Methodology of application of open-source platform Protégé in the measurement and computing systems development for diagnostics of heat supply networks

Alexey Petrov[1], Anton Popov[1], Mikhail Chekardovsky[2] and Alexander Pushkarev[1]

[1] Tyumen State University, 6, Volodarskogo St., Tyumen, Russia
[2] Industrial University of Tyumen, 38 Volodarskogo St., Tyumen, Russia
264241@mail.ru

Abstract. In this article the authors focus on the growth of accidents of heating networks due to the increase in their length. The existing key properties of measuring and computing complexes for diagnostics of external heat networks that satisfy the requirements of 4GDH are considered. It is proposed to apply a systematic approach to construct an engineering ontology, based on the collected database. it is assumed that the engineering ontology will be built using the Protege software, which will eventually be expressed in the form of an ontograph and a report based on it. It is considered that the classical engineering method in this context is no longer sufficiently effective, since creating new technologies, there is a focus on each cost item, based on technological necessity (standards for resource consumption are established). Thus, developing some technology, they focus primarily on its cheapness, and only then on the effectiveness of its application. It is proposed to form such an engineering ontology based on heuristics (non-traditional logic) and implemented in the form of program code. The advantages of the approach are to obtain heuristic ontology tools that become more "flexible" to implement changes. Also and they do not require adjustment of most of the program code of the ontology. The authors notice that the key problem that they need to solve when developing an ontology is "knowledge extraction" (the process of extracting data from a data source). There is a selection of the main directions in the field of development and design of heat supply networks, which have already been implemented or supported by scientific teams from different countries. Various methods and technical features of diagnostics are viewed. The strengths and weaknesses of the presented solutions are highlighted. The considered works were subjected to a detailed analysis. It is revealed that there is a presence of a high scientific and industrial interest of the community to integrate and improve existing digital technologies in the heat supply systems development, which would be closely related to the forecasting and modeling of processes in this industry.

Keywords: Measuring systems, Protégé, Computing systems development.

1 Introduction

Nowadays Russia has the longest district heating network in Europe (summarized it is about 125 000 km). Taking into account that the volume of construction areas is increasing constantly the length of the heat network will increase in direct ratio. Besides, there are main pipelines (the total length is about 230 000 km.) that constantly require maintenance. Naturally, that with the constant growth of the above objects, the number of accidents and, as a result, their stops increases.

Consequently, a request appears to increase the reliability of heat supply networks. To satisfy the request, it is necessary to increase the volume and quality of comprehensive diagnostics of heat supply networks while reducing time costs. This is possible only if a new generation of measurement and computing systems for diagnostics of heat supply networks is developed.

2 Materials and methods

2.1 Determination of key properties of measuring and computing systems for 4GDH requirements

Analyzed other works [1-5] supported by researches we can determine the key properties of measuring and computing systems to diagnose outdoor heating networks that would satisfy the 4GDH's request. We mean properties such as:

- Unification is a property of measuring and computing complex that allows making measures regardless of the diameter and bend of the pipe;
- The homogeneity of space is a property of the measuring and computing complex, allowing to correct the results of a calculation taking into account that the measured phenomena in the same conditions, but in different places in space are the same (the change in the calculation only in case of changes in pipe design;
- Coherence is a property of measuring and computing complex that allows coordinating several types of working medium flow in a pipe in time;
- Interactivity is a property of measuring and computing complex that allows determining the degree and nature of measured elements of the heat supply system on each other;
- Versatility is a property of measuring and computing complex that allows refocusing the complex to other types of working medium, other measured parameters, and different configurations of heat supply networks;
- Robustness is a property of measuring and computing complex that allows being independent of "information noise" due to correction factors or other methods and ways to eliminate it.

To develop the new generation measuring and computing systems it is necessary to combine effective methods of engineering science and synergetic methods of information sciences. Moreover, in cases where the devices had full-fledged software the capabilities of information science increased the efficiency of using these devices. System engineering is the closest to the specified requirements.

