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Development of Dynamic Geoinformatics

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Abstract

The article explores a new direction in geoinformatics – dynamic geoinformatics. The diversity of spatial data and temporal problems motivates the differentiation of applied geoinformatics. Dynamic geoinformatics is a development of applied geoinformatics and studies a special area of dynamic processes and dynamic states. The article shows the place of dynamic geoinformatics in the system of sciences. The structure of dynamic geoinformatics is studied. The significance of two types of monitoring in dynamic geoinformatics is shown. Dynamic geoinformatics uses a system of models and a system of technologies. The main theory of dynamic geoinformatics is spatial and temporal analysis. It includes the study of information uncertainty. An important technology of dynamic geoinformatics is geoinformation monitoring. It includes state monitoring and process monitoring. These types of monitoring allow the formation of models in three-dimensional and analytical form. Models facilitate decision-making and compress information in conditions of large volumes. The main theoretical direction of research in dynamic geoinformatics is associated with the study of spatio-temporal processes and the identification of functional dependencies in a spatial environment. The information field and information space are used as auxiliary models in dynamic geoinformatics. The primary goal of dynamic geoinformatics is to generate new knowledge. Dynamic geoinformatics is applied in high-speed and intelligent transport. It is essential for unmanned transport systems.

Keywords: dynamic geoinformatics, applied geoinformatics, spatial monitoring, temporal data.

1. Introduction

The development of dynamic photogrammetry (Blume et al., 2020) contributed to the emergence of dynamic geoinformatics (Raev, 2022). Dynamic geoinformatics is a development of applied geoinformatics (Elbshbeshi et al., 2023). The main research focus in dynamic geoinformatics is the study of spatio-temporal processes and patterns in the environment. The information field and information space are auxiliary models used in dynamic geoinformatics. Dynamic geoinformatics is constantly evolving, driven by the needs of society, science, and technology. The development of dynamic geoinformatics depends on the areas of its application. These areas include transportation, Earth exploration from space, and artificial intelligence. Dynamic geoinformatics, like classical geoinformatics, is a spatial science (Gospodinov, 2022). The object of study is processes and states in space. Dynamic geoinformatics is primarily the science of dynamic spatial processes. Research in the field of intelligent UAVs falls within the field of dynamic geoinformatics (Tsvetkov, Oznamets, 2020).

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2. Results and discussion

The place of dynamic geoinformatics in the system of sciences.

Dynamic Geoinformatics is a development of applied Geoinformatics. It is related and interacts with transport Geoinformatics, ballistics, logistics Geoinformatics, space Geoinformatics, Earth exploration from space, cadastre, ecology, land use, and military operations. The place of Dynamic Geoinformatics (DG) among other sciences is shown in Figure 1. Logistics Geoinformatics (Ndayishimiye, 2023) occupies an intermediate position between applied Geoinformatics and dynamic Geoinformatics. Transport Geoinformatics is most closely related to DG. Transport poses special challenges for Dynamic Geoinformatics. Dynamic Geoinformatics in the field of transport studies fast and slow processes. Fast processes include the movement of vehicles. Slow processes include changes in the state of the transport infrastructure.

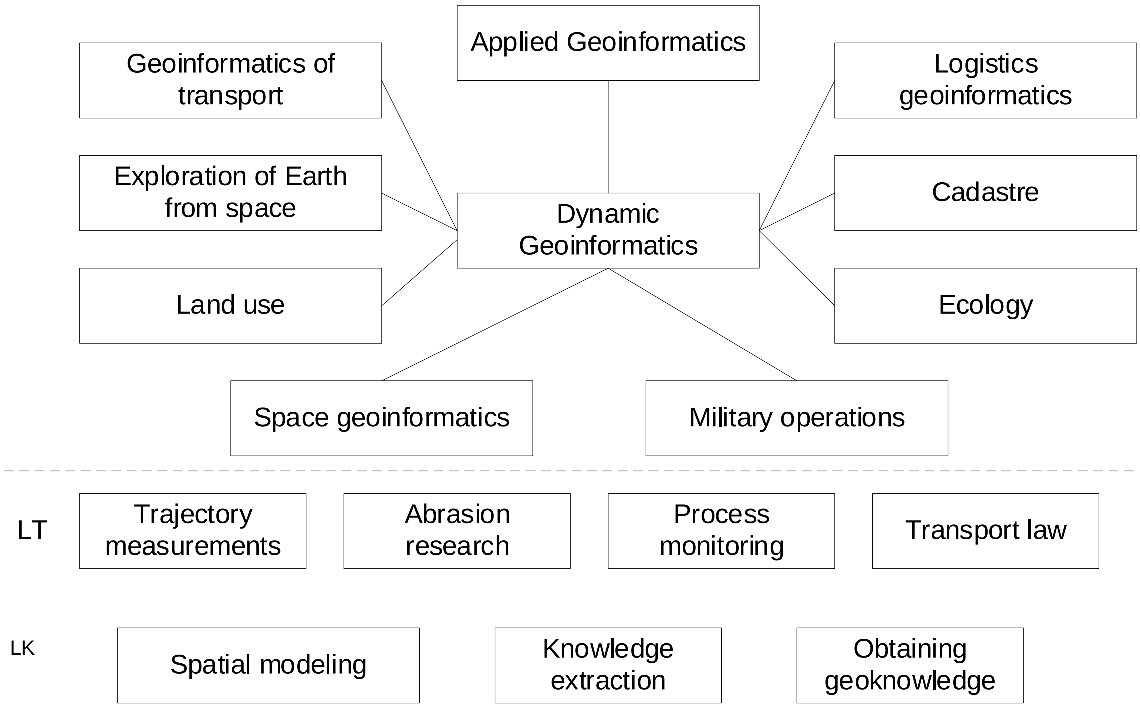

Fig. 1. The place of dynamic geoinformatics among other sciences.

Modern transportation includes intelligent transport (Gong et al., 2023), cyber-physical transport systems (Levin, Tsvetkov, 2018), and unmanned vehicles, transport robots, digital transport (Tsvetkov et al., 2019), and digital twins (Attaran, Celik, 2023). All modes of transport are studied using dynamic geoinformatics.

Dynamic geoinformatics is applied in Earth exploration from space. It is used to monitor the dynamics of the Earth's surface based on remote sensing data. DG, as part of space monitoring, is used for global control of vehicles, primarily maritime transport.

Dynamic geoinformatics is used in land use, cadastral surveys, and ecology. In these areas, it is used to monitor the state of the environment and the Earth's surface. Dynamic geoinformatics is used in conjunction with space geoinformatics to study the motion of celestial bodies. DG is used in combat operations to monitor the position of enemy forces and identify hidden changes in the situation of their armed forces. Dynamic geoinformatics has two levels of implementation: the technology level (LT) and the knowledge level (LK).

The technology level includes specific or frequently used technologies. The knowledge level contains research results in the form of process models or knowledge models. Examples at the technology level include technologies for trajectory measurements of ballistic and tactical missiles; coastal abrasion monitoring; monitoring of transport processes; and transport law. Transport law is considered in connection with the development of digital transport and digital law. At the DG knowledge level, spatial modeling, knowledge extraction in the form of ontology models, and spatial knowledge extraction in the form of spatial ontologies are noted. Dynamic geoinformatics is aimed at obtaining spatial knowledge (Lin et al., 2020) and geoknowledge.

Modern dynamic geoinformatics uses spatial dynamic models (Rosenberg, Tsvetkov, 2010). Dynamic geoinformatics develops spatial monitoring (Shahzaman et al., 2010), which supports the management of dynamic infrastructure. Spatial monitoring in dynamic geoinformatics is based on geoinformation monitoring and uses temporal data. Dynamic geoinformatics uses two types of monitoring: state monitoring and process monitoring. Geoinformation monitoring of states uses temporal labels and time series. Geoinformational process monitoring reveals temporal functions.

Characteristics of dynamic geoinformatics

Geoinformatics applies five basic classes of models: data models, object models, process models, spatial situation models, and knowledge models. Dynamic geoinformatics applies the same classes of models, but the main classes of DG are the class of process models and the class of situation models. Dynamic geoinformatics applies spatial logic (Dolgy et al., 2021) to the study of complex situations involving the movement of unmanned vehicles. Modern dynamic geoinformatics applies spatial analysis and logic to the study of the movement of transport modes: digital railways, cyber-physical transport systems (Pundir et al., 2022), unmanned vehicles (Dolgy et al., 2021), high-speed transport, and transport robots.

Qualitative analysis in dynamic geoinformatics revealed the presence of dynamic geoinformatics categories. Categories in dynamic geoinformatics can be considered the most general concepts that divide the DG research area into subdomains. The boundaries of categories are fuzzy and overlap. This situation necessitates the use of fuzzy set theory. Categories in dynamic geoinformatics are a means of knowledge generalization. A common category in dynamic geoinformatics is the "information field." Studying these categories reveals the state and development trends of dynamic geoinformatics. Categories in dynamic geoinformatics help explore its structure. Figure 2 shows the categorical structure of dynamic geoinformatics.

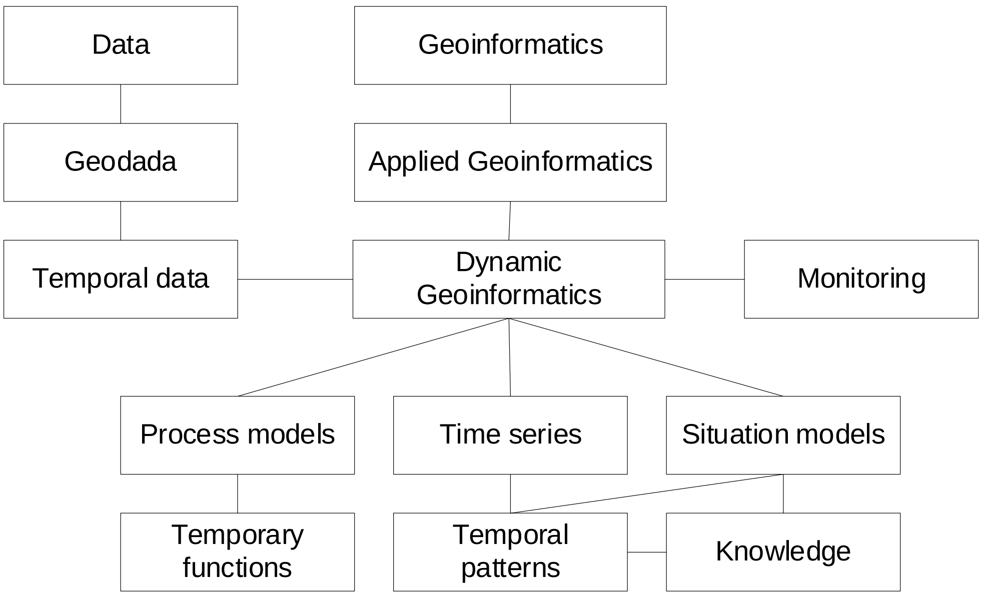

Fig. 2. Structure of dynamic geoinformatics

Modern dynamic geoinformatics uses automated measurement systems to collect data. Initial spatial data is transformed into geodata. The time factor is important for dynamic geoinformatics. This is reflected in the use of temporal data, which is not used as extensively in other types of geoinformatics. In modern dynamic geoinformatics, information is collected using a variety of sensor systems.

Dynamic geoinformatics is based on the integration of dynamic process research, applied geoinformatics methods, dynamic photogrammetry methods, spatial monitoring methods, spatial management methods, and informatics.

Informatics is the methodological basis for information processing. Currently, a large amount of information is received visually. This creates the need for intelligent processing of sensory data. The cognitive factor is taken into account through the use of information reception technologies.

Monitoring is an important component of dynamic geoinformatics. In monitoring, the primary object of observation is a spatial complex, including objects, situations, processes, process patterns, and interaction models. Based on observations and monitoring, time series, process models, and situation models are created. Monitoring results are stored in spatial databases or geodatabases. Monitoring in dynamic geoinformatics is used to study the condition of right-of-way.

Models of information situations are also important for dynamic geoinformatics. The dynamics of object movement are assessed relative to spatial information situations. In dynamic geoinformatics, two types of information situations are qualitatively distinguished: moving (dynamic) and external (stationary). A moving information situation represents the immediate surroundings of an object. It moves along with the object. For a transport object, this includes a railway track and objects adjacent to the route: crossings, trees, other vehicles, and animals. For an aircraft or an incoming missile, this is the potential impact zone around the object.

Dynamic geoinformatics uses spatial logic to study complex spatial situations. Dynamic geoinformatics observes and analyzes the movement of vehicles. The main object of study in dynamic geoinformatics is a complex model that includes a moving object and a dynamic situation. Space-based dynamic geoinformatics is used to monitor the Earth's surface and space objects.

The volume of data in space-based dynamic geoinformatics is significantly larger than in stationary geoinformatics systems. This is due to the large flow of counter-information along the path of a moving object. This counter-information includes not only the visible or immediate area but also information hidden several kilometers away that can affect the object's movement. For this reason, a number of moving objects (unmanned vehicles, cyber-physical transport systems) have built-in onboard computers.

The large volumes of data that onboard computers must process are processed using artificial intelligence methods. This is the only option for controlling high-speed objects. This also creates a connection between dynamic geoinformatics and artificial intelligence. This connection leads to control theory being included in dynamic geoinformatics to a greater extent than in applied geoinformatics.

A contemporary feature of dynamic geoinformatics is its consideration of the digital transformation of society and mobile objects.

Since the scale of information situations studied in dynamic geoinformatics is very large, it is necessary to use models to support situation analysis. The main support models are various spaces: Such support models for dynamic geoinformatics include information space (Hughes et al., 1997), cyberspace (McCarthy, 2018), information field (Tsvetkov, 2014), and transport cyberspace.

DG uses various types of modeling. Geoinformation modeling (Samoilenko et al., 2021) and information modeling are the most important types of modeling. Newer types include onomasiological modeling and semasiological modeling. Information interactions are also important for dynamic geoinformation systems due to the highly dynamic nature of situations. Types of information interactions in dynamic geoinformation systems are divided into object-based, subject-based, and situational. Monitoring moving objects in dynamic geoinformation systems primarily examines the dynamics of movement and, secondarily, the dynamics of state. This is an operational task. The tactical task consists of identifying patterns in the object's movement. Overall, dynamic geoinformation systems examines a spatial complex, including objects, situations, processes, interactions, as well as the connections and relationships between them. All of this together forms the basis for developing a spatial ontology.

The construction of spatial models utilizes a semiotic approach. This involves using information units as a vocabulary ontology. For moving objects, the semantics of the object are considered first and foremost, followed by its morphology. The processing results in the creation of digital maps and digital models.

Dynamic geoinformatics utilizes complex spatial and temporal analysis. Complex analysis includes qualitative analysis, comparative analysis, system analysis, situational analysis, logical analysis, correlative analysis, semantic analysis, and cause-and-effect analysis. Complex analysis in dynamic geoinformatics utilizes spatial and environmental information. The results of the analysis are stored in databases. The analysis identifies latent variables, reveals tacit knowledge, and makes predictions. The overall result of the analysis is the acquisition of new knowledge about movement patterns.

A prerequisite for the functioning of dynamic geoinformatics is the use of a unified global coordinate system. Many types of applied geoinformatics make do with local coordinate systems. In these cases, research is conducted in a single local spatial zone. The global coordinate system of dynamic geoinformatics allows for the comparison of observation results obtained in different spatial zones. The primary information system in dynamic geoinformatics is a geographic information system (GIS). Technically, a GIS simplifies the interaction of attributes with spatial data. GIS reduces the user's workload when analyzing situations and traffic patterns.

Dynamic geoinformatics is used to assess the dynamics of the impact of harmful pollutants. Environmental assessments are performed in three ways. The first relates to the impact of transport on environmental pollution. The second relates to the impact of industrial pollutants on the environment. The third relates to the placement of housing and green spaces. Therefore, dynamic geoinformatics addresses placement issues.

3. Conclusion

Dynamic geoinformatics emerged from applied geoinformatics as a unified group of methods and tasks for studying spatial dynamic processes. The results of such research are temporal functions or time series. Dynamic geoinformatics enables retrospective analysis and forecasting of future processes. Dynamic geoinformatics primarily studies processes and, secondarily, the state of observed objects. Dynamic geoinformatics of transport networks studies the state and deformation of networks. It primarily studies the geometry and, secondarily, the topology of networks. Dynamic geoinformatics of transport studies the movement of various objects: conventional trains, digital railways, cyber-physical transport systems, unmanned systems, and transport robots. From space, dynamic geoinformatics studies the dynamics of the Earth's surface state and processes on the Earth's surface. In this area, it is closely related to space geoinformatics.

DG is the primary tool for analyzing the state and development of processes in geosystems. The use of dynamic geoinformatics is an essential component of transport management.

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