TECHNIKA TRANSPORTU SZYNOWEGO

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THE SYSTEM FOR MONITORING A VEHICLE STATE WITH THE USE OF RELATIONAL COGNITIVE MAP

Abstract

Identification of the current and the projected condition of the vehicle has crucial meaning to its proper exploitation. This is an issue of particular importance from the point of view of decision-making on the necessary repair and maintenance work. The growing complexity of vehicles design increases the level of uncertainty of the decisions taken in the classic mode, which is based on the simple observation of symptoms, which in turn stimulates the search for more appropriate methods of monitoring the state and supporting decision process.

The article is devoted to the presentation of a certain method of decisional monitoring of a vehicle state based on the interpretation of diagnostic signals from the sensors by the mathematical model, which uses the relational cognitive map for reproducing the interactions of key elements of vehicle electrical equipment. The paper presents mathematical foundations, construction assumptions and an example of work of the monitoring system.

The work was carried out in the framework of the research project No. N N510 468136.

INTRODUCTION

Modern motorcar vehicles are generally equipped with sets of sensors located in key locations, so on-board computers can make a partial self-diagnosis and inform users about some of the states of emergency. Wider opportunities in this area one can find in specialized service stations, equipped with a suitably dedicated testers. Such automated diagnostic methods allow rapid detection of major faults, but they don't give the possibility to make a broader analysis of the condition of the vehicle. It is possible only after a careful study, conducted by an experienced expert equipped with a set of expensive tools. This is due to the high complexity of the interaction of individual elements and of the instability of impacts of the environment, in which some of them work, which in turn makes it difficult to build a classic mathematical models that could be used as comparative simulators. Existing mathematical support tools, that use binary diagnostic matrices, can be applied rather theoretically than practically because of the multi-level values of symptom signals. Therefore, for some time, attempts are being made to introduce artificial intelligence elements [1, 7, 8], such as artificial neural networks, which would enable to avoid the problem of the complexity of the tested system, and to reduce the state recognition issue into the classification problem. However, such methods, although useful in some areas, do not allow take into account the dynamics of the analyzed system, which is manifested e.g. by the existence of closed-loop feedbacks between elements. In addition, they require an explicit distinction of input and output signals, which imposes a predefined direction of the flow of information, which in turn makes the monitoring system too few flexible.

In connection to the above, there is proposed to construct a monitoring system, in which the role of the comparative simulator is played by the model based on a relational cognitive map. Operation of such a system has a dual character. It retrieves the information from the monitored system, then, after appropriate processing, introduces them into specific points of the cognitive model tailored to the structure of the monitored object. The cognitive model processes the data, and then sends the results to the decision-making module that presents (to the user) conclusions about the state of the monitored object and proposals for further action. In such terms, the concepts of the cognitive map would be both: equivalents of signals measured in the monitored object, and - at least some - states of the object, so that it becomes possible to map the impact of the symptom on the state as well as the state on the symptom.

1. MODEL BASED ON RELATIONAL COGNITIVE MAP

The name "relational cognitive map" refers to a certain kind of mathematical models that are helpful in the analysis and monitoring of complex systems that are difficult to describe through the standard form of a classical system of differential equations. In the model of such type the object of interest are the main features the tested system (called concepts) and the nature of relationships between them. In this, concepts as well as interdependences (the so-called relations) have a numeric measurement from a certain range of values. So defined model can be represented in the form of pairs of sets (1) [2, 5]:

$$\langle \mathbf{X}, \mathbf{R} \rangle \tag{1}$$

where: $\mathbf{X} = [X_1, X_2, ..., X_n]^T$ – vector of values of the relational cognitive map concepts;

$\mathbf{R} = \{r_{i,j}\}$, $(i,j = 1, ..., n)$ – relation matrix between concepts;

$r_{i,j} \in [0, 1]$ or $r_{i,j} \in [-1, 1]$;

n – number of concepts of the relational cognitive map.

