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A. CELMS[1], I. TREVOHO[2], A. RATKEVICS[1], I. REKE[1], L. SULAKOVA[3]

[1] Latvia University of Life Sciences and Technologies, armands.celms@llu.lv;
[2] Lviv Polytechnic National University
[3] Riga Technical University

POSSIBILITIES OF AEROFOTOGRAMMETRIC TECHNOLOGIES FOR MONITORING OF THE STATE BORDER OF LATVIA

The paper describes the possibilities and results of the application of aerial photography and photogrammetry technologies in the Latvian state border maintenance processes (Ratkevics *et al*, 2017a) and the practice of using GIS technologies (McHaffie *et al*, 2018) in these works, to observe the obligations of international agreements.

The monitoring of the state border of Latvia resulted in considerable practical and theoretical experience. Photogrammetric technologies, together with GIS capabilities, offer significant reductions in monitoring of the state border costs and time surveying control works (Ratkevics *et al*, 2017b). In Research are used advantage, which practiced in Latvia, if aerial photography is regularly organized.

Describe possibilities of technologies of aerial photography – photogrammetric works for inspection and research works of terrain situation in the world are widely applied and developed already since the beginning of the previous century. These technologies at present in many cases (but not always) can replace also the classical geodetic and topographic surveying works, specially, when they shall be performed for considerable areas, this can be applied also to territories of state borders.

As the tasks of monitoring of the state border of Latvia are prepared, photogrammetry specialists can from the existing photographs obtain information on technical condition of the borderline, border zone and elements of border fastening. By use of GIS technologies, the effectivity of these activities obtains additional possibilities for correct spatial documenting, measuring, mapping and also modelling of all above mentioned activities and allows performance of this all in short deadlines.

Key words: State Border; surveying; geodetic reference system; GNSS; aerofoto.

Introduction

Possibilities of technologies of aerial photography – photogrammetric works for inspection and research works of terrain situation in the world are widely applied and developed already since the beginning of the previous century. Today they are widely used in the creation of cartographic materials and their databases, for evaluation of terrain situation, identification of the changes and identification of many other practical statuses of terrain situation and their changes (Ratkevics *et al*, 2017b). These technologies at present in many cases (but not always) can replace also the classical geodetic and topographic surveying works, specially, when they shall be performed for considerable areas, this can be applied also to territories of state borders (Ratkevics *et al*, 2016).

Impact of contemporary technologies considerably increases the possibilities of aerial photography technologies in the segment of obtaining and processing of results, as well as in segment of quality and possibilities of use of obtained results. They simplify and reduce in the same time the resources necessary for obtaining and processing of them. Therefore, availability and volumes of usage of these technologies increase rapidly and occupy new niches of usage.

Similar trends and possibilities are visible in the development of maintenance processes of state borders and of technologies applied there (Burban, 2012). The most important product of aerial photography, which in increasingly wider extent is used in the measures of maintenance of state borders, are digital orthophoto maps or orthophoto plans, which have completely replaced earlier traditional photo plans or photo maps [9].

Deadlines for development of products simultaneously with considerably higher quality indices (accuracy and resolution) are considerably reduced. Advantages of usage, speed and possibilities in the usage of equipment of geographic information systems (GIS) have considerably increased the effectivity of wide usage of these products (Pourabbas, 2014, McHaffie *et al*, 2018).

Following measures can be regarded as works of maintenance of state border, in the framework of which it is necessary to perform a number of geodetic and topographic surveying works, such as:

– creation and maintenance of a joint geodetic reference network necessary for maintenance of state border, regularly measurement of the selected geodetic networks, calculations and alignment of coordinates included;

– control of the location of the demarcated line of state border – comparison with the real terrain situation (monitoring);

– identification of places of incongruity of state border compared to documentation of the demarcated state border and determination of their parameters, documenting of incongruities, preparing for adoption or pushing of decisions of intergovernmental commission;

– provision of restoration or repair of lost or damaged border fastening elements and documenting of results;

– provision of re-demarcation processes of state border or their section according to decisions of intergovernmental commission (Law on the State Border…, 2009, Law on Agreement of the Government…, 2013).

