Research on the Effectiveness of Lidar Survey for Large Mapping

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Key words: Large Mapping, Unmanned Aerial Vehicle, Technology Performance.

Abstract

The analysis of the time spent on the processes and the complex of works on topographic mapping in accordance with production projects is given. The projects were carried out according to traditional technological schemes of work and technological schemes using airborne laser scanning materials to generate digital topographic plans at scale the 1:2000 based on the use of unmanned aircraft. The comparative performance of the technologies was determined based on taking into account the time spent for field and in-house work. When using air laser scanning data in addition to air photography, there is an increase in work productivity.

1. General Provisions

The current stage of development and use of remote sensing methods for topographic mapping tasks dictates the need to improve technologies for topographic geodetic and cartographic works, including on the basis of airborne laser scanning (ALS) methods and technologies implementation.

In this regard, researches on comparative analysis of productivity for processes and complex of works on generation of topographic products in accordance with the production projects carried out under traditional technological schemes and technological schemes with the use of airborne laser scanning materials have been carried out.

The main purpose of the research is to analyse and substantiate the main parameters of efficiency, which will serve as a baseline for planning technical policy, as well as the introduction of modern technologies in topographic, geodetic and cartographic production for the medium and long term.

Comparative technologies performance with the use of airborne laser scanning was determined on the basis of accounting of time expenses for field surveying and in-house processing performed in 2022 and 2023 on prospective technologies of production of works for the creation of digital topographic plans at scale the 1:2000 with a contour interval 1.0 m and 0.5 m based on the use of ALS for unmanned aerial vehicles (UAV).

Important factors to be taken into account in this regard are the current use of state topographic maps at scale the 1:2000 in various sectors of the economy, as well as trends in the development of geodesy and cartography at the present stage in the field of large-scale mapping.

Research to determine the economic efficiency of technologies for creating state topographic maps at scale the 1:2000 is based on the actual data obtained from the analysis of the current state of demand for these products, the degree of its satisfaction, as well as prospects for future development.

In order to determine the economic efficiency of the proposed technologies, the current state topographic provision of the territory of the Russian Federation with topographic maps at scale the 1:2000 and the amount of work performed were taken into account.

State topographic maps and orthophoto mosaic at scale the 1:2000 are intended to provide sectors of the economy, local authorities, legal entities and citizens with information about the area and are used in solving tasks in the field of:

– construction and housing and communal services;
– transport complex;
– fuel and energy complex;
– land use;
– conducting environmental protection measures and environmental management;
– agriculture and food supply;
– forestry, hydrometeorology and environmental monitoring;
– aviation and space complex;
– civil defense and elimination of consequences of emergencies and natural disasters;
– security, protection of the state border and maintenance of public order, etc.

At present a sufficiently high degree of topographic and geodetic study of the territory of the Russian Federation has been achieved at scale the 1:2000. Based on the results of topographic surveys, digital topographic maps or orthophoto mosaic at scale the 1:2000 have been created for all cities and urban-type settlements.

Analysis of the current state of use of state topographic maps and orthophoto mosaic at scale the 1:2000 in various sectors of the economy indicates that they are successfully used in a wide range of works:

– design of railways and highways at the stage of technical design in mountainous areas and for working drafts in flat and hilly areas;
– development of general plans for small towns, urban-type settlements and rural settlements;

https://doi.org/10.5194/isprs-archives-XLVIII-1-2024-529-2024

– drawing up detailed planning projects and building sketches; urban industrial area planning projects, projects of the most complex transport junctions in cities at the stage of development of the master plan;

– drawing up executive plans for mining enterprises (mines, pits, quarries, sections);

– drawing up technical projects and general plans for seaports, ship repair plants and individual hydraulic structures;

– design of general schemes for the reconstruction of railway junctions;

– drawing up working drafts of pipeline, pumping and compressor stations, linear points and repair bases, crossings over large rivers, complex approaches to substations, complex intersections and approaches of transport and other highways in places of individual projects of the roadbed (for linear construction).

According to the application experience of topographic survey at scale the 1:2000 with the use of ALS, these technologies have a number of advantages in comparison with the use of traditional technologies in modern conditions of development:

- the possibility of surveying forested areas, for which the use of other survey methods is laborious and expensive;
- high accuracy and granularity of plan and vertical measurements, independent of human physiological limitations and individual errors;
- processing of airborne laser scanning results is more technological, operative and productive compared to other methods;
- obtaining other additional spatial data - digital terrain model (DTM), digital surface model (DSM), 3D models along with digital topographic maps and orthophotos;
- fixation of up to four reflections of one sent pulse (possibility of separation of vegetation crown and ground surface);
- promptness of final data acquisition (final cartographic materials can be obtained within a few days depending on the scope of work).

