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METHODOLOGICAL ASPECTS OF INFORMATION MODELING OF SPATIAL OBJECTS USING LASER SCANNING TECHNOLOGY

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The article examines laser scanning technologies as a tool for information modeling of spatial objects. The scan results are considered as an information model of a certain type. Three main information models are considered using the example of laser scanning for examining transport routes: a point cloud model, a three-dimensional model of object points, and a digital image as an information model on a plane. Laser scanning is associated with the processing of a large amount of data, which necessitates the processing of spatial objects in parts. It is shown that information collection technologies based on point-by-point information collection lose their connections between the parts of the object. The same problem occurs when processing spatial objects in parts. In order to restore connections in object models, a comprehensive technique is proposed for interfacing information models obtained by laser scanning of an object. The developed approach to the transformation of a large amount of data based on information modeling provides a holistic representation of a spatial object with high accuracy. In order to improve the visual perception of the model, color coding of points based on photography and thematic mapping is proposed. The article presents the stages of information modeling using mobile laser scanning using the example of a specific section of the Bulgarian highway (Troyan – Karnare pass) with high-quality measurements. The results of the study can be useful to specialists in the field of monitoring transport infrastructures, transport construction, geodesy, big data processing, and road safety.

Keywords: information modeling, laser scanning, mobile terrestrial laser scanning, point cloud, information spatial models, monitoring, big data, data processing

МЕТОДИЧЕСКИЕ АСПЕКТЫ ИНФОРМАЦИОННОГО МОДЕЛИРОВАНИЯ ПРОСТРАНСТВЕННЫХ ОБЪЕКТОВ С ПРИМЕНЕНИЕМ ТЕХНОЛОГИИ ЛАЗЕРНОГО СКАНИРОВАНИЯ

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В статье исследуются технологии лазерного сканирования как инструмент информационного моделирования пространственных объектов. Результаты сканирования рассматриваются как информационная модель определенного вида. Рассмотрены три основные информационные модели на примере лазерного сканирования для обследования транспортных трасс: модель облака точек, трехмерная модель точек объекта и цифровой снимок как информационная модель на плоскости. Лазерное сканирование связано с обработкой большого объема данных, что вызывает необходимость обработки пространственных объектов по частям. Показано, что технологии сбора информации, основанные на сборе информации «точка за точкой», теряют связи между частями объекта. Эта же проблема возникает при обработке пространственных объектов по частям. Для восстановления связей в моделях объекта предлагается комплексная методика сопряжения информационных моделей, получаемых при лазерном сканировании *объекта. Разработанный подход к трансформации большого объема данных на основе информационного моделирования обеспечивает целостное представление пространственного объекта с высокой точностью. Для улучшения визуального восприятия модели предлагается цветовое кодирование точек на основе фотосъемки и тематического картографирования. В статье представлены этапы информационного моделирования с применением мобильного лазерного сканирования на примере конкретного участка болгарской трассы (перевал Троян – Карнаре) с высоким качеством измерений. Результаты исследования могут быть полезны специалистам в области мониторинга транспортных инфраструктур, транспортного строительства, геодезии, обработки больших данных, дорожной безопасности.*

Ключевые слова: информационное моделирование, лазерное сканирование, облако точек, пространственные объекты, мониторинг, большие данные, обработка данных

Introduction

In the context of global urbanization and digitalization, approaches to monitoring transport infrastructure require high accuracy and a high level of automation. Laser scanning, both terrestrial and mobile, meets these challenges, allowing us to quickly receive and process large amounts of spatial information [1].

Big data characterizes highways and railways in their study and research as geotechnical systems. The use of laser scanning technologies is used to manage transport infrastructure. On the one hand, laser scanning creates large amounts of data (millions of points are obtained for small areas), on the other hand, it allows us to create a detailed situation about the condition of the object under study [2].

Numerous works in the field of laser scanning focus on the technological problems of information collection [3; 4]. However, laser scanning involves processing a large amount of data, which necessitates handling spatial objects in parts. Information collection technologies based on point-by-point information collection lose their connections between the parts of the object. Connecting individual scanned areas and creating a single and consistent point cloud, which is a spatial representation of the object under study, involves the use of special methods and tools. There is a difference between digital spatial modeling and other types of digital modeling [5]. The issues of information modeling of spatial objects and processing of the obtained big data as a result of laser scanning are insufficiently covered in the scientific literature [6; 7].

