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MODEL AND METHOD DEVELOPMENT FOR DETERMINING THE COMPLETENESS OF INFORMATION FOR REMOTE DETECTION OF LANDMARKS FOR AUTONOMOUS MOBILE ROBOTS

The object of research is the completeness of information for making a navigation decision by an autonomous mobile robot when it performs a task in an unfamiliar area without GPS. It is difficult to identify a landmark in the absence and abundance of information. One of the most problematic places is the mathematical description of the criterion according to which an autonomous robot makes a decision about the completeness of information. The paper substantiates a model and method for determining the completeness of information by a robot equipped with several landmarks detection tools operating on different physical principles. It is shown that the implementation of the method requires a priori information on the probability of detecting various landmarks by passive and active means against a continuous and discontinuous background at different illumination of objects, in day and night conditions under different weather conditions. The values of the probability of detecting a specific type of landmark obtained in such studies serve as the basis for constructing an information cadastre for a job performing tasks on the ground. Three formulas are proposed for determining the coefficient of completeness of information, taking into account a priori and a posteriori inventories, and recommended areas of application. The value of this coefficient depends on the threshold level of the probability of detecting a landmark. The reliability of a decision made by a robot is greatest when it is made under conditions of a certain level of completeness of information. The proposed method can be used for other technical objects from which the measurement information is received. Compared with the known methods, it expands the boundaries of application and reveals the possibility of assessing the completeness of information in constantly changing conditions. Along with a change in these conditions, the characteristics of the completeness of information also change. The coefficient of completeness of information can approach unity even in the absence of separate means of detecting landmarks, and then the method makes it possible to assess the need for their use in the given conditions.

Keywords: *information completeness, mobile robots, landmarks, identification of landmarks, information cadastre.*

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1. Introduction

The completeness of information is logically related to its sufficiency for making a decision. With a small amount of information, it is difficult to make a high-quality decision about the state of a technical object. If there is a surplus of information, the decision-making algorithms are usually complex. Both incomplete and superfluous information reduce the quality of automatic solutions created at a technical facility [1]. Most often, the amount of information for modern technical research objects is very large and the decision should be made according to the most important or generalized parameters. For such a technical object as, for example, a bridge structure, the dynamic factor is a generalized parameter, which requires measurements of static and dynamic deflections of this structure. For an autonomous mobile robot (AMR), a similar parameter is the ability to correctly detect a landmark (LM). Decision-making on the decommissioning of a bridge or its part is carried out not on the basis of one value of the dynamic factor, but on the basis of statistical processing of the measured information on the deflections of the structure. Likewise, the decision to detect the LM is made on the basis of statistical processing of the parameters reflected from the landmark of the signals. A statistical sample of parameter values should be representative, which leads to obtaining representative information sufficient to make a decision for the entire general population of parameter values. It is clear that the bridge structure can be disabled not only due to exceeding the critical value of the dynamic factor. Other reasons may be, for example, the need to increase the number of lanes for vehicles on the bridge, various emergency situations, but such cases and related information are not analyzed in the work. Cases of LM detection using systems not installed on board the robot are also not considered, since this goes beyond the scope of its autonomous navigation in the absence of GPS.

The widespread introduction of robots in various types of human activities has put forward the requirement for the promptness of reliable decisions, which can be implemented on the basis of complete information about the environment. Both superfluous information and lack of fundamental information aggravate the quality of AMR decision-making in the process of its navigation in unfamiliar terrain [2]. The concept of completeness of information is widely used both in social research [3] and in the natural sciences [4]. Consequently, the completeness of information is a generally accepted concept, but there is no single interpretation of it for all industries with a mathematical description of the corresponding indicator.

Therefore, it is relevant to develop a method for determining the completeness of information and its model for a wide class of technical objects, in particular, for the navigation of an autonomous mobile robot in an unfamiliar area in the absence of GPS.

So, *the object of research* is the completeness of information for making a navigation decision by an autonomous mobile robot when it performs a task in an unfamiliar area without GPS. *The aim of research* is to substantiate a model and a method for determining the completeness of information about the state of a technical object using the example of information about the detection of a landmark by autonomous mobile operations.

