DIAGNOSTYKA, 2016, Vol. 17, No. 1

ISSN 1641-6414
e-ISSN 2449-5220

DIAGNOSTIC SHELL EXPERT SYSTEMS

Marcin AMAROWICZ, Krzysztof PSIUK, Tomasz ROGALA, Sebastian RZYDZIK

Silesian University of Technology
Institute of Fundamentals of Machinery Design
Konarskiego 18A, (+48) 32 2371360,
marcin.amarowicz@polsl.pl, krzysztof.psiuk@polsl.pl,
tomasz.rogala@polsl.pl, sebastian.rzydzik@polsl.pl

Summary

The paper presents the issues related to shell expert systems which are presented from different perspectives among others end-users, knowledge engineers engaged in the acquisition of knowledge and its edition and system administrators. The main characteristic of described shell expert systems is the ability to integrate knowledge from many different sources and an explicit form of representation of acquisited knowledge which allow to permanent maintenance and management of knowledge stored in the knowledge base.

Keywords: shell expert system, knowledge acquisition, signals processing,

DIAGNOSTYCZNE SZKIELETOWE SYSTEMY DORADCZE

Streszczenie

W artykule przedstawiono zagadnienia związane z budową szkieletowych systemów doradczych. Opisano podstawową funkcjonalność takich systemów z różnych perspektyw tj. widzianych od strony użytkownika systemu, inżynierów wiedzy zajmujących się pozyskiwaniem wiedzy i jej edytowaniem oraz administratorów systemu. Główną cechą charakterystyczną opisywanych systemów doradczych jest możliwość integracji wiedzy z wielu źródeł oraz jawna postać pozyskiwanej wiedzy umożliwiająca ciągłą pielęgnację i zarządzanie baz wiedzy szkieletowego systemu doradczego.

Słowa kluczowe: szkieletowy system doradczy, pozyskiwanie wiedzy, przetwarzanie sygnałów szybkozmiennych,

1. INTRODUCTION

The process of diagnosis of technical complex objects is difficult and requires specialized knowledge and experience about considered domain from people involved in this process. Often there is a large discrepancy between the selected class of machines and specialist who able to correctly maintain and diagnose these machines. In these cases an on-line monitoring is applied which, in turn, unfortunately leads to the big data collection and necessity of their processing. Contemporary approach to above mentioned activities may be supported by computer systems e.g. expert systems.

For technical objects that have complex structure, particularly for critical machines, the optimal solution is to use the expert systems that have their root in the field of artificial intelligence. The primary purpose of using expert systems is to solve specific tasks that require professional knowledge and experience in the application of this knowledge. In practice, expert systems are used to collect, storage and selection of data, and then use these data in the process of reasoning about the technical state of the observed object. The advantages of such systems include the ability to conduct multiple diagnostic inference processes using the knowledge from different sources of knowledge e.g. different domain experts.

Nowadays experts systems have modular construction. This allows to flexible development of such systems by different engineers from different disciplines: artificial intelligence, computer science e.g. database. The final product in the form of related modules with empty databases i.e. no specialized knowledge domain is delivered to end user and is ready to perform its function to selected technical object. These systems are called *shell expert systems*.

2. GENERAL CONCEPT OF SHELL EXPERT SYSTEMS

Currently available measurement methods make it possible to operate on collecting data from technical objects in a continuous way. These data can be stored and processed to allow diagnosticians to assess the technical state of these objects also with the application of different information systems among others expert systems. These systems can be dedicated to a certain class of machines. Although the specificity of the diagnosis of technical objects depends on the variety of classes of technical objects for which the process of diagnosis can be carried out to assess their technical state. This implies that it is necessary to determine the different ways of description for both data and knowledge about the technical object. Such a solution often limit the range of application of traditional expert systems. Because all expert systems have similar structure and include basic elements such as a knowledge base or inference engine, the idea was to develop a system containing no knowledge of the technical object, and only a set of tools to represent and store this information. Therefore, it results in developing shell expert systems having an empty, not filled with knowledge, built-in knowledge base.