There is a larger or smaller volume of geodetic and topographic surveying works in the listed types of works, for which diverse usable quality indicators to be reached are set.[1]

Creation and maintenance of geodetic reference network according to requirements of quality comply with parameters of creation and maintenance of state geodetic reference, which shall provide surveying and mapping works that shall be carried out in further border maintenance works, provision of accuracies of used remote sensing (photogrammetry) works included (Arhipov, 2011).

In further works, importance of photogrammetry works and accuracy of performance of them in connection with high quality geodetic support obtains large importance.

Remote sensing materials let to obtain possibilities of an additional – independent control of surveying results also in cases, when for specialists of both countries complete and independent criterion of recurrence of surveying is determined.

As the control of location of the demarcated state border is performed – comparison with the real terrain situation (monitoring) it is classically performed by visit to the field, usually it is done by representatives of the border guard (Arhipov, 2011). It is clear that more than 10 years old border demarcation maps are a bad aid for these inspectors, therefore, when inspection is started, it is advisable to prepare newest possible cartographic material or at least its replacement – usually orthophotomaps.

As the tasks of inspection are prepared, photogrammetry specialists can from the existing photographs obtain information on technical condition of the borderline, border zone and elements of border fastening. Result can be used for making inspection tasks more accurate and for planning of technical works of maintenance of state border elements.

By use of GIS technologies, the effectivity of these activities obtains additional possibilities for correct spatial documenting, measuring, mapping and also modelling of all above mentioned activities and allows performance of this all in short deadlines.

In the processes of re-demarcation of sections of the border and in design of results, contemporary aerial photography technologies together with GIS and GNSS technologies ensure enviable speed of performance of geospatial works, effectivity, quality and accuracies, which considerably reduces dear surveying and geodesy field technologies (Zagars *et al*, 2014), also contemporary unmanned aircraft aerial photogrammetry – photogrammetric technologies.

The entire complex of ongoing technological possibilities and changes today sets requirement to transform radically processes of development of documentation of classical state border demarcation and of maintenance– re-demarcation of border according to possibilities, requirements and needs of use of contemporary technologies in modern computerized environment (Law on the State Border…, 2009, Law on Agreement of the Government…, 2013).

In Latvia, requirements of maintenance of borders are determined by the law “Law of the state border of the Republic of Latvia”, its Article 5 “Maintenance of the state border” (Law on the State Border…, 2009). Procedure of maintenance of specific state borders is determined by international agreements. Based on agreement between two governments on April 10, 2013 *agreement* of government of the Republic of *Latvia* and of government of the Republic of *Belarus* on regime of *Latvian-Belarussian state border*, II section of which determines “PROCEDURE OF MAINTENANCE OF THE STATE BORDER” was signed (Law on Agreement of the Government…, 2013).

Taking into account that at present real state border maintenance activities are realized only on Latvian – Belarussian border, most of the research materials and examples apply to this state border.

When the paper was developed, goal was set – find out, what the extent is and what are quality indicators, with which it is possible to apply possibilities of technologies of aerial photography in the processes of maintenance of state borders.

For reaching of the goal following tasks were set:

1. To carry out identification of the location of the state border in most recent available aerial photography materials (orthophoto plans).

2. To carry out comparison of the new (according to aerial photo) place of state border line with official materials of demarcation of the state border.

3. To carry out field inspection for the state border in the entire length of it.

4. To perform comparison and analysis of the results of the field inspection and of cameral (on basis of aerial photography materials) inspection.

5. To carry out comprehensive evaluation for obtained comparisons and analyses.

Materials and methods

As the state border maintenance works on the Latvian – Belarussian state border, were started in 2013, after the signing of the agreement with the Republic of Belarus, Latvian specialists of geoinformation started to identify the situation for the solution of issues of their competency.

In the case of Latvian – Belarussian state border, it was stated that a great number of aerial photography materials is available, for which full-fledged photogrammetric processing is carried out and the materials are transformed into orthophoto maps and orthophoto plans of high accuracy.

