Development of a Methodology for Geodetic Support of Cadastral Works for Creating and Maintaining a 3D Cadastre of Highways

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Annotation: Establishing three-dimensional cadastral systems for highways requires precise geodetic support capable of representing the spatial location, geometric parameters, and legal boundaries of complex linear infrastructure in three dimensions. This study aims to develop a methodology for the geodetic support of cadastral activities related to the creation and maintenance of 3D highway cadastres. The research employs a comprehensive approach integrating modern geodetic surveying, Global Navigation Satellite System (GNSS) positioning, electronic total stations, Unmanned Aerial Vehicle (UAV) photogrammetry, 3D modeling, and Geographic Information System (GIS) technologies. The proposed methodology encompasses the collection and integration of geospatial data, the establishment of a geodetic control network, the determination of 3D boundaries for highway land plots and infrastructure objects, quality control of spatial measurements, and the updating of cadastral data within a 3D geodatabase. The results indicate that the integration of modern geodetic and geoinformation technologies can enhance the accuracy, completeness, consistency, and efficiency of highway cadastral data management.
Keywords: 3D cadastre; highway cadastre; geodetic support; cadastral measurements; GNSS; UAV photogrammetry; GIS; 3D modeling; geospatial data; cadastral database; linear infrastructure; land management.

Аннотация: Создание трехмерных кадастровых систем для автомобильных дорог требует точного геодезического обеспечения, позволяющего отображать пространственное положение, геометрические параметры и юридические границы сложных объектов линейной инфраструктуры в трехмерном формате. Целью данного исследования является разработка методики геодезического обеспечения кадастровых работ, связанных с созданием и ведением 3D-кадастров автомобильных дорог. В работе применяется комплексный подход, объединяющий современные методы геодезической съемки, позиционирование с использованием глобальных навигационных спутниковых систем (GNSS), применение электронных тахеометров, фотограмметрию с использованием беспилотных летательных аппаратов (БПЛА), 3D-моделирование и технологии геоинформационных систем (ГИС). Предлагаемая методика охватывает сбор и интеграцию геопространственных данных, создание геодезической опорной сети, определение трехмерных границ земельных участков и объектов инфраструктуры автомобильных дорог, контроль качества пространственных измерений, а также обновление кадастровых данных в 3D-геобазе данных. Результаты исследования свидетельствуют о том, что интеграция современных геодезических и геоинформационных технологий позволяет повысить точность, полноту, согласованность и эффективность ведения кадастровых данных об автомобильных дорогах.
Ключевые слова: 3D-кадастр; кадастр автомобильных дорог; геодезическое обеспечение; кадастровые измерения; GNSS; фотограмметрия с БПЛА; ГИС; 3D-моделирование; геопространственные данные; кадастровая база данных; линейная инфраструктура; землеустройство.

Annotatsiya: Avtomobil yo‘llari uchun uch o‘lchamli kadastr tizimlarini yaratish murakkab chiziqli infratuzilmaning fazoviy joylashuvi, geometrik parametrlari va huquqiy chegaralarini uch o‘lchamda aks ettira oladigan aniq geodezik ta’minotni talab qiladi. Ushbu tadqiqot avtomobil yo‘llarining 3D kadastrini yaratish va yuritish bilan bog‘liq kadastr ishlarini geodezik ta’minlash metodologiyasini ishlab chiqishga qaratilgan. Tadqiqotda zamonaviy geodezik o‘lchash ishlari, Global navigatsiya sun’iy yo‘ldosh tizimi (GNSS) yordamida joylashuvni aniqlash, elektron total stansiyalar, uchuvchisiz uchish apparatlari (UUA) fotogrammetriyasi, 3D modellashtirish va Geografik axborot tizimi (GAT) texnologiyalarini birlashtiruvchi kompleks yondashuv qo‘llaniladi. Taklif etilayotgan metodologiya geofazoviy ma’lumotlarni yig‘ish va integratsiyalash, geodezik tayanch tarmog‘ini yaratish, avtomobil yo‘llari yer uchastkalari va infratuzilma ob’ektlarining 3D chegaralarini aniqlash, fazoviy o‘lchovlar sifatini nazorat qilish hamda 3D geoma’lumotlar bazasidagi kadastr ma’lumotlarini yangilab borish jarayonlarini qamrab oladi. Natijalar shuni ko‘rsatadiki, zamonaviy geodezik va geoinformatsion texnologiyalarning integratsiyasi avtomobil yo‘llari kadastri ma’lumotlarini boshqarishda aniqlik, to‘liqlik, izchillik va samaradorlikni oshirishga xizmat qiladi.