2.2 Applying a systems engineering approach and heuristics

Since the approach of systems engineering is interdisciplinary and can cover both the technical component of the process of creating a measurement and computing complex and the development of software (taking into account its further development and verification), it should be applied when creating an engineering ontology that could combine both quantitative data about its elements and qualitative, key properties for 4GDH. The result of the application of this campaign will be a concretized vision of both the device of the measuring and computing complex itself and the digital solutions used in it, excluding the subjective influence of the author of the work.

Realization of the systematic approach will be implemented by building an engineering ontology based on collected a database. The engineering ontology will be built using software Protégé. However, for a deeper understanding, it is necessary to make a sequence of inferences that will be presented in the ontograph and report form.

The classic engineering method is not effective enough because creating a new technology there is a focus on each expense item. Thus the technology is created primarily focusing on the cheapness of its production and only then on efficiency.

Forming such engineering ontology, it is necessary to be based on heuristics (non-traditional logics) and create them using a program code. The advantage of this method is that heuristically instruments become more “flexible” to implement changes, and, therefore, do not require adjustment of most of the program code of the ontology.

The key problem that we have to solve is knowledge extraction (the process of extracting data from a data source). The problem occurs due to listed elements of the future ontology. They are submitted by standards (they are subjective) and satisfy specific requirements. That is the database which includes tables, formulas, links, diagrams and so on is a kind of “indoor language” with a kind of “indoor engineering language”.

To make it outdoor is possible with the help of methods of Data Mining with the help of using Web Ontology Language specially designed to describe ontologies, the elements of which are placed in the “semantic network’’. Using these instruments, we can transform the database into the knowledgebase (written the engineering ontology for it) and visualize it in Protégé [6].

As a result, we have the formal language to describe a chosen device and software for developed measuring and computing complex, formalized in the form of an engineering process, the product of which is a complex that includes all the properties listed above. Thus, the vision of the measurement and computing complex is formed for 4GDH not only in the “generative design” form but also in “generative manufacturing” one with a request to the functional features of its software.

3 Results. Creation of an engineering ontology in Protégé

3.1 Filling the ontology

The ontology creation starts with the selection of the main formations (Entities) of the system that are similar to objects and subjects in classical logic terms. Since we consider the term "measuring and computing complex" as an automated diagnostic tool for the heat supply network that is which is a software-controlled set of measuring, computing, and auxiliary devices, then in our case it will be the following entities:

- Artificial neural networks as a base for the software;
- Sensors as measuring devices;
- Microcontrollers as computing devices;
- Auxiliary devices such as memory devices, wireless data transmission devices, communication devices, network adapters.

Now we have to define their place in the class hierarchy in the Protégé system. Since within the framework of our heuristic all formations are equal, the hierarchy of the first level will look like this (Figure 1).

Fig. 1. Hierarchy Of Entities.

Then it is necessary to form the subentities hierarchy. To do this, it is necessary to describe all types of artificial neural networks [7], microcontrollers [8], sensors [9], and auxiliary devices [10], which are used in the creation of measurement and computing systems for the diagnosis of outdoor heating networks. We should note that we take all types of artificial neural networks and all types of microcontrollers, since for them there is no fundamental difference between what elements to control and what data to analyze. At the same time, sensors and auxiliary devices in our ontology are limited.

It is necessary to list sensors that measure only such physical parameters as are used in the heat supply network diagnosis.

Auxiliary devices are selected according to the same principle. The ontology includes devices that are used in measurement and computing systems for the diagnosis of heat supply networks.

As a result, an engineering ontology was obtained included 111 finite elements. The ontograph of this ontology is shown in Figure 2.

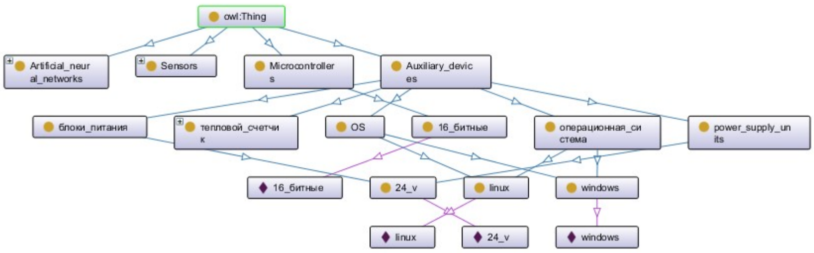

Fig. 2. Fragment of the ontograph.

