METHODOLOGY OF ACQUISITION OF KNOWLEDGE CONCERNING DIAGNOSTICS OF MACHINERY AND PROCESSES

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Summary

The paper deals with an outline of a methodology of acquisition of diagnostic knowledge concerning machinery and processes. The problem formulated in the paper concerns the possibility to develop a general methodology of acquiring knowledge of technical diagnostics. Two issues are discussed: methods of knowledge acquisition about machinery mainly considered as static objects, and methods of acquiring knowledge in the form of heuristic models of dynamic objects and processes. Methods developed in the author's research group are mainly dealt with. The paper concludes with future work envisaged.

Keywords: technical diagnostics, knowledge acquisition, heuristic models of processes.

METODYKA POZYSKIWANIA WIEDZY DOTYCZĄCEJ DIAGNOSTYKI MASZYN I PROCESÓW

Streszczenie

W artykule przedstawiono zarys metodyki pozyskiwania wiedzy diagnostycznej dotyczącej maszyn i procesów. Sformułowany problem badawczy dotyczy możliwości utworzenia i rozwoju ogólnej metodologii pozyskiwania wiedzy w zakresie diagnostyki technicznej. Omawiane są dwie grupy metod: pozyskiwania wiedzy o maszynach interpretowanych jako obiekty statyczne, a także pozyskiwania wiedzy w postaci heurystycznych modeli obiektów (dynamicznych) oraz procesów. Przedmiotem opisu SA w głównej mierze metody rozwijane w grupie badawczej, w której pracach uczestniczy autor. Artykuł zakończony jest próba określenia przyszłych prac dotyczących pozyskiwania wiedzy diagnostycznej.

Słowa kluczowe: diagnostyka techniczna, pozyskiwanie wiedzy, modele heurystyczne procesów.

1. INTRODUCTION

Recently technical diagnostics has been developed to the practical domain whose objects of interest are both machines and equipment, and processes the machines are involved in. Although many processes can be considered, such as process of degradation of elements, process of maintenance, and many others, the most broadly investigated type of processes corresponds to the operation of the object. It is worth emphasizing two main tasks of technical diagnostics, i.e. diagnostics of machinery, and diagnostics of processes, that at their very beginning have been developed by two different scientific societies: the former by mechanical engineers, while the latter by control engineers.

Let us consider for a while how these historical issues have influenced main paradigms of both the branches of technical diagnostics. The goal of technical diagnostics is to diagnose the given object (machine/process), i.e. to formulate a statement about the object's state or occurrence of possible faults. To this end, the subject of diagnosing, regardless of being human or automated unit, shall have access to sufficient knowledge. This knowledge may be represented in many ways. Process diagnostics mainly takes advantage of models, which represent either the behavior of machine (or its elements) operating properly, or the behavior of the machine in different faulty conditions. On the other hand, machinery diagnostics usually does not use any apparent model at all, therefore it is sometimes referred to as model-free diagnostics (or: *diagnostics with a hidden model*). However, knowledge represented mainly in declarative form, and more rarely in procedural one, is used in order to arrive at a conclusion about the state of the diagnosed object.

Technical diagnostics is a highly knowledge-intensive technical domain of both theoretic and applied character. To deal with diagnostic knowledge, methodology of Knowledge Engineering (KE) is being used. Methodology of KE:

- allows acquiring relevant knowledge and assessing chunks of knowledge in a very systematic way;
- allows taking advantage of enormous streams of data collected nowadays, which can carry relevant knowledge upon objects of diagnosing;
- allows managing knowledge by:
  - preserving it,
  - sharing and making it available to end-users;
- allows applying knowledge in an automated way.

The author has taken part in several projects that could be classified into both the branches mentioned above. He and his research group have been involved in different projects focused on knowledge acquisition for technical diagnostics. This paper briefly addresses several issues concerning methodology of knowledge acquisition for technical diagnostics, and is based upon the author's experience in the field. Limited volume of the paper does not allow to enumerate and describe many methods that have been developed in research centers interested in technical diagnostics. There are described mainly methods developed in the author's research group. Due to very limited space no applications are presented. However, some of them can be found in the bibliography cited thorough the paper.

2. PROBLEM FORMULATION

The problem to be solved may be formulated by means of the following fundamental questions:

1. Can comprehensive methodology of acquiring diagnostic knowledge be developed?
2. Is it possible to efficiently acquire knowledge from diverse knowledge sources?
3. Can chunks of knowledge collected from different sources be linked together allowing to create knowledge-based applications that would operate more efficiently?
4. Is it possible to develop tools supporting diagnosticians in acquiring and managing diagnostic knowledge?

To find answers to these questions, a comprehensive research has been initiated in mid-nineties of 20th century by the author and the research group collaborating with him. An exhaustive description of the results is contained in [3]. Some issues are addressed in the following sections.

