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Mathematical model of the general problem of state classification in wireless sensor networks

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Abstract. This paper considers a mathematical model of the general classification problem in wireless sensor networks. We present the fields of application of sensor networks, the existing types of sensors used in data networks are listed, as well as the most typical conditions of sensor networks. The main attention is paid to the analysis of mathematical models of classification tasks, evaluating its parameters. As a result, there has been developed a mathematical model of the problem of the classification of states in wireless sensor networks, taking into account factors such as inaccuracies in the sensor readings, the dynamics of the number of sensors, dynamic network conditions, and their priority. This object allows you to move on to the next stage of the classification network conditions, the development of the classification algorithm**.**

1. Introduction

The continuous growth of computing power of modern software-controlled devices and the availability of a variety of different sensors has made it possible to build sensory information processing networks that provide the automation of various processes.

Temperature sensors, pressure, sound, motion, and other distance sensors distributed over a controlled area or site gather information about the environment with speed and precision that are ten times higher than when using sensory evaluation techniques. On the basis of the collected data in a short time can be taken the most correct decisions for follow-up, at which the costs of human resources are minimal or nonexistent.

A popular modification of the sensor network is a wireless communication, which expands the range of use by eliminating the need for physical contact between the elements. As a result, sensors can easily be connected to the network, and that serves to be in tight areas or on moving objects. [1]

In the simplest case, the sensor network is a collection of an interconnected wireless network of sensors located in a controlled environment, where the sensor - a module, consisting of the sensor that registers a change in one or the other of the physical parameters of the environment, the data processing unit, and a transceiver battery. Thus, in some systems, the sensor acts as a relay station in a network, thereby achieving a significant coverage area of the network at a low cost.

Wireless sensor networks enable recognition of specific situations in the environment and accordingly respond to them, at which one of the systems can control the behavior of others in algorithms that were made in advance. An important result of combining subsystems is the synergistic effect. Currently, sensor networks are used in industry, agriculture, medicine and other fields. [2]

In recent years, methods of machine learning (Machine Learning) are rapidly gaining popularity. Machine Learning operates with large numbers of structured data and solves the problem of classification, ranking, and regression. They are widely used in various spheres of life, such as medicine, banking, IT, etc. [3]

Machine learning methods focus on the construction of a mathematical model of the behavior of the environment, where the parameters of the system are determined by training to obtain data from the sensors and sample results of the decision of the main module or the operator. The data in the wireless sensor networks are structured and are based on local metadata. This paper proposes the use of a new approach to the application of machine learning to analyze data from the sensor and the subsequent decision of such a problem, as the classification of states of the system and prediction of its behavior in the future. Also proposed are information processing techniques to increase the potential to solve the following tasks: improvement of the noise immunity of the sensor network, adaptation to environmental changes.

The task at hand in using machine learning in sensor networks is the classification of the states of systems as a whole. In other words, the operator does not need to know about the indications of all the sensors (the number may reach hundreds or thousands of units). Nonetheless, the total information is most important to make the correct decisions for future actions. The sensory network system can be described with a limited number of states. In the simplest case, it is sufficient to identify the two states: "correct" and "incorrect."

2. Sensors in wireless sensor networks

The main task of sensor networks is to define the parameters of the environment. For this purpose, we developed a great number of sensors: sensors of temperature, pressure, humidity, light, sound, position, flow and concentration of a substance, vibration frequency, speed, distance, voltage, electric current, and radioactivity.

The development of MEMS technology has reduced the size of the sensors to micro sizes, which expanded the range of applications of sensor networks. For example, it was possible to significantly reduce power consumption, and hence the size of power supplies, control parameters of small objects, place a large number of sensors on the same object, mask sensors.

The main characteristics of the above sensors are sensitivity and accuracy, and for MEMS sensor to also take into account the dimensions of the elements. [4]

3. States of the wireless sensor network

Most wireless sensor networks, of which the main task is to monitor the area or object, have the following standard conditions: violation of temperature conditions, fire, flood, gas leak, explosion, increased vibration, destruction of the object, foreign object detection, lack of controllable objects, etc. Each state of the system is characterized by a certain set of conditions for the environmental parameters and/or object. For example, for fire characterized by a sharp increase in temperature, decrease in air humidity; the destruction of the object - an abrupt change in frequency of the object, change of noise, sharp claps, change in the position of the object, etc. It is worth noting that some of the states of the system cannot be determined only by static reasons, and it is necessary to know their dynamics. [5]

In practice, at one moment a wireless sensor network may have multiple states. For example, fire, explosion or excessive vibration and temperature violation. On the one hand, the operator, first of all, needs to know about the most important state of the system (for example, a fire is more important than the finding of foreign objects), on the other hand, it is necessary to know about the most dynamic states (for example, the consequences of the explosion will come faster than from flood). All the while, different parameters of the sensor networks priority system may differ materially depending on the task.