The next step is to specify the rules for the functioning of the ontograph. We use the "Disjoint with" function to specify that the Entities listed by us should not be related to each other. Thus, in the case when the relationship of the optimal parameters of Entities with each other is detected, the situation of choosing two neural networks or two microcontrollers at the same time should not arise.

After entering the "rules", we need to enter the properties in the ontology (Figure 3).

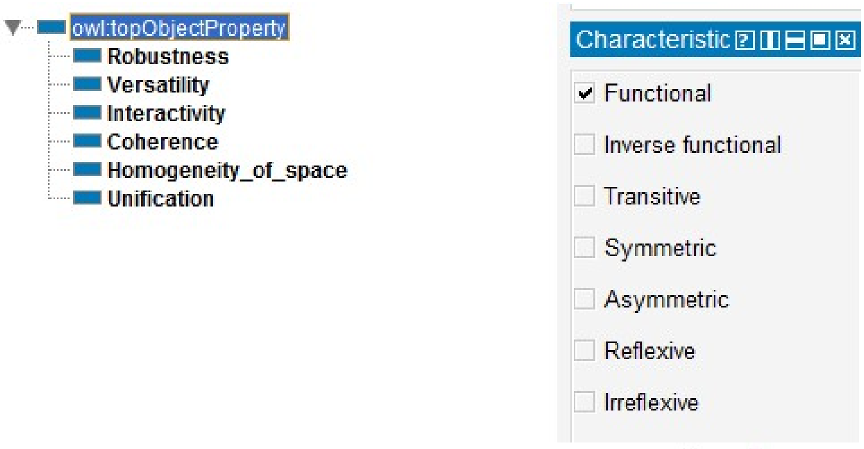

Fig. 3. The hierarchy of the ontology elements characteristics.

Every property has got the “Functional” parameter. It establishes that a chosen property can have only one value for one element of the ontology.

Next, we need to create a hierarchy of properties in the Data Property section to express the listed properties in the form of quantitative indicators. To do this, we create "Individuals" for each final element of the ontology and write "rules" in it, formed the following logic: Each element has 6 properties.

Each property can be expressed as a quantitative parameter "long" from 0 to 2 (Figure 4).

Fig. 4. Example of forming "rules" for an ontology element.

It is necessary to explain the meaning of the allowed values of the property:

The property is evaluated to "0" when the evaluated element does not satisfy the requirements.

The property is evaluated to "1" when the evaluated element partially satisfies the requirements.

The property is evaluated to "2" when the evaluated element fully satisfies the requirements.

3.2 Ontology heuristic

For each Entity, the interpretation of each property is separate.

For Entities "Artificial neural networks", the interpretation is:

- Unification is a set of properties of the software of the measuring and computing complex that allows distributing of incoming data into categories, taking into account the design features of the source;
- Homogeneity of the state space is a set of properties of the software of the measuring and computing complex that allows adjusting the results of data calculation taking into account the source characteristics;
- Coherence is a set of the software properties of the measuring and computing complex that allows carrying out the procedure of coordination of several data streams;
- Interactivity is a set of the software properties of the measuring and computing complex that allows determining the relationship between data flows;
- Universality is a set of the software properties of the measuring and computing complex that allows reorienting it to calculations of other types of data;

- Robustness is a set of software properties for the measuring and computing complex that allow it to be independent of "information noise" during operation.

For Entities "Sensors", the interpretation is:

- Interactivity is a set of the software properties for the measuring and computing complex that allows determining the relationship between data flows;
- Homogeneity of the state space is a property of sensors for the measuring and computing complex that allows providing correct data about the measured object, regardless of changes in external conditions;
- Coherence is a property of sensors for the measuring and computing complex that allows two or more data streams to be directed simultaneously;
- Interactivity is a property of sensors for the measuring and computing complex that determines the ability to adjust the data flow depending on external conditions;
- Universality is a property of sensors for the measuring and computing complex that allows you to quickly reorient it to a different data source or data flow type;
- Robustness is a property of sensors for the measuring and computing complex that allows the measuring system to be independent of “information noise”.

