THE MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
KHARKOV NATIONAL UNIVERSITY OF RADIOELECTRONICS

Artificial Intelligence Department

Industrial Ontologies Group
Kharkov's Branch

REPORT

On System Development Project

"ONTOLOGY DEVELOPMENT FOR GAS COMPRESSING EQUIPMENT DIAGNOSTICS REALIZED BY NEURAL NETWORKS"

Done by:	**Semen Simkin**	Researcher, B.Sc., Kharkov's Branch of Industrial Ontologies Group, AI Department, Kharkov National University of Radioelectronics
Supervised by:	Volodymyr Kushnaryov	Head of the Kharkov's Branch of Industrial Ontologies Group
Consulted by:	Prof. Vagan Terziyan	Head of the Industrial Ontologies Group, MIT Department, University of Jyvaskyla
	Prof. Yevgeniy Bodyanskiy	Head of Control Systems Research Lab., AI Department, Kharkov National University of Radioelectronics

2003

The Task

for the System Development Project to be done by Semen Simkin

1. Project Theme: “Ontology Development For Gas Compressing Equipment Diagnostics Realised By Neural Networks”

2. Delivery term of the report: May 25, 2003.

3. Project output data: Ontology, Program Module for ontology filling from the Oracle Database Management System, Neural Network trained by data from ontology and situations described in ontology diagnostics, Project Explanatory Note.

4. Explanatory note contents: Introduction, Object domain analysis, Problem setting, Ontology principles construction description, The description of the method applied to solve the problem, The developed ontology description, Applied program description, agent approach suggested for equipment diagnostics, Conclusions, References.

5. Date of giving the task: April 1, 2003.

The schedule

№i/o	The name of the term paper	The due-date	Comments
1	Object domain analysis		done
2	Problem setting development		done
3	Ontology development		done
4	Applied program specification development		done
5	Programming and debugging		done
6	Testing		done
7	Program reengineering		done
8	Applied program description engineering		done
9	Report defending	1 June 2003	done

ABSTRACT

Project explanatory note consists of: 25 p.,15 Fig., 6 references.

The research object are Ontology And Neural Networks used for equipment diagnostics purposes.

The work objectives are: the ontology development and filling and neural network realization for selective situation diagnostics with revealing its causes.

Research Method is based on the Neural Network training with various neurons number in the hidden layer and with various training parameters for achieving the best diagnostics results.

Research Result is the developed and actualised data-filled ontology structure, the program for real time systems data loading, the developed and debugged program allowing to train a neural network for different test extracts with its subsequent use for malfunction diagnostics and revealing its causes. Developed agent approach suggested for equipment diagnostics.

The diagnostic system is realized with Java programming language.

Emergency situation diagnostics function is realised in the project by using the Neural Network.

The software product can be implemented in the diagnostics organizations and gas compressing equipment operators. The project economic efficiency is defined by both data processing algorithms optimization and emergencies prevention.

Keywords: NEURAL NETWORK, DIAGNOSTICS, BACK PROPAGATION, ONTOLOGY, ORACLE, GCU, SITUATION, SIGNAL, AGENT.

Contents

The shortcuts and terms list

AFC	Axial-Flow Compressor
GCU	Gas Compressing Unit
GEC	Gas-Engine Compressor
HPT	High - Pressure Turbine
JB	Journal-Bearing
JTB	Journal -Thrust Bearing
LPT	Low - Pressure Turbine
MLP	Multi Layer Perceptron
NN	Neural Network

Introduction

The gas compressing equipment diagnostics is an integral part of efficient condition equipment maintenance at a highest reliable level. For timely detection and prevention of possible emergencies it is necessary to continuously service every GCU (Gas Compressing Unit) and diagnose its basic units. The GCU diagnostics result lies both in detection and prediction of possible emergencies reasons and operative probability calculation for a specific emergency occurrence at any moment. In cases where the calculated emergency occurrence probability exceeds 50 %, it is necessary to take measures for emergency prevention and to localise its causes.

For gas compressing units diagnostics it is necessary to have:

1) The ontology with a formal description of the basic terms, the relations between them and filled instance of classes in an object domain;

2) The program of creating instance of classes in ontology, which fills them with the real time systems data;

3) The program for equipment condition diagnostics in neural network.

The qualitative ontology developing is possible on the basis of specially developed description principles of models and equipment units, the said principles using such slots as “Is part of”, “Has parts”. Besides, ontology uses advanced classification system of parameters measurement units, life cycle events, situations and occurrence reasons.

Many existing equipment-diagnosing systems use the neural networks. The information comes from sensors after insignificant processing and filtration [1] - [3]. There are local databases aimed for the equipment’s work measures data trends storage [4].

In this work, as distinct from known works, the neural networks are used jointly with ontology. Joined ontology and Neural Network are Agents’ base. That allows carrying out the data exchange between agents and Global Base of Knowledge for automatic insertion a new object into the existing ontology. The new situations and reasons instances of classes of failures occurred in objects come into ontology by the data exchange between different agents. The agents can exchange not only the data, but also the trained neural networks. That will considerably raise the quality and speed of diagnosing.

The neural network, based on the multilayered perceptron, allows after training to reveal malfunctions and to calculate the probability of their occurrence.

1 PROJECT OBJECTIVE

Studying:

1. Existing methods of diagnosing equipment;
2. Existing diagnosing systems;
3. Modern methods of monitoring equipment's technical condition;
4. Constructional and technological features of gas compressing equipment;
5. Approaches used for data interpretation in the brands and equipment units;
6. Systems for Ontology creation [6];
7. Neural network training algorithms.

The development and the realisation:

1. Ontology of Object domain;
2. Software for ontology data filling;
3. Neural network training algorithm;
4. Neural Network-based diagnostics System;
5. Agent approach for the data exchange between the ontologies.

2 THE OBJECT DOMAIN ANALYSIS

2.1 Diagnostics and monitoring systems description

Equipment monitoring systems, that means supervision over their technical condition, are the most effective means for the decrease in expenses during transition to the equipment maintenance service on their actual condition.

The modern system of monitoring and diagnostics includes four components:

- the signals analysis and measurement means,
- monitoring means,
- diagnostics means,
- maintenance service means.

The monitoring system choice usually begins with an estimation of their opportunities to the following parameters:

- overall detection of worst-case situations,
- minimal time from the defect detection up to emergency,
- probability of error in critical decision-making,
- scopes and complexity of the measurements and means for their monitoring.

For the last years the technical service and repair of equipment did not comply to the standard rules. In practice they were carried out by three basic ways:

- Operation unless failure occurs,
- Withdrawal of equipment for repair after technical examination,
- Withdrawal of equipment for repair on the basis of the results obtained from diagnostics and performance prediction.