In shell expert systems, a certain way of knowledge representation is assumed. Knowledge in these systems can be written with the application of different knowledge representation among other in the form of rules, belief networks, or statements networks. The type of knowledge representation requires adequate process of inference. There are some systems in which the inference process is carried out by different inference modules which based on one method of knowledge representation. Very often the management of such systems is realized by knowledge engineers. The role of the knowledge engineer is to write the knowledge elicited from specialists and record it in expert system or to support experts in this process. The role of the knowledge engineer is also to care of such systems, in particular of gathered knowledge. The use of shell expert systems enables also to capture and store knowledge from many sources also from archival data. It allows to use one system for a variety of technical objects, which leads to reduction of the diversity of such systems and facilitate their maintaining and use.

3. SOFTWARE STRUCTURE OF SHELL EXPERT SYSTEMS

The operation of shell expert consists in the applying of many different modules which refers to different functionality of this system. In all types of expert systems the following modules can be distinguished [6]:

- module of communication with end user (could have interactive form),
- inference engine,
- explanation module,
- database,
- knowledge base.

The module of communication with the end user is an important part of shell expert systems. This module should ensure simple and intuitive solution of the exchange information between the system and user. The communication with the user should allow to put many different types of data among others: knowledge of considered domain, scheduling task, authorization settings. Equally important is to present the results of diagnosis in the simple and comprehensive form.

For large shell expert systems that most often are applied for real systems in which the knowledge base is prepared by many independent knowledge engineers and is concerned with critical objects the aspects of safety of data play an important role. In this case the communication with the user modules is restricted with authorization elements which require introducing a system login and preparation of various types of security levels.

Due to the complexity of such systems, the user interface [7] also includes subsystems for the system management. Special features are concerned with the system authorization settings, management of structure of the system or performing administrative operations.

Depending on requirements, such systems based on various solutions, the commands to the system are given by command line or special window applications that are added to cover the existing solutions.

Nowadays due to the rapid development of mobile devices, communications modules with the shell expert systems are designed as Internet/Intranet applications or as dedicated solutions for mobile devices (tablets or smartphones).

One of the main element of each expert systems is an inference engine module. The main function of this module is to perform scheduled tasks concerned with interpretation of the observed data on the base of defined knowledge. Depending on the type of the system many different or one type of tasks can be conducted: diagnosis, prediction, monitoring and control.

The inference process run by the inference module can take place in a changing environment (on-line), or in the constant environment (off-line). The application process, which takes place in this changing environment we call dynamic, and the one that takes place in a fixed environment is called a static [6].

To carry out the inference process the inference module requires some input data. The same module generates also some other data which are the output data. Both types of data should be stored because other analysis on archival data may be performed by the same inference system in the future. Therefore, in such systems it is necessary to prepare the space for storing such data which can fall into one of two groups of fixed or variable data. In the case of shell expert systems for storing data, database are often used. From the available database types are commonly used such as a relational database MS SQL Server, Oracle Server, MySQL PostgreSQL or DB2. In some solutions it is preferred to use object-oriented databases. The databases also can store object oriented structure of considered object and the rules of access to object subcomponents.

The inference module cannot performs its function without the knowledge about an object stored in knowledge base. Despite many attempts, all trials failed to develop a coherent formal knowledge representation. Therefore, such systems often use different methods for knowledge representation. The known representation of knowledge may take a form of:

- mathematical formulas,
- decision tables,
- predicates,
- rules,
- semantic networks,
- belief networks,
- statement networks,
- abstractive objects,
- neural networks.

The specific representation of knowledge domain is stored in the knowledge base. Knowledge bases are often represented as a properly prepared databases. In a specially prepared databases knowledge can be represented in different ways. Thanks to this, the inference system, during its own operation may employ different ways of knowledge representation.

An important functionality of shell expert systems is an ability to explanation of some results. In order to justify the users to the results obtained in the process of inference, systems are equipped with explanation module. The role of these modules is to explain how the system performed the inference process and identify the conditions that led to obtained results. Modules of this type are generally based on a solution based on references. An example of such solutions is HTML or various types of help systems.