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4. Mathematical model of the general problem of state classification in wireless sensor networks

Let X be a plurality of indications of the sensor network, Y – the set of states of a wireless sensor network.

Each sensor $\overrightarrow{x_k} \in X$, where k = 1..K (K – number of sensors in a sensor network) is a vector in N-dimensional space, where N – the number of unique parameters obtained from the external environment. The value x_{kn} in most cases is a *binary* or *quantitative* trait. [6]

In other words, at a certain point in time the sensor network is represented by a matrix of objects-signs:

$$\begin{pmatrix} x_{11} & x_{21} & \cdots & x_{k1} \\ x_{12} & x_{22} & \cdots & x_{k2} \\ \vdots & \vdots & \ddots & \vdots \\ x_{1n} & x_{2n} & \cdots & x_{kn} \end{pmatrix} \quad (1)$$

Gaps in the data.

Each sensor transmits readings from 1 to N parameters of the environment, i.e., gaps can be present in the data. The most common omissions in the matrix are arranged not by chance, that is, for a long period of time the sensor will not provide data on certain parameters. It turns out that there are many $P \subseteq X$, where $\forall\, x_{kn} \in P:\ x_{kn} \notin \mathbb{R}$.

The errors in the data.

As mentioned earlier, the sensors are characterized by error. Consequently, an additional condition to the problem of the classification algorithm is established to ensure noise immunity when errors are permissible.

Sensor tolerance is due to its type, model, and component elements. Also, operating conditions affect the error. It can be considered in order to simplify the problem that one environment parameter is measured by one sensor model: $x_{kn} = x'_{kn} \pm \delta_n$, where n – the measured value of the environment, k = 1..K (K – the number of sensors in a sensor network), δ_n - error for the selected type of sensor. If one environmental parameter is measured by several types of sensors, the number of N can accept a number of different types of sensors, and as a result, the problem is reduced to the above condition.

The dynamics of the sensors and the network conditions.

On the one hand, the number of sensors in the network may constantly change: the defective sensors can be removed from the network, and at any time new can be added. The system should take account of this provision and continue to perform the classification. In other words, the set is not limited, and at some point in time, the system operates with a specific subset $X' \subseteq X$. On the other hand, the set of states of the system, too, has its own dynamics. Some state sensor networks may lose relevance, while the emergence of new types of sensors can be monitored by earlier unknown states. Therefore, the set of states Y is also not limited, however, at some point, the set of parameters of the sensor network $X' \subseteq X$ system can have a plurality of states $Y' \subseteq Y$.

The task of classification.

The problem of classifying the wireless sensor network is to establish a state of dependence (display) $y^*\colon X' \to Y'$.

A mathematical model of the general problem of state classification in wireless sensor networks:

Let X - many kinds of indications of the sensor network, Y – set of all possible states of a wireless sensor network. In a certain period of time $t = [T_x; T_{x+1}]$ sensor network described by subsets $X' \subseteq X$ и $Y' \subseteq Y$:

$$X' = \begin{pmatrix} x_{11} & x_{21} & \cdots & x_{k1} \\ x_{12} & x_{22} & \cdots & x_{k2} \\ \vdots & \vdots & \ddots & \vdots \\ x_{1n} & x_{2n} & \cdots & x_{kn} \end{pmatrix}, Y' = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_L \end{pmatrix}, \quad (2)$$

where k = 1..K (K – the number of sensors in a sensor network at $t = [T_x; T_x)$, n = 1..N (N – number of different sensors at $t = [T_x; T_x)$, l = 1..L (L – the number of wireless sensor network states in $t = [T_x; T_x)$. Wherein $\exists P \subseteq X$, where $\forall x_{kn} \in P: x_{kn} \notin P$ and for $\forall x_{kn} \notin P: x_{kn} = x'_{kn} \pm j$, where j - error for a particular type of sensor.

It is necessary to establish a relationship $y^*: X' \to Y$ taking into account the priorities and the dynamics of network conditions.

To solve this problem, it can be used by machine learning methods. Training on case law implies a finite training sample $X'^M: \{\{x_1, y_1\}, \{x_2, y_2\}, \dots, \{x_m, y_m\}\}$ [7].

5. Conclusion

A wide variety of sensors allow you to define different states of environment or object by means of a sensor network. If the data from the sensors are displayed to the operator directly, then it must independently analyze the information and make a decision on the system status. Classification function can be passed on to the network. To this end, this paper presents a mathematical model formulation of the general problem of the classification status of the wireless sensor network.

The most popular sensors of sensor networks: a temperature sensor, pressure, humidity, light, sound, position, flow, and concentration of a substance, the frequency of vibration, speed, distance, voltage, electric current, radioactivity. Their main characteristics are the sensitivity, accuracy and overall dimensions.

A wireless network in a certain time interval has a limited number of states, while it is at a particular point can be in one or more states. To classify the important priority of the state and its dynamics.

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