2. Methods of research

There is no general theory of the completeness of information, since such a theory is not applicable to all objects of different nature. Methods for determining the completeness and reliability of statistical data are known [5], which are the basis for obtaining information. More often, the completeness of information is assessed for various objects using specific methods. In [6] the definition of completeness of information on design documentation for technological preparation of production is given. The completeness of the information essentially determines the extent to which this documentation complies with regulatory or customer requirements. Completely different criteria and indicators are used in humanitarian systems, for example, in public administration when creating websites for governing bodies [7]. Here, the coefficient of completeness of information reflects the sufficiency of the amount of information posted on the official website for the formation of a holistic view of the corresponding parameter. Currently, with the growing interconnection of information systems, the integration of information from various autonomous and independent data sources is becoming the subject of many studies. In [8], the intensive character of information quality, called density, and the extended character of quality in the form of a coverage factor, which describes how many objects a source of information can provide, is considered. Density describes how much data a source can provide for each of these objects. The data from the sources are then combined and the coverage ratio and density of the combined result are estimated. For both dimensions of quality, connecting functions are created and the two considered aspects are combined in a general completeness criterion, which is used to optimize user queries to databases, which is an important task of information technology. The paper describes an approach to determining the completeness of information from the point of view of decision-making, and the optimization of information technology elements is not considered.

3. Research results and discussion

The concept of completeness of information is inseparable from the concept of an information cadastre of an object. Most often, the cadastre is linked to geoinformation concepts [9]. In modern conditions, cadastre data are being introduced into information systems [10].

In autonomous navigation AMR without GPS, information is collected from landmarks, which must first be found, and then determine the coordinates of the work relative to the detected landmark. Remote measuring systems work with high accuracy to assess their coordinates relative to a specified landmark, and the most difficult task is to identify it with a probability acceptable for practice with a predetermined probability of a false alarm. The main problem is that the landmark is fixed in relation to the surrounding area, which let's call the background. In such conditions, it is difficult to find differences between the parameters of signals reflected from the background and the landmark during active location by different waves (electromagnetic, ultrasonic, etc.). In [11], a method is proposed for expanding the conditions for the use of radars based on the developed system for detecting jumps in the amplitude of signals reflected from a landmark. In passive location with the use of video cameras or night vision devices that receive waves of different ranges (optical, visible and infrared), it becomes possible to identify landmarks with a high probability using the methods described in [12]. Taking into account the fact that the possibility of identifying landmarks significantly depends on the surrounding background and the illumination of the area for individual measuring instruments, let's give an example of creating an information cadastre of a land landmark. In the Table 1, the rows indicate the totality of the main means of remote detection of a land landmark, and the columns show the average probability of detecting the selected landmark for various conditions, which can be obtained by modeling or experimentally.

The information will be considered complete if the decision to detect a landmark is made with absolute reliability, that is, it is enough for this that the probability of detecting a landmark by at least one of the means approaches unity. In addition, if the specified opportunity for all funds is close to zero, then let's consider that the information is completely absent. In other cases, the information completeness factor K_n for a wide range of conditions is determined by the formula:

$$K_n = \frac{1}{m \cdot k} \cdot \sum_{i=1}^{m} \sum_{j=1}^{k} p_{ij}, \quad (1)$$

where m, k – the number of rows and columns, respectively Table 1, and p_{ij} – the average probability of detecting a landmark for the i-th means under the j-th conditions (time of day, the presence of the corresponding background according to Table 1). If the probability of detecting one agent is dominant, other detectors can significantly reduce K_n. However, this is not a disadvantage of the given information cadastre, since none of the tools is universal in all situations. In particular, the table can be expanded by including other conditions in it: twilight, precipitation, interference, etc. Since the conditions in the Table 1 are not strict, for example, a non-integral background, then the information cadastre contains approximate information and can be used as a priori information about a given object to build optimal information processing methods. A similar table can be created for the construction of a bridge and other technical objects.

Table 1

Landmark information cadastre for autonomous mobile robot

Landmark detection tools	Landmark detection probability					
	In the daytime			In the nighttime		
	Solid background	Discontinuous background	No background	Solid background	Discontinuous background	No background
Radar	p_{11}	p_{12}	p_{13}	p_{14}	p_{15}	p_{16}
Laser	p_{21}	p_{22}	p_{23}	p_{24}	p_{25}	p_{26}
Ultrasonic	p_{31}	p_{32}	p_{33}	p_{34}	p_{35}	p_{36}
Infrared	p_{41}	p_{42}	p_{43}	p_{44}	p_{45}	p_{46}
Optic	p_{51}	p_{52}	p_{53}	p_{54}	p_{55}	p_{56}

Example. To illustrate the use of an information cadastre to determine the coefficient of completeness of information in Table 2 shows the values of the a priori probability of detecting a certain landmark by different means under averaged conditions.