An empty database and knowledge base is a characteristic feature of shell expert systems. This gives them the ability to save the knowledge on various technical objects. It also offers the opportunity to fill these knowledge systems specified by different specialists. As examples of the shell expert systems are the following:

- The K015 - Internet expert system which allows to carrying out the process of inference based on different types of diagnostic models.
- DiaDyn System - enhanced Internet expert system for building a diagnostic model based among others on models based on belief networks and the creation of complex systems explanations [5].
- System REx – shell expert system to create a graphical models operating on the basis of multilayer statement networks [3].

4. MANAGEMENT OF KNOWLEDGE ACQUISITION

Diagnostic knowledge acquisition process is in many cases extremely difficult and time-consuming. Therefore, a comprehensive approach to this issue, through appropriate management is needed. The implementation of appropriate management methods is particularly necessary in the case of an attempt to acquire knowledge from a different sources as well as from many independent experts. The basic element gathered during the process of knowledge acquisition are statements. Apart from the statement content attributes including identifier, version number, the author of the content, explanation, keywords, etc. can be attached. Based on these attributes, it is possible to filter the set of gathered statements in order to separate the desired subset of statements. In the case of more complex systems, it is possible to apply solutions based on the analysis of the content of individual statements including automatic generation of keywords. Defined statements are collected in the sets of statements that are called thesauri which can be dedicated to individual issues. Developed sets of statements can then be combined into one larger set of statements. For the purpose of maintaining the semantic and syntactic consistency in the combined set of statements, knowledge acquisition systems are equipped with, among others, generators of unique identifiers and dictionaries of synonyms. An important element of the management of statements is to determine the history of changes to the content of individual statements. This functionality make it possible to track changes in the content of the statements and versioning of these contents according to different subsequent authors. Another important element is to ensure the export and import of the collected resources (thesauri) to external data formats. XML and serialization procedures are commonly used.

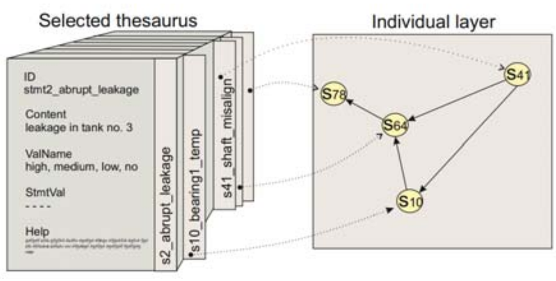

Fig. 1. Preparing individual layer by selecting statements from thesaurus

In order to facilitate the process of defining statements, thesauri can be fitted with the explanation systems. Explanations may be given to both the individual terms used in the content of statements, e.g. relative vibration exceeded the limit value, etc. as well as the full content of the statement. Explanation assigned to the content of statements, may expand the meaning of the statement, or describe some specific context of use of a given statement.

Selected statements are used to construct multimodal statements networks [4]. They illustrate the considered domain, taking into account its various aspects. Defining statement networks includes defining individual network nodes and the relationships between them which represents the general relations between statements (Fig. 1) .

A particularly important element in the construction and use of the network is their visualization. For individual statement networks visualize of the graph on the two-dimensional plane is sufficient. Quite a difficult task and in many cases impossible is an arrangement of nodes of the graph, without any intersections between the edges of the graph. Various types of algorithms including Fruchterman-Reigold, Reingold-Tilford etc. can be used for this purpose [9]. In the case of the multimodal statement networks it is necessary to use three-dimensional space to present a complete structure of statement networks. An example of a multimodal statement network visualization is shown in Fig. 2. In the case of three-dimensional visualization the two additional features of this type of networks are presented. The first is an additional so-called zero layer, which presents all the nodes included in the individual network components. The second element are edges between layers which depicts common nodes in subsequent layers.