Before entering discussion of the methodology it is worth paying some attention to static and dynamic objects of diagnosing. Static objects are described by means of models that are not (openly) dependent on time. Hence, any representation of knowledge about the object of diagnosing does not involve time variable at all. Conversely, dynamic objects are described by means of models that engage parameter(s) of time, either lifetime of the object, or dynamic time corresponding to the timescale where take place dynamic operations of the object, such as single revolution of the shaft of a rotating machine, and many others.

It is nature of diagnostic objects that *they are involved in processes* such as: usable processes, wear, service, repair, and many others. Understanding dynamics of objects and taking advantage of dynamic models allows better diagnosis. On the other hand, let us understand that static models, although they have been implied especially in machinery diagnostics since many years, allow less accurate and more approximate diagnoses. Therefore, more attention is paid thorough the paper to the elements of methodology, that allow acquiring dynamic models of processes. Furthermore, diagnostics with apparent model (or *model-based* one) is addressed instead of model-free diagnostics (or – better speaking – *diagnostics with hidden models*).

3. METHODS OF KNOWLEDGE ACQUISITION ABOUT MACHINERY

At the earlier stage of the author's research [1, 3] several methods concerning static knowledge have been developed and implemented, including methods of knowledge acquisition, methods and techniques of knowledge assessment and a scenario of knowledge acquisition process. In the following sections some groups of methods applied within the described research are briefly discussed.

3.1. Methods of Knowledge Acquisition

Methods of knowledge acquisition are strongly related to knowledge sources: human experts (who may take active or passive part into the knowledge acquisition process) and databases. The latter group may be further classified into supervised Machine Learning (ML) methods and unsupervised methods of Data Mining (DM) and Knowledge Discovery (KD).

Domain experts are very valuable sources of diagnostic knowledge and cannot be omitted through the whole process. Their role is especially important in the introductory phase of this process when a description of the domain is acquired. However, these methods are inefficient if we have to acquire great amount of knowledge counted e.g. in numbers of rules. Therefore ML and KD methods are even more and more frequently applied.

3.1.1. Methods of Knowledge Acquisition from Domain Experts

Two methods have been implemented: knowledge acquisition using paper forms and using an electronic form. They differ in range of required activity of a knowledge engineer.

The first method consists in that the expert elicits his/her own knowledge without participation of a knowledge engineer and represents it filling in cells in a special paper form. Then the forms have to be interpreted by the knowledge engineer who puts down respective records into the knowledge base. This method is suitable for the experts who are unfamiliar with modern software and hardware. However, the influence of the knowledge engineer on the final portion of knowledge is very crucial.

The second method depends on the use of some specialized software tool which the author called an electronic form [1, 3]. This application is a knowledge base editor, which allows reducing role of the knowledge engineer to integration and merging knowledge acquired from different experts and in many cases his/her activity is not required.

Both the methods have been implemented using supporting means [1, 3].

Apart from these classical methods of knowledge acquisition from domain experts, a new class of methods targeted at belief networks is rapidly developed, e.g. by W. Cholewa and his team [8]. Experts represent their knowledge in the form of a structure of the network, variables associated to nodes, topology of links, and tables of conditional probabilities associated with the nodes. There are also solutions where knowledge represented in the form of a belief network is acquired from classified examples provided by the knowledge engineer.

Another method that is worth mentioning is representation of knowledge in the form of fuzzy-neural networks (FNN, see [7]) where experts' knowledge is used for the domain description.

3.1.2. Methods of Knowledge Acquisition from Databases

Both supervised and unsupervised methods have been used extensively. Machine Learning (ML) methods that belong to the supervised ones can be used if a database containing previously classified examples is available. The whole process of knowledge acquisition may be carried out within a special diagnostic experiment, either numeric or active one. Several steps can be distinguished. Active diagnostic experiments require measurements of needed diagnostic signals. Realizations of signals are stored in the system's database. Features of diagnostic signals consist examples, each of them being represented by one record in the database. Fields in this record contain several values of conditional attributes and value(s) of at least one decision attribute(s) denoting the class(es) where the classified example belongs. Each example is considered as positive one for some concept that corresponds to some given technical state and as negative one (counterexample) for all other classes. Values of attributes are usually represented as qualitative ones, hence some kind of discretization of continuous variables is required.

To make the whole process computationally efficient a subset of relevant attributes should be selected. There are several methods of selection, e.g. based on minimal reducts using rough-sets approach, or statistical methods such as PCA. After that the database of examples is prepared for knowledge acquisition using supervised ML methods.

To acquire knowledge from databases of examples several very well-known ML methods can be applied, including induction of rules and decision trees, and many others.

Validation and assessment of acquired knowledge depends on the application of either special set of testing examples or some resampling technique and then calculation of classification errors. The very convenient and frequently used criterion concerns the overall empirical error rate. If the error rate obtained is unacceptable then the process may be repeated iteratively.