For Entities "Microcontrollers", the interpretation is:

- Unification is a microcontroller property for the measuring and computing complex that allows making measurements, regardless of the types of sensors;
- Homogeneity of the state space is a microcontroller property for the measuring and computing complex, which allows you to adjust the calculation results taking into account external conditions;
- Coherence is a microcontroller property of the microcontroller for the measurement and computing complex that allows coordinating several types of information flows;
- Interactivity is a microcontroller property for the measuring and computing complex that determines the degree and nature of the interaction of information flows on each other.
- Universality – a microcontroller property for the measuring and computing complex, which allows reorienting it to other types of information flow;
- Robustness is a microcontroller property for the measuring and computing complex that allows it to be independent of" information noise" due to correction factors or other methods and methods of its elimination;

For Entities "Auxiliary devices", the interpretation is:

- Unification is a property of auxiliary devices for the measuring and computing complex that indirectly affect the efficiency of measurement production;
- Homogeneity of the state space is a property of auxiliary devices for the measuring and computing complex that indirectly affect the correction of the calculation results;

— Coherence is a property of auxiliary devices for the measuring and computing complex that indirectly affect the possibility of effective coordination of several types of information flows from the working fluid in the pipe in time;
— Interactivity is a property of auxiliary devices of the measuring and computing complex that indirectly affect the efficiency of the interaction of system elements with each other;
— Universality is a property of auxiliary devices for the measuring and computing complex, indirectly influencing the speed of its transformation (re-equipment) if necessary;
— Robustness is a property of auxiliary devices for the measuring and computing complex that indirectly affect the reduction of the degree of influence of "information noise" on the information flows of the system.

4 Discussion

Then it is necessary to evaluate each property for each element of the ontology. For a deeper understanding of this action, it is necessary to consider a separate example for each Entity and describe the logic of assigning a certain number of points.

For Entities "Artificial neural networks", we consider the element "Kohonen neural networks" (Figure 5).

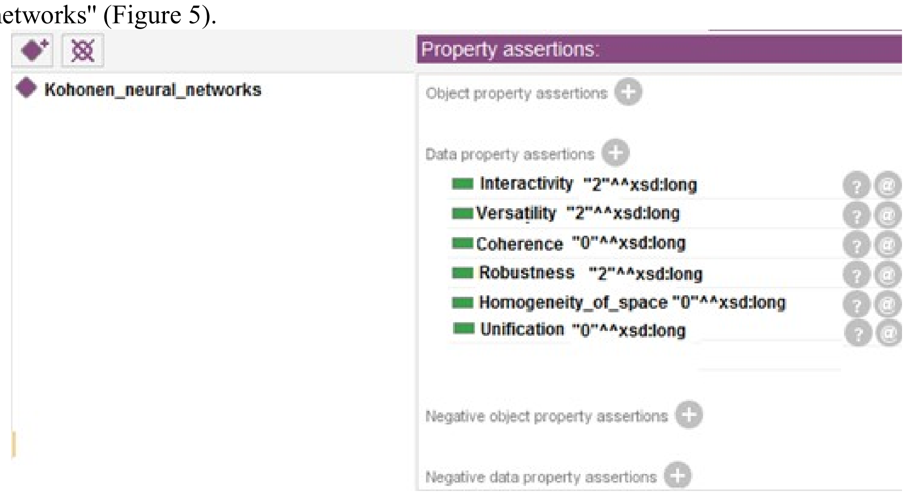

Fig. 5. Example of complete filling of the ontology element for Entities "Artificial neural networks".

Since the functioning of the Kohonen neural network can be described as:

$$E_i = i * P_c \tag{1}$$

Where:
Ei – the final pulse;
i – pulse passing through the link;

Pc – link weight.