Currently, laser scanning (LS) technologies are more focused on the creation of digital models of objects and the use of their results for the design, construction and monitoring of linear objects, industrial and infrastructure facilities. The level of LS technologies implementation for topographic mapping and cadastre requires their larger scale and multi-purpose distribution (Bacher, 2021), (He and Li, 2020), (Nakano et al., 2020), (Nekhin, Babashkin, 2022), (Wierzbicki et al., 2021).

It should be taken into account that high-precision spatial data are created both on the basis of pixcelwise matching of aerial images and on the basis of ALS. Both directions have their advantages and disadvantages and are viable, depending on the tasks to be solved and realization conditions.

In turn, the development of aerial survey systems and ALS is going in two directions: 1) on the basis of aircraft and 2) on the basis of UAV. The choice of one or the other direction is determined taking into account the nature of the tasks to be solved, the cost of equipment, the volume and efficiency of work and other factors.

2. Comparative Analysis of Traditional and Proposed Technologies Performance

Current projects involve the generation of digital orthophoto mosaic at scale the 1:2000 as the Unified Digital Basemap for which the requirements to the accuracy of digital terrain model are much lower than to the contour lines. The technological scheme includes traditional processes: 3-D control; aerial survey with GNSS-based determination of aerial images projection centres coordinates (PCCs); aerial triangulation using PCCs; DTM generation for orthorectification and contouring from stereomodel; orthorectification and digital orthophoto mosaic generation.

The result of the works are digital orthophoto mosaic, as well as digital aerial images with exterior orientation elements (EOE), obtained as a result of aerial triangulation adjustment matching, intended for their subsequent stereoscopic processing (objects extraction, contours lines).

The alternative technology using ALS materials allows to obtain additional types of products in the form of classified points of laser reflections (PLR) of up to 25 classes, DTM, DSM, photorealistic object (terrain) model.

These are the differences between the alternative and the basic technologies:

- if the contour interval is more than 0.5 m, 3-D control is performed only to determine the coordinates of check points;
- simultaneously with aerial survey, aerial laser scanning is performed to determine not only projection centres coordinates, but also EOE on the basis of inertial measurement unit (IMU);
- aerial triangulation is not performed, as the required vertical accuracy is provided directly by the LiDAR with the use of EOE and PCC during the flight;
- DTM generation for orthorectification is performed not by photogrammetric method, but directly by the LiDAR points.

The use of DTM, generated from LiDAR points cloud for orthophoto mosaic allows to avoid aerial triangulation, which significantly reduces time costs for in-house processing.

The "narrowest" process in generation of digital topographic maps at scale the 1:2000 with contour interval of 1.0 m, much less of 0.5 m is relief surveying. In accordance with the regulatory requirements the accuracy of the contour position depending on the relief nature and the selected contour interval is given in Table 1.

Relief nature	Contour interval (m)	Contour positions accuracy (average error, m)
Plain with tilt angles up to 2°	0.5	0.12
Hilly with tilt angles up to 4°	1.0	0.33
Cross-country with tilt angles up to 6°	1.0	0.33

Table 1. The accuracy of the contour position depending on the relief nature and the selected contour interval for maps at scale the 1:2000.

In accordance with the regulatory requirements, the average errors (AE) of distinct points elevation inscribed on the map should not exceed 75% of the average errors of relief surveying, and in mountainous and high-mountainous areas should not exceed ½ of the contour interval. Thus, for topographic maps at scale the 1:2000 with a contour interval of 1.0 m the accuracy (AE) of determining the distinct points elevation should be

25 cm, and with a contour interval of 0.5 m - 8 cm, or when passing from average to mean square errors it should be 31 cm and 10 cm, respectively.

For the Sony RX1RM2 non-metric aerial camera installed on the UAV, to provide appropriate accuracy in accordance with GOST R 59328-2021 (National standard of the Russian Federation GOST R 59328-2021) the ground sample distance (GSD) shall be no more than 10 cm when the contour interval is 1.0 m, and no more than 5 cm when the contour interval is 0.5 m.