But only the third way gives a significant economic benefit. Its successful use allows:

- to reduce time and scope of repair and spare parts amount,
- to reduce a number of sudden breakdowns by tens times,
- to reduce by several times the missed profit caused by the downtimes.

Now the equipments' service methods can be subdivided generally into three types:

1)The first type is the equipment service after every failure. In this case, the equipment is used up to its breakdown (Fig. 2.1). Basically it concerns the inexpensive support equipment if its reservation is available, when its replacement is cheaper, than the cost of repair and service. If such reservation is not available for the repair period, the production has to halt. Frequently during the equipment maintenance up to its breakdown the periodic measurements of the technical condition have to be carried out additionally, which allows to reduce the repair time (see the bottom graph, Fig. 2.1) due to an opportunity to define the time to a first approximation, when the equipment may fail, and to provide timely the maintenance staff with spare parts, and to estimate, which spare parts are required in this case.

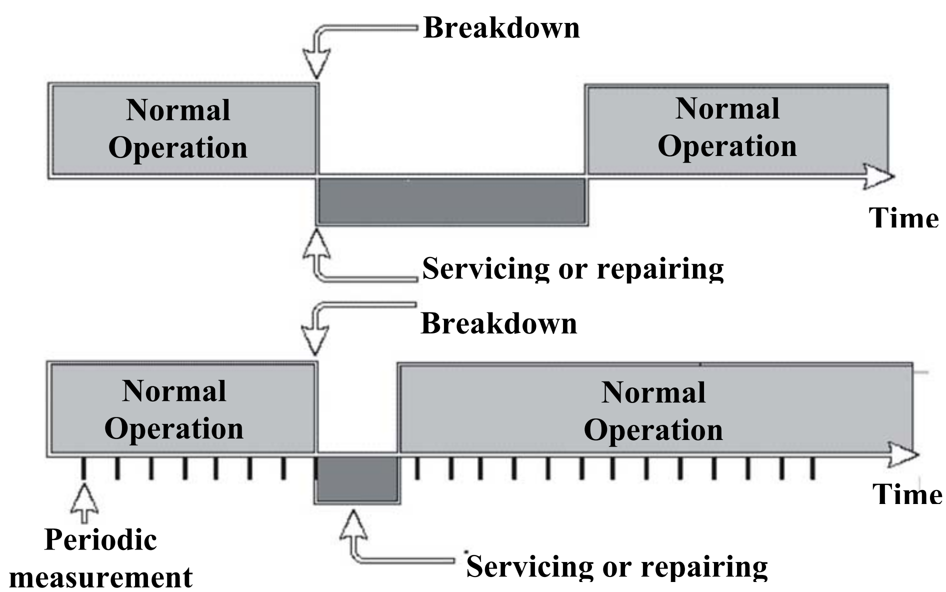


Figure 2.1 - The equipment maintenance up to its breakdown

2) The second type is the equipment service in compliance with the standard rules. In this case the service is made according to the manufacturer's recommendations over the certain time intervals. For example, weekly or monthly, irrespective of the equipment's technical condition. Such service type usually refers to as scheduled – preventive. If the service periodicity is defined by the statistical analysis methods, then according to the regulating documents, then the period between the services usually comes when not less than 98 % of the equipment works without breakdowns. When the service is carried out in compliance with the standard rules, the manufacturer's guarantee will not be lost. But it appears, that not less than 50 % of all the maintenance service under the standard rules is carried out without actual necessity. Besides, for many types of equipment the service and the repair under the rules does not reduce the frequency of their failures (see Fig. 2.2).

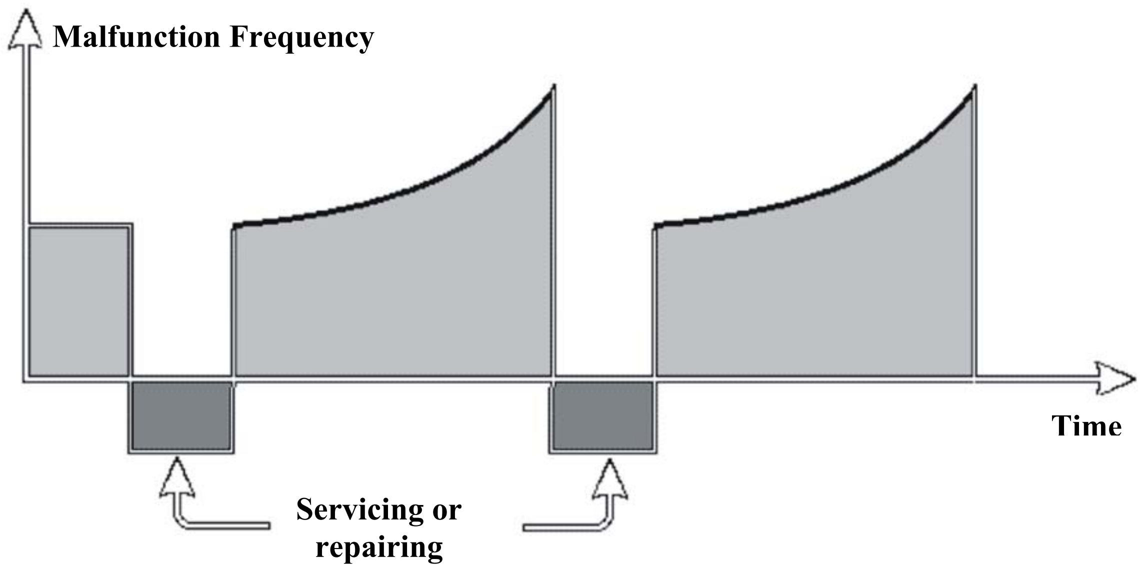


Figure 2.2 The equipment service under the standard rules

Moreover, the reliability of the equipment after the maintenance service, if such service provides disassembly of the equipment or replacement of the details, is frequently reduced, sometimes temporarily, till their running-in, and sometimes this reduction in reliability is caused by the occurrence of the factory and installation latent defects. The researches have shown that the equipment service reveals about 70 % of defects.

3) The third type is the service based on the actual technical condition (Fig. 2.3).

