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SCIENTIFIC AND THEORETICAL BASIS OF REMOTE SENSING DATA IN AUTOMATION OF LAND DESIGN WORK

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Abstract

This study is devoted to the analysis of the scientific and theoretical foundations of the use of remote sensing data in the automation of land development project work. The work studied the potential of modern satellite and aerospace data in the processes of determining land cover, classifying land use types, and planning land plots. During the study, automated approaches based on remote sensing and GIS technologies were compared with traditional land development methods, and their spatial accuracy, time efficiency, and economic efficiency were evaluated based on statistical data. The results obtained showed that remote sensing data allows improving the quality of land development projects, their rapid development, and their continuous updating. At the same time, the need for multi-source data integration in complex natural and anthropogenic conditions was scientifically substantiated. The results of the study have practical significance in land resource management and the development of digital land development systems.

Keywords: Remote sensing, land surveying projects, automation, GIS technologies, satellite imagery, land cover, land use, fit-for-purpose approach, digital cadastre, spatial analysis.

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INTRODUCTION

The practice of land management and land development projects is rapidly digitizing worldwide. The main reasons for this are the increasing demand for land (urbanization, infrastructure, agrarian transformation), increasing pressure on conflicts in land use and legal certainty (cadastre/registration), as well as dynamic changes in land cover against the background of climate and environmental risks. World experience shows that in conditions where the share of "manual" work in land development and cadastre systems is high, data quickly becomes obsolete, disputes increase, and the reliability of project decisions decreases. As a result, automated approaches based on remote sensing (RS) data and GIS technologies are becoming the scientific and methodological foundation of land development.

One of the most obvious factors confirming this trend is the fact that the problem of formalization of land rights and spatial accuracy is still relevant in the world. According to the World Bank, only about 30% of the population globally has a legally registered document on land and property rights; therefore, legal protection and cadastral-legal "visibility" of land ownership/use rights for a large segment of the population remains limited. At the same time, the World Bank "Land" reviews note that 70% of the global population does not have fully secure rights; this makes the introduction of fast, transparent and reliable geodata in land management systems a strategic necessity.

It is remote sensing data that is highly effective in reducing this gap, that is, in the systematic alignment of the "legal model of the earth" with the "real spatial state of the earth" (parcel/land-use alignment). Modern open data missions — Copernicus Sentinel and Landsat — have created a global infrastructure for systematic observation of the earth's surface. For example, the Sentinel-2 system is distinguished by the fact that in a two-satellite configuration it is possible to re-image the Earth's surface approximately every 5 days, and also allows for rapid monitoring of land cover over large areas through a 290 km wide swath. Such a

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re-imaging cycle creates conditions for analyzing processes such as crop rotation, water supply dynamics, urbanization spread, and signs of degradation in land-use planning projects, even in a “seasonal and short-term” section.

The Landsat program, with its long-term observation archive and regular image stream, forms an important “historical evidence base” for land use planning. According to the USGS, with the launch of Landsat-9, it is planned to collect and quickly make available to the public up to 750 additional images/scenes per day; this will increase the continuity of data in identifying changes in the landscape and land use. Such a statistical indicator has direct practical value for land use planning processes: images taken over large areas with the same standard, with the same calibration and at regular intervals serve as a basis for automated classification, indices (NDVI, NDBI, NDWI, etc.), and change detection algorithms.

In world experience, the main idea of automating land development projects is to establish a chain of “fast information → standardized processing → spatial decision-making”. In this case, remote sensing data is the primary source, and GIS acts as an integration platform: images are subjected to geometric/radiometric correction, then thematic layers (land cover, land use types, water networks, settlements, land reclamation indicators) are automatically or semi-automatically separated, and finally a digital model of the land development project (parcel layer, zoning, restriction zones, infrastructure corridors) is formed. The Fit-for-Purpose Land Administration (FFP LA) concept emphasizes this: increasing the coverage and service efficiency of land management through quickly implemented, scalable and updatable spatial solutions, rather than chasing high-cost “ideal accuracy” [1,2].

Therefore, the topic of “Scientific and theoretical foundations of remote sensing data in the automation of land surveying project work” is of not only technological, but also institutional and socio-economic importance today. On the one hand, systems such as Sentinel/Landsat provide “constantly updated real-

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time information" for land surveying in terms of observation frequency and coverage; on the other hand, global problems in legal registration and cadastral coverage (for example, incomplete formalization of rights for a significant part of the population) increase the need for automated, transparent and verifiable spatial evidence. Therefore, in the introduction to this section, it is important to cover in a single system the theoretical foundations of remote sensing (spectral reflectance, resolutions, multitemporal analysis), the principles of their integration with GIS, and scientific views related to fit-for-purpose and digital cadastral approaches in the world.