At the same time for confident determination of the horizontal position of objects and their interpretation the sufficient size of GSD can be 20 cm in accordance with GOST R 59562-2021 (National standard of the Russian Federation GOST R 59562-2021). Thus, we observe an obvious imbalance in the accuracy of planimetric coordinates (AE not more than 1.0 m) for mapping at scale the 1:2000 and vertical coordinates (AE is 0.25 m and 0.08 m for contour intervals of 1.0 m and 0.5 m, respectively). When using ALS together with aerial camera, the necessary accuracy of relief surveying is provided by application of GNSS/IMU system (ASPRS Positional Accuracy Standards for Digital Geospatial Data. Edition 2, 2023).

It should be noted that it is problematic to generate DTM by stereoscopic method with 8 cm vertical error with GSD 5 cm or less on the terrain both for economic reasons and due to the lack of practical experience in performing such works. Therefore, ALS technology is the most acceptable way of obtaining vertical information both from the position of accuracy and productivity. It is possible, of course, to use ground survey methods, but they are certainly inferior in terms of productivity in mass production application.

Distinct processes (for field surveying and in-house processing) of basic and advanced technology of digital topographic maps generation at scale the 1:2000 with contour interval of 1.0 m are geodetic support, aerial survey, aerial triangulation, DTM generation, orthorectification.

Distinct processes of basic and advanced technology of digital topographic maps generation at scale the 1:2000 with contour interval of 0.5 m are the above mentioned processes of field surveying and in-house processing with the exception of geodetic support.

For the basic technology, the geodetic support process includes the using of base stations to accompany the aerial survey. The number of stations is determined by the area to be surveyed, but not less than two. Their maximum distance from the object of aerial survey is no more than 30 km.

According to GOST R 59562-2021 (National standard of the Russian Federation GOST R 59562-2021) for advanced technology at duration of aerial survey flight not less than 50 min, topographic map at scale the 1:2000 and smaller and contour interval of 1.0 m and more for determination of aerial images PCCs and the origin of LiDAR coordinate system it is allowed to use the precise point positioning (PPP) method. In this case the use of base stations are not required.

At the same time for both basic and advanced technology geodetic referencing of horizontal/vertical check points is performed. The total number of such points, used for accuracy checking of intermediate and final results of surveying of the whole object, should be not less than 1 point per 9 map sheets of the topographic map at scale the 1:2000 according to GOST R 59562 (National standard of the Russian Federation GOST R 59562-2021).

During the relief surveying at scale the 1:2000 with a contour interval of 1.0 m and 0.5 m with the use of ALS and traditional technology, measurements of the time spent on technological processes were made. Then the comparative analysis of the effectiveness of the two methods was performed based on the results of the study of these measurements.

The total area of 230 rural settlements, which were surveyed using basic technology, is 800 sq. km. The total area of 25 rural settlements, which were surveyed using advanced technology, is 120 sq. km. The settlements selected for timing with the use of both technologies have similar parameters in area, border configuration and are typical for rural areas.

The traditional topographic survey was performed with a Sony RX1RM2 camera mounted on an UAV Geoscan 201, aerial laser scanning was performed with the laser scanner Riegl VUX-240 and the same camera mounted on an UAV Superam SX300H (VTOL). The UAV`s average cruising speed is 50 km/hour. The used UAVs are shown in Figure 1.

Figure 1. UAV Geoscan 201, Supercam SX300H

Figures 2 and 3 show the comparative time per square kilometer for basic and advanced technologies for mapping at scale the 1:2000 with a contour interval of 1.0 m for field surveying and in-house processing, respectively.

Figure 4 show the comparative time per square kilometer for basic and advanced technologies for mapping at scale the 1:2000 with a contour interval of 0.5 m for field surveying and in-house processing, respectively.

This contribution has been peer-reviewed.
https://doi.org/10.5194/isprs-archives-XLVIII-1-2024-529-2024 |

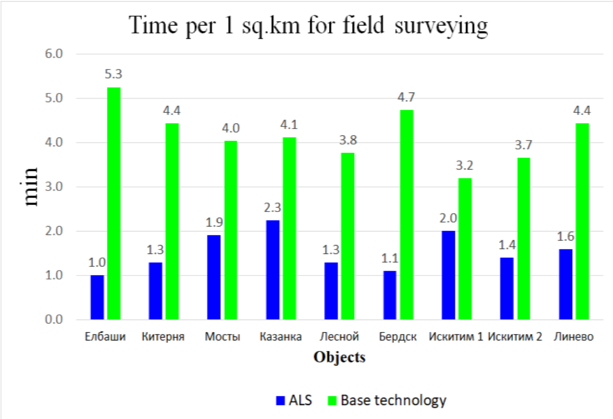

Figure 2. Time per sq.km for mapping at scale the 1:2000 with a contour interval of 1.0 for field surveying

