Development of a conceptual model and methods for multi-agent state assessment of technogenic systems

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Abstract. For geodetic monitoring of the spatial-temporal states of technogenic systems under the conditions of hazardous processes that are fast-moving in time, the speed of obtaining objective information and minimizing the human factor are important, which contributes to the timely adoption of the most effective solutions. This is possible by using modern digital technologies based on multi-agent systems, methods of intellectualization and robotization. Based on the analysis of the state of the geodetic monitoring problem, spatial-temporal states of technogenic systems, a conceptual model and methods of multi-agent state assessment are proposed, which will minimize the human factor and significantly improve the quality and speed of obtaining an active information function for timely management decisions in the context of fast-moving processes and emergency prevention.

1. Introduction

The development of all branches of science and technology has led to the complication of technogenic systems. On the one hand, this testifies to scientific and technological progress, and on the other hand, it gives rise to unprecedented potential and real threats to a man, the objects created by him, the local and global environment. A technogenic system (TS) is a complex system, which includes industrial, municipal, domestic, natural, technical objects, relatively stable and independently functioning as a whole based on a certain type of exchange of matter, energy, information. The safety of TS is based on a set of tasks related to various fields of knowledge, including geodesy.

One of the signs of the occurrence of manmade disasters from the point of view of geodetic monitoring is a change in the spatial-temporal state (STS) of the technogenic system (TS) as a result of the dangerous dynamics of fast-moving processes. These processes occur as a result of complex physical interactions of TS, nature and a man and they are the most dangerous for TS, as they occur in the “compressed” time mode. The established methodology for geodetic monitoring of technogenic systems is limited in most cases to the implementation of a passive information function that allows determining the STS of TS as an accomplished fact, which significantly reduces the monitoring capabilities and effectiveness for detecting, tracking and responding to emerging dangerous even threatening and fast-moving processes. This is not enough in modern conditions, when, on the one hand, the complication and expansion of the range of TS leads to an increased risk of technological accidents, an increase in the severity of their consequences. And, on the other hand, new digital
methods and technologies are already available, the use of which can reduce the risk of emergencies will provide early warning.

This solution of the problem can be achieved by introducing new methodologies and technologies, the basis of which are multi-agent, intelligent systems, robotics and related technological solutions that implement the active management function of the STS of TS monitoring, selecting and launching the necessary actions on TS, which will increase the safety of their operation and reduce the risk of emergencies.

2. Materials and methods
The basis of research in the field of geodetic monitoring of STS of TS in fast-moving processes is the theory of multi-agent systems.

The multi-agent system (MAS) uses a system of agents to solve extremely complex problems or global problems, for example, to solve the problems of processing large amounts of data and increase the productivity of these processes in real time. Each intelligent agent solves its problem in order to achieve the overall goal of the system and to develop an active information function for making an optimal management decision. The causes of emergencies and technological disasters are mainly the human factor and various geodynamic processes and phenomena. The multi-agent approach allows you to create an intelligent (“smart”) system for monitoring STS of TS in real time to minimize the influence of the human factor. The development of a multi-agent system is necessary, first of all, for analysis and quick decision-making in the case of fast-moving, dangerous processes, in conditions where the speed of threatening dynamics is greater than the speed of a person's reaction to it. The consequence of incorrect or untimely decisions, in most cases, is an emergency situation that poses a threat to the environment, health and human life.

3. Research Results
The author has developed a conceptual model and technological solutions based on the theory of multi-agent systems, intellectualization methods, robotic collection and autonomous processing, analysis of data on STS of TS. This significantly contributes to improving the quality and speed of obtaining the necessary information about STS of TS for timely management decisions in conditions of fast-moving processes and prevention of emergency situations.

Geodetic monitoring is a system of measures for the collection of data, analysis, evaluation and forecast of the STS of TS. At present, to collect data on the STS of TS, modern geodetic control technologies are used, such as leveling methods, laser scanning. Global Navigation Satellite System (GNSS), etc., the main purpose of which is to determine with high accuracy of the deformation processes developing slowly over time [1, 2, 3]. Automated monitoring systems (AMS) are used to monitor fast-moving processes over time in order to ensure the safe operation of technogenic systems. They allow continuous monitoring of the STS of TS, regardless of weather conditions or time of the day with any degree of discrete sampling. In general, AMS consist of a set of instrumentation (sensors) connected to the server and data processing algorithms. The AMS functions are to collect the TS parameters set, with a certain degree of discrete sampling, compare the received parameters with the normative indicators and transmit the received information via Web services to any access point to the Internet. Leading global companies in the field of AMS development are Leica Geosystem, Leica GeoMoS, “MonsolRus” LLC. The relevance of the use of automated monitoring systems is currently due to the introduction of Russian National Standard 22.1.12-2005 “Safety in emergency situations” and the general requirements of the Federal Law of the Russian Federation, No. 384, dated December 30, 2009 “Technical regulation on the safety of buildings and structures”.

The result of the AMS operation is information on changes in the STS of TS indicators, notification of the customer about their unacceptable deviations from the norm, graphs of the dependence of indicators on time or other values [4, 5, 6]. In fact, the AMS is a stationary monitoring and warning system, which gives a passive information function about the STS of TS according to the given parameters, the change of which is recorded as a fact. To identify cause-effect relationships and
predict changes in STS, information obtained from the AMS requires additional processing and analysis using mathematical algorithms and software, which is time-consuming, and the essence of monitoring fast processes for preventing dangerous situations and, as a result, initiating accidents is lost. The author has developed a conceptual model of the STS of TS geodetic monitoring system (Figure 1), based on multi-agent principles, which will solve this problem.

