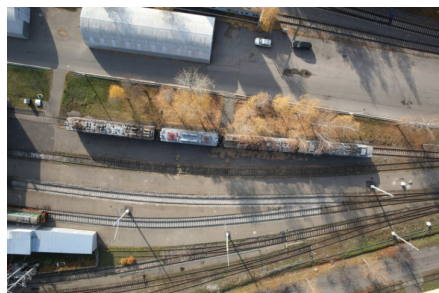
Pic. 6. Examples of initial images taken by RPA.

191
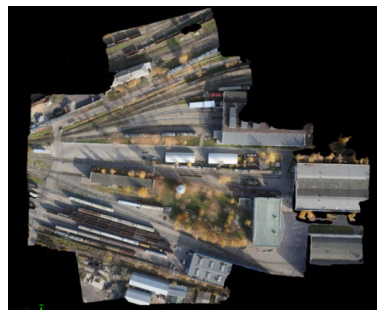
Pic. 7. Three-dimensional model of the surface.

Conclusion. *The analysis of the possibilities of using Earth remote sensing devices (ERS satellites and RPA equipped with various sensors) confirms that they can be effective for ensuring traffic safety on the Russian railways. Teh obtained information can be used to solve other problems, for example, when designing and building a railway infrastructure. The article shows that the effectiveness of remote sensing tools can be increased thanks to combination of satellite information systems and RPA, and the use of modern video processing facilities enables the construction of synthetic three-dimensional images of the infrastructure.*

REFERENCES

1. Eyre-Walker, R. E. A., Earp, G. K. Application of Aerial Photography to Obtain Ideal Data for Condition Based Risk Management of Rail Networks. The 4th IET International Conference on Railway Condition Monitoring, June 18–20, 2008, Conference Centre, Derby, UK.

2. Lievin, B. A., Bugaev, A. S., Ivashov, S. I., Razevig, V. V. Distantly Piloted Aircrafts and the Track Security. *World of Transport and Transportation*, Vol. 11, 2013, Iss. 2, pp. 152–157.

3. Grey, Eva. Worker drones: maintaining railway tracks from the air, May 16, 2016 [Electronic resource]: http://www.railway-technology.com/features/featureworker-drones-maintaining-railway-tracks-from-the-air-4893229/. Last accessed 24.06.2018.

4. Flammini, F., Pragliola, C., Smarra, G. Railway Infrastructure Monitoring by Drones, 2016. International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles & International Transportation Electrification Conference (ESARS-ITEC 2016), 02–04 November 2016, Toulouse (France), DOI: 10.1109/ESARS-ITEC.2016.7841398.

5. Shutko, A. M. Microwave radiometry of the water surface and soil [*SVCh-radiometriya vodnoi poverhnosti i pochvogruntov*]. Moscow, Nauka publ., 189 p.

6. Passive radiolocation. Methods of detection of objects [*Passivnaya radiolokatsiya. Metody obnaruzheniya ob'ektov*]. Ed. by A. P. Bystrov and A. V. Sokolov. Moscow, Radiotehnika publ., 2008, 318 p.

7. Bugaev, A. S., Ivashov, S. I., Levin, B. A., Nedorchuk, B. L., Razevig, V. V. Evaluation with the help of unmanned aerial vehicles of the danger of avalanches in the areas of passage of railway tracks [Otsenka s pomosch'yu bespilotnyh letatel'nyh apparatov opasnosti shoda snezhnyh lavin v raionah prohozhdeniya zheleznodorozhnyh putei]. Renaissance of railways: Fundamental scientific research and breakthrough innovations. Ed. by B. M. Lapidus. Moscow, Analytica Rodis publ., 2015 [Electronic resource]: http://www.rslab.ru/downloads/rzd_renaissance.pdf. Last accessed 24.06.2018.

8. [Electronic resource]: https://sentinel.esa.int/web/sentinel/missions/sentinel-1/observation-scenario/archive. Last accessed 24.06.2018.

9. Fischler, M., Bolles, R. Random sample consensus: a paradigm for model fitting with applications to image analysis and automated cartography. *Communications of the ACM*, Vol. 24, Iss. 6, 1981, pp. 381–395.

10. Hartley, R., Zisserman, A. Multiple View Geometry in Computer Vision. Cambridge University Press, 2004, 672 p.

11. RASKAN-4/4000. Radar for sounding of building structures [*RASKAN-4/4000. Radiolokator dlya zondirovaniya stroitel'nyh konstruktsii*]. [Electronic resource]: http://rascan.ru/download/rzd.mp4. Last accessed 24.06.2018.

12. Pix4Dmapper [Electronic resource]: https://pix4d.com/product/pix4dmapper/. Last accessed 24.06.2018. ●

Information about the authors:
Ivashov, Sergey I. – Ph.D. (Eng), head of Remote Sensing Laboratory, Bauman Moscow State Technical University, Moscow, Russia, sivashiv@rslab.ru.
Bugaev, Alexander S. – Academician of the Russian Academy of Sciences, D.Sc. (Physics and Mathematics), professor, head of the department of Moscow Institute of Physics and Technology, Moscow, Russia, bugaev@cos.ru.
Tataraidze, Alexander B. – Ph.D. (Eng), junior researcher of Remote Sensing Laboratory, Bauman Moscow State Technical University, Moscow, Russia, tataraidze@rslab.ru.
Skrebkov, Alexey V. – Ph.D. (Eng), associate professor of the department of Electric Trains and Locomotives of Russian University of Transport, Moscow, Russia, skrebkov_av@mail.ru.

● **WORLD OF TRANSPORT AND TRANSPORTATION, Vol. 16, Iss. 4, pp. 180–192 (2018)**

Ivashov, Sergey I., Bugaev, Alexander S., Tataraidze, Alexander B., Skrebkov, Alexey V. Enhancement of Transportation Safety by Remote Sensing Devices