Since the completion of demarcation of Latvian – Belarussian border works of aerial photography for the entire territory of Latvian state were performed in 2011, 2014 and 2018 and also territories of the state border were included there. Border demarcation documents were created by use of aerial photography works performed in 2005 – 2006[3].

The new aerial photography materials had considerably higher resolution than works performed during the demarcation. Material quality with each cycle of aerial photography was higher and higher and among the obtained photographs were also infrared images. Orthophoto plans created from infrared images increased possibilities of situation analysis, when works of interpretation of images were performed.

In original orthophoto maps of 2005, resolution was 0.8–0.7 m, which was very well for compilation of demarcation map of scale 1:10 000. Orthophoto plans of 2014 and 2018 had resolution 0.3–0.4 m, from them orthophoto plans of scale 1:5 000 were made, but they could be zoomed in to 1:1 000 and also to 1:500. Theoretically achievable accuracy of identified and fixed terrain objects was near to limits of 10 cm. Condition of accuracy is complied, if geodetic support of corresponding quality is available for creation of the orthophoto plan and theoretically achievable accuracy transforms into real accuracy.

Taking into account the obtained experience, for Latvian - Belarussian border (length of border 172.9 km) in 2015, a remote monitoring of the situation of the border was performed by use of aerial photography materials of 2014.

Results of aerial photography (orthophoto plans) were used for work in GIS environment, where they could be spatially matched with border demarcation map – accordingly prepared digital data sets of border demarcation map. For work in this environment, also orthophoto materials of earlier years (2005 and 2011) and lists of landmark coordinates were included. In Belarussian side, works were carried out similarly, however they were performed in stereo drawing mode. Specialists of Latvian side performed visual comparison of matching data with the most recent orthophoto material.

At the beginning, border boundary pillars and border vistas, which were visible, were identified - where land border was created. It was found out, that in the sections land border were not any deviations from the demarcated border, the only inaccuracies were connected with the impact of the graphic accuracy of the image of the demarcation map (M 1:10 000) to the depiction of the borderline. The places were identified in the new orthophoto material, where the borderline could be determined more accurate – borderline was put in centers of the landmarks visible in the images (which in 99 % cases were unambiguously recognizable in orthophotos).

The second stage of visual inspection was section of the state border along river Daugava. Here, in determination of terrain changes and of their extent, it was stated that two new islands are created in the riverbed. One island – in the Latvian side of the border (Fig. 1), the other in the Belarussian side (Fig. 2), which have already overgrowth of trees and shrubs.

Both islands, although they directly do not touch the borderline that is defined in the middle of the river, nevertheless indicated to the possibility to make location of the borderline that is defined in the river more exact in the future with condition that islands will remain during several years. It was possible without difficulties to find out that Latvian island in Daugava that is depicted in the demarcation map has considerable increased (more than two times). End points of this island upstream and downstream have already touched or even cross the demarcated state border line in the river (Fig. 3).

It was possible to determine quickly the areas of the identified islands or their differences, as well as to measure distances to the demarcated border or landmarks by use of measuring tools available in the environment of ArcGIS software[10]. In the same way it was possible to create quickly the vector data of the new shoreline drawing. Actually, a new map is created.

The third and most complicated stage of visual inspection are places, where border is defined along little rivers, brooks and ditches. In these cases, border zone was not created and cleaned from overgrowth, specially trees and shrubs. In these sections, visual inspection was considerably encumbered in all cases, when there was dense overgrowth of trees along the shores of watercourse. Foliage of trees and shrubs did not allow often to identify places of shoreline of watercourses and also state border boundary pillars situated below the trees. If photographs would be taken before trees have leaves – in spring it would make work considerably easier. However, it was possible to identify locations of more than 50 % of landmarks in theses sections. In these sections from orthophoto material, many deviations from the state border depicted in demarcation maps were stated. Most of these deviations were within the permissible limits of the

accuracy of the demarcation map. That is connected with the fact that the new orthophoto material provided much more detailed and accurate information on shorelines of little rivers and watercourse meanders. That is more detailed than it could be depicted in demarcation maps.

Fig. 1. New island on the border river Aerial photography 2014 with No. change's place.