The system consists of a data acquisition unit (agent 1), an analytics unit (agent 2), and a control unit (agent 3), interacting with each other according to the given algorithms, at the level of intelligent communication. The technological basis of Agent 1 is an automated AMS monitoring system that allows transmitting data on the STS of TS with any degree of discrete sampling in any weather conditions, regardless of the time of day. It consists of many control devices (robotic sensors collecting data about the STS of TS), a receiver and a signal converter (R and SC), a database (DB), and a Web server. The data collection stage involves the receipt of complete (necessary for making a decision) information about the technogenic system and its transfer to the analytics block. The data transmitted by the control devices have n degrees of freedom, which allows us to further establish the correlation of processes and establish cause-effect relationships. Agent 2 contains a database of mathematical algorithms for solving the problems of determining the spatial-temporal state of TS, and an algorithm for choosing a strategy based on the efficiency function of applying one or another algorithm. The development of the analytics block (Agent 2) in the general concept of the multi-agent system for geodetic monitoring of the spatial-temporal state of the technogenic system (Fig. 1) is due to the fact that existing methods in geodetic production that take into account NS and Construction Norms & Regulations embedded in software products have the rules of mathematical algorithms.

The uniqueness of the TS and the peculiarities of changing the STS sometimes require an individual approach to processing the results of geodetic control. In some cases, the necessary mathematical algorithms in the programs simply do not exist, as there is no unified algorithm for processing geodetic data for a comprehensive assessment and analysis of the dynamics of changes in the STS of TS, as well as forecasting scenarios for the development of dangerous dynamic processes. The lack of a unified algorithm is explained by the fact that each object is individual in its constructive solution and, due to the influence of various external influences, changes in the STS of the TS occur in different scenarios. The main tool that is used in most software for solving complex engineering problems and modeling are mathematical methods. Some have great generalization, others have a special purpose and are used to solve a narrow range of practical problems [7, 8]. Moreover, difficulties often arise in choosing the optimal mathematical method for solving the problem. It depends on the goals, features of the shape and geometric parameters of the system, methods of geodetic survey, features of dynamic processes, etc.
Figure 2. A comprehensive algorithm for determining and analyzing the spatial-temporal state of technogenic systems based on geodetic data

As a result of research and analysis of existing methods of mathematical processing of the results of geodetic monitoring, mathematical algorithms are proposed for determining the spatial-temporal state of a vehicle [7, 9, 10]. The phase space method for determining the STS of the TS allows aggregating all the initial data into an explicit function of coordinates and time $S(t)$ (phase trajectory) and considering the TS as a single integral system of functionally interconnected elements:

1) the statistical method of quality control charts that allows you to analyze the dangerous dynamics of the STS of TS, identify the boundaries between the “safe” and “dangerous” state of the TS, determine the bifurcation points of the STS of TS and determine the risk of transition from the “safe” to the “dangerous” state;

2) the method of exponential smoothing, which allows predicting the function $S(t)$, which characterizes the change in the spatial-temporal state of the TS.

As a result of the research, the predicted functions for changing the spatial-temporal state of the TS obtained by the method of exponential smoothing were constructed, examples of possible options for
changing the function $S(t)$ were considered. Graphs of empirical risk functions were constructed, and the probability distribution of scenarios of changes in the STS of the TS was obtained;

3) numerical mathematical methods for determining the shape, size and orientation of the vehicle in space and time;

4) a spline interpolation method for detecting deformation of areal structures.

Agent 3 makes management decisions, provides feedback to the TS and transmits information to the customer. The functions of this agent are to make decisions about the discrete sampling rate of the data received from agent 1, decompose the object, determine its structural parts, which require detailed consideration and identify the causes of the change in the STS, localize the places of deformation and establish cause-effect relationships. The management agent is the core of the system. If necessary, the management agent performs a request for missing information from agents No. 1 and No. 2. The global task of the management agent is to analyze all decision strategies and develop the most effective management function that solves the general problem of monitoring the vehicle. The functions and decisions of agents No. 1 and No. 2 may vary depending on the overall strategy for the functioning of the system to achieve a global goal. Unlike social systems and GIS systems, multiagency involves automation, intellectualization and robotization of all processes occurring in the system. Due to this, the problem of the influence of the human factor is solved. For the control unit, a complex algorithm is proposed for determining and analyzing the spatial-temporal state of technogenic systems based on geodetic data, based on system analysis procedures: decomposition and aggregation, <<the decision tree>> method for deciding on TS decomposition. The complex algorithm is represented by a diagram of interconnected levels of decomposition of the problem of determining the STS of TS (Fig.2)

In general, the systematization of knowledge for the formation of a complex of mathematical models for the analysis of the STS of the dangerous dynamics of technogenic systems has been performed. A comprehensive unified algorithm for processing geodetic data has been developed to determine, evaluate and predict STS of TS of any complexity, providing an opportunity to select the optimal management solution for minimizing the risk of emergencies. The described mathematical methods for determining the spatial-temporal state of TS can be used in multi-agent systems, as well as in software products designed for processing geodetic data. The selection of the optimal mathematical solution for evaluating the STS of TS will allow timely management decisions to be taken to prevent emergencies during the operation of man-made systems and significantly reduce the risk of emergencies.

4. Conclusion
Based on the analysis of the state of the geodetic monitoring problem of TS STS, a conceptual model and methods for multi-agent assessment of the state of technogenic systems are proposed focused on the theory of multi-agent systems, methods of intellectualization and robotization of collection, autonomous processing and analysis of data on STS of TS. It will enable to minimize the human factor, increase the quality and speed of obtaining an active information function significantly that determines the STS of TS for timely management decisions in the conditions of fast processes and prevents emergencies.

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