A characteristic feature of the structure described by (1) is (in general) the absence of a specially highlighted direction of the signal flow, which means that, depending on the current purposes of modeling, any group of concepts may be used as inputs or outputs, or all concepts will be equally treated. Thank to potential possibility of building connections between any concepts, signals in this model can move in different directions, and its graphical representation may for example be of a spatial nature. An additional advantage of this type of model is the opportunity to observe not only the direct and obvious interactions, but also indirect relationships, more difficult to preliminary determination by the experts. Exemplary graphical representation of relational cognitive map is presented in Fig. 1.

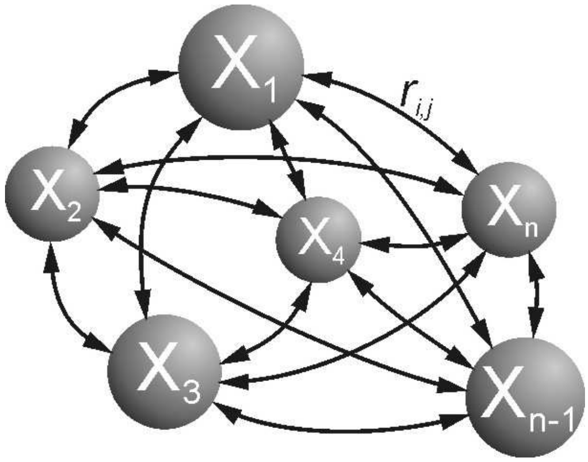

Fig. 1. Exemplary graphical representation of relational cognitive map, where: X_1-X_n – values of individual concepts; n – number of concepts; $r_{i,j}$ – relation between the i-th and j-the concepts (arrows show directions of relations).

In the modeling based on a relational cognitive map, as in other methods, the accuracy of determination of values of the monitored variables in the consecutive steps of discrete time has crucial meaning. The adopted method for determining these values depends on the structure of the modeled system as well as on the needs identified by the expert. One of possible approaches is the use of nonlinear model with the nonlinearity of "rate of change" [4], in which the values of concepts in time are determined according to (2) [4]:

$$X_i(t+1) = F\left(X_i(t) + \sum_{\substack{j=1 \\ j\neq i}}^{n} r_{j,i} \cdot \Delta X_j(t) \right) \tag{2}$$

where: X_i – value of the i-th concept (in the range [–1, 1]);
$\Delta X_i(t) = X_i(t) - X_i(t-1)$;
$X_i(0)$, $X_i(-1)$ – given;
$r_{i,j}$ – strength of the relation between concepts numbered i and j (in the range [–1, 1]);
$i = 1, ..., n$; n – number of concepts;
t – discrete time;
F – threshold function.

The task of the function F (x): R → R with (2) is to reduce the value of the concept to the maximum level 1. It may take a following form [4]:

$$F(x) = \frac{1 - e^{-\beta x}}{1 + e^{-\beta x}} \tag{3}$$

where: $\beta > 0$ – parameter.

In some situations (for a small number of concepts) the use of the function F is not necessary.

From the utility point of view, the crucial aspects are: proper selection of concepts and proper determination of relations that are connecting them. Basically, this is a job for an expert, although the value of the relations can be later modified in the process of the adaptation (learning procedure). Keep in mind that this learning process requires access to a large number of training data, what, in the case of real objects, is not always possible. This increases the importance of expert knowledge during the design of model parameters.

Equation (2) can be used both to determine the current states of the object, as well as for prediction, it also allows to take into account the internal dynamics of the object. A certain problem is defining the scale of the discrete time and referring it to the real time.

2. PREPARATION OF MEASUREMENT DATA

Proper operation of the monitoring system that uses a model of the relational cognitive map, depends on the regular updating of the measurement data. However, these data cannot be processed without pre-treatment, because values of concepts need to be in the range [-1, 1], while the measured quantities take values much more diverse. In addition, some of the values, expressed in SI units, are of significantly higher orders of magnitudes than others, but that does not necessarily mean their greater impact. Therefore, the measured values must be pre-treated - through normalization, which will allow reducing them to the assumed (dimensionless) limits. Such normalization can have various characters. One of the methods is to use modified max-min normalization.

$$X_i(t) = Sgn\left(X_i^*(t)\right) \cdot \frac{\left|X_i^*(t)\right| - \min\left(\left|X_i^*\right|\right)}{\max\left(\left|X_i^*\right|\right) - \min\left(\left|X_i^*\right|\right)} \tag{4}$$

where: $X_i^*(t)$ – real value of the i-th concepts at moment t of discrete time;
$X_i(t)$ – normalized value of the i-th concepts at moment t of discrete time.

