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Network knowledge bases for technical diagnostics

K e y w o r d s

Statement network, multilayer statement network, belief network, expert system.

S ł o w a k l u c z o w e

Sieć stwierdzeń, wielowarstwowa sieć stwierdzeń, sieć przekonań, system doradczy.

S u m m a r y

The paper briefly discusses the application of a multilayer statement network as a qualitative model of a diagnosed object and a model of a diagnostic knowledge base. The reasoning process in statement networks is based on searching for an equilibrium state of the network.

Introduction

Decision-making support systems, as for example advisory systems, allow taking rational actions based on available information, domain knowledge and knowledge about methods of decision making. A special category of such systems is diagnostic systems. There are many applications of such systems. Further discussion will concern only the systems of technical diagnostics.

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Diagnostic systems

The overall objective of diagnostic systems is to recognise the current state or changes in the current state of a studied object. The results of their actions create the basis for decisions on further exploitation of the object, the decision about the necessity of its inspection, tuning or repair.

The term "state of the object" is an ambiguous concept. A concise definition can be introduced by limiting the study to system object models, where the state is a set of variable factors affecting the transformation of inputs into outputs of these objects. For the general study of technical objects we can distinguish a functional state of the object (e.g. switched-on, start-up, the nominal load, run, ...), often referred to as a set of operating conditions of the object and the so-called technical state of the object including its calibration, wear and damage to components, abnormalities in the process of manufacturing the object, and the effects of errors performed during the design process.

Inference about the state of the object can be conducted based on data supplied by the operator (user) of the object and the results of observations of the object performed directly or indirectly by observing the interactions occurring between the object and its surroundings (e.g. inputs and outputs in the system object model). These interactions are the carriers of information on the state and the operation of the object. The results of observations should include process variables. It should be noted that we often do not have the ability to observe all the impacts. Impacts that are not observed and may affect the performance of the object are interpreted by the model as noise.

Operation of most diagnostic systems lies in the fact that the values of selected features of diagnostic signals are subjected to classification in which the result indicates the state of the object. It is possible to use various kinds of classifiers. Simple classifiers are based on comparing the classified features of signals with threshold values (warning, alarming, etc.) as defined in the standards, recommendations, technological procedures, etc. Complex classifiers are based on the knowledge of symptoms accompanying the considered states of the object. Their function is to recognise the symptoms indicating the state of the object.

A diagnostic signal whose characteristics can be input data for the classifiers is, for example, the course of the observed impacts (including process variables). In order to obtain signals with high diagnostic sensitivity, we have applied systems based on models. The main element of such systems is the object model. A model for the assumed state of the object and for selected courses of impacts allows for the determination of the anticipated course of other impacts, which are compared with the observed actual impacts to determine the residual (differential) signals. Residual signals can be regarded as diagnostic signals whose values are subject to the classification of characteristics to recognise the state of the object or to verify hypothesis about the state of the object.

Particularly interesting, but difficult, is the task to build a diagnostic system for a complex object, where a reasonable solution is to use different types of partial diagnostic subsystems for selected parts of the studied object. Assuming that the suggested subsystems are autonomous systems makes it easier to design them and allows their independent identification and development. It is important that a whole diagnostic system should not be considered as a simple assembly of such subsystems, because between the selected parts of the diagnosed object there may be interactions affecting the operation of the discussed diagnostic systems.

Knowledge Base

The main elements of systems for collecting the domain knowledge and its application in the inference process about a technical condition are knowledge bases. They can be built in the form of sets of exact and/or approximate rules. A significant step in the development of knowledge bases was to use the concept of subjective conditional probabilities and the introduction of belief networks. Sets of rules allow building complex systems of explanations, which create an essential element of the considered expert systems. Building similar system explanations for belief networks is a very difficult task.

Expanding upon the concept of belief networks, it was assumed [1] that the nodes of these networks are statements. The introduction of statements make it possible to consider the knowledge base in the form of a statement network, in which the relations between statements may belong concurrently to different types. These may be cause-effect relationships, association relationships, dependencies described by multivariate probability distributions, approximate relations, fuzzy relations, and many others. The studied relationships, which are currently developed, are necessary and sufficient approximate conditions [1, 2, 3].

Statement Network

The essence of the proposed solution is to introduce a qualitative description of the object and its action in the form of a specific, fixed set of statements.

A statement is information about the recognition of expression resulting from the observed facts or representing a specific opinion. The statement s can be written in the form of a pair $s = <c, v>$, where c is the statement content, e.g. a statement that the designated object has a specified attribute of a fixed value and v is a statement value, which is for example one of the two elements of *{true, false}*. The statement content can only be a declarative sentence. For approximate statements their value *v* can be defined, for example, as the degree of truth or degree of belief about the truth (validity) of the sentence which is the statement content.

The results of the observation of the object are the basis for the recognition of selected statements about the values of process variables, values of the features of observed interactions, values of the state features, etc. The set of these statements may include the statements representing the results of diagnostic subsystems, making known the occurrence of symptoms or even syndromes of specific states [1].

A model of a set of statements can be a network whose nodes represent statements and whose branches represent the dependencies between the statements. It is assumed that the statements are partially dependent, i.e., changes in the value of the selected statement may cause changes in the values of other statements. The structure of the network, its nodes and branches as well as the content of the statements and the related explanations and comments, represents the diagnostic knowledge, including the detailed diagnostic knowledge of the studied object. A view of the considered set of statements can be a bulletin board or a synoptic table. Such a table contains elements with a known value (e.g. the results of the observation) and elements of unknown values (such as the characteristics of the state). Operation of the system aimed to determine the diagnosis could be viewed as an inference about the unknown values of the selected elements from the known values of other elements in the table.

Changing the values of selected nodes causes a change in the values of other nodes. It is assumed that these changes lead to a state of equilibrium of the network corresponding to the minimum value of the applied functionals (defined for the network) [1]. It is not assumed that the considered functional reaches a global minimum, i.e., a local minima may occur. A determined minimum value of the functional may measure the degree of conditional contradictions represented by a knowledge network. One of the many reasons for these contradictions may be the approximate and qualitative character of the models.

The above assumptions allow describing the task of inference about the state of the object in the following way [1]:

- Based on observation of the object, we set values of the selected nodes in the statement network.
- We are looking for unknown (not specified) node values representing the statements describing the state of the object that ensure the equilibrium state of the network. The values of these nodes allow the describing of the state of the object and are the solution to the task of inference about the state of the object.

It should be noted that the assumptions regarding the equilibrium state of the network show that there is a possible simultaneous existence of many different solutions to the tasks of inference about the state of the object. Such a situation can be interpreted as the recognition of a set of states indistinguishable from the current, limited knowledge about the object.

Defining a statement network requires the specification of a set of statements and relations between statements. The set of statements is specified by the designer of the network. Specifying a set of statements can be supported by providing statement thesauri that allow one to pick the pre-prepared statements. Relationships between statements can be specified openly by the designer of the network. They can also be acquired automatically based on an appropriate set of examples. Activities related to determining the relationships can be supported by examples of the earlier built networks.

Multilayer statement network

Interesting possibilities for practical applications are related to the concept of multilayer statement networks [1]. Building a multilayer network starts with establishing a set of statements appearing in it. Subsequent layers are spanned on the statements selected from this set. It allows the considering of these layers as partial submodels of different issues. Such submodels can be built independently from the others.

A multilayer network is a model that should be interpreted as a set of partial submodels, appearing in the form of successive layers. Some statements (not necessarily all) may occur simultaneously in several layers. The results (statements values) returned by successive layers may vary. These differences may result from different viewpoints and different simplifications adapted in the partial models. They should not to be interpreted as a symptom of multilayer network inconsistencies.

Application of a multilayer network requires assembling partial submodels. Assembling the layers can be achieved through negotiating or aggregating the results of the layers operation.

The aim of negotiating the results of the operation of the layers is to establish a single common value for all occurrences of each node in the layers. The direct way of negotiating the layers is the flattening of a multilayer network and replacing it with a simple single-layer model. Unfortunately, the flattening operation is not possible for all models and types of networks. Most types of networks require that they do not contain cycles. Fulfilling this condition by all the networks occurring in successive layers does not mean that in the network resulting from flattening the cycles will not occur. Flattening a multilayer network is also impossible when relationships in component networks are defined in different ways. Particularly manageable to such proceedings and free from mentioned difficulties are statement networks modelling sets of approximate, necessary and sufficient conditions, represented in the form of systems of approximate inequalities [2].

An alternative way of negotiating the results of the layers operation is an iterative correction of the results of the component layers. However, this causes numerical problems and does not guarantee convergence.

There are many methods of aggregating the partial results. Unfortunately, the use of aggregation, interpreted as an averaging of different points of view, is not a recommended procedure. The only advantage of aggregation is that the folded layers can be different types of networks, i.e. networks in which relationships between the statements are described in different ways. This advantage justifies the use of aggregation, especially when the negotiating of layers is not possible.

Summary

This limited volume of work allowed pointing out only certain issues. A more detailed discussion is presented in [2].

Sets of statements can be qualitative images of the considered objects. Statement networks are their qualitative models. Diagnostic systems based on statement networks are designed especially for those objects for which we do not know the complete and sufficiently detailed quantitative model and the approximate knowledge on diagnostic relationships is obtained based on experts opinions.

It is necessary to point out that expert systems based on statement networks allow inference on the state of an object only within a so-called "closed world," i.e. one within the pre-defined, finite set of statements. This solution is suitable for most industrial applications, in which the diagnostic system occurs as part of an automatic system of continuous surveillance. It should be noted that such systems are designed mainly for the routine use of knowledge represented by them and do not allow the automatic generation of new statements. This limits the possibilities of their application where it is necessary to discover knowledge, for example, in studies of unusual operational behaviours of little-known objects.

The Silesian University of Technology developed *MMNET* environment [2] and the environment *REx*[1] [3] is being developed, allowing the group development and verification of the discussed multilayer network knowledge bases, intended in particular for diagnostic applications. These environments are distributed in forms of packages in R.

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Sieciowe bazy wiedzy w diagnostyce technicznej

S t r e s z c z e n i e

Omówiono zwięźle możliwość zastosowania wielowarstwowej sieci stwierdzeń jako jakościowego modelu diagnozowanego obiektu oraz jako modelu diagnostycznej bazy wiedzy. Wyjaśniono, że proces wnioskowania w sieciach stwierdzeń polega na poszukiwaniu stanu równowagi sieci.