The use of text models in the formation of heuristics to solve tasks of diagnosing technical objects

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Abstract
This paper describes research related to the use of heuristics in diagnostic tasks of complex technical objects. To build heuristics, the use of text models for technical objects is proposed. Therefore, this paper examines output methods of heuristics from text models and their transformation into logical formulae suitable for use in diagnostic algorithms. Analysis has been carried out for tasks solved during diagnostics, and methods of using heuristics in certain tasks have been reviewed. It is proposed to use heuristics for decision making while implementing certain algorithm steps of monitoring tasks for diagnostic parameters that are solved during diagnostics.

Introduction

The task of diagnostics for complex technical objects (STO) is actually in the sphere of naval technologies, because examples of such objects are ships themselves or power units of large cargo ships. The task of diagnostics involves the detection of malfunctions which start taking place or are forecasted, their localisation and further elimination. We can accept that STO, in general can be described by some mathematical model, adequate for processes taking place in STO, so that we can solve the aforementioned tasks in the framework of the model.

In the framework of this work, the task of diagnostics is reviewed as a composite task, consisting of monitoring diagnostic and functional parameters, allowing the detection and localisation of possible malfunctions as well as the task of recognising and fixing the detected malfunctions. The monitoring task involves checking the parameter values in one or more sequences. As STO are large and complex, in the framework of one monitoring cycle it is impossible to check all possible parameters. Therefore, the task of forming a monitoring strategy arises, which would enable the detection of malfunctions at an early stage.

To form the appropriate monitoring strategy, in this work the use of heuristics is proposed, based on diagnosed process text descriptions, using formal means of non-monotone logic. This will allow the development of separate steps for the real-time monitoring strategy, to ensure the strategy is efficient in malfunction detection.

Basic concepts and tasks

There is a wide range of definitions and concepts of heuristics which represent features such as soft asks, and require them to be solved (Michalewicz & Fogel, 2006). To interpret the concept used in this paper unambiguously, let us introduce a definition of heuristics.

Definition 1. Heuristics (衡r) is a single rule or a system of rules for making a certain decision while solving a task. These rules cannot be deduced within the scope of functional tools or a mathematical
The use of text models in the formation of heuristics to solve tasks of diagnosing technical objects

Based on this definition, in order to build a heuristic system, further note das $\mathcal{S}$, a certain extended description is needed for a subject area where the task which is solved can be interpreted. This extension must allow analysis and description of the situations which can occur in the object related to the task being solved, and it has to enable entering of changes, occurring within the object, into the corresponding object description. To implement such a description, it is proposed here that text models previously described (Korostil & Korostil, 2012) be adopted. In general, a text model is a text description of technological processes that take place in a complex technical object in the normalised form, in the native language of its user. Let us review the definition of such an object, which will be used in this paper.

Definition 2. A complex technical object (STO) is a technical object which does not allow, at least not without difficulties, to build a unified functioning model, which provides a sufficiently relevant and constructive object description, with regard to all possible malfunctions which may occur during its functioning.

Because a text model (TM) is a text description of the processes taking place in STO, this description is relevant enough to represent processes of functioning (PR) for the correspondent STO. To ensure the necessary amount of constructiveness of the TM, the model has to provide the following functional possibilities:

- the model TM has to be able to be modified in order to represent changes occurring in PR and take place in STO;
- the model TM has to give the possibility to detect dependencies, not only between directly related parameters from PR, but also indirectly related parameters, as well as to give the opportunity to detect dependencies that could be latent within STO;
- the model TM has to give the possibility to transform the processes PR or their fragments into a system of logical models which will be written as $\mathcal{L}(STO)$.