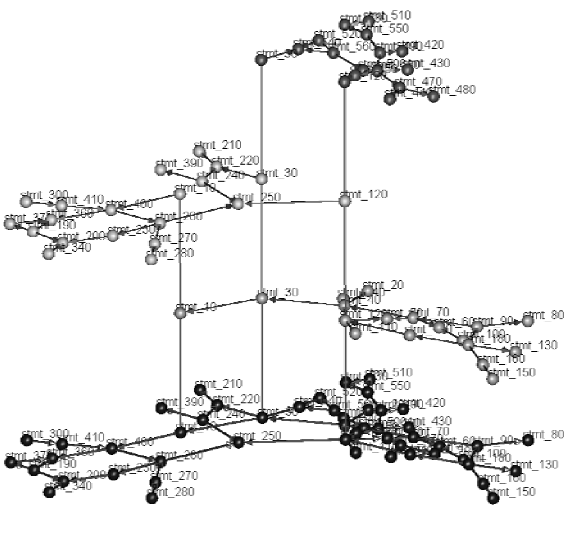

Fig. 2. An example of multimodal statement network visualization with the use of REx environment [3].

5. SIMULATION EXPERIMENT IN KNOWLEDGE ACQUISITION

Simulation studies could be the additional sources of knowledge. Simulation studies that are aimed to obtain diagnostic relations about the possible defects associated with malfunctions, damages or improper conducting of the processes, require the adequate preparation of the model intended for the model studies. It requires the adoption of adequate description of the considered object or process, that will be take into account the most important, from the simulation experiment point of view, aspects of the process and the potential adverse events including the defects.

In this case, the role of the simulator is, among other things, the possibility to supply the data for the events, that are not feasible in an industrial environment or during the active diagnostic experiments. These data can then be used to identify the relationships between the simulated states of an object and the covariant with these states the features values of process variables for the given operation conditions of the object. The identified relationships can then be represented by different types of diagnostic models including previously mentioned graphical models which supports the possibility of modeling of domain knowledge [2].

Simulation studies are very time consuming and require the development of a detailed plan of the simulation experiment that take into account, among other things, the need to determine the diagnostic relations, especially in those regions of state space of an object, for which there are no data or the data are incomplete or irrelevant. For this purpose, the techniques for planning experiments or information that arising from the testing the previously machine learned (in selected regions of the state space) diagnostic models, can also be used.

An important challenge is to carry out the simulation experiment for the complex technological installations that are equipped with complex control structures e.g. optimal control, that the aim is to minimize the effect of variable system loading that is recognized as a disturbance. This object, due to the difficulty in the identifying of the nature of the disturbance requires appropriate approach for the modeling the disturbance what is an additional difficulty [1].

From the diagnostics point of view, the operation of processes that are controlled in the overriding manner may lead to adverse effects. In such cases, the occurrence of damages or malfunctions is compensated by the setting the new operating point by the overriding layer of control system. The new set of setpoints for the direct layer of control systems are determined. At the same time, the control system compensates the effect of stochastic disturbances, preventing a direct assessment of the technical state, e.g. based on observations of setpoints. This leads to the necessity of isolation the description of the diagnosis manner from the impact of disturbances and carry out the studies in the transient conditions.

To summarize the role of the experimental simulation for the purposes of diagnostic knowledge acquisition, it should be emphasized that it requires:

- the detailed description of the modeled object, that will be taking into account its specification including the control system and modelling of disturbances which significantly determine the conditions of operation of an object,
- the need of introduction such description that allow to isolate the changes of operating conditions from the changes of technical states,
- the appropriate planning of the diagnostic experiment, that will be take into account the need to supplement the knowledge, in these areas of the state space, for which this knowledge is incomplete or irrelevant,
- the need of documenting the process of knowledge acquisition for the purpose of easier process of knowledge acquisition based on the collected data,
- the identification of the diagnostic model with using the knowledge obtained through the model studies and the possibility to integration of this knowledge with the knowledge that is obtained from other sources e.g. explicit knowledge obtained from the experts.

The simulation experiment also allows to:

- preliminary prototyping of the diagnostic system by using a set of useful features which are the basis of diagnostic inference and determine the level of discretization that is defined as the level of granularity of these variables,
- conduct a preliminary verification of diagnostic models developed based on a set of test data (simulation data) and based on selected functions of qualitative assessments of diagnostic models especially for the object for which there is no available data from active or passive experiments.