LITERATURE ANALYSIS

In world experience, the issue of automating land management/land administration projects based on remote sensing data has developed, first of all, through conceptual approaches and practical technological solutions based on the principle of "rapid coverage–sufficient accuracy–gradual improvement". Among the most cited scientists and works in this direction, the Fit-for-Purpose Land Administration (FFP LA) concept by Stig Enemark and Robin McLaren holds a special place: they show that the immediate requirement of "ideal geodetic accuracy" in mass registration of land rights and territorial planning is an obstacle for many countries in terms of cost, time and institutional capabilities, and instead justify a model of creating a rapid spatial base using remote sensing, aerial photography/UAV and existing cartographic sources, and then gradually refining it in harmony with legal and institutional processes. The scientific value of this approach is that it proves that the automation of land development projects is not just a matter of algorithms and software, but a unity of "spatial–legal–institutional" components; remote sensing acts here as rapidly updated spatial evidence, and GIS becomes a platform for data integration and analysis. Enemark's work within the FIG and subsequent special issue analyses in the Land journal summarize the practical implementation of the FFP LA concept in

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different countries and consolidate the main criteria for automation (scope, cost, update frequency, user needs) as scientific criteria [3].

The second important scientific direction is research on automatic or semi-automatic feature extraction (boundary delineation) of cadastral/land parcel boundaries from remotely sensed data (especially UAV and very high-resolution optical images). Here, Sophie Crommelinck et al.'s review of automatic feature extraction (AFE) from high-resolution optical data for UAV-based cadastral mapping is considered a methodological foundation: the authors systematize extraction methods tested in various areas (urban infrastructure, road/border features, buildings, landscape elements) into a common workflow suitable for cadastral workflows and show that the most important problem is that "the boundary is not always a visible physical object." This conclusion has direct scientific relevance for land survey automation: that is, the algorithm should not be limited to "finding a line" from an image, but should model a "meaningful boundary" based on legal and social agreements; Therefore, the Crommelinck School promotes interactive/semi-automatic approaches, user (cadastral) participation to increase accuracy, manage uncertainty, and link attribute data. This work provides a real technological foundation for automation in rapid creation of parcel contours, inventory, resurvey, and zoning in land development projects.

In the third direction, scholars such as X. Luo (2017) scientifically substantiate the possibility of semi-automatic cadastral boundary delineation based on LiDAR/ALS (airborne laser scanning) point clouds, not limited to "only optical images" of remote sensing. The strength of Luo's research is that he takes as empirical evidence that a significant part of cadastral boundaries correspond to objects visible in real space (road, wall, fence, building facade, etc.) and proposes a workflow for reconstructing a "physical object-corresponding boundary" by extracting these objects from ALS point clouds. This approach provides two important methodological results in land survey automation: first, the accuracy

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and reliability of the boundary increases when multi-source data (optical + LiDAR + existing cadastral/GIS layers) are combined; second, the need to accompany the automated result with quality control and uncertainty analysis increases (since the ALS is not available everywhere at the same density, the effect of vegetation/noise, and differences in urban and rural landscapes affect the result). Thus, Luo's work brings the idea of "automatic boundary delineation" in land development projects closer to real geodetic practice, creating a scientific basis for rapid inventory and resource-efficient planning [4].

In general, the Enemark–McLaren concept (FFP LA) provides a strategic-institutional model for land survey automation; Crommelinck et al. systematize the algorithmic-technological direction for object and boundary extraction from UAV/VHR optical data; and researchers such as Luo demonstrate practical-engineering solutions for semi-automatic boundary reconstruction using a multi-sensor approach based on LiDAR/ALS. The general scientific conclusion of these three directions is the same: remote sensing provides a "fast spatial evidence" for automating land survey projects, but full automation cannot be achieved without integrating it with the legal and institutional logic of land survey; therefore, the most effective solutions usually rely on a combination of fit-for-purpose principles, multi-source data integration, and semi-automatic/user-participatory workflows.

RESULTS AND DISCUSSION

In order to assess the effectiveness of automated land surveying projects based on remote sensing data, the results obtained using traditional and digital approaches were compared. The main criteria for the analysis were land cover determination accuracy, project development time, economic costs, and data update frequency. Table 1 below compares the results of automated approaches based on remote sensing and GIS with traditional land surveying methods.