It is planned, on the basis of the model TM, [PR, STO], to implement processes for deducing rules or conditions that describe certain heuristics $\mathcal{E}_r$, which compose the system $\mathcal{S}$. Thus, a system of rules for deducing heuristics from TM must be built, which will be written as $\mathcal{S}$. For this system we have to determine input formulae as well as formulae obtained on the basis of deduction, which would allow for their interpretational extension, so that these formulae would transform into certain heuristics $\mathcal{E}_r \in \mathcal{S}$. Extension of $\mathcal{E}_r \in \mathcal{S}$ with interpretations $j(\mathcal{E}_r)$ will allow us to obtain the necessary rules $\varphi_r$, that represent heuristics $\mathcal{E}_r$. Then, the following correlation can be written:

$$\mathcal{E}_r = F[\mathcal{S}, (L_{1}, \ldots, L_{m}) \& j(\mathcal{S})] \quad (1)$$

where $\mathcal{E}_r$ are single heuristics in the diagnostic model of STO, $\mathcal{S}$ is a system of rules for transforming $L_{1}, \ldots, L_{m}$, built on the basis of transformations $\varphi_r(TM) \rightarrow L_{ij}$, $F$ is a function that describes the interrelation between $\mathcal{S}(L_{ij}, \ldots, L_{im})$ and $j(\mathcal{S})$, $J(\mathcal{S})$ is a system of interpretation for certain $L_{ij}$, from which they obtain the form of $\mathcal{E}_r$. The system $\mathcal{L}$ is oriented towards using a finite area of interpretation for logical variables that is defined by a model $TM_i(STO)$. So, a logical system must be formed on the basis of formal logics, an example of which is non-monotonous logics (Thayse et al., 1990). One of the features of this logic, unlike classical logic, is that it gives rise to formulae which do not have to be valid on infinite sets of their interpretation (Mordechai, 2005).

Diagnostic tasks that are solved within the diagnostic model (MD) have to be able, within their own interpretation of diagnostic tasks, to use the correspondent $\mathcal{E}_r$. The diagnostic tasks, within the scope of this paper, are the following (Korbic et al., 2002):

- task of monitoring ($Z_m$) diagnostic parameters $p_i^d$ and functional parameters $p_i^f$;
- task of detecting the appearance of a malfunction in STO, which will be written as ($Z_a$);
- task of detecting a malfunction not yet manifested in the functioning process of STO, ($Z_v$);
- task of recognizing the malfunction ($Z_r$).

The tasks of withstanding detected malfunctions, or detected factors of their appearance, are not reviewed in this paper because they are related to the tasks solved within the security system of STO.

Each of the above-stated tasks $Z_m, Z_a, Z_v$ and $Z_r$ required the use of its own heuristics $\mathcal{E}_r$. Heuristics for each task must allow interpretation, consistent with the interpretation of the corresponding task, described by the following relation:

$$J(\mathcal{E}_r) \& J(Z_k) \rightarrow J(Z_k, \mathcal{E}_r) \quad (2)$$

where $Z_k$ is one task in a set $\{Z_m, Z_a, Z_v, Z_r\}$. In the case of a monitoring task, heuristics $\mathcal{E}_r(Z_m)$ takes part in determining the implementation strategy for the corresponding monitoring. In the case detecting the appearing malfunction, heuristics $\mathcal{E}_r(Z_v)$ takes

Zeszyty Naukowe Akademii Morskiej w Szczecinie 47 (119) 23
part in identifying the fact of the malfunction occurring. In the case of detecting a malfunction not yet manifested in the functioning process of STO, heuristics $\mathcal{E}_{\text{r}}(Z_i)$ takes part in the analysis of diagnostic parameters read within the task $Z_m$, in order to detect changes related to the malfunction which occurred. In the case of recognizing the malfunction, heuristics $\mathcal{E}_{\text{r}}(Z_i)$ takes part in recognizing the type of malfunction, if it is unknown and only certain parameters characterizing the malfunction are known. Heuristics $\mathcal{E}_{\text{r}}$ also takes part in determining the possible ways of affecting the parameters under change to in appropriate values. In this case, we cannot speak in detail about diagnostic parameters as about a separate class of functional parameters.