Taking into account the above, it is relevant to develop a comprehensive information modeling technique for converting large amounts of data obtained by laser scanning of a spatial object, providing a representation of an integral object with the required accuracy of data used for subsequent comprehensive and detailed examination.

1. Methods and means of research

There is a difference between mobile terrestrial laser scanning (MTLS) [8; 9] and terrestrial laser scanning (TLS) [10]. These are two methods for obtaining three-dimensional digital models of objects using laser scanners, but differing in the way data is collected. TLS defines the spatial coordinates of points on the surface of objects in a conditional coordinate system. The device includes a pulsed non-reflective laser rangefinder and a system of two mirrors (for stepwise deflection of the beam in two mutually perpendicular planes). The coordinates of each point are calculated based on the angle of rotation of the mirrors and the measured distance. The scanner is aimed at the objects under study either using the built-in digital camera or based on the results of a preliminary scan. The error in determining the position of a point in three-dimensional space in modern laser scanners is about 2÷12 mm.

The measurement result is a primary information model in the form of a set of object points (a point cloud). After processing, a secondary information model of the points (3D model) is obtained, for each of which the spatial coordinates X, Y, Z and the image density d are determined. The scanner is a device that essentially combines a theodolite, a laser rangefinder and a digital camera (figure 1).

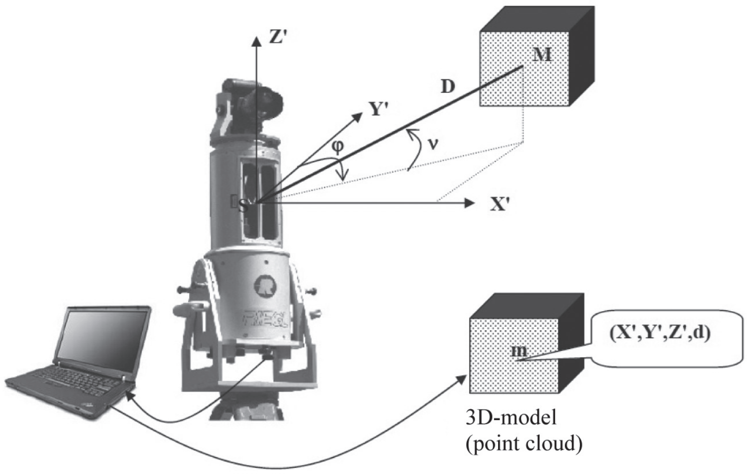

Figure 1 – Ground-based laser scanner[1]

The spatial coordinates *X, Y, Z* and the image density *d* are defined for each point. For any point of the object, the horizontal φ and vertical ν angles are determined using a theodolite, the distance *D* using a laser rangefinder, and the image density *d* using a digital camera. The coordinates of the object points *X', Y', Z'* are obtained in the spatial coordinate system of the scanner. This coordinate system is related to the reference system of horizontal and vertical angles in the scanner and is generally arbitrarily oriented in space. In order to obtain the coordinates of the object's points in the object's coordinate system, the usual external orientation of the model based on reference points is performed.

TLS determines the spatial coordinates of points based on a permanently installed scanner. It has one point from which measurements are performed. MTLS determines the spatial coordinates of points using a scanner mounted on a moving object (car, railway transport object).

MTLS technology is more complex, since it is necessary to connect data obtained from different measurement points. Therefore, MTLS has an additional technology for measuring the trajectory, which is used to scan when the scanner is moving. MTLS and TLS complement each other. They provide fast and accurate measurements with analysis of various objects and features such as collapses, road markings, road barriers, curbs, and road signs. Technologies provide the necessary level of accuracy and detail of spatial data, which is essential for analyzing the state of road infrastructure and identifying potential hazards in order to improve road safety. With MTLS and TLS, extensive detailed road condition surveys can be carried out without interruptions and traffic restrictions.

The problem of converting a large amount of data obtained by laser scanning of spatial objects into information for subsequent comprehensive and detailed analysis of the object's condition is proposed to be solved by information modeling.

2. Practical implementation of a comprehensive information modeling methodology

Mobile laser scanning includes several stages. The first stage is the preparation and carrying out of measurements. The implementation of the chosen technology was carried out through an integrated complex, including: a hybrid laser system (RiEGL -\TL- 2000) mounted on a mobile platform (car), combined with a pair of GPS receivers and a high-resolution digital camera, as well as a 3D inertial navigation system. For a more thorough refinement of the trajectory, two basic GNSS receivers (Leica GS18i and Leica GS08 plus) operating in static mode were used on the platform. The alignment and the height of the point cloud binding was carried out using pre-applied markings on the asphalt. Their location was chosen in advance, after a thorough

[1] Geodesy, cartography, geoinformatics, cadastre / A.V. Borodko, L.M. Bugaevsky, T.V. Vereshchaka, L.A. Zapryagaeva, L.G. Ivanova, Yu.F. Knizhnikov, V.P. Savinykh, A.I. Spiridonov, V.N. Filatov, V.Ya. Tsvetkov // Encyclopedia: In 2 volumes. – Moscow: Cartocenter-geodesizdat, 2008. – Vol. II. N – Ya [Rus].

study of the area. The positioning of the labels (binding and control labels) is carried out using GNSS definitions (GNSS – Global Navigation Satellite System) in RTK (Real Time Cinematic) mode.

These technologies have been tested on a specific section of the Bulgarian highway (Troyan – Karnare pass), outside the urbanized territory, where all the necessary objects related to road safety are located.

The mapping of rock formations through the Troyan – Karnare pass was implemented using MTLS technology. A section of the republican road of the second class II-35 was surveyed. The length of the surveyed route is 19 km. The measured section begins with a long and continuous descent from the Beklemeto pass (the normal height of the pass is 1525.5 m), passes through numerous bends on the southern, rocky and steep slope of the mountain and descends into the northwestern part of the Karlovo Plain, near the village of Karnare, to a normal height of 562 m.

As a result of the analysis, the working team carried out the implementation of measurements by dividing the route into sections. The images of each of the sections (with some overlap) were taken twice (in both directions) with the scanner positioned horizontally in order to cover the length of the roadway in more detail. The entire route was captured once, with the scanning device positioned vertically to cover most of the surrounding area, including road excavations, embankments, and other terrain features.

In cases where the GNSS signal was not available (for areas with dense woody vegetation "overhanging" the road), the trajectory was positioned using a 3D inertial system, an integral part of the measuring complex.

The processing of mobile laser scanning data begins with the processing of the survey trajectory. The initial trajectory along which the IMU/GPS image was taken has an accuracy comparable to that of differential methods (DGNSS – Differential Global Positioning Systems). With the help of specialized post-processing software, the desired trajectory is calculated and determined in real time. Subsequently, it is bound to a point previously selected as a base station.

According to GNSS measurements, coordinate-oriented gyroscopes of the inertial system and additionally measured control markers, the trajectory is aligned using remote sensing technology (Light Detection and Ranging (LIDAR)), which is used to estimate the distance between two objects. The function of the software for automatic recognition of control marks is also used. This survey mainly used recognized tags from recordings obtained from a scanner positioned in a horizontal position [11]. After that, the resulting point clouds are combined into one common file [12].

2.1. Point cloud processing

The scanning system creates images that overlap each other after a certain time interval or at equal distances. Each of them has timestamps containing information about the recording time and orientation of the image obtained from the camera antenna. The software needs them to attach the resulting photos to the point cloud. The result of the alignment is called *a colored point cloud* (figure 2).

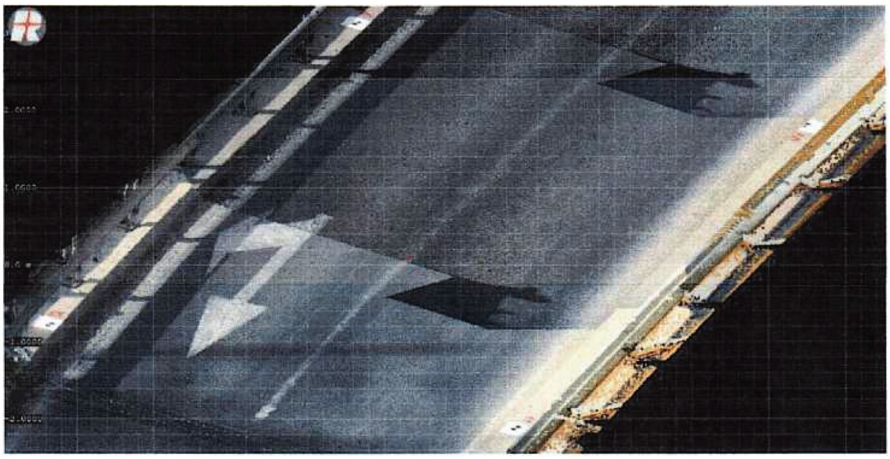

Figure 2 – A colored point cloud

A colored point cloud obtained by mobile laser scanning provides detailed information about the geometry and condition of a real object, in our case, the condition of the road surface. Analyzing the scan results allow us to identify dangerous sections of the road and to plan repairs or strengthen measures to enhance safety and prevent accidents.

The method of geological stereography was used to identify and visualize cracks. This method involves using a stereogram of crack systems and a rose diagram to graphically depict measurements of the occurrence of cracks. Surveys of rock formations near the road infrastructure are extremely useful for improving road safety.

2.2. Indirect registration method

The indirect registration method was chosen to coordinate the measurements. Indirect registration involves the use of labels, both artificial and natural. Artificial marks are pre-defined objects that are often placed to facilitate the registration process. Before measuring, the marks were applied with a black spray gun to the asphalt surface. Their coordination was carried out using a STONEX "S900A" dual-frequency GNSS receiver. The real-time kinematic method (RTK) was used, and a suitably selected virtual reference station (VRS) was used.

The ground-based laser scanner Leica ScanStation P40 was used for measurements, which guarantees extremely high scanning quality and stability in extreme conditions (-20°C to +50°C). A rate of 1 million dots per second ensures fast data collection, and the integrated camera and HDR images ensure realism and clarity. With a broad 360° horizontal and 290° vertical field of view, it can scan objects in all directions. Integrated positioning tools such as the laser plumb line, laser level, and tape measure add functionality and increase measurement accuracy.

The measurements themselves are carried out from several stations for the purpose of a comprehensive and detailed inspection of the facility. This approach ensures that there are no "dead" zones.

The data obtained as a result of tag scanning was used to register the general point cloud of the object. This ensures the connection of the individual scanned areas and the creation of a single and consistent point cloud, which is a spatial representation of the object under study. Thus, the accuracy of the data used for subsequent analysis and application is guaranteed.

The standard errors of the markings in the plan range from 4 mm to 11 mm, and in height from 1 mm to 12 mm. These results are actually information about the accuracy of linking data from the point cloud to the coordinates of the control markers. They serve as an assessment of the reliability of the method used and the accuracy of the data obtained, which is essential for the reliability and actual applicability of the survey results.

In order to identify only significant crack planes in the rock mass, the point cloud is "filtered". Filtering includes removing possible information "noise", removing duplicate points, and consolidating data about specific objects or surfaces [11]. However, the main task of filtering is to get a high-quality image of a real object. Due to the use of this technique, greater clarity and accuracy of the image of the rock mass structure is achieved (figure 3).

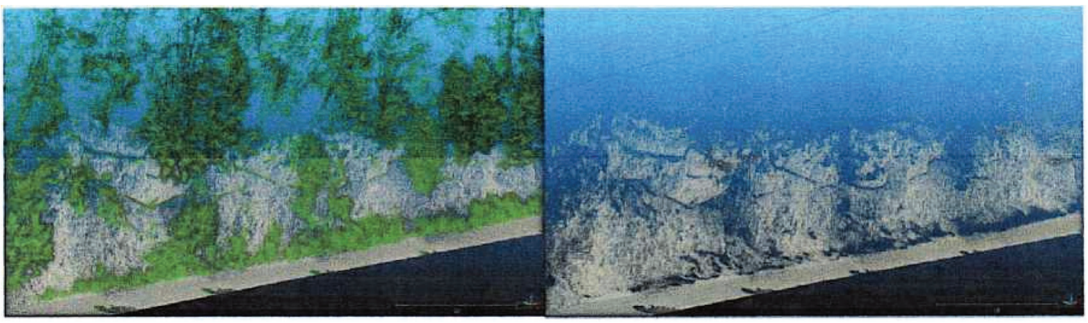

Figure 3 – The result of filtering point clouds

Color information was extracted from panoramic images taken during the scanning process. This allows each point to be colored according to the corresponding location in the scan, resulting in a more realistic representation of the environment and objects within it. This enhances the understanding and interpretation of the data, which is crucial for subsequent analysis and application.

The created three-dimensional model of the rock slope includes geometric and color data that play a key role in analyzing the structural characteristics of the rock. This model makes it possible to map and classify crack systems using appropriately selected software.

The advantage of information modeling in laser scanning is the possibility of using thematic mapping methods. This allows us to use color to highlight and emphasize the characteristics of an object within the framework of the task being solved.

The performed work takes into account the orientation and fracture intersection angle, which ensures a detailed and comprehensive analysis of their characteristics. This allows rock mechanics specialists to distinguish between different fracture systems and obtain valuable data on the geological structure of the rock slope. The final results of the information modeling are shown in figure 4.

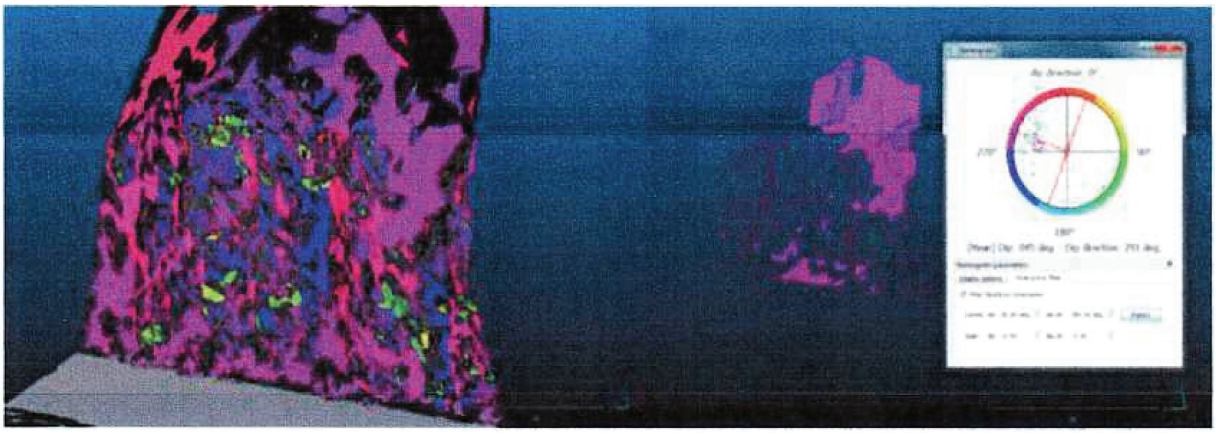

Figure 4 – Three-dimensional model of a rocky slope

Thus, the comprehensive survey provided complete volumetric data on the condition of the object using information modeling techniques.

Conclusions

Methodological aspects of information modeling of spatial objects using laser scanning encompass issues related to the creation, use, and management of information models. The study proposes to consider scanning results as a specific type of information model. Three primary information models used for the survey of spatial objects with laser scanning are identified: a point cloud model, a 3D point model of the object, and a digital image as a planar information model. A comprehensive methodology for integrating information models has been developed to represent a holistic spatial object. This solves the problem of losing connections between parts of the object during the separate processing of data obtained by laser scanning. The research results are demonstrated through the practical application of MTLS on a specific section of a Bulgarian highway (the Troyan – Karnare pass) with high measurement quality. The stages of the methodology's practical implementation are discussed in detail. In order to improve the model's visual perception, color coding of points based on photogrammetry and thematic mapping is proposed. As a prospect for using this approach, a wider application of color information modeling to reflect changes in the condition of the spatial object can be recommended.

The research results can be useful for specialists in the fields of transport infrastructure monitoring, transport construction, geodesy, big data processing, and road safety.

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