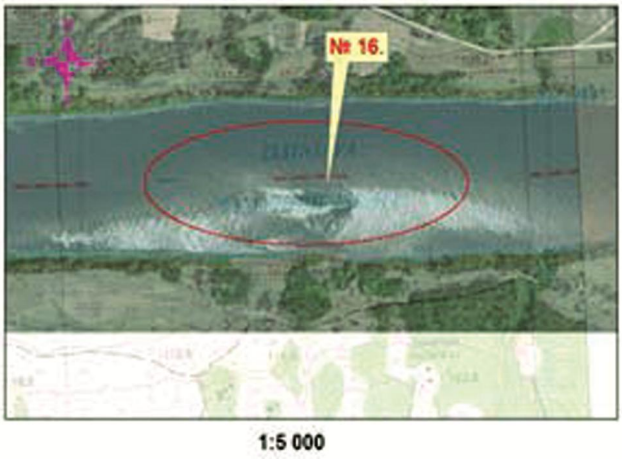

Fig. 2. New island on the border river. Aerial photography 2014 with No. change's place

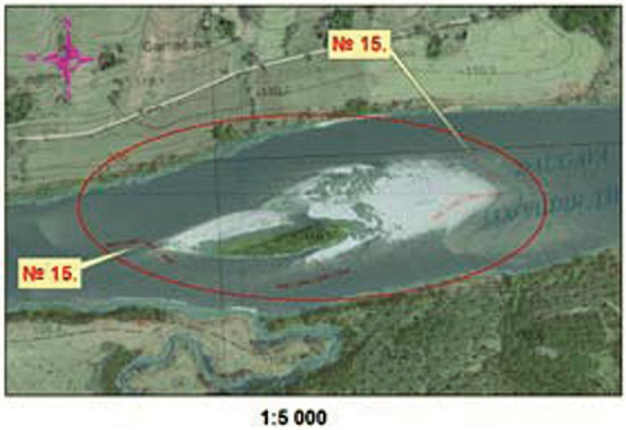

Fig. 3. Changes the size of island in border river. Aerial photography 2014 with No. change's places

In the same time, images indicated that there are many cases, when shorelines of little watercourses systematically change their location and place of the demarcated borderline touched newly established shorelines of these watercourses. Taking into account the size of permissible deviations defined in commission – 15 meters, all the identified changes of shorelines, which complied with this indicator, were fixed only for the knowledge of specialists. However, the changes that exceeded this indicator qualified for field checks and procedures of control surveying. However, in cases, when in the riverbeds of little watercourses, new islands or objects similar to them were identified, the size of permissible deviations was not taken into account and it was decided to inspect all these places in terrain.

Results and Discussions

In the result of the photogrammetric research, for inspectors of Latvian – Belarussian border, 17 fragments of the map (orthophoto combined with demarcation map) with 20 places provided for inspection were prepared. Specific tasks were defined for each inspection place. After the inspection of the border, in eleven cases parameters of changes were not questionable, they should only be confirmed. However, in nine cases of inspection there was not confidence in the obtained result.

Task of field inspection of the border was performed in 2016 (for the entire border 172.9 km). In the course of it, it was stated that such objects of changes as islands were unambiguously identified in full extent. However, changes of shores of little rivers were unambiguously determined only in half of cases. In other cases, they have not taken place at all (mainly, all cases under the foliage of trees) or stated in very insignificant extent (Table 1).

Table 1

Tasks of field inspection and results of their performance

Photogrammetrically identified problematic places	Places of inspection task		Results of inspection		
	Changes of riverbeds	Possible new islands	Changes of riverbeds	islands	Changes are not identified
20	13	7	6	7	7

In order to make sure on changes of the state border obtained, in 2017, geodetic-topographic surveying of the identified objects was organized. Mathematic determination of object parameters, of coordinates of locations of terrain objects and size of changes was carried out. At the works of topographic surveying, specialists of both

countries participated and used GNSS professional geodetic measurement instruments.