**Solving of basic tasks**

**Using text models**

A text model $TM_i$ is a text description, in the normalised form of STO design and processes occurring within STO. Using $TM_i$ allows the automation of processes for implementing different tasks which need to be solved during STO maintenance. Using $TM_i$, for solving tasks of STO maintenance is rational because of the following key features of STO:

- periodic modification of STO, which is necessary because of the requirement to update resource parameters for system nodes or components;
- inclusion of new elements in STO that represent new technological means which can be used during STO maintenance;
- carrying out repairs on STO, which can lead to some changes in the original set of system components, the design of STO and so on.

While performing these changes, the occurrence of critical situations during certain conditions of STO maintenance can eventuate. Because $TM_i(STO)$ contains descriptions of all functioning conditions of STO, within $TM_i$ it is possible to detect inappropriate values of parameters on the basis of conducting a semantic analysis of $TM_i$. Thanks to the introduction of semantic parameters $\delta^i$ it is possible not only to detect inconsistencies at quality level, but also to estimate their values in numbers (Korostil & Korostil, 2013).

A text model at quality level, or with a certain approximation, can be considered to be an analogue of technical documentation for the corresponding STO. To make it possible to perform analysis and modification of $TM_i(STO)$, semantic vocabularies $S_C$ and $S_P$ are used. A vocabulary $S_C$ contains data regarding all components and process fragments implemented in STO, and is a text description of the corresponding components which compose $TM_i$. A vocabulary $S_P$ contains identifiers of diagnostic and other parameters which are used to analyse the current state of STO. A structure of these vocabularies is described by the following relations:

$$S_P = \begin{cases} p_1^d, \ldots, p_n^d \end{cases}$$

$$p_i^d < \beta_{i1} \ast \ldots \ast \beta_{im} > I < \delta_1, \ldots, \delta_m \leq \delta_m >$$

(3)

where $\beta_{ij}$ is a word from a phrase of text interpretation of the parameter, $p_i^d$ is an identifier of a diagnostic parameter, $P_i$ is a value of the parameter $p_i$, and $\delta_i$ is a boundary value of the parameter $p_i$. A certain value is introduced for $p_i^d$ which, depending on the current value of the parameter $p_i$, will have different text interpretations $j(p_i^d, \delta_{ij})$. For example, within the threshold $\delta_{ij}$ the value of parameter $p_i^d$ can have the following interpretation: $[\delta_{ij} \rightarrow j(p_i^d) = \langle \text{dangerous value} \rangle]$, another example of interpretation is $[\delta_{i+1} \rightarrow j(p_i^d) = \langle \text{dangerous value} \rangle]$, or $[\delta_{i+2} \rightarrow j(p_i^d) = \langle \text{unacceptable value} \rangle]$. From these examples it can be seen that within the vocabularies $S_P$ and, respectively, in $TM_i(STO)$, discrete methods of parameters evaluation, described by interpretative extensions, are used.

To implement processes for transferring information regarding changes of values of parameters occurring in STO, a system SMA is used that transfers the corresponding information in the model $TM_i$ to modify the corresponding text fragments in $TM_i$. STO modification during maintenance is implemented in the following cases:

- in the case of implementing changes in the STO system, caused by the replacement of certain system components, conducted by maintenance staff;
- in the case when it is necessary to enter the current data analysed by the diagnostic system;
- in the case of changes occurring in STO as a result of external factors influencing the system, which can demand to add new fragments in the text description of the corresponding model $TM_i$.

In the first case, the maintenance staff enter the corresponding data into the system SMA, using different semantic vocabularies $S_i$, to describe the subject area $W_i$ of an STO object. This generates an information stream $IP_i$ and transfers it into the corresponding model $TM_i$. In the second case, the system SMA chooses the necessary text description from vocabularies of $S_i$ type, on the basis of parameter identifiers $p_i^d$ and the values