Kalit so‘zlar: 3D kadastr; avtomobil yo‘llari kadastri; geodezik ta’minot; kadastr o‘lchovlari; GNSS; UUA fotogrammetriyasi; GAT; 3D modellashtirish; geofazoviy ma’lumotlar; kadastr ma’lumotlar bazasi; chiziqli infratuzilma; yerdan foydalanishni boshqarish.

Introduction

The rapid development of transport infrastructure and the increasing complexity of highway networks have created new requirements for cadastral registration, spatial data management, and geodetic support of linear infrastructure. Highways occupy extensive areas and interact with numerous land parcels, engineering structures, utility networks, administrative boundaries, and environmental protection zones. In conventional cadastral systems, these objects are predominantly represented in two-dimensional space, where their horizontal boundaries and locations are recorded on a plane. Although a 2D cadastral representation is sufficient for many traditional land administration tasks, it becomes increasingly limited when dealing with infrastructure characterized by different elevations, overlapping spatial objects, bridges, tunnels, interchanges, embankments, and underground or elevated components.[1]

Three-dimensional cadastre provides an opportunity to overcome these limitations by representing cadastral objects according to their actual spatial extent, including their horizontal and vertical dimensions. In the case of highways, a 3D cadastral model can represent not only the land parcel occupied by a road but also the spatial boundaries of the roadbed, carriageways, bridges, tunnels, overpasses, slopes, safety zones, and other infrastructure elements. Such an approach makes it possible to establish a more comprehensive relationship between physical infrastructure, land rights, restrictions, easements, and spatial planning requirements. [3] Consequently, the development of reliable methodologies for creating and maintaining 3D highway cadastres is becoming an important direction in modern land administration and geospatial information management. The quality of a 3D cadastral system is highly dependent on the accuracy and completeness of the geodetic data used to establish the spatial position of cadastral objects. Geodetic support provides the fundamental measurements and reference framework required for determining coordinates, elevations, boundaries, and geometric parameters of highway infrastructure. Modern technologies, including Global Navigation Satellite Systems (GNSS), electronic total stations, digital leveling, unmanned aerial vehicle (UAV) photogrammetry, terrestrial laser scanning, and Geographic Information Systems (GIS), provide new opportunities for obtaining high-accuracy spatial data. However, the effective integration of these technologies into cadastral workflows requires a scientifically justified methodology that considers

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measurement accuracy, coordinate reference systems, data interoperability, geometric modelling, quality control, and periodic updating of cadastral information.[2]