6. INPUT SIGNAL PROCESSING

6.1. Values of the signal features

Diagnosed technical object is observed through the signals, whose features determine the interactions between the object and the environment, and the interactions between the individual elements of this object [6]. For the purposes of diagnostic inference, the signals that are carriers of the information about the technical state of an object or its operating conditions are needed. From a practical point of view, this information takes the form of: features of observed signals, features associated with changes in the observed signals, the residues determined by the comparing the features of observed signals with the values of features obtained during the numerical experiments conducted on the respective models ect. In order to obtain the information that is contained in the signal, it is necessary to apply the respective description. An example of this description may be the sets of features values that are determined based on analysis of considered signal in the time, frequency or modal domain.

The values of the features of diagnostic signals fall into one of two classes: quantitative or qualitative one. In the case of quantitative values, they may be exact or approximate nature. Whereas, in the case of qualitative values they may have the order nature (e.g. *small*, *medium*, *large*) or nominal nature (e.g. *oil type*).

The signals can be analyzed taking into account the changes of their statistical parameters. Mean, variance and root mean square value are the frequently determined statistical parameters. Additionally, the more advanced methods of analysis, such as: higher-order spectral analysis, wavelet transform analysis , time-frequency analysis or Wigner-Ville transform analysis are used also. These methods of determining the values of the features are related with single signal. The analysis with using two or more signals e.g. cross-correlation analysis, are also conducted. Ultimately, the sets of features of diagnostic signals are recorded, stored and shared through the diagnostic data repositories (e.g. with using database).

6.2. Statements values

The statement is an information about the recognition of the sentence that adjudicates about the observed facts or represents a specific opinion [6]. The statement consists of the content and value, which is a measure of the belief about the truthfulness of this content. Statement is often written as ordered four:

$$<o, a, v, b>,$$

where: o, a, v – object, attribute, value; b – assessment about the truthfulness of statement.

The simplest form of assessment of the truthfulness of statement is the adoption of the divalent scale with logical value, where:

- “1” is marked as yes, true;
- “0” is marked as no, false.

The another method, is the assessment which based on the degree of truthfulness of statement $b(x)$, that is a measure of the acceptance of the sentence which is the content of this statement. The degree of truthfulness of statement usually is a real number from the interval [0;1]. The degree of truthfulness of statements may be considered as a measure of the probability $p(x)$. This enables the use of models based on statistical probability e.g. Bayesian and Markov model [5].

6.3. Determination of the statements value based on of the value of signal features

The simplest way to determine the values of statement based on values of selected features of observed diagnostic signal is the transformation which based on determining the thresholds (Fig. 3 A). Determination of the threshold value consists in indication of a certain limit value for the feature of considered signal. After exceeding this value the degree of truth statement is changed. This method can be used both for individual statements, as well as for a set of excluded statements e.g.:

<"oil in bearing", „temperature", „low">
<"oil in bearing", „temperature", „medium">
<"oil in bearing", „temperature", „high">

In this case, the number of threshold values must be reduced by one, according to the number of statements in considered set. When this method is used, it is important to take into account the experience from control theory, that the change of the state of an object by the same transfer function (without additional delay) can leads to instability of the system. In this case, the hysteresis for each threshold value may be introduced (Fig. 3 B).

In the case of sets of statements for which there is not certainty about their values, and it is necessary to take into account this uncertainty, the transformation that will return the values from the specified range, e.g. [0, 1] can be used. One of such transformation is to determining the degrees of membership of the values the feature of considered signal to the defined previously classes of fuzzy sets (Fig. 3 C) [8]. Generally, the Gaussian distribution, triangle, trapezoid or sigmoid are used as membership functions. The use of singleton type of membership function allows to determine the value of the statements in the same way as in the case of threshold values.

In practice, the used transformation methods of the features of the diagnostic signals to statements values can be recorded in selected programing language in the form of computational procedures. The sets of these procedures are gathered in libraries that are recorded in knowledge base of diagnostic system.

6.4. Determination of procedures parameters that appoint the values of statements

Depending on the used method of calculation of statements value, created computational procedure will be have parameters which will affect to the quality of the result of the inference process (e.g. values that define the shape of fuzzy set). The choosing of the right values of these parameters should be the subject of the optimization activities. Determination of the procedure parameters can be regarded as a process with feedback (Fig. 4).

