A robotic system for determining the state of a man-made object in space and time

T Bugakova¹, A Sharapov¹ and I Knol¹*

¹ Siberian State University of Geosystems and Technologies, 10 Plakhotnogo str, Novosibirsk 630108 Russia

E-mail: ivanknol@mail.ru

Abstract. The article proposes a conceptually new, intellectually oriented approach with a higher degree of automation to the monitoring of man-made objects and the prediction of the space-time state of man-made objects. The paper describes an algorithm of functioning of the multi-agent system for determining and controlling the space-time state of a man-made object is completed. The article describes the development of a robotic stand, which is a prototype of a multi-agent system.

1. Introduction

The space-time state of an object (STS) is a position of the object as a whole or its structural parts with respect to a fixed coordinate system. A man-made object is an object, or a collection of objects created by man in the process of production and economic activities and interacting with the environment (buildings, engineering structures, bridges, tunnels, etc.).

Each man-made object (MMO) has its own design features that must be taken into account when monitoring and controlling its space-time state [1]. Operational safety of man-made objects depends on the quality of monitoring and forecast of STS.

According to GOST R 22.1.12-2005, the man-made objects should be equipped with structured systems for monitoring engineering structures, coupled with automated systems of dispatching services and EDDS to prevent the occurrence and elimination of emergency [2].

Existing automated monitoring systems (AMS) operate on the basis of various algorithms. One of the important tasks in the development of AMS is the selection of effective algorithms for determining and predicting the STS of the object.

The paper proposes a conceptually new intellectually oriented approach with a high degree of automation to the monitoring of man-made objects to determine and predict their space-time state, based on the creation of the space-time state of a man-made object.

2. Materials and Methods

An intelligent agent is a simulation model of a certain active element whose state and behavior in the presence of a specific goal changes in direct proportion to the state and behavior of the environment, as well as the agents existing in it [4].

The MAS assumes the functioning of agents to achieve intermediate and primary goals [5]. The main purpose of creating the MAS in the published work is to determine and predict the space-time state of man-made objects to prevent accidents and emergencies.
A multiagent modeling of systems with the presence of actively flowing processes is a new concept in the field of geodesy and geoinformatics. This system is aimed at the consistent use of models and methods of natural and artificial intelligence for software research, state determination (with forecast function) and system behavior in a specific environment.

3. Results
It is assumed that building structures and the foundation of a building or structure must be of such strength and stability that during construction and operation, the threat of harm to human life or health, property, and the environment does not arise as a result of the following actions:

1. Destruction of individual supporting building structures or their parts;
2. Destruction of the entire building, structure, or part thereof;
3. Deformation of an unacceptable value of building structures, a base of the building or structure, as well as the geological massifs of the adjacent territory;
4. Damage to a part of a building or structure, engineering networks or engineering systems as a result of deformation, displacement or loss of stability of load-bearing building structures, including deviations from verticality [6], [7].

Knowing possible space-time changes of a MMO, we can create a list of intermediate states of a multi-agent system of a MMO. We will highlight the following states:

1. A translational motion: the movement of the entire man-made object, conventionally taken as an absolutely solid body along some vector;
2. A rotational motion (torsion roll man-made object);
3. A relative movement: a technogenic object changes its state by moving its structural parts (blocks) along multidirectional vectors with different speeds.

The MMO’s structural blocks are identified as a result of the MMO decomposition procedure based on specified algorithms [8]. We consider one of them, which is the algorithm of the nearest neighbors. The essence of this algorithm is to determine the set of control points of the object, the coordinates of which have changed with respect to the values determined in the zero era of time. Based on this information, we can determine the boundaries of the structural division of MMO into sub-blocks, i.e. deformation zones.

With the emergence of a new block, new characteristics of this block arise, namely the motion vector, the speed of movement, the axis of rotation, the angular velocity of rotation, the compression ratio. Thus, if we create software analogies of these structural elements (MMO blocks) and establish the laws of interaction between them and the environment, it would be possible to predict a change in the STS of the MMO. Fig. 1 shows an algorithm of the software package based on the multi-agent approach.

In this algorithm, $M_1(x,y,z)$ is a cloud of points resulting from the operation of complex multifunctional sensors (CMS) with an update resolution $T$; $M_2(x,y,z)$ is a cloud of points obtained as a result of surveying geodesic stamps with update resolution $T*24$; $M_3(x,y,z)$ is a cloud of points obtained as a result of a laser scanner survey with the incremental update $T*24*30$.