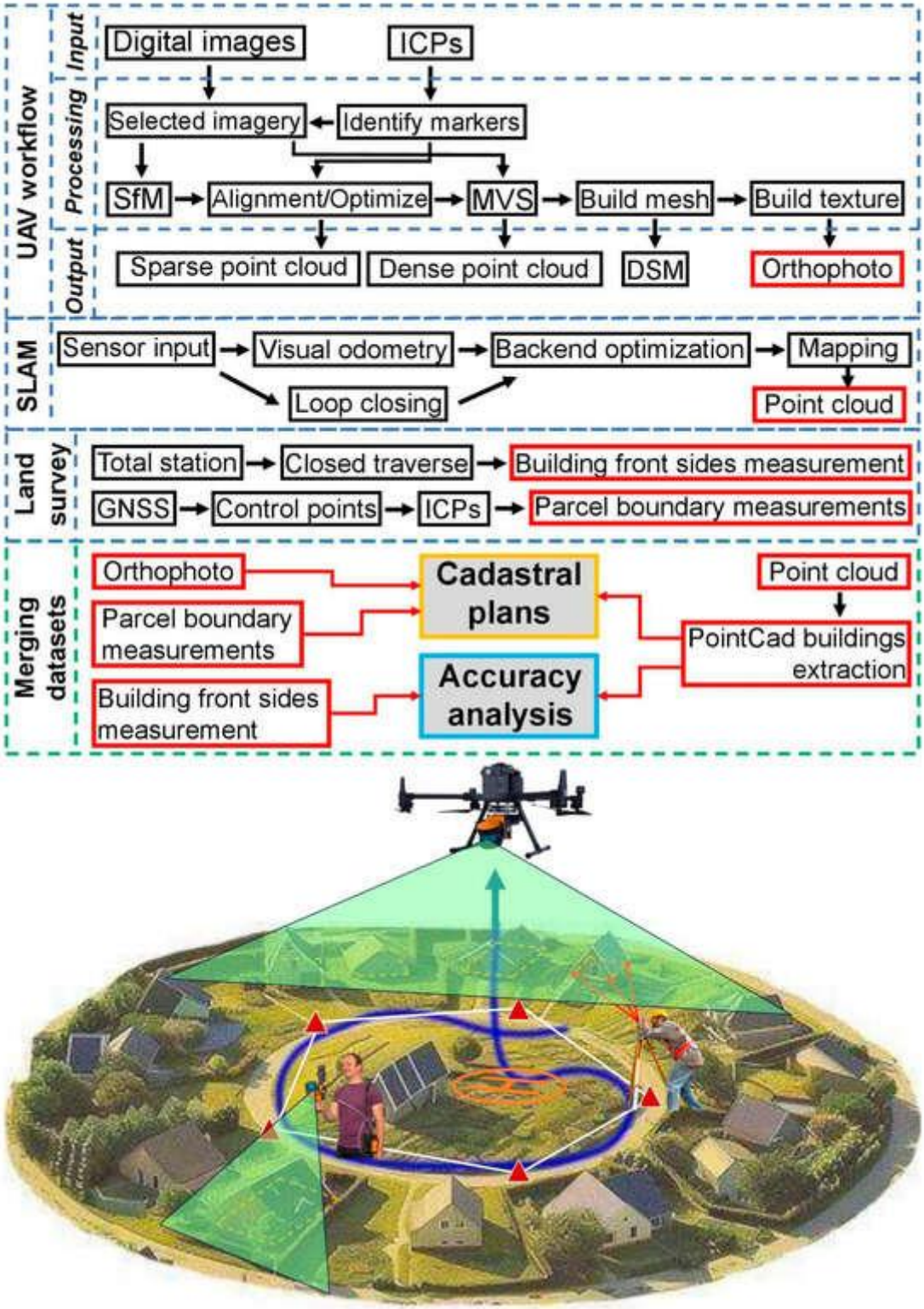


Figure 1. Workflow for cadastral surveying using UAV photogrammetry, SLAM, and conventional land survey methods. The integrated approach ensures accurate cadastral plans and geospatial data acquisition. [1]

A particular challenge is associated with the linear and spatial characteristics of highways. Unlike conentional land parcels, highway corridors may extend over considerable distances and include sections with substantial changes in elevation and complex three-dimensional configurations. Furthermore, highway infrastructure may cross existing land parcels, water bodies, railway lines, utility networks, and other infrastructure. Bridges and tunnels can create situations in which different spatial objects occupy the same horizontal area but exist at different elevations. Therefore, a purely two-dimensional cadastral approach may not adequately represent the spatial relationships and legal boundaries associated with such objects. A 3D cadastral model, supported by precise geodetic measurements, can provide a more complete representation of these spatial relationships. Another important issue concerns the maintenance and updating of cadastral information. Highway infrastructure is continuously modified through reconstruction, widening, repair, modernization, and the construction of new interchanges and engineering structures. As a result, cadastral databases must be capable of incorporating new measurements and reflecting changes in the geometry and spatial status of infrastructure objects. This requires the development of procedures for repeated geodetic surveys, quality assessment, data integration, change detection, and updating of 3D cadastral models. Without an appropriate methodology, inconsistencies may arise between the actual physical condition of a highway and its cadastral representation. Despite significant advances in geodetic surveying, photogrammetry, laser scanning, GIS, and 3D modelling, the methodological integration of these technologies for the specific requirements of highway cadastre remains an important research problem. Existing approaches often focus on individual technologies or general principles of 3D cadastral modelling, while insufficient attention may be given to the complete geodetic workflow required for establishing, validating, and continuously maintaining three-dimensional cadastral information for extensive highway corridors. In particular, there is a need for a systematic methodology that connects the geodetic reference framework, field measurements, spatial data processing, three-dimensional modelling, accuracy assessment, and cadastral database updating within a unified workflow. [4]

Therefore, the development of a methodology for geodetic support of cadastral works for creating and maintaining a 3D cadastre of highways is relevant for improving the reliability and efficiency of contemporary cadastral systems. Such a methodology can provide a structured framework for obtaining accurate spatial information, determining three-dimensional boundaries, integrating heterogeneous geospatial datasets, and maintaining up-to-date cadastral records of highway infrastructure.