The author and J. M. Żytkow have also begun the research on applications of KD methods to machinery diagnostics [6]. The KD process included several steps. To discover qualitative (approximate) dependencies and estimate their strength, contingency tables were applied, which suggested very strong functional dependencies. However, obtained results were imprecise. Contingency tables are suitable for identification of approximate dependencies, that may be refined by finding equations. These equations correspond both to 'direct' knowledge and 'inverted' one, the latter being suitable for diagnostic concluding from the collected evidence (diagnostic symptoms).

3.2. Methods of Knowledge Assessment

Methods of assessment of knowledge acquired previously may be also divided into those applied by human experts and 'automatic' ones.

Expert-based methods consist in an assessment of either a single rule or the whole ruleset (which is rare because of many rules contained in a typical ruleset) with respect to its/their substantial correctness. A value of the belief degree is assigned to each individual rule being assessed. Only several qualitative (predefined) values of the belief degree [3] are used. Such activity of the human expert may be aided by a special tool.

'Automatic' methods of assessment of acquired knowledge depend on the application of either special set of testing examples or some resampling technique and then estimation of classification errors. To this end, the overall empirical error rate is often used, defined as the ratio of errors to the total number of testing examples. In case of uneven distribution of examples across previously specified classes, weighted overall empirical error rate defined by the author is used [3].

Moreover, hybrid couples of methods of knowledge acquisition and subsequent assessment of this knowledge base have been suggested [3]. There are two 'cross-like' possibilities: knowledge acquired from a domain expert may be verified using a set of testing examples, or knowledge acquired by ML methods may be assessed by human experts. The former pair is particularly interesting since it makes possible to assess quality of a dataset of examples using a set of generally acknowledged rules [3]. These rules may be acquired e.g. from very much experienced and widely recognized domain experts.

4. HEURISTIC MODELS OF DYNAMIC OBJECTS

Similarly to methods of knowledge acquisition about machinery, it is possible to acquire knowledge in the form of models either from experts, or from databases.

This is not the task for this paper to discuss possible kinds of models that are applied in process diagnostics. Very comprehensive descriptions of this methodology can be found in [7]. Nowadays physical and mathematical models are created by experts. They also develop logical and rule-based models of dynamic objects. A very efficient kind of models takes advantage of fuzzy neural networks, which are based on sets of rules created by experts.

A new approach to model identification consists in applying and/or developing methods of soft modeling whose application will allow automatic discovery of models in databases. In the author's opinion the task formulated above is very similar to the process of Knowledge Discovery in Databases.

Methods of heuristic modeling can be considered according to the general way of representing models, and to their application. Models can globally represent data in the form of multivariate time series collected from the object.

Carriers of the global heuristic models can be:

1. Neural and Fuzzy-Neural Networks representing relations between spaces of inputs/controls and delayed outputs, and the spacer of output(s); this application is similar to functional dependencies in the form of equations that allow calculation of output values [7];
2. Neural and Fuzzy-Neural Networks whose topology and coefficients tuned in result of training represent generalized knowledge about the process [5];
3. Functional dependencies in the form of equations that allow calculating numerical values of output(s) basing on values of inputs, controls and states, as well as values of previous outputs (for dynamic objects).

Multivariate time series can be also modeled in intervals using hypersurfaces (hyperplanes, multivariate splines etc.) whose dimension is equal to the dimension of the space of independent variables. For the data represented in such a way it is possibile to define an event as some determined pattern (regularity) in the database that is assigned some semantic meaning. The support of the event (time interval, on which the regularity holds) can in some cases reduce to a single point located at the time axis.

Furthermore, a historically the most early method of modeling dynamic processes has to be recalled, which is based on sequences of events that correspond to some discrete control actions and inputs as well as observed outputs. An example of such an event can be opening or closing a valve, switching on the supply, signaling warning or danger, adjustment of an element of the system and the others. In such sequences of events it is possible to identify characteristic sequences that allow detecting some faults.

Several methods are developed with the author's supervision and participation:

1. Modeling multivariate time series with the use of sequences of events (P. Tomasik);
2. Modeling one-dimensional courses of control variable by means of linguistic description (R. Szulim);
3. Discovering dependencies that describe operation of dynamic objects (D. Wachla);
4. Modeling dynamic processes with the use of neural networks and fuzzy-neural ones (P. Przystałka, R. Wyczółkowski, B. Wysogląd).

5. RECAPITULATION

The paper dealt with very brief description of the comprehensive methodology of knowledge acquisition about machinery and processes. The methods mentioned in the paper were developed and implemented in the author's research group. Since it is ever more widely believed that further development of technical diagnostics depends on application of efficient methods of knowledge acquisition, the problem addressed in the paper will become ever more and more attractive for many researchers. Other important issue that causes systematic development of this methodology is the growing possibility to collect data about machinery and processes. This data really carry very crucial information about the objects and processes to be diagnosed. Implementation of automated methods should boost creation of valuable applications that would help the personnel in operation of machinery and control of processes.

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