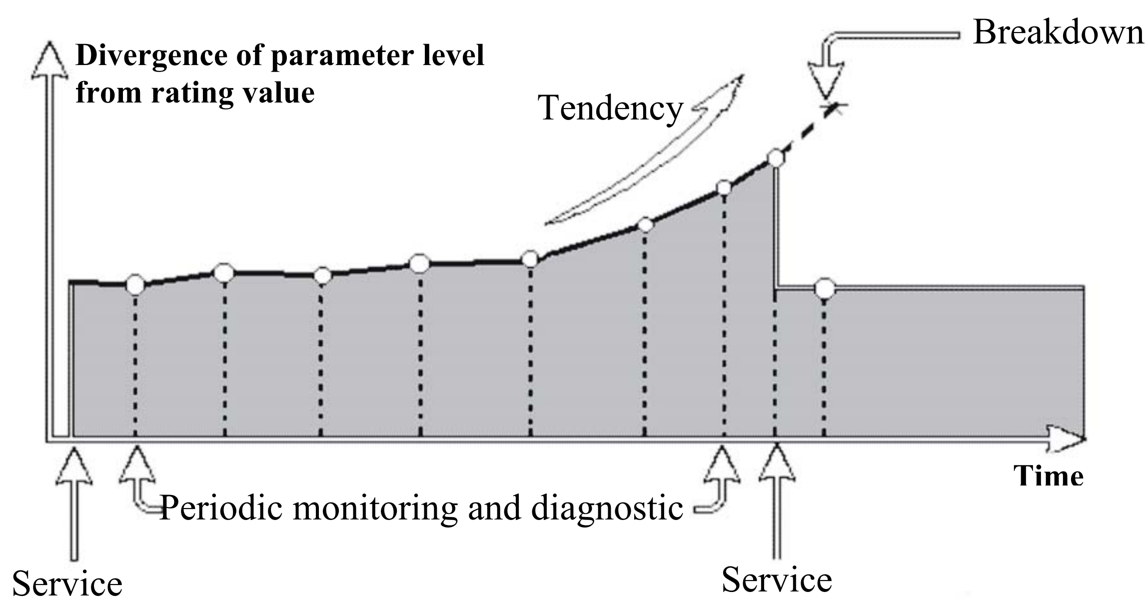


Figure 2.3 - Service of the equipment based on the technical condition

At this type of service the condition of machines and mechanisms is supervised either periodically (even if no defects found), or depending on the results of diagnostics and forecast of the technical condition. The maintenance service carried out in this case is made only when necessary, according to the approach, that assumes high probability of the equipment breakdown. Thus a good mechanism works properly, because there no intervention of a service man.

Using of the offered automated diagnosing system, allows to fully employ the gas compressing equipment and its basic units in good technical condition and determine the probability of emergencies.

2.2 The diagnosing systems analysis

The methods and means of estimation of the technical condition in gas compressing equipment include various parameters control means and their monitoring with subsequent diagnostics and forecast of the technical condition. The technical condition diagnostics methods include creation of the conditions for transition to the actual condition service.

The control means provide the data on parameters, sizes and zones of their maximum deviation. During the monitoring there are additional data on tendencies of parameters change at a time which can be used for the forecast. Even a larger data volume provides diagnosing, in particular, to identify place, type and size of defect. The development of defect forecast, instead of analysis of controllable parameters changes, allows to determine the remaining life or to predict trouble-free operation is the most difficult task.

The “condition monitoring” term is understood as the finding of complex procedures for the ultimate technical condition determination. The existing systems, which are called the monitoring systems, do not always solve the problem of defects’ identification and the forecast of their development. The monitoring means controlling key parameters, revealing tendencies in terms of their changes and forecasting the controllable parameters development. The modern monitoring systems and the machine diagnostics for the power equipment are built on the basis of non-destructive monitoring methods and diagnostics.

The monitoring task implies the detection of changes of condition in equipment or its units by measurements within the shortest possible time intervals. After changes have been detected, the diagnostics system starts up a complete cycle of diagnostic measurements with permanently installed sensors.

Most of the defects developing in the equipment units, start to affect the technical condition several months before emergency. Exception is made only for some of the manufacturing defects and the defects, that appear as a result of the violation of the machine practices. They can show up at any stage of the equipment life cycle and for a short term develop up to the damage-risk values. If to assume, that such defects are absent, the necessity of the equipment monitoring within short intervals between measurements disappears.

In this work the perspective technology of diagnostic data reception – a method of **statistical conditions (patterns) recognition** is used. The system for conditions recognition described by the set of parameters is used in its neural network. It allows to solve identification problems of dynamic processes with the significant casual components. This technology allows to reduce the probability of erroneous decisions if any defects occur during either the work or the change of operating modes of the objects to be diagnosed.

2.3 The ontology used for the concepts of object domain description

Ontology plays an important role in the knowledge accumulation processes on the Web-base in both the joint use and the exchange of knowledge between the applications. The ontology, determined as a concrete formal concept for object-sharing in domain, gives a general representation of the topics, the data on which people and the applications can exchange.

The ontology is offered to be used for the support of the automated data exchange between various diagnostics systems for a joint reuse of equipment and descriptions of emergencies. Ontology, as a rule, contains the concepts hierarchy of an object domain and describes important properties of each concept by means of the " attribute - value " mechanism. The relationship between concepts can be described with the additional logic statements.

3 THE PROBLEM DEFINITION DESCRIPTION

3.1 The Problem Formulation

Most of gas turbine-compressor stations are located in remote areas and plan execution guarantee is mandatory. Therefore high availability and reliability is the main requirement for these stations. Operational demand for these stations is variable. Higher demand comes after working hours, adding extra maintenance costs. Any single failure in the station will cause a complete shutdown for the whole station. Sometimes the equipment is broken. For breakdown prevention it is necessary to accumulate knowledge about them. This knowledge must be analyzed, classified and used for prevention of such situations in future.

For diagnostics of gas compressing units it is necessary to have:

1) The ontology with the basic terms formal description, the relations between them and filled instance of classes in an object domain;
2) The program for creation of instance of classes for ontology. The program fills them with the real time systems data;
3) The neural network-based program for equipment condition diagnostics.

The purpose of such diagnostics is the calculation of the probabilities of the future emergencies and the identification of their causes.

3.2 The description of the method applied to solve the task of equipment diagnostics

The calculation of emergency probabilities is offered to be executed with the trained neural network on the set of known and probable emergencies and pre-emergency situations. The set of such situations and the causing reasons is **based inside ontology as an object.** The list of possible situations is generated on the basis of both the factory passport list and the analysis of emergencies occurred during operation of various GCE models. The set of the parameters training values results from the parameters statistical processing of actual operation trends during the various pre-emergency periods.

Besides, the interpretation of models for the equipment brands and units forming the GCU is represented in ontology and diagnostics of the objects. All units of the GCU are considered as a part of the whole GCU and as the sets of other parts. Emergencies are connected to both the whole units and its separate parts.

For equipment diagnostics the model of a neural network with return distribution of errors (back propagation) is used. The trained neural network allows to make the equipment diagnostics with the high accuracy. In the process of the information receipt from other agents working in the same object domain, the relearning of the NN is made for the recognition of an extending spectrum of emergencies.

The use of ontology and the neural networks will allow to achieve a new qualitative level of online diagnosing of the technical condition and therefore to timely prevent the emergencies. For example, during a change of the value of one or several signals or their ratio with respect to the nominal values in a pre-set mode, when the necessary data is absent, then the agent interrogates other agents or the global knowledge base of the situations in order to receive the probability of the predicted situations.