To achieve this aim, the following research objectives are established:

1. to analyse the spatial and cadastral characteristics of highways that determine the requirements for three-dimensional cadastral representation;
2. to identify the geodetic data and surveying technologies required for establishing accurate 3D cadastral information;
3. to develop an integrated workflow for geodetic data acquisition, processing, quality control, and three-dimensional modelling of highway cadastral objects;
4. to develop procedures for determining and validating the three-dimensional boundaries of highway land parcels and infrastructure elements;
5. to establish an approach for integrating geodetic measurements into a GIS-based 3D cadastral database; and
6. to develop procedures for updating and maintaining 3D cadastral information in response to changes in highway infrastructure.[2]

The scientific significance of the study lies in the development of an integrated methodological approach that combines modern geodetic technologies with three-dimensional cadastral modelling and geoinformation systems. The practical significance is associated with the potential application of the

methodology in cadastral surveying, highway infrastructure management, land administration, spatial planning, and monitoring of land rights and restrictions along highway corridors. [5]

Results

The main result of the study was the development of an integrated methodology for geodetic support of cadastral works associated with the creation and maintenance of a 3D highway cadastre. The methodology establishes a continuous relationship between field surveying, geodetic data processing, three-dimensional modelling, cadastral registration, quality control, and subsequent database updating.

The proposed workflow can be represented as:

Geodetic reference framework → spatial data acquisition → data processing and adjustment → 3D boundary determination → 3D cadastral modelling → accuracy assessment → database updating.

This structure reduces the separation between conventional geodetic surveying and cadastral data management and provides a unified procedure for transforming field measurements into cadastral information. [4]

Three-dimensional representation of highway infrastructure: Application of the proposed methodology enables highway infrastructure to be represented as three-dimensional cadastral objects rather than only as two-dimensional lines or polygons. The resulting model contains both horizontal and vertical information and therefore provides a more complete description of the spatial extent of the infrastructure. The model allows the geometric representation of road corridors, carriageways, embankments, bridges, tunnels, interchanges, slopes, and other infrastructure components. In areas containing vertically overlapping structures, individual objects can be distinguished according to their elevation and three-dimensional boundaries. This approach is particularly important for bridges, overpasses, tunnels, and multi-level interchanges, where a 2D representation may indicate spatial overlap without adequately describing the actual three-dimensional relationship between objects.

Practical significance of the developed methodology: The developed methodology provides a structured basis for improving the accuracy, consistency, and completeness of cadastral information concerning highway infrastructure. Its principal contribution is the integration of modern geodetic technologies with 3D cadastral modelling within a single workflow. The resulting methodology can support cadastral registration, land administration, highway asset management, spatial planning, infrastructure monitoring, and the management of rights and restrictions associated with highway corridors. It also provides a methodological basis for transitioning from conventional 2D highway cadastral records toward an integrated three-dimensional cadastral environment.[6]

Conclusion

The study developed a methodological framework for the geodetic support of cadastral works associated with the creation and maintenance of a three-dimensional cadastre of highways. The proposed approach responds to the increasing complexity of highway infrastructure and to the limitations of conventional two-dimensional cadastral representations in describing objects with significant vertical and spatial relationships. The developed methodology integrates a geodetic reference framework, GNSS observations, total-station surveying, UAV photogrammetry, GIS-based spatial data processing, three-dimensional modelling, accuracy assessment, and cadastral database updating. The integration of these components provides a continuous workflow from field data acquisition to the formation and maintenance of a 3D cadastral model.

Overall, the developed methodology provides a framework for transitioning highway cadastral information from predominantly two-dimensional representations toward an integrated 3D environment. Further research should focus on testing the methodology on different highway types and terrain conditions, establishing standardized accuracy requirements for 3D highway cadastral objects, integrating temporal information for 2D cadastral applications, and investigating automated change detection and updating of 3D cadastral databases.

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