As a result, we get that during the operation of this network, the pulse that has gained the largest signal becomes a single one, and the rest become zero. This implies that the final neuron receives the sum of all pulses. It means that the possibility of distributing incoming data is excluded. Therefore, the value of the "Unification" property is "0". Also, the value "0" gets the property "homogeneity of the state space", since the "Kohonen layer", which forms the basis of the neural network, cannot be corrected. For the same reason, the value of the "coherence" property is "0", because the Kohonen network, given the specifics of its operation on the principle of "only one signal is powerful", is not able to coordinate several data streams.

At the same time, since the Kohonen network perfectly solves problems related to cluster analysis, and the input weights of the adder can be customized, the property "interactivity" and "universality" is estimated at “2”. In addition, inasmuch as the Kohonen network is capable of self-organization and is completely autonomous from external influences (the so-called "information noise"), the property "Robustness" is also estimated at "2".

If the Kohonen layer could be affected, or if it had the ability to output two signals at the same time, then all properties would be evaluated at "1".

For Entities "Sensors", consider the element “Contactless (remote action)” (Figure 6).

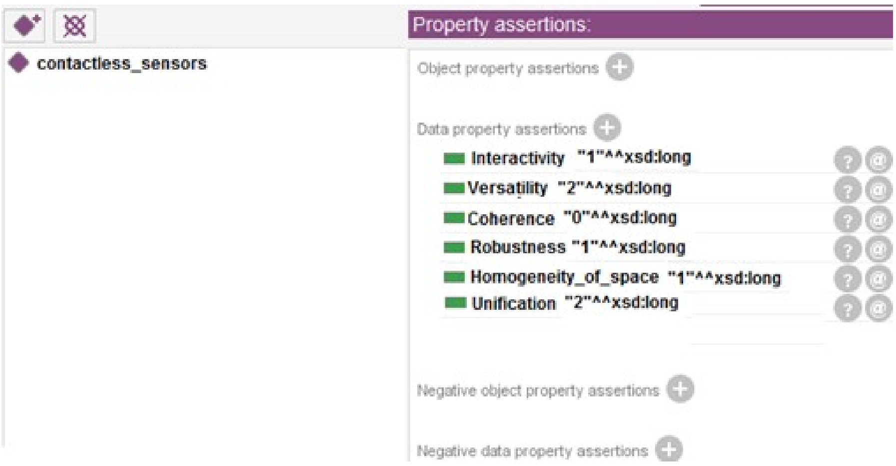

Fig. 6. Artificial neural networks". Example of full filling of the ontology element for Entities “Sensors”.

Since the element under consideration allows capturing data without contact with the measured object, the design feature of this object is not important for it. Therefore, the "Unification" property is evaluated to "2".

However, most non-contact sensors transmit data about the measured object by means of a radio signal which can be distorted by external conditions (for example, an electromagnetic field, signal overlap, atmospheric phenomena). This means that such properties as" uniformity of the state space"," interactivity "and" robustness "will be evaluated in" 1", since they can only reach" 2 " if additional equipment is added that uses signal correction software, network filters, and so on.

The "coherence" property is evaluated at "0", since one contactless sensor can only make one measurement and, as a result, direct one data stream.

The "versatility" property is rated at "2", since contactless sensors overwhelmingly have a final signal in digital form, which means that the received data can be quickly reoriented to a different form.

For Entities "Microcontrollers", consider the element “8-bit” (Figure 7).