Table 2

Information cadastre for the example

Landmark detection tools	Landmark detection probability					
	In the daytime			In the nighttime		
	Solid background	Discontinuous background	No background	Solid background	Discontinuous background	No background
Radar	0.15	0.67	0.95	0.15	0.67	0.95
Laser	0.20	0.71	0.89	0.20	0.71	0.89
Ultrasonic	0.33	0.56	0.91	0.33	0.56	0.91
Infrared	0.15	0.24	0.36	0.25	0.78	0.90
Optic	0.60	0.75	0.94	0.10	0.18	0.30

The information completeness factor, which takes into account the probability of detecting landmarks in the daytime and at night with three basic background models, is calculated by the formula (1) and taking into account the data in Table 1 is 0.543. Separately for daytime and nighttime for the given example, this factor is 0.561 and 0.525, respectively, and for various means of detecting a landmark, taking into account three model types of background, it is given in Table 3.

Table 3

Information completeness factor for different means of detecting a landmark

Landmark detection tools	Information completeness factor	
	In the daytime	In the nighttime
Radar	0.590	0.590
Laser	0.600	0.600
Ultrasonic	0.600	0.600
Infrared	0.250	0.643
Optic	0.763	0.193

From this example, it follows that the greatest completeness of information is achieved for optical means of detecting a landmark (video cameras), which, unlike radar, laser and ultrasonic means, are passive and therefore the background less affects the probability of detecting a landmark.

After conducting experimental studies on the selected area, a posteriori values of the probability of detecting any landmark for all detection means installed at work are obtained. These values are used to assess the completeness of information for operation and individual detectors. It should be expected that for the indicated detection means the information completeness factor may be greater or less than the corresponding factor for the robot. This can serve as a basis for the selection of landmarks for work, especially for specialized robots. For universal robots that carry out autonomous navigation in unfamiliar terrain without GPS, it is important to have the maximum number of detectors working on different physical principles. In different navigation conditions, the performance of the detection means changes and the coefficient of information completeness can both decrease and increase.

The calculation of the coefficient of completeness of information according to the formula (1) does not always meet the practical requirements. For example, if one of the means of detecting a landmark has a detection probability close to one, then wit is possible to confidently assert that the task of autonomous navigation has been completed in full, that is, the information completeness factor should be equal to one or be close to one. The results obtained according to the formula (1), however, can give a number much less than one, if other means of detection are ineffective in specific conditions. For the user, it does not matter how the goal is achieved – the detection of a landmark by the robot. If the goal is achieved, the user believes that the completeness of information contributed to this, that is, the coefficient of completeness of information should be close to one or one. This implies a different, in comparison with formula (1), approach to assessing the completeness of information.

From a practical point of view, it is possible to assume that when the probability of detecting a landmark exceeds a certain threshold value:

$$p \geq p_{th}, \quad (2)$$

the goal of autonomous navigation of the robot is achieved and then $K_n = 1$, which indicates the completeness of the information. Formally, this can be described by the ratio:

$$K_n = \frac{1}{s}\sum_{i=1}^{s} \kappa_i, \quad (3)$$

where κ_i – Boolean variable equal to one if (2) is fulfilled and zero in other cases, and s – the number of landmark detectors for which condition (2) is satisfied. With this approach, K_n takes only two values: 0 and 1. If none of the detection tools provides inequality (2), then another formula should be used to estimate the completeness of information, taking into account the modified inequality (2):

$$p_l \leq p \leq p_{th}, \tag{4}$$

where p_l – minimum (lower) value of the probability of detecting a landmark, which is of practical importance, for example, p_l=0.5. In this case, relation (1) is transformed into the following form:

$$K_n = \frac{1}{n_0} \cdot \sum_{i=1}^{m} \sum_{j=1}^{k} \alpha_{ij} p_{ij}, \tag{5}$$

where n_0 – the number of units in the Table 1, and α_{ij} – weight coefficients equal to one if inequality (4) is satisfied and zero otherwise. If, for example, p_l=0.5, and p_{th}=0.96, the weight coefficients α_{ij} acquire the values given in Table 4.