Sometimes, a better method is to use the normalization defined in tabular form, with graphical representation shown in Fig. 2. It should be remembered that one of the tasks of the monitoring system is examining the correctness of operation of the object, and the optimal normalized value of each concept is 0. Any deviation from this value indicates the approaching to the incorrect ranges of values.

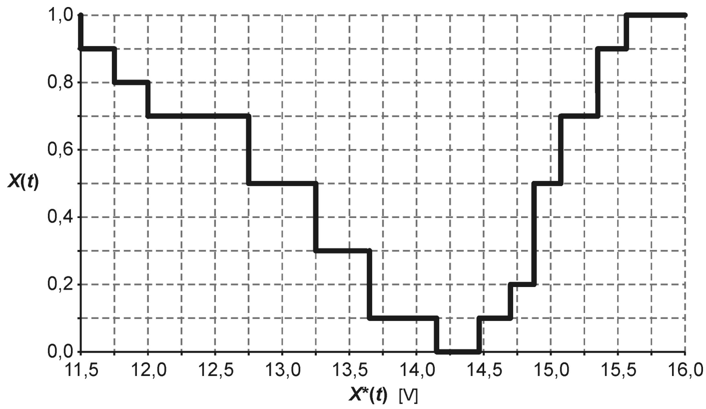

Fig. 2. Graphical visualization of the exemplary tabulated normalization of the measured value of a concept. $X^*(t)$ – real value of the concept, $X(t)$ – normalized value of the concept.

3. LEARNING PROCEDURE FOR THE MODEL OF THE RELATIONAL COGNITIVE MAP

Selection of concepts (number and nature) of the relational cognitive map depends mainly on the monitoring objectives. The concept can be the quantity measured (directly or indirectly) in the modeled object as well as one of the observed states of the object (e.g. correct operation of the selected module). Moreover, concepts don't need to have physical counterparts in the analyzed object. In general, they can be purely abstract, what is justified when the number of concepts is less than the number of measured values and, nevertheless, the interactions need to be somehow mapped. This approach makes the role of experts (that determine the model parameters) more difficult and creates the need to develop mechanisms that would allow for additional adjustment (adaptation) of the parameters of relations according to the actual work of the object. Adaptation of the model (learning process) is possible under condition of the access to a sufficient number of training data. If it is satisfied, it is possible to use one of the many approaches (for example, using a differential algorithms [6]), however, because of the operation time, the most favorable method seems to be a gradient [4], which consists in the minimization of a criterion $J(r)$:

$$J(R) = \frac{1}{2}\sum_{i=1}^{n}\delta_i(t)^2 \rightarrow \min_R \tag{5}$$

where: $\delta_i^2 = (z_i(t) - X_i(t))^2$;

R – vector of relations ($R = \{R_{i,j}\}$);

$z_i(t)$ – reference function of values of changes of the i-th concept;

$X_i(t)$ – modeled function of values of changes of the i-th concept;

$i,j = 1, ..., n;$

n – number of concepts;

t – discrete time ($t = 0, 1, ..., T$).

Adaptive algorithm has a recursive form (for $t \rightarrow t+1$):

$$r_{j,i}(t+1) = r_{j,i}(t) + \Delta J(t) \tag{6}$$

where: $\Delta J(t)$ – change of the values of the function $J(t)$ depending on the parameters.

The example of $\Delta J(t)$ is anti-gradient direction: $\Delta J(t) = -\text{grad } J(t)$, which can be calculated for $r_{j,i}$ in the following way:

$$\text{grad } J(t) = -(z_i(t) - X_i(t)) \cdot y_{j,i} \tag{7}$$

where: $y_{j,i}$ – the function of the sensitivity of value of concept X_i to the changes of values of $r_{j,i}$ ($j = 1, ..., n$; $j \neq i$), determined as follows:

$$y_{j,i} = \frac{\partial X_i}{\partial r_{j,i}} \tag{8}$$

The form of equations calculating the sensitivity $y_{j,i}$ from (8) depends on the taken treshold function F from (3), while the training algorithm itself can be presented in the form:

$$r_{j,i}(t+1) = r_{j,i}(t) + \eta \cdot \delta_i(t) \cdot y_{j,i}(t) \tag{9}$$

where: $0 < \eta < 1$ – the step of the algorithm.