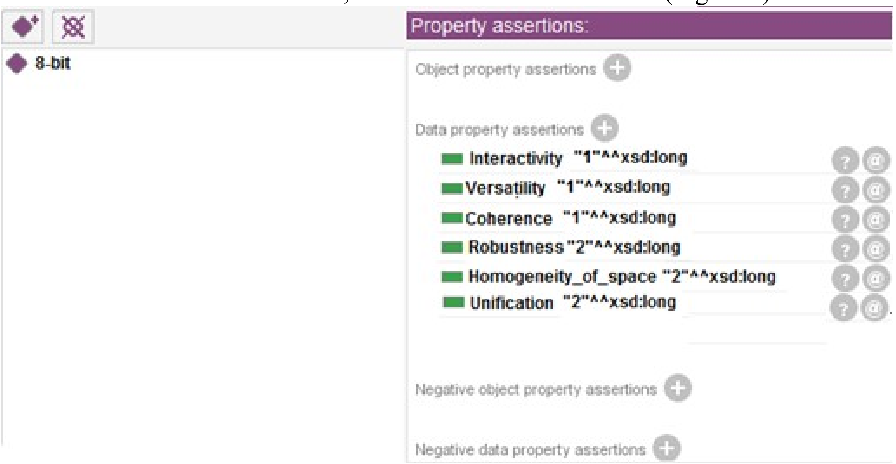

Fig. 7. Example of full filling of the ontology element for Entities “Microcontrollers”.

Currently, all 8-bit controllers have built-in protection against "information noise". In this regard, the property "robustness" is rated at "2". The design also provides for the connection of various types of sensors, so the "Unification" property is also evaluated in "2". Given that each microcontroller of this type can be programmed (or already the corresponding software is installed in it) so that it is possible to adjust the input data flow, the property "uniformity of the state space" is also estimated at "2".

The "Coherence" property of an 8-bit microcontroller is estimated at "1", since, in comparison with its 16-bit and 32-bit counterparts, the number of simultaneously coordinated information flows is less. For the same reason, the value "1" is assigned to the properties "Interactivity and "Universality".

For Entities "Auxiliary devices", consider the element "ultrasonic" (meaning an ultrasonic heat meter) (Figure 8).

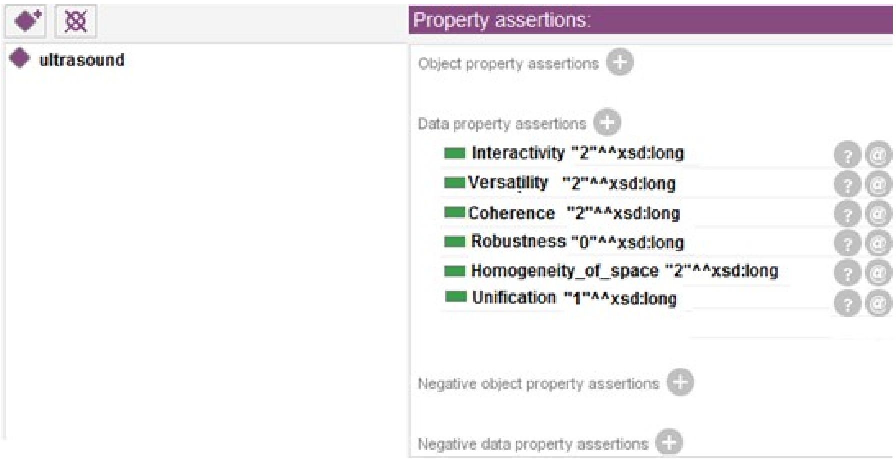

Fig. 8. Example of complete filling of the ontology element for Entities “Auxiliary devices”.

Since the operation principle of an ultrasonic heat meter is based on sending and receiving an ultrasonic signal after a certain period of time, such properties as "coherence", "homogeneity of the state space", "universality" and "interactivity" are evaluated in "2". Inasmuch as this device allows coordinating several types of data received from the measured object, we can track the interaction of all elements of the system and correct the results of calculations. However, because the ultrasonic signal is easily subject to distortion (information noise), the property "Robustness "is estimated at "0". For the same reason, the "Unification" property is estimated at "1", since due to the susceptibility of the ultrasonic signal to" information noise", the measurement efficiency may not be accurate.

After all the objects are evaluated and included in the general ontology, we can start searching for "hidden knowledge" and use such a Protege tool as "Reasoner".

The purpose of Reasoner is to find hidden dependencies by "reasoning". To do this, we create new "individuals" called "optimal microcontroller", "optimal artificial neural network", "optimal sensor", "optimal auxiliary device", prescribe maximum Data Properties to them (Figure 9), and carry out reasoning.