Such approach offers an exchange of neural networks. It allows to define the situation probability. It will allow to increase the speed of diagnosing because there won't be a necessity to train a new NN for already existing situations. Also for an agent it is enough to keep only the base of NN for the typical situations for the given equipment type.

3.3 The developed Ontology description

The object domain of the ontology for diagnosing GCU contains the specially organised concepts (classes) hierarchy of an object domain and describes the important properties of each concept with the "attribute - value"(slot-instance) mechanism. The relationship between the concepts is described with the additional logic statements like "part - whole". The ontology basis are the classes corresponding to the conceptual understanding of an object domain. The relationship hierarchy of the basic classes is presented in Fig. 3.1.

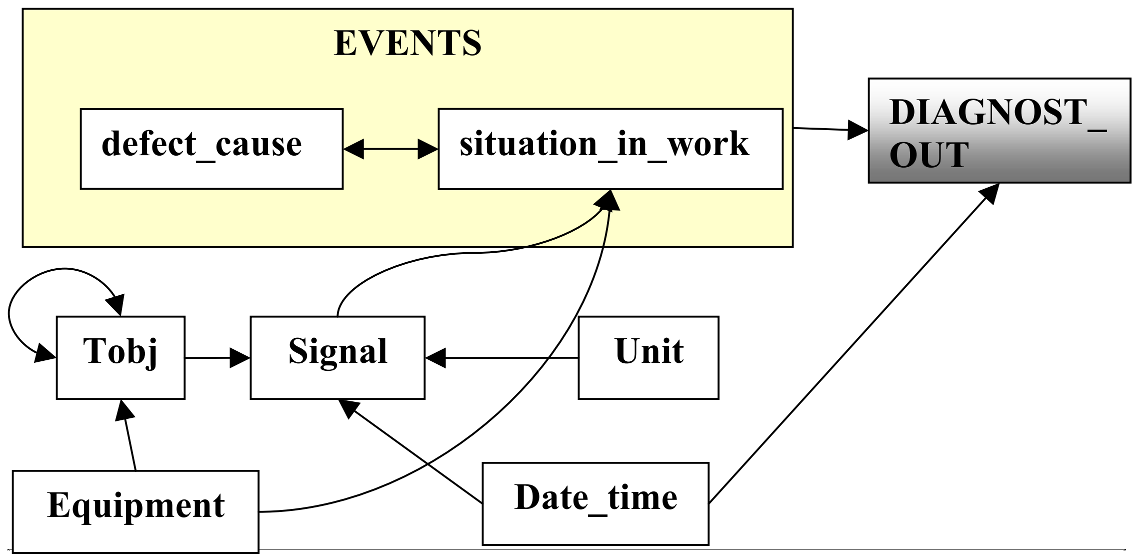


Figure 3.1 - The relationship hierarchy of the basic classes in an object domain

For the diagnosing system the correct choice of classes for ontology has a paramount value. Joining up the reasons and failures situations in one class is caused by their identical information properties and the common essence as events. The class of events “Events” contains two subclasses: “defect_cause” (the reasons of the failure) and “situation_in_work” (emergencies). Every situation has one or more causes. Situations in the relation “many to many ” are connected to signals (Signal), coming from sensors. Depending on signals’ values the neural networks’ algorithm chooses the corresponding situations and estimates their probability.

The breakdown and the reasons of their occurrence are typified and classified as subclasses of their parental classes. Fig. 3.2 shows the corresponding classification of reasons and breakdown (situations). The reasons of each type are given together with the slots, describing such reasons in the ontology. Figure 3.3 illustrates the interpretation of the defect “The design-manufacturing trouble” as an instance of a class with slots’ values. For each instance of the “breakdown reason” class a list of resulting situations was developed. For all known situations the classified subclasses were also developed. The instance of class “The compression pump rotor axled shear” for subclass “Rotor Axled shear” is shown in Fig. 3.4.