Taking into account the above considerations one can formulate the set of equations for the parametric adaptation of the relational cognitive map of type (2):

$$\begin{cases} X_i(t+1) = F\left(X_i(t) + \sum_{\substack{j=1 \\ j\neq i}}^{n} r_{j,i}(t) \cdot X_j(t) \right) \\ r_{j,i}(t+1) = r_{j,i}(t) + \eta\delta_i(t) \cdot y_{j,i}(t) \\ y_{j,i}(t+1) = (y_{j,i}(t) + X_j(t)) \cdot F'\left(X_j(t) + \sum_{\substack{j=1 \\ j\neq i}}^{n} r_{j,i}(t) X_j(t) \right) \\ i = 1,...,n; \quad j = 1,...,n; \quad j \neq i; \quad 0 < \eta < 1; \quad t = 0, 1, ..., T \end{cases} \tag{10}$$

with the following initial conditions:

$$
\begin{cases}
X_i(0) & - \quad \text{setpoint (e.g.: } X_i(0) = 0 \text{ if the lack of information)} \\
y_{j,i}(0) & - \quad \text{setpoint (e.g.: } y_{j,i}(0) = 0 \text{ if the lack of information)} \\
r_{j,i}(0) & - \quad \text{setpoint (e.g.: } r_{j,i}(0) = 0 \text{ if the lack of information)} \\
i = 1, \ldots, n; & j = 1, \ldots, n; \quad j \neq i
\end{cases}
\tag{11}
$$

Coefficient η, which appears in the adaptive model, is used to adjust the rate of change of power of the relation the current state of the model. In the general case, its value can be variable (e.g., may decrease as the model approaches the steady state).

4. BUILDING THE MONITORING SYSTEM

For the study, and subsequent practical use, there was built the system for decisional monitoring, which supports the processes of design and adaptation of relational cognitive map. This system works with a measuring network, which collects values of selected concepts of the real object, processes them into a normalized form, and then transfers these values to the processing unit equipped with the relational cognitive map. The system work is controlled by specially developed application, created with the use of the Microsoft. NET 4.0 platform, with the graphical user interface which is shown in Fig. 3.

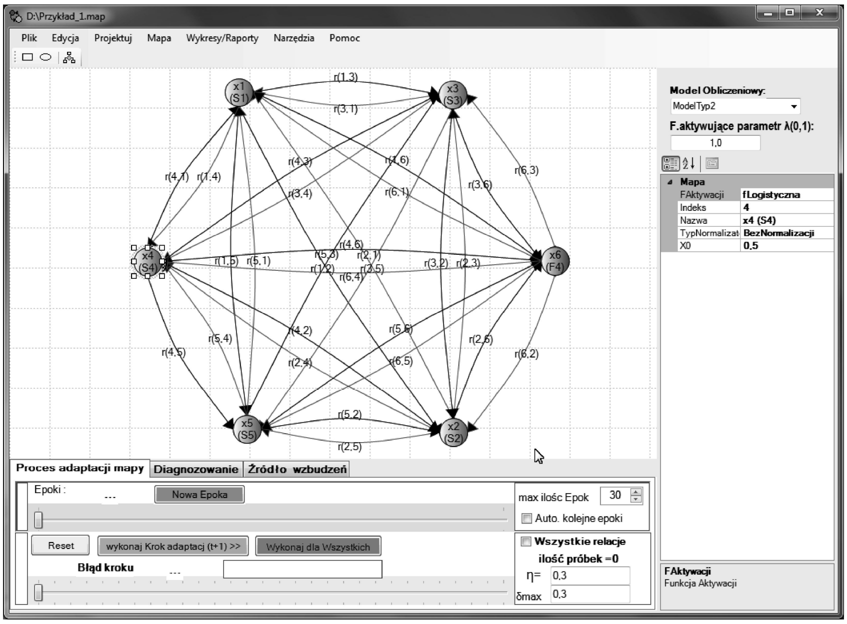

Fig. 3. Graphical interface of the application developed for the needs of operation of the system for decisional monitoring.

The structure of the application which is shown in Figure 3 enables the creation as well as further use of relational cognitive map. Within the frames of the constructional modules, the system allows to design the structure of cognitive map, make changes in it basing on the expert knowledge of, and conduct the map learning process (with the method described in chapter 4) with the use of the data generated to date (by the reference map) or downloaded from the previously prepared disk file. Built in this way, relational cognitive map can then be used for simulation research (in which the data source is set of signals generated or retrieved from a file), or to the real monitoring the object, during which the system receives data from the measurement network, designed and built specially for this purpose.

General structure of the system is presented in Fig. 4.

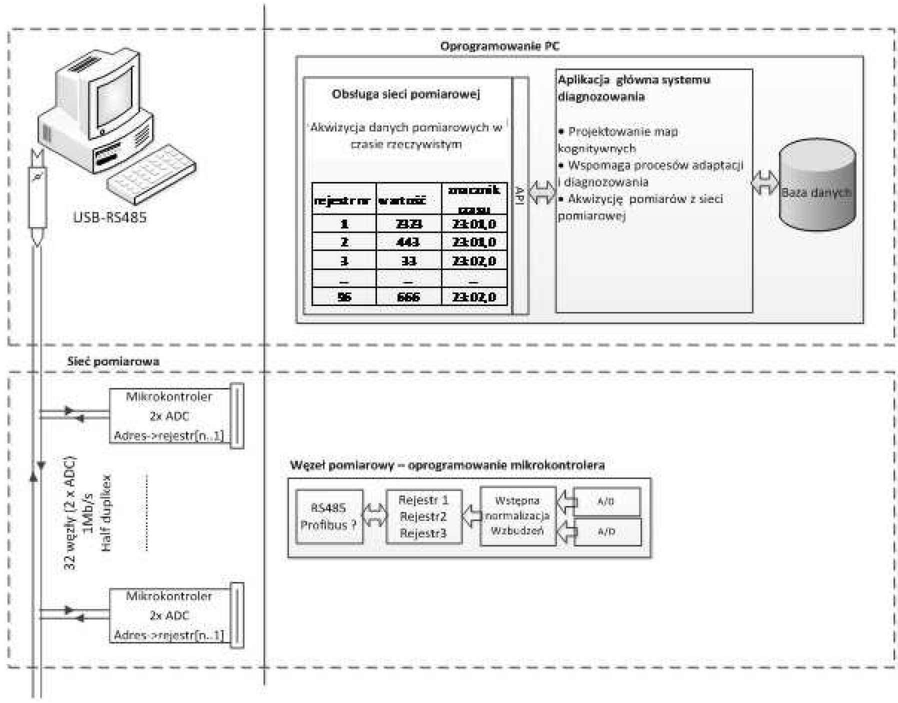

Fig. 4. General structure of work of the system for decisional monitoring.

Measuring network is made up of ten independent measurement nodes (the number can be increased) built basing on microcontrollers ATMEGA8L. Each node allows to measure and adapt two voltage signals from dedicated sensors. Common communication bus based on RS485 standard provides communication with the computer at a rate of 1 Mb/s. Depending on the requirements, the measuring network can, in a single bus, support up to 32 nodes (64 measured signals). The use of digital data causes that measurement nodes can be located at a considerable distance to the main computer, what on the one hand reduces the effort to provide protection against transmission errors, and on the other hand facilitates the control of the monitoring processes. Controlling and retrieving the data from the measuring nodes is done using alphanumeric messages formatted in seven-bytes frames. Communication is initiated on the side of the controlling computer through cyclic polling of nodes, each of which has a unique address, thanks to that at a given moment the information is collected only from this node that has been declared in the communication frame. Communication can be supported by any text terminal equipped with a serial port. Individual microcontrollers are programmed using a dedicated development environment AVR Studio and the programmer STK 500. The appearance of a single measuring node is shown in Fig. 5.

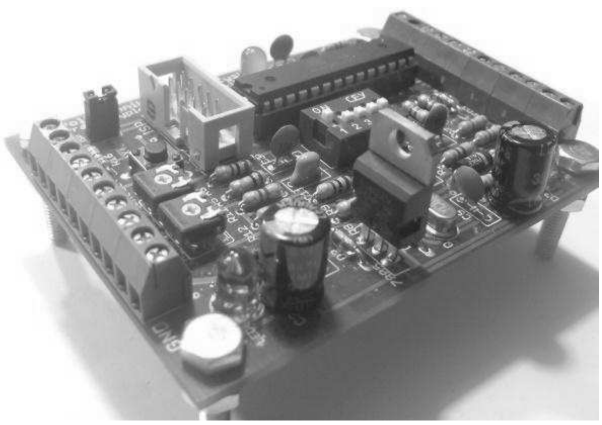

Fig. 5. A view of a single node measuring built based on the microcontroller ATMEGA8L.

Measurement system described above has been tested in simulation and laboratory tests to check and improve the algorithms of the model and programs of the measurement network.

5. SELECTED RESULTS OF THE RESEARCH

For the purpose of testing the system one of the vehicle electrical circuits – power supply circuit was chosen with selected six key concepts identified as follows:
X_1 – voltage at the battery terminals,
X_2 – voltage adjustable - output from the alternator,
X_3 – alternator excitation current,
X_4 – signal from the ignition switch of the vehicle 1,
X_5 – ignition signal from the ignition switch of the vehicle,
X_6 – alternator state.

The purpose of the test was to build a relational cognitive map, which would serve to identify the state of the alternator based on available measured information from sensors placed in the tested object, which was a Daewoo Lanos vehicle. Pre-designed structure of the map was introduced into the system (its graphical representation is shown in Fig. 3), assuming zero initial values of all relations. In the follow steps of discrete time the system was receiving external learning data (complete), adjusting, according to it, the structure of the cognitive map (by modifying the value of the relations) and then, with the use of such modified map, it performed a simulation of the object operation. The results of this simulation were then compared with received data, which constituted the basis for further modifications in successive steps of discrete time. The study involved a state of an incorrect work of the alternator. Concepts were conventionally divided into two groups: concepts of a symptom nature (whose values can be read on the basis of measurements) and concept of a decision-making nature (which value can be the basis of inference). Figs 6 and 7 show the waveforms of the concepts in successive steps of discrete time. In this case, to better illustrate the operation of the system, in Fig. 7, in addition to the results of the cognitive map operation, also the course of value of the corresponding learning signal was presented.

Fig. 6. Values of symptom concepts obtained by the monitoring system. *t* – discrete time.

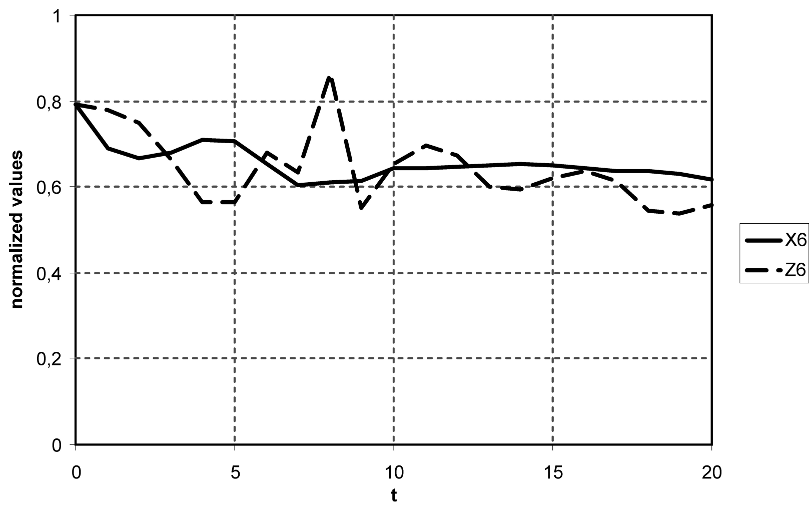

Fig. 7. Values of the decisional concept. X_6 – value determined in the simulation way by the monitoring system, Z_6 – reference value (for the learning purposes), t – discrete time.

The waveforms gathered in Fig. 7 show that in the process of gradual adaptation (according to the method (5)) the monitoring system achieves the state, in which it reproduces, with a high accuracy, real values of the decisional concept, by using to that purpose the introduced values of the symptom concepts.

Fig. 8 illustrates how the system reaches the stable, optimal values of relations and sensitivity coefficients.

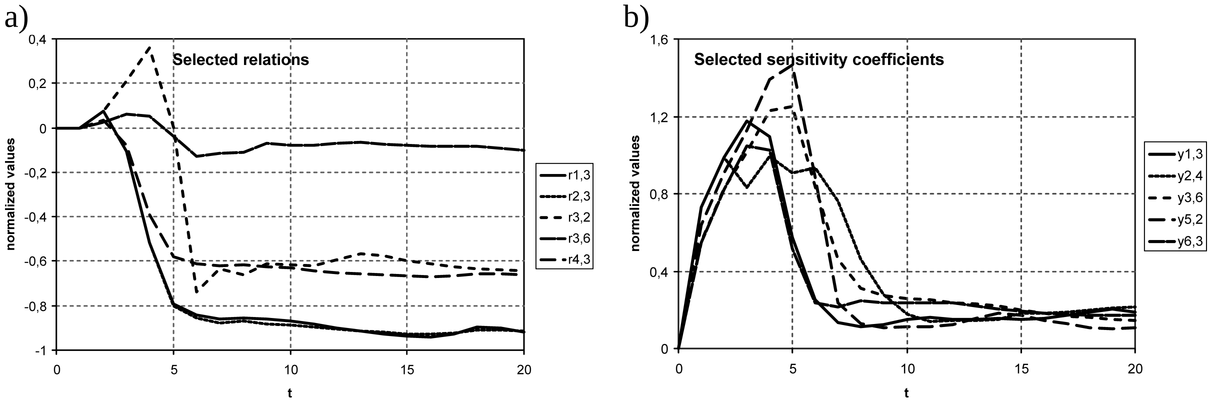

Fig. 8. Values of selected relations (a) and sensitivity coefficients (b). t – discrete time.

For the sake of clarity, Fig 8 shows only some of relations and sensitivity coefficients (in fact, there are many more of them). How it's easy to conclude, in the process of adaptation, after several steps of discrete time, both relations and sensitivity coefficients achieve stable, optimal values, and the levels of sensitivity coefficients are relatively low, which confirms the good mapping of the object by the monitoring system.

CONCLUSIONS

Constructed system of decisional monitoring uses a relational cognitive map to determine states of selected modules of the motorcar vehicle basing on partial data of the selected vehicle parameters. Tests carried out so far have shown the accuracy of recognition of such states and have confirmed the high potential of the proposed method. Current works focus on improving procedures and expanding their activities with a larger number of components of electrical and electronic equipment of a vehicle.

SYSTEM MONITOROWANIA STANU POJAZDU Z UŻYCIEM RELACYJNEJ MAPY KOGNITYWNEJ

Streszczenie

Identyfikacja aktualnego i przewidywanego stanu pojazdu ma kluczowe znaczenie dla jego prawidłowej eksploatacji. Jest to zagadnienie istotne zwłaszcza z punktu widzenia procesu podejmowania decyzji odnośnie koniecznych prac naprawczych i obsługowych. Rosnący stopień złożoności konstrukcyjnej pojazdów powoduje wzrost poziomu niepewności decyzji podejmowanych w klasycznym trybie, opartym na prostej obserwacji symptomów, co z kolei skłania do poszukiwania bardziej odpowiednich metod monitorowania stanu i wspierania procesu decyzyjnego.

Rozdział poświęcono prezentacji pewnej metody monitorowania decyzyjnego stanu pojazdu opierającej się na interpretowaniu sygnałów diagnostycznych, pochodzących z czujników, przez model matematyczny wykorzystujący relacyjną mapę kognitywną do odwzorowywania wzajemnych oddziaływań kluczowych elementów wyposażenia elektrycznego pojazdu. Przedstawiono podstawy matematyczne, założenia konstrukcyjne oraz przykład działania systemu monitorowania.

Pracę zrealizowano w ramach projektu badawczego nr N N510 468136

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