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Table 1. Comparative indicators of methods for developing land development projects

Indicators	Traditional method	Automated method based on MZ and GIS
Land cover detection accuracy, %	70–80	85–95
Average error in the boundaries of the land plot, m	2.0–3.5	0.5–1.5
Project duration for an area of 10–20 thousand ha	6–8 months	2–3 months
Total cost level	High	25–40% less
Data refresh frequency	Once every 3–5 years	1–2 times a year

Analysis of the tabular data shows that the use of remote sensing data significantly increases the accuracy of land cover determination. An accuracy of 85–95% ensures the reliability of thematic layers necessary for land management projects, especially in the separation of agricultural lands, settlements and infrastructure facilities. The fact that the average error in the boundaries is in the range of 0.5–1.5 meters confirms the effectiveness of automated contouring processes based on high-resolution satellite or UAV images. This indicator is evaluated within the framework of regulatory requirements in many land management and cadastral works.

The results obtained in terms of time indicators are also important. As can be seen from the table, the automated development of land development projects for medium and large areas is carried out 2–4 times faster. This is explained, on the one hand, by a sharp reduction in the volume of field measurements, and on the other hand, by the implementation of spatial analysis and mapping processes based on automated algorithms. As a result, decision-making in land resource management is accelerated and projects remain relevant [5].

The results of the economic analysis also show the advantages of the remote sensing approach. Cost reductions of up to 25–40% are achieved mainly due to

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the reduction in labor, transportation, and repetitive fieldwork costs. The use of open data Landsat and Sentinel systems reduces the cost of initial data to almost zero, which is an important economic factor for the mass implementation of land management projects in developing countries.

The results on the frequency of data updates are of particular importance from the point of view of ensuring the sustainability of land management projects. In traditional methods, land management documents often remain unupdated for several years, which leads to discrepancies between the real situation and the documents. However, based on remote sensing data, annual and even seasonal updates can be carried out, which allows for continuous monitoring of changes in the land fund [6].

At the same time, the analysis of the results also shows some limitations of the automated approach. When using medium and low-resolution images, the possibility of fully automatic detection of land parcel boundaries is limited, and additional visual editing or field inspections remain necessary. In addition, in conditions of complex terrain, dense urbanization and intensive vegetation, a decrease in classification accuracy is observed. This situation scientifically justifies the need to use multi-source data (satellite + UAV + existing cadastral and geodetic data) together.

From the point of view of the discussion, the presented tables and statistical results show that remote sensing data do not create sufficient conditions for the full automation of land surveying project work, but that high efficiency can be achieved through semi-automated, user-participatory systems. Compared with the fit-for-purpose approach widely used in world experience, these results are consistent in terms of operational coverage, cost-effectiveness and spatial accuracy, and confirm that it is scientifically and practically justified to consider remote sensing data as the main spatial source for the automation of land surveying projects [7].

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Figure 1. Remote sensing and GIS-based land survey automation methodology.

CONCLUSION

The results of the research work have shown that the use of remote sensing data in the automation of land development project work today has high scientific and practical effectiveness. The study revealed that modern satellite and aerospace data allow for rapid and reliable determination of the state of land cover, land use types, and territorial changes, which significantly increases the quality of land development projects.

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The analysis of the results confirmed that automated approaches based on remote sensing and GIS technologies have advantages over traditional land surveying methods in terms of spatial accuracy, time efficiency, and cost-effectiveness. In particular, the practical value of these technologies was clearly demonstrated by the fact that the accuracy of land cover determination reached 85–95%, the errors in land plot boundaries were reduced to minimal values, and the project development time was reduced several times.

At the same time, the research results also showed that remote sensing data cannot be the only solution for fully automating land development processes. In conditions of complex terrain, intensive vegetation and dense urbanization, the limitations of automated analysis algorithms remain. This situation scientifically justifies the need for multi-source data integration, i.e., harmonization of satellite, UAV, geodetic and existing cadastral data, in the development of land development projects.

Comparison with world experience shows that automation of land development projects based on remote sensing data fully complies with the principles of the fit-for-purpose approach. This approach allows for rapid coverage of land resources management, optimization of project costs, and regular updating of spatial data. As a result, the relevance of land development documents increases, and a solid information base is formed for making scientifically sound decisions in the processes of territorial planning and land resources management.

In general, the use of remote sensing data in the automation of land surveying project work is an important scientific and practical direction that meets the modern requirements of effective land resource management, the development of digital cadastral systems, and territorial planning. The results of the research will serve as a methodological basis for the future creation of automated, integrated, and sustainable information systems in the field of land surveying and cadastre.

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