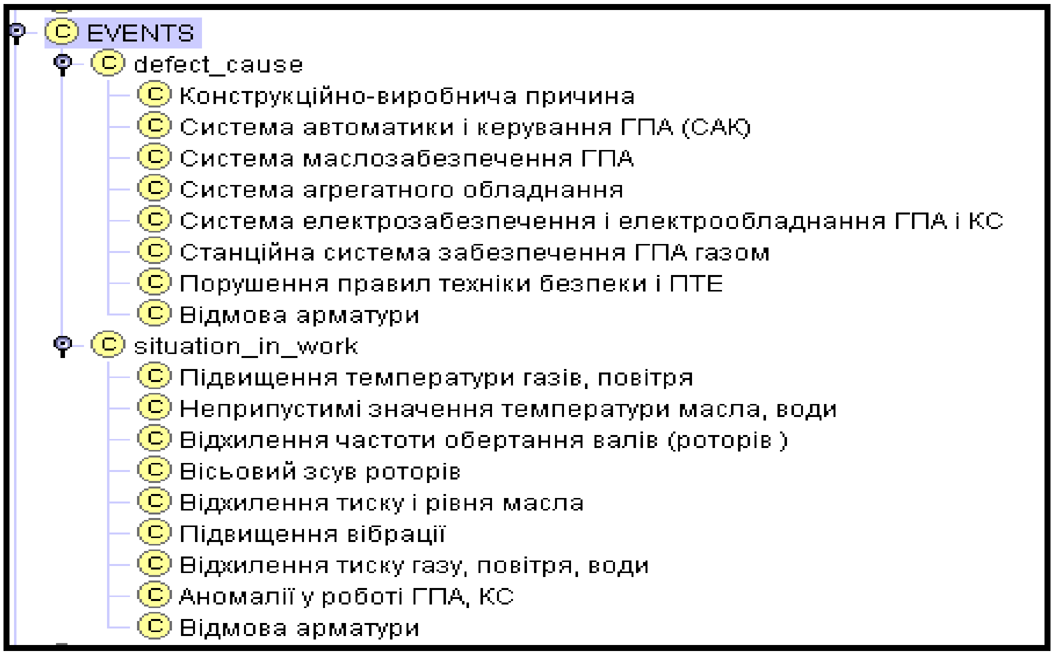


Figure 3.2 - Classification of Breakdowns and their causes

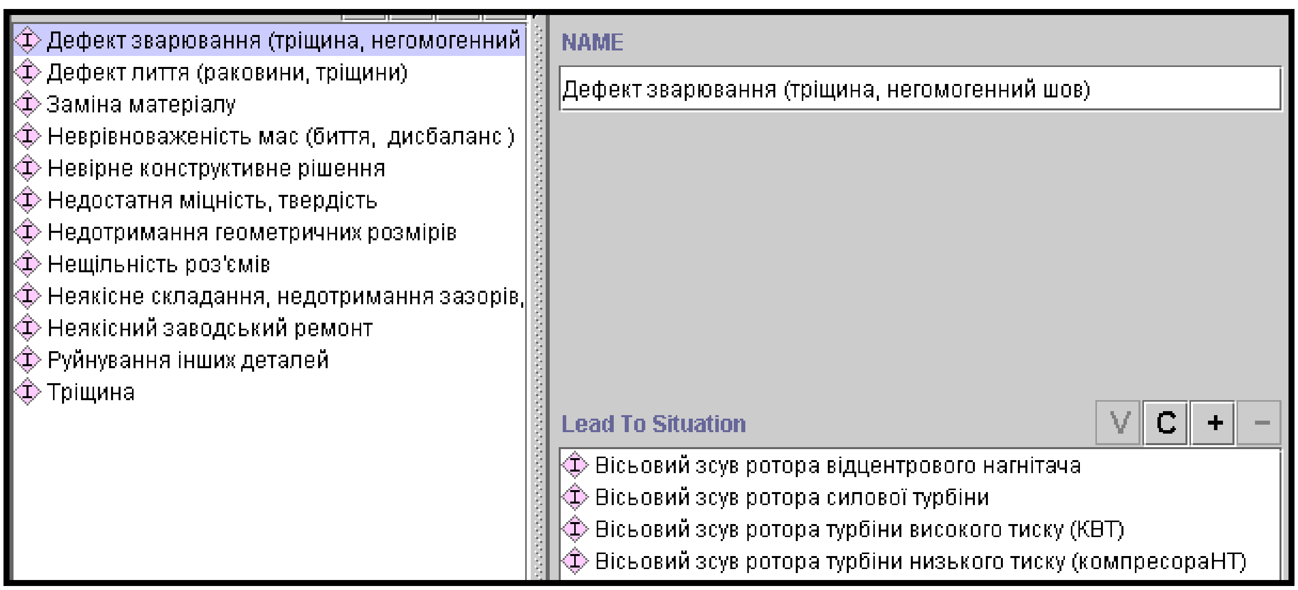


Figure 3.3 - The defect class instance “The design-manufacturing trouble”

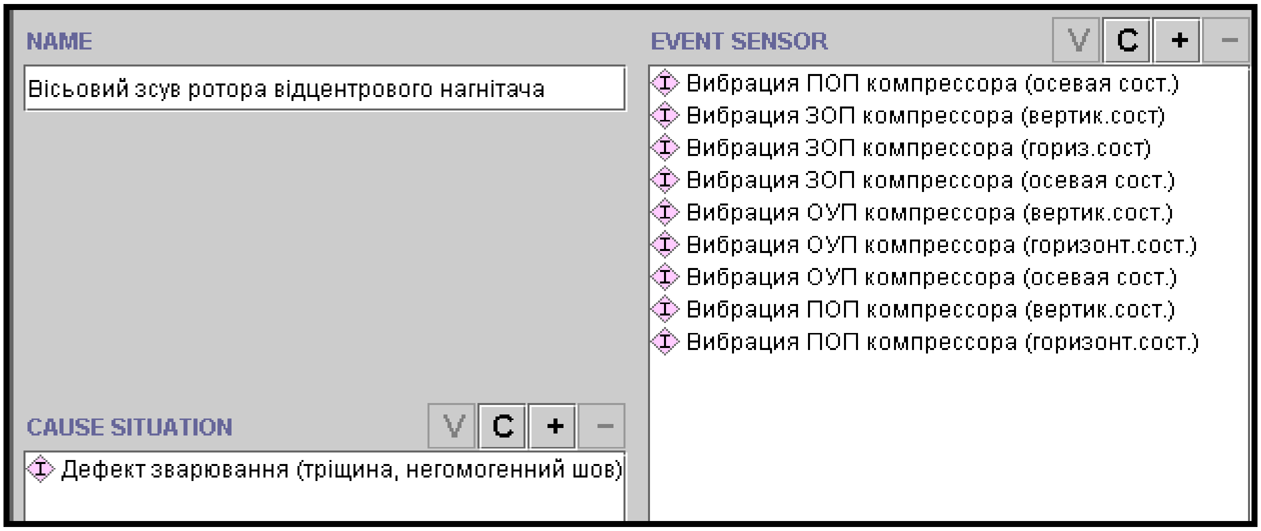


Figure 3.4 – The class "situation" instance "The compression pump rotor axled shear"

The identical signals come from the single-type equipment. Every signal is characterised by the time of the data concerned, by the sensor that transmitted that signal, and also by the physical value. The signals cannot be inside a class of the equipment units because they depend on the receipt time. From each sensor the set of signals is time-bound and value-dependant. Therefore the signals together with their properties are allocated in a separate class (Fig. 3.5).

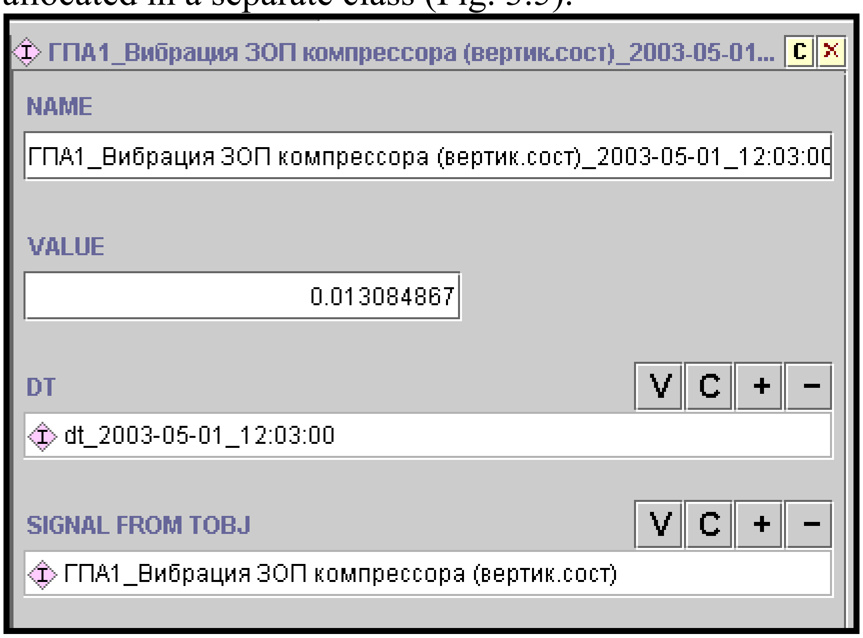


Figure 3.5 - The signal instance for the vertical vibration's actual value, coming from the JTB of the GCU_1 compressor.

The signals are characterised by such properties as a measurement unit, date-time, technological object unit, from which the signal has come. The signals represented in ontology come from the real time systems, and then are used for training a neural network. There's no sense in describing inside each signal the properties of sensors and the technical characteristics of units, to which these sensors are attached. The necessary slots, containing such characteristics, are also classes instances. For the signals, for example, such classes instances are sensors on a unit of the equipment and the date. For the units of the equipment such classes instances are the brands (models) (Fig. 3.6).