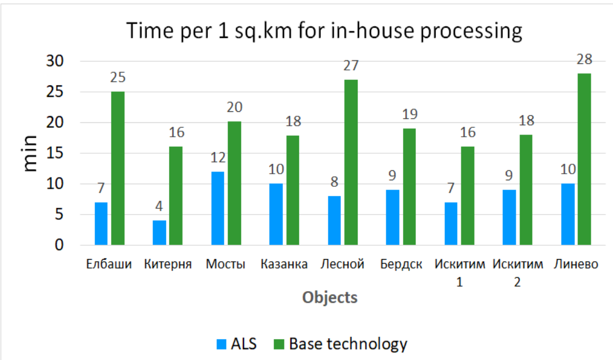

Figure 3. Time per sq.km for mapping at scale the 1:2000 with a contour interval of 1.0 for in-house processing

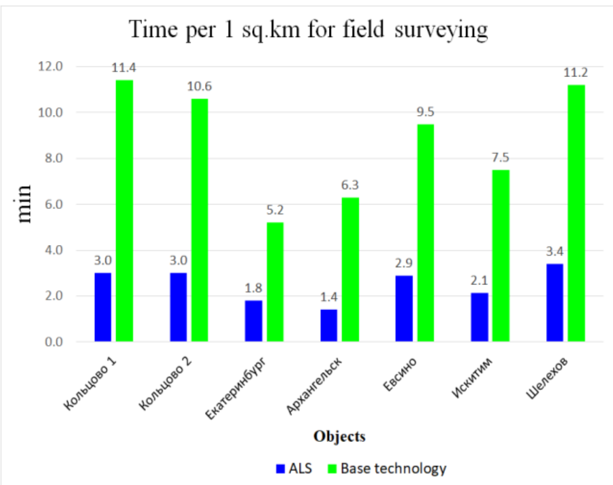

Figure 4. Time per sq.km for mapping at scale the 1:2000 with a contour interval of 0.5 m for field surveying

The timing of technological processes was carried out in conditions that ensure the use of modern production technologies and rational organization of work in compliance with safety requirements, as well as in the absence of complicating external factors in the surveying area at a favorable time of the year.

Table 2 shows the comparative performance of UAV imagery for basic and advanced technologies for mapping at scale the 1:2000 with a contour interval of 1.0 and 0.5 m.

Survey parameters	Figures for	
	Basic technology (Sony RX1RM2 camera)	Advanced technology (Riegl VUX-240 VLS and Sony RX1RM2 camera)
Contour interval of 1.0 m		
Vertical determination AE, m	0.25	0.12
GSD, m	0.10	0.20
Flight above ground level, m	750	1500
Number of images per km^2 of map at scale the 1:2000	35	3
Performance, km^2 per hour	14	41
Contour interval of 0.5 m		
Vertical determination AE, m	0.08	0.08
GSD, m	0.05	0.10
Flight above ground level, m	250	500
Number of images per km^2 of map at scale the 1:2000	280	20
Performance, km^2 per hour	7	25

Table 2. Comparison of performance of surveying from UAV for basic and advanced technologies for mapping at scale the 1:2000 with contour interval of 1.0 m and 0.5 m.

Table 2 shows that when using LiDAR Riegl VUX-240 (Data Sheet Riegl VUX-240) together with Sony RX1RM2 camera for relief surveying with contour interval of 1.0 m the performance of aerial surveying works increases 3 times, and for contour interval of 0.5 m it increases 3.4 times. It should be emphasized that the tables show the estimated performance, which refers only to the process of direct execution of aerial survey, without taking into account the processes related to organization and liquidation measures, preparation of the carrier and equipment, registration of permits for the use of airspace, waiting for flying weather and others. Taking into account these processes, the actual time is significantly increasing. Preparatory work and in-house processing make a major contribution to the time spent on airborne laser scanning using UAVs. The share of the very aerial survey is 10%.

3. Performance Evaluation

To determine the performance the data of experimental studies at the production sites of the works were used. Calculation of performance was made on the basis of analysis of data on the objects of ALS with UAV for mapping at scale the 1:2000 with contour interval of 1.0 m.

Table 3 summarizes the performance on differentiating processes in the generation of orthophoto and digital topographic maps at scale the 1:2000 with contour interval of 1.0 m.

For contour interval of 0.5 m and a terrain pixel size of 5 cm, the performance of the promising ALS-based technology is even more significant.