When the set of training data in the form of suitably prepared sets of test data is available, it is possible to perform the following iteration:

1. Download the current values of the features of signals from the bank of diagnostic data.
2. Based on the computational procedures that are stored in the knowledge base, determine the values of the input statements of inference module.
3. Perform the inference process.

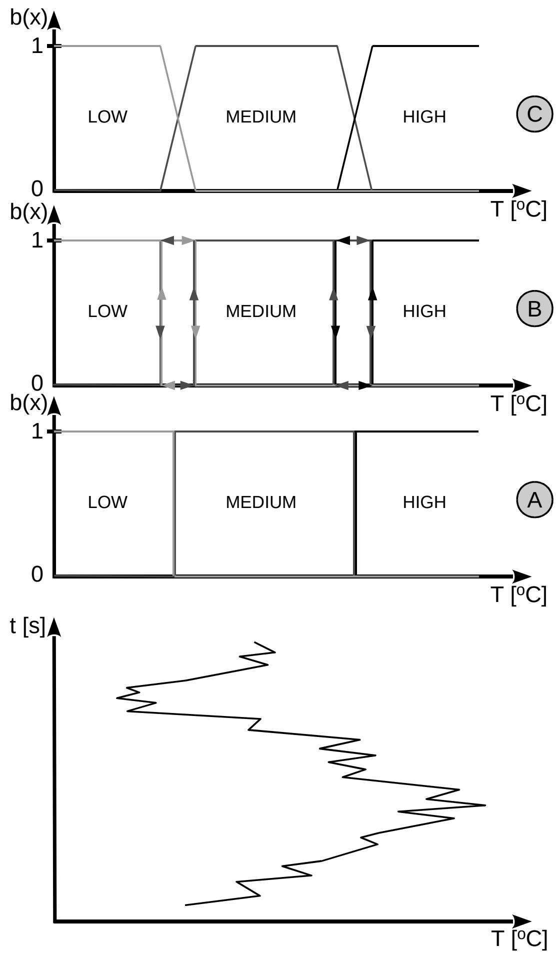

Fig. 3. Conversion the values of diagnostic signals to the statement values based on: (A) – threshold; (B) – hysteresis function; (C) – fuzzy sets;

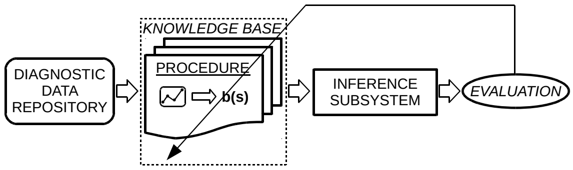

Fig. 4. The optimization the values of the procedures parameters that appoint the values of statements.

4. Compare the obtained results with results for testing data.

5. If the evaluation is consistent with the expected, save the values of procedures parameters and finish the tuning process. In another case change the values of parameters and return to the point 1.

Presented above, in a general manner, the process of optimization the values of the procedures parameters that appoint the values of statements can be made by various strategies, e.g. as genetic algorithms, neural networks, gradient methods etc.

7. SUMMARY

The use of expert systems brings many benefits e.g. flexibility of configuration, adaptation to each classes of machines, replacement the specialist in the tedious and repetitive expertise, availability of expertise archive, inference based on incomplete data, access to specialized knowledge etc. The main reason, that discourages before using such kind of information systems, is the initial amount of work that must be inserted in the early stages of its implementation. This is particularly related to the necessity of acquisition, from specialists or based on data mining, of existing knowledge and next its correct recording in the knowledge base. The next steps of implementation e.g. acquisition of data with adequate quality (e.g. process data) or tuning of individual modules (inference and process data processing modules) can cause difficulties as well.

It is important to emphasize, that despite the efforts that are inserted to the process of design of general models of inference systems, the providing data and knowledge with low quality is an another discouraging factor for potential customers to the use of expert systems. However, the efforts that are inserted to the implementation process of the expert system will be returned during its use. Expert systems are also used as the systems with limited functionality and structure, that are designed for precisely specialized tasks e.g. for monitoring technical state of car's combustion engine.