Specialists of both countries used geodetic instruments in real time correction mode by use of the nearest active GNSS base stations in the territory of the respective country. All the identified islands and places of changes of shores of rivers confirmed in the field inspection were measured. In the control process, measurements were made on border boundary pillars. Results in the most cases showed high level of coincidence of results between the positions of changes identified in orthophoto and positions obtained in the result of measurements. However, for the islands of Daugava river in relation to the lines defined in orthophoto map of 2014 noticeable changes have taken place due to spring flood in 2015 and 2016. Therefore, the mathematic accuracy for these results was not compared. In other cases, this period has not created significant changes.

In order to make sure on mutually comparable indicators of methods of identification of changes, field measurements were organized for a number of sections of the state border. For this purpose also border boundary pillars measured during the works of demarcation, which have not changed their place, were used. In total, test measurements were performed for 100 selected objects of the state border. In the result, the average comparison of new measurement results with places of objects determined in the orthophotos and their coordinated places in demarcation documents was obtained (Table 2).

Table 2

Mutual comparison of results of measurement of objects

Obtained average deviations		
Instrumental measurement - Orthophoto	Demarcation map - Orthophoto material	Instrumental measurement – Demarcation map
14 mm	120 mm	54 mm

As the gained experience and its results are analyzed, we can draw a conclusion that the modern possibilities of usage of aerial photography provide results of high quality, where accuracy of measurements complies with the highest requirements of surveying and geodetic measurements. Obtaining of the result of the measurement after the receipt of materials of aerial photography gives considerable economy of the consumed time and allows to ensure considerably greater density of points to be measured for diverse elements of terrain, contours and their boundaries.

The main precondition for achievement of successful result is obtaining of images of high resolution corresponding to the purpose of use during the photography. Proportion of the size of pixel of the image to the size of the territory to be included there is the main factor that limits the potentially achievable accuracy result. The greater is the resolution of images, the greater accuracy of measuring can be achieved as a result.

Precondition of the achievement of maximal accuracy is connected with availability of geodetic support of adequate quality in the territory of photography. This allows to increase the accuracy of orthophoto and photogrammetric works and their credibility above the level, which is ensured for these works by GNSS and inertial navigation systems existing in the equipment of photography. As additional geodetic support elements in the case of state borders, geodetically surveyed element of state border landmarks – border boundary pillars, which in open terrain can be identified unambiguously and clearly in aerial photographs of high resolution. These border boundary pillars ensure additional alignment of image blocks with visible support points, which have accurate data of geodetic surveying in three dimensions and their mutual distances along state border line do not exceed distance of 1km.

Theoretical accuracy of each point identified on orthophoto plan at such distances is identical with indicators of accuracy of surveying of the nearest border landmarks. Practically, the accuracy is limited by the certainty of the identification of the points to be measured, which depends on qualification of the specialist and on specifics of the depiction of recognizable elements in aerial photographs. For objects with clearly pronounced contours, accuracy of depiction is high, but in cases of partially covered or shadowed contours, they are considerably worse recognizable and therefore can be measured with lower accuracy.

Practice shows that the most important source of quality problems in the use of photography data is vegetation, trees and shrubs with leaves, which directly cover visibility of contours. In such situations, overgrown places make unwanted shading that make the quality of recognition worse. In general, problem of the impact of vegetation is significant in Latvia; it can be alleviated by organizing photography in suitable conditions (when trees do not have leaves).

Conclusions

1. Technologies of aerial photography and photogrammetric remote sensing in modern version become an effective complex of technologies of measures of monitoring and of maintenance of state borders, planning, realization and control of results.

2. Aerial photography works and photogrammetric measurements allow to replace works of field topographic

and geodetic surveying of large volumes and in measures of documenting of the state borders.

3. For the implementation of aerial photography technologies adequately prepared specialists of geoinformation and GIS are required.

4. Increase of the volumes of usage of aerial photography works and of indicators of quality of the obtained results is considerably furthered by the modern possibilities of GIS involved in the usage of them and equipment of GNSS measurement works.

5. In the performance of the aerial photography works, it shall be taken into account that in works of maintenance of the border, as the source of the most negative impact and problems, the negative impact of the vegetation of the territory continues to remain, especially, when trees and shrubs have leaves.

6. In order to make works more accurate, issues of resolution of aerial photography images and quality of the usage of the geodetic support of work territories shall always be addressed.

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