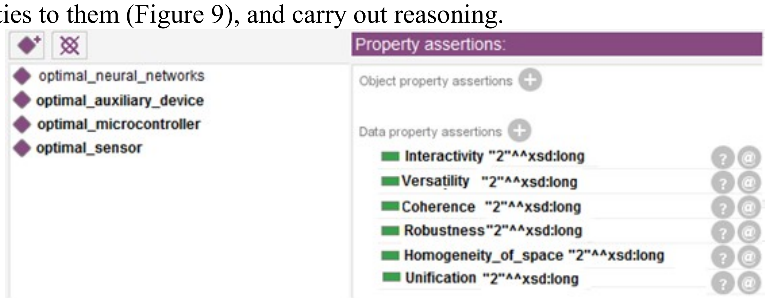

Fig. 9. Elements for processing via Reasoner.

For convenience, the "reasoning" is summarized in Table 1.

Table 1. Reasoner's reasoning.

Reasoner	Selected artificial neural network	The selected sensors	The selected microcontroller	The selected auxiliary device
ELK 0.4.3	The recurrent neural network	Analog ones	-	Ultrasonic Heat Meter

As you can see in the table, the "reasoning" did not affect every category of the ontology. It means that the other parameters, from the Reasoner's point of view, are not important and you can choose any of the suggested categories.

5 Conclusion

Thus, we can make the conclusion that the method is workable, and the developed measuring and computing complex for diagnostics of external heat supply networks:

- Must be based on analog sensors (depending on the measured parameter);
- Must have software based on a recurrent neural network;
- Can include any microcontroller;
- As auxiliary equipment should have an ultrasonic heat meter.

The listed elements will form the basis of the developed measuring and computing complex [11], which will be covered in the following scientific works.

References

1. Gaponenko Sergey Olegovich, Kondratiev Alexander Evgenievich, Politova Tatyana Olegovna: Measuring and diagnostic complex for determining the location of hidden pipelines. Izvestiya VUZov. Energy problems, 3-4 (2013).
2. Kuznetsov R.S.: Means of monitoring, control and diagnostics of systems of automatic weather regulation of heat supply. NIKA (2016).
3. Sazonova Svetlana Anatolyevna, Sushko Elena Anatolyevna: Development of methods and algorithms for technical diagnostics and security of fire extinguishing systems, heat, water, gas supply and industrial technological pipelines. Modern problems of civil protection, 2(23) (2017).
4. Petrushenko Yuri Yakovlevich, Vankov Yuri Vitalievich, Ziganshin Shamil Gayazovich, Tyryshkin Vladislav Nikolaevich: Vibroacoustic method and diagnostic complex for determining pipeline defects using a neural network. Izvestiya VUZov. Energy problems, 9-10 (2009).
5. Akhvaev Arman Amangeldyevich, Shurshev Valery Fedorovich: Application of machine learning in prediction of emergency situations in heat supply systems. Bulletin of AGTU. Series: Management, Computer Engineering and Informatics, 3 (2020).

6. Guenter Tusch, Martin Joseph O'Connor, Timothy Redmond, Ravi Shankar, Amar Das: The Protégé-Owl SWRLTab and Temporal Data Mining in Surgery. Project: SWRLAPI (2010).
7. Reinhard Klette: Concise Computer Vision. An Introduction into Theory and Algorithms Springer-Verlag London (2014).
8. Rubizova Sofya Andreevna Review and comparative study of microcontrollers. Problems of Science 25(107) (2017).
9. Volkov A.V., Malenkov A.S., Yavorovskiy Yu.V., Shelginskiy A.Ya.: Features of using absorption heat transformers as an element of fourth generation heat supply systems. Industrial Energy, 6, 25-31 (2019).
10. Ilyin Roman Albertovich, Stolyarov Denis Vladimirovich: Complex modernization of heating points in centralized heat supply systems. Symbol of Science (2015).
11. Petrov A., Popov A., Molotok A.: Development of a laboratory installation of a digital measuring system for visualization of internal pipeline processes. Journal of Physics CS, 1614 2-5 (2020).