Independent surfaces that are the basis for generating a single digital 3D model are built on the basis of sets of points. At the next stages, automated addition of characteristics to points and surfaces based on data from CMS, processing a single cloud of MMO points by decomposition and clustering algorithms, is carried out to identify new MMO blocks.

As a result of the identification of new autonomous structural elements, the MMO generates a software analogy (agent) of this structural element with the addition of characteristics with the subsequent determination of dependencies between these agents.

The final stage is the derivation of correlation graphs for agents and a predictive 3D model with the display of structural blocks.
As part of the research, a platform for obtaining initial data is the development of the Center for Engineering and Robotics (TSIIIR) of the Siberian State University of Geosystems and Technologies (SSUGiT). This is a robotic stand for determining and controlling the space-time state of a man-made object [9-13].

We are currently involved into creating integrated multi-functional sensors that would allow to determine the coordinates not only of a point in space, but to control some cloud of points of its environment. These sensors are planned to be tested on the basis of SGUGiT in a specially prepared anechoic chamber, without interference from radio and mechanical waves.

Development and implementation of the MAS for the control of the STS (of MMO) is a complex and lengthy process. Therefore, a multi-agent system modeling should include the following step-by-step processes:

1. Creating a 3D-model of the object;
2. installing the integrated multifunctional sensors on the MMO;
3. Acquiring all necessary object data from sensors with an incremental data refresh \(d\).
4. Installation of geodesic marks;
5. Obtaining data on the object by the tacheometric (teodolite, leveling) survey of geodesic marks with the resolution of updating data \(d \times 24\);
6. Getting a point cloud based on laser imaging;
7. Selecting an algorithm for data processing, based on the methods of the systems approach (decomposition, aggregation) and decision making;
8. Determining the frequency of receipt of geospatial data;
9. Deciding on further action;
10. A software implementation;
11. A web interface development.

Fig. 2 shows the diagram of the web application of the MAS, based on the principle of “client” - “server.” In that Figure, “A1..An” is the spatial and semantic data obtained by complex multifunctional sensors installed on the object under study (\(n\) is the number of blocks (structural parts of the object) obtained as a result of decomposition, \(d\) is the resolution of data update). “B1..Bn” is the spatial data obtained as a result of geodetic measurements based on tacheometers, theodolites, and levels (\(n\) is the number of geodetic marks (data refresh resolution is \(d\times24\)), the point cloud of the studied technogenic object is a set of spatial coordinates obtained as a result of geodetic measurements based on laser scanners (data refresh resolution is \(d\times720\)). “Algorithm № 1 .. n” stands for the data processing algorithms.
4. Discussion

Heterogeneous information may come in to determine the STS, the functions that allow to supplement or adjust the data processing algorithms are built into the system. Algorithms for data mining and “machine learning” and algorithms of “decision trees” are included in the decision block. Decision trees are a way of representing rules in a hierarchical, sequential structure, where each object has a single node that provides a solution. The advantage of using data mining algorithms is that a sufficiently clear classification model, which has a high prediction accuracy, is implemented in the “machine learning” process [14-17].

It is assumed that the system being developed will be for multi-users, with the ability to connect several man-made objects, which is why the Internet was chosen to organize the connection between the client and the server.

The server is written in Java and PHP. The multifunctional interface of a client part of this web application is implemented on the basis of various libraries of the JavaScript language (in particular, WebGL) and the synthesis of HTML5 and CSS3.

The interface allows one to display graphs of dependencies between the structural parts of the object (blocks), obtained as a result of the decomposition process, and also allows one to visualize the current 3D model MMO.

5. Conclusion

The developed robotic system is endowed with the following functionality:

- Determining an offset model of the MMO in the plane OXY;
- Determining a free movement of the MMO model in space, relative to OXYZ and the parameters of this movement;
- Determining the deformation of the MMO model (integral, differential), the definition of the structural elements of the object.

As part of continuing to work with this project, we have planned to implement the following functions:

- Modeling various factors influencing a man-made object;
- Conducting an intellectual analysis of the influence of external factors on the change in the MMO state;
- Determining the criteria for the transition of the MMO from the “safe” state to the “dangerous” one, based on the analysis of the correlation of external factors and object states;
- MAS testing at a real object.
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