Table 4

Weight coefficients α_{ij} for calculating the information completeness factor

Landmark detection tools	Weight coefficients α_{ij}					
	In the daytime			In the nighttime		
	Solid background	Discontinuous background	No background	Solid background	Discontinuous background	No background
Radar	0	1	1	0	1	1
Laser	0	1	1	0	1	1
Ultrasonic	0	1	1	0	1	1
Infrared	0	0	0	0	1	1
Optic	1	1	1	0	0	0

The information completeness factor calculated by formula (5) is 0.785, while by formula (1) it is 0.543. The reason for this is the neglect of low values of the probability of detecting a landmark. From a practical point of view, formula (5) is more suitable and therefore, to determine the coefficient of information completeness, it is advisable to use formulas (3) and (5).

For the practical use of the above models of the information completeness ratio, preliminary large-scale statistical studies are required. They should assess the likelihood of detecting by the equipment the operation of landmarks of different types against the background of different types of solid and non-targeted backgrounds in wide conditions of illumination, precipitation, season characteristics, etc. The results of this study will be used in the compilation of an information cadastre for the specific tasks set by USAID. In parallel, when processing the results, it is possible to train a neural network, which will then be able to independently recognize landmarks, which simplifies the task of autonomous navigation. Of course, the general theory needs further development, according to which it is possible to assess the completeness of information for any applied information process in various fields of science, technology and, possibly, in social research. All this goes beyond the thematic scope of the work.

4. Conclusions

To make a decision on the state of a technical object, it is necessary to obtain a certain amount of information, characterized by the coefficient of information completeness. In the work, this coefficient is normalized in such a way that its maximum value is equal to one and this would correspond to complete information. There can be much more information, but it is not needed to make a decision. For each technical object, an information cadastre must be drawn up, revealing the information capabilities of the object from the point of view of making a specific decision. The paper presents a methodology for compiling such cadastre using the example of detecting a landmark by an autonomous mobile robot. Formulas for calculating the coefficient of completeness of information are justified for the main practical cases. If the specified coefficient exceeds a certain threshold value selected for each technical object separately, it is considered that the information for making a decision is complete. The coefficient of its completeness can approach unity even in the absence of separate means of detecting landmarks, and then the proposed method makes it possible to assess the need for their use in the given conditions. The model and method for determining the completeness of information, justified in the work, can be used for any technical object.

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COMPARATIVE ANALYSIS OF GLOBAL AND NATIONAL SYSTEMS FOR OBSERVING, MONITORING AND FORECASTING NATURAL DISASTERS AND HAZARDS WITH A VIEW TO REDUCING RISK

The object of research is modern systems for observing, monitoring and forecasting natural disasters and hazards. Although early warning systems are often used to predict the magnitude, location and time of potentially hazardous events, these systems rarely provide impact estimates, such as the expected amount and distribution of material damage, human consequences, service disruption or financial losses. Supplementing early warning systems with predictions of impact has the dual advantage of providing better information to governing bodies for informed emergency decisions and focusing the attention of various branches of science on the goal of mitigating or preventing negative effects.

The publication analyses current trends in the growth of natural risks, taking into account the risks associated with global climate change. The issues related to the growing risks of natural disasters and catastrophes at the present stage of societal development and directions of activities at the international and national levels for their reduction are considered. Disaster risk prevention and mitigation measures are described and areas of work in this area are highlighted. The decision-making sequence model is given, global and regional systems of observation, analysis, detection, forecasting, preliminary warning and exchange of information on natural hazards related to weather, climate and water are described. The factors that «unbalance» the global economy in terms of intensity, magnitude, magnitude of losses due to catastrophic events are analyzed.

Addressing disaster prevention requires a structure at the national level in each country that includes policy, institutional, legal, strategic and operational frameworks, as well as at the regional and societal levels. This structure will organize and implement disaster risk reduction activities and establish an organizational system that will understand disaster risk and ensure that it is reduced through public participation.

Keywords: *disaster monitoring, observing systems, natural hazards, risk minimization.*

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1. Introduction

Natural disasters are natural phenomena of a catastrophic nature that contribute to the destruction of the social, economic and environmental spheres of human civilization and impede their sustainable development.

Natural disasters occur worldwide and frequently. They threaten human society, natural ecosystems and major infrastructures. According to the United Nations (UN), global average annual losses caused by disasters such as earthquakes, floods, droughts and tornadoes ranged from 250 to 300 billion USD in 2015 [1, 2]. Over the past decade (2010–2019),