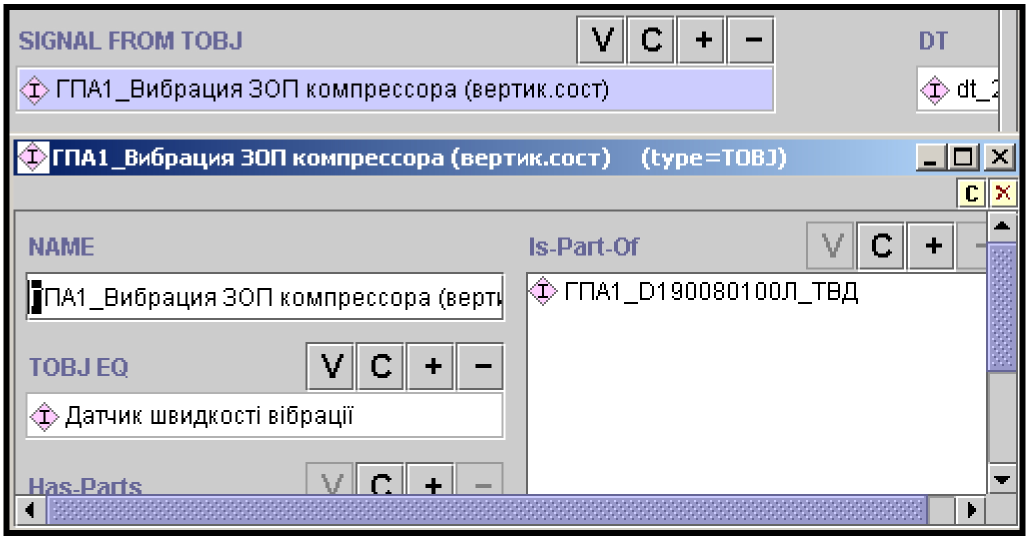


Figure 3.6 – View of the chosen unit equipment class instance for a signal

It is similarly possible to use the instances of other related classes according to the hierarchy of classes represented in Fig. 3.3. The classes of the highest types of hierarchy inherit the properties of the lower hierarchy levels classes. The class DIAGNOST_OUT describes the resulting diagnostic concept with the slots, which characterise the probability of the specific situations for an equipment unit.

The equipment units class (TOBJ) is intended for the interpretation of objects to be diagnosed and their basic parts. Equipment parts are included into a larger unit of equipment (is part of). The presence of parts (has part) is also the property of the equipment units. Both properties are presented as slots. The properties (is part of) and (has part) are inverse (inverse slot). Using such properties allows to build (describe) the hierarchical structure of such sophisticated units of equipment as GCU. The entry of hierarchical structure into units is the property of the equipment units. The technical characteristics of equipment brands are inherited by the equipment units. Fig. 3.7 shows the hierarchy of the GTU equipment units.

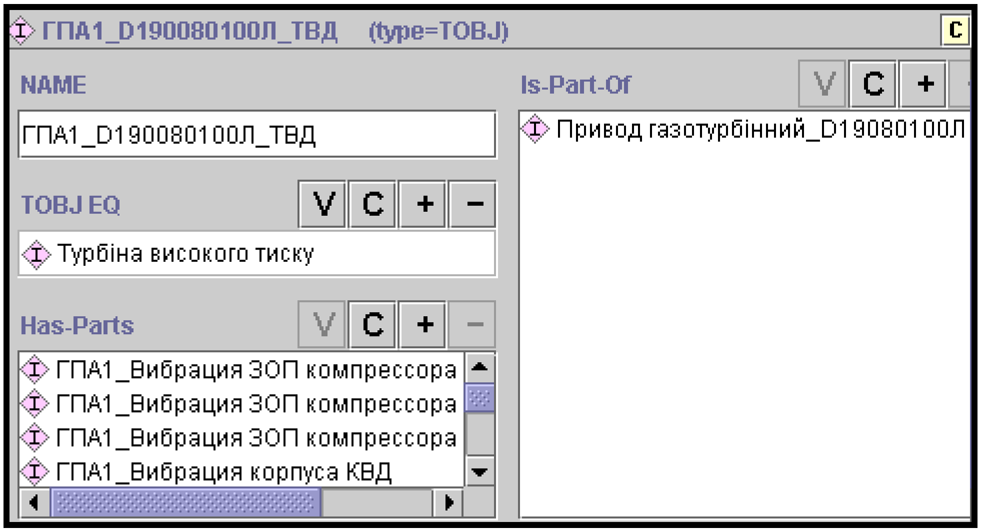


Figure 3.7 – The hierarchy of the GCU units.

From Figure 3.7 we can see, that the high pressure turbine (HPT) is a part of GTE GCU, No. 1, with Factory Number D190080100Л, and at the same time it has such parts as sensors attached thereto (Has Parts). All units of GCU (turbines, oil systems, rotors, blades and sensors) are treated and used similarly.

The equipment brands (Equipment) are represented by subclasses for the concrete types of the equipment. Each equipment subclass of the brand has the specific technical characteristics. Fig. 3.8 shows the classification of the gas compressing equipment and its components. There are three basic types of the gas compressing units, which are distinguished by an operating principle and by design features. Thus they can have a complex structure, which includes the slots necessary to characterise brands.

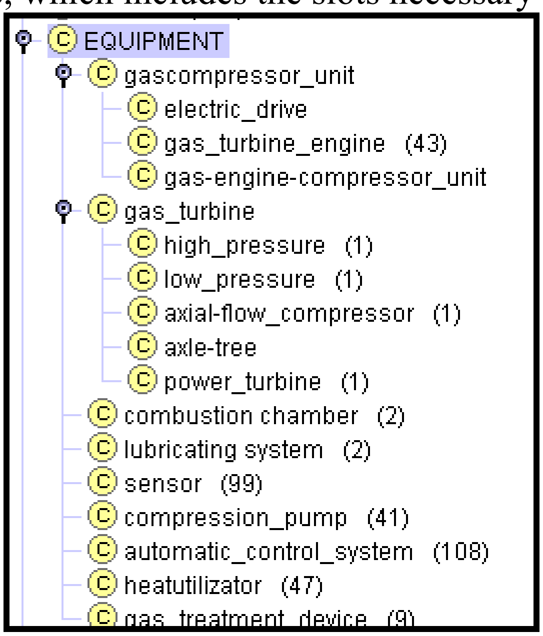


Figure 3.8 - The gas compressing equipment and its units classification. The amount of instances of each type classes is indicated in brackets.

Each brand of the equipment has its own characteristics necessary to calculate the technical condition during the pre-emergency period. Fig. 3.9 illustrates the characteristics of a centrifugal supercharger "16/75-1,44".