№	Name of works	Performance, km^2 per hour	
		Basic technology	Advanced technology
1	Aerial survey work	14	41
2	Aerial triangulation	3	-
3	Generation of DTM for topographic map at scale the 1:2000 with contour interval of 1.0 m	3	8
4	Orthophoto mosaic generation	1.1	6.6
	Total	21.1	45.6

Table 3. Performance of works on generation of orthophoto and digital topographic maps at scale the 1:2000 on different technology processes

Conclusions

Application of aerial laser scanning from UAV for generation of orthophoto and digital topographic maps at scale the 1:2000 allows to exclude a number of expensive and costly processes of works, such as creation of 3-D control, but at the same time requires additional capital investments in equipment.

The results of the analysis for aerial laser scanners installed on UAV demonstrate an increase in the performance of ALS survey by reducing the scale of aerial survey while maintaining the required accuracy of DTM generation and reliability of contour interpretation. The performance of the ALS field work from UAV using Riegl VUX220 scanner and Sony RX1RM2 camera increases by 3 and 3.4 times for mapping at scale the 1:2000 with contour interval of 1.0 m and 0.5 m, respectively.

When performing in-house processing on generation of topographic maps and orthophoto on the basis of the suggested technology the performance increase occurs due to exclusion of aerial triangulation process, replacement of DTM generation process by images with more productive process of DTM creation by laser scanning points.

To estimate the time costs of generation products using laser scanning, production materials were used based on the application of modern technologies taking into account the modernization of technological processes. To calculate the costs, the data of ALS from UAV for 7 regions of the Russian Federation were used.

In addition to the calculated direct effect of performance increase there is a multiplicative effect due to multiple use in the industries that create and consume topographic, geodesic and cartographic products.

Thus, the results of the analysis indicate that when performing works on the generation of orthophoto and digital topographic maps at scale the 1:2000 technologies with the use of ALS are preferable to traditional ones.

Implementation of laser scanning technologies is aimed at creating organizational and technological conditions for effective work of enterprises and organizations of topographic, geodesic and cartographic production, which will allow to:

- reduce costs by cutting expenses and improving labour organization;
- increase accessibility of topographic, geodesic and cartographic information for public authorities, business and citizens;
- create favourable conditions for the development and improvement of public administration, production, science and education through the use of modern topographic, geodesic and cartographic information.

However, it is worth noting that the high cost of LiDAR is a limiting factor in the implementation of the advanced technology.

Discussing the advantages and disadvantages of the two fundamentally different methods of mapping, it is necessary to point out a number of advantages of the airborne laser scanning. This is first of all its insensitivity to low-contour, low-textural and even completely textless terrain, stable performance in conditions of forest vegetation, in conditions of shielding the Earth's surface with dense multi-storey buildings.

On the contrary, the stereotopographic method for these reasons is unsuitable for adequate transmission of relief in a number of listed cases, as well as the shape, size and composition of individual compact objects, which is unacceptable when solving problems of mapping, cadastre, design, etc. The stereoscopic correlation method within a fixed window of several pixels does not allow for the correct display of sharp relief changes in the stereo model, which leads to distortions of the real picture.

LiDAR systems installed on UAVs are not adversely affected by the above factors and have high performance. However they have problems of a different nature. In particular, it is financially difficult to recoup the high cost of equipment and software in a short time using airborne laser scanning only for relief surveying. Therefore, when analyzing the effectiveness of using laser scanning systems for the purposes of large-scale mapping, cadastre and engineering surveys, new approaches are needed to assess the effectiveness of using laser scanning technologies based on:
- new types of products along with traditional ones;
- multi-purpose application of spatial information in various sectors of the country's economy;
- reusable information on the principle of "received once, use repeatedly".

Rapidly developing laser scanning technologies make it possible to introduce significant changes in production and business processes. In recent years, the following promising areas have been developing: digital twins, augmented and virtual reality, smart city, artificial intelligence. In industries such as construction and infrastructure, these technologies, along with specialized, industry-specific (BIM technologies), have led to almost revolutionary changes, developing not only new approaches to the creation of objects, but contributing to the formation of an entire ecosystem. In particular, we observe such a process in relation to digital twins.

The integration of these technologies in the construction field contributes to a deeper understanding of the processes of design, construction and operation of buildings and infrastructure facilities, reduces the cost of their creation, increases the level of safety and comfort during operation. Laser scanning systems play a vital role in this. Their implementation helps to improve the quality and detail of information about objects, speeding up the processes of creating digital models and BIM.

The introduction of laser scanning technologies and BIM technologies in urban development is very relevant. At the same time, it is possible to save significant financial resources during designing and future operation of urban areas and surrounding infrastructure by obtaining high-precision and detailed spatial data on them.

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