In such case, the knowledge base is strongly limited and closed, but it is sufficient to conduct the diagnostic reasoning process. Database of variable data does not exist at all, or it is a buffer with a very limited capacity. Inference about technical state is conducted directly based on provided by the measuring system data. Whereas, the communication with the user, is generally focused on identifying the one of two states: "engine works correct" or "engine is faulty".

Based on experiences, which were obtained during the elaboration and implementation of expert systems, it is possible to conclude that when the more expanded technical object is used, the smaller part of inference systems are based on classical logic. In these cases, are used the techniques that allow to representing the approximate knowledge that is characteristic for the human way of reasoning. Thus, the Bayesian networks, intuitionistic statement networks or statement networks in general are used more and more in inference modules. However, the direction of the nearest future, are the expert systems that used the knowledge recorded in the form of semantic networks. It allows to easier integration of the knowledge base, inference system and explanation system. Although, the conception of the semantic network is not new, their use is still difficult and sensitive to adopted assumptions about their construction - a glossary of terms or types of relationships.

BIBLIOGRAPHY

[1] Bielecki, A., Barszcz M., Wójcik A. *Modelling of a chaotic load of wind turbines drivetrain*. Mechanical Systems and Signal Processing, Vol. 54, pp. 491-505,

[2] Cholewa, W., Amarowicz M., Chrzanowski P., Rogala T.: 5th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management. IC3K 2013, Vilamoura, Portugal, 2013 Proceedings of the International Conference on Knowledge Engineering and Ontology Development KEOD 2013. Eds.: J. Filipe, J. Dietz. [B.m.] : SciTePress - Science and Technology Publications, 2013,

[3] Cholewa W., Amarowicz M., Chrzanowski P., Rogala T. *Development environment for diagnostic multimodal statement networks*. Key Engineering Materials, Vol. 588, pp 74-83

[4] Cholewa W. *Multimodal statements networks for diagnostic applications*. In: Sas P., Bergen B. (Eds.) Proceedings of the International Conference on Noise and Virbation Engineering ISMA 2010, September 20-22, Katholique Universiteit Lueven, Lueven, Belgium, pp. 817–830, 2010.

[5] Dawid F., Cowell R., Lauritzen S., Spiegelhalter D. *Probabilistic networks and expert systems*. Springer, New York, USA, 2007.

[6] Korbicz J., Kościelny J. M., Kowalczuk Z., Cholewa W. Eds: *Fault diagnosis*. Models, artificial intelligence, applications. Berlin, Springer-Verlag, 2004

[7] Psiuk K. *Knowledge editor for the diagnostic expert system Diadyn*. 4th International Congress on Technical Diagnostics. Diagnostics'2008, Olsztyn, Poland, 09-12 September 2008. Olsztyn, 2008, p. 147

[8] Ross T.J. *Fuzzy Logic with Engineering Applications*. Third Ed., John Wiley & Sons, United Kingdom, 2010.

[9] Tamasia, R. *Handbook of Graph Drawing And Visualization*. Discrete Mathematics And Its Application, London, Chapman & Hall/CRC, 2007.

Received 2015-11-03
Accepted 2016-02-15
Available online 2016-02-22

Marcin AMAROWICZ, PhD. Eng., Institute of Fundamentals of Machinery Design, Silesian University of Technology. He is interested on artificial intelligence methods and techniques and their applications in technical diagnostics and data analysis. Moreover, his research interests include requirements acquisition and estimation due to risk analysis for technical diagnostic system design.

Krzysztof PSIUK, PhD. Eng. Institute of Fundamentals of Machinery Design, Silesian University of Technology. He is interested in artificial intelligence techniques, technical diagnostics, CAD as well as in e-learning systems in technical diagnostics and CAD systems.

Tomasz ROGALA, PhD Eng., Institute of Fundamentals of Machinery Design, Silesian University of Technology. His main interests focused mainly on: diagnostic knowledge modeling, application of simulation experiments in technical diagnostics. He also has research interest in application of computational intelligence methods for different engineering problems.

Sebastian RZYDZIK, PhD. Eng. Institute of Fundamentals of Machinery Design, Silesian University of Technology. His main interests focused mainly on artificial intelligence techniques and their applications to designing of machinery and to technical diagnostics.