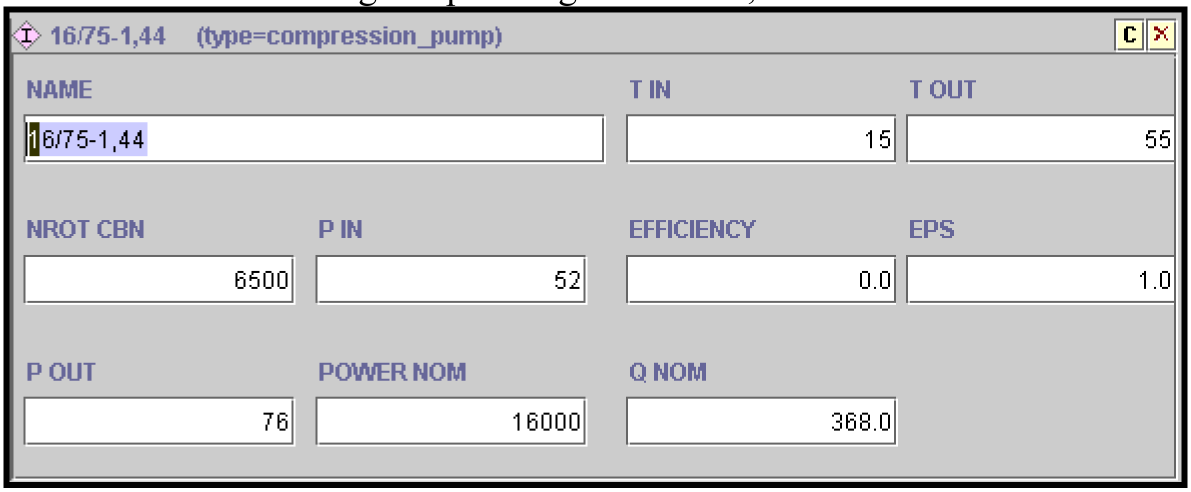


Figure 3.9 – The characteristics of a centrifugal supercharger

The class of measurement units (unit) includes an extensive list of the subclasses of measurement units relating to the operation of the gas compressing equipment (Fig. 3.10).

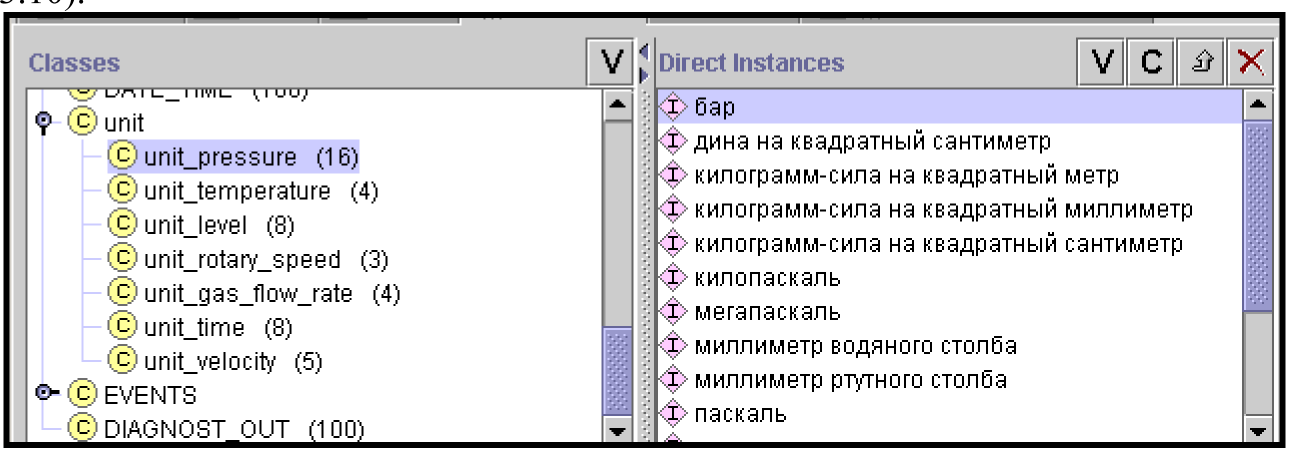


Figure 3.10 – The list of subclasses of measurement units with the instances of subclasses

The class “date-time” allows to connect the information of signals to the specific moments and to build trends of signal values. The example of the instances of classes is given in Fig. 3.11.

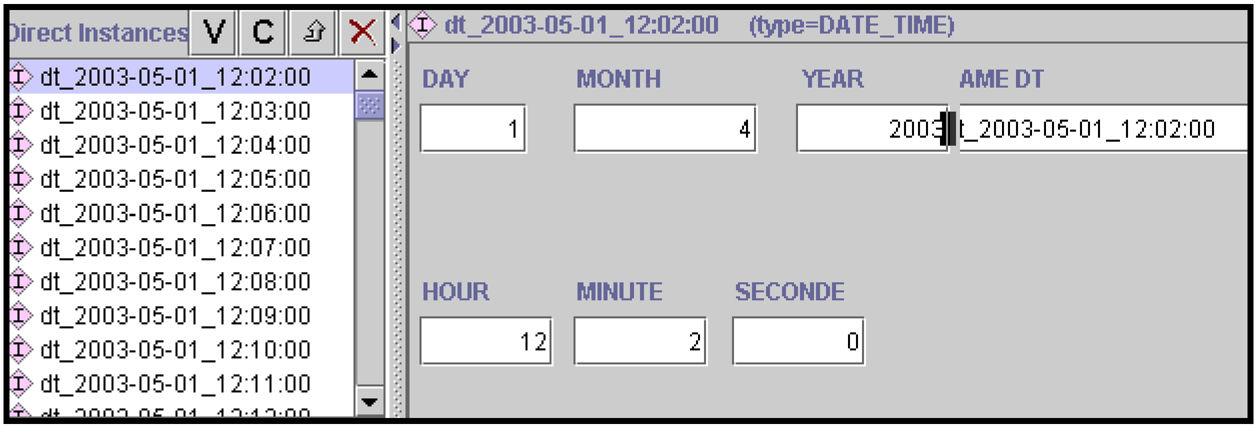


Figure 3.11 – The classes "dates-times" List

Also the diagnostics results are stored in ontology. This ontology can be used by several agents for an exchange of the training results. Agents can exchange the classes instances for the expansion and development of their own ontology due to ontology classes openness and relocatability. The wide spectrum of the described situations allows to train a neural network with a high degree of accuracy.

The subclasses and their slots forming and instances being filled by the data are carried out automatically with the Java-based software. The filling occurs from RDBMS Oracle, which contains the base used in [4].

4 AGENT APPROACH SUGGESTED FOR EQUIPMENT DIAGNOSTICS

Agent approach suggested for equipment diagnostics (Fig. 4.1) enables various agents to communicate both between themselves and global knowledge base.

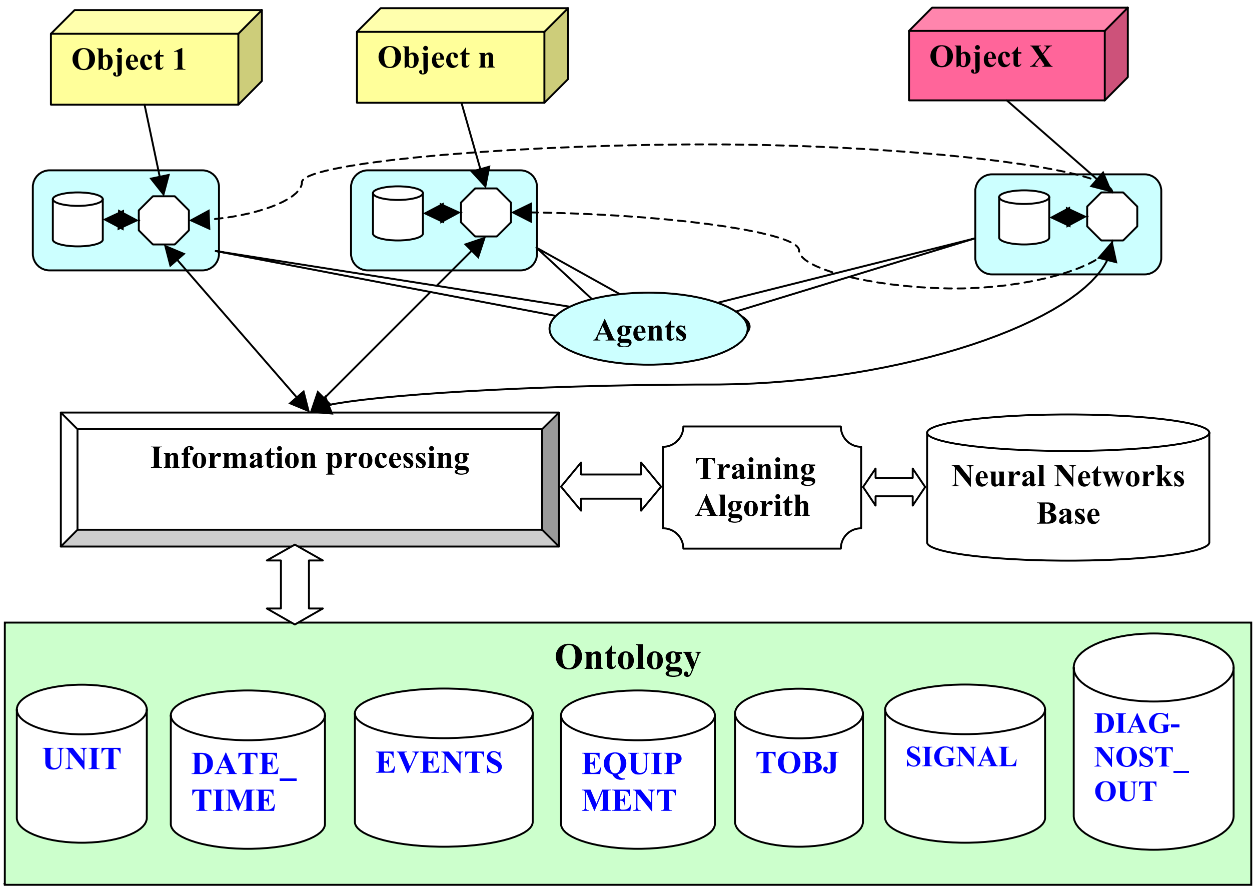
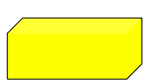
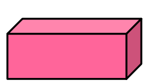


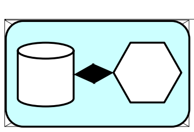
Figure 4.1 –The general structures of the suggested approach



Objects after breakdown occurred



Objects with high breakdown probability



Data gathering and processing Agent

Such approach is offered for carrying out an exchange of neural networks, which allows to determine emergency probability and to increase speed of diagnosing because there is no necessity to train a new network for the already existing situations. Also it is enough for the agent to store only the trained neural networks for typical situations for that type of equipment. Every Agent contains ontology describing its object unit.

After any situation has occurred if its description is not available in ontology the agent sends the picked up signals for training a Neural Network, which can determine a similar situation. If the probability of such situation is high on the given equipment type then a neural network alerts all agents working on the similar equipment.

If the value of one or several signals or their ratio with respect to rating values has changed so that the necessary data in the given mode is absent, Agent interrogates either other agents working on the same type of equipment or global knowledge base of situations in order to receive neural network, which will help in the diagnostics.

Conclusions

The developed ontology and the applied program, against the existing methods of parametrical diagnosing, allow using neural networks after their training to diagnose equipment on the basis of experience generalization on the previous emergencies. The use of ontology and neural networks will allow achieving a new qualitative level of the online diagnosing of technical condition with detection and identification of all potentially dangerous defects at their initial stage of development. Due to the timely prevention of emergencies it is possible to make transition to repairs planning in view of the actual technical condition. The increase in a between-repairs period will considerably lower cost of operation and repair service and will raise economic efficiency of gas transportation. Offered agent approach allows to raise equipment diagnosing quality due to the use of both the centralized knowledge base of emergencies and own experience stored by Agent during work on a concrete equipment unit. Also such approach allows using optimum information resources because each agent stores only the necessary diagnostics information.

The offered algorithm allows classifying any patterns of any object in domain. It's possible to increase the classification accuracy by using the aprioristic knowledge of an object domain. The Diagnostic Systems with numerous NN for various GCU, in gas turbine-compressor stations can successfully lead to higher availability, reliability and safety of the whole station. The increase in reliability and availability of the GCU will consequently reduce the cost of gas supply through the use of diagnostics and continuous serviceability of gas pipeline.

References

1. Turbine Engine Diagnostics Using Artificial Neural Networks (TEDANN) Pacific Northwest National Laboratory and the US Army Ordnance Center and School, http://www.pnl.gov/
2. Gas Turbine Monitoring Systems: Intelligent Turbine Engine Diagnostic System (iTEDS) http://www.iac-online.com/
3. A Parametric Investigation Of The Diagnostic Ability Of Probabilistic Neural Networks On Turbofan Engines Laboratory of Thermal Turbomachines, National Technical University of Athens, http://www.ltt.mech.ntua.gr
4. RC "Ukrtransgas"
5. The system of the automatic diagnostics " DREAM for Windows " http: // www.vibrotec.com
6. Protégé 2000 http://protege.stanford.edu/
7. **Metso Corporation http://www.metso.com/**
8. Supervisory Control And Data Acquisition (SCADA) http://www.centrax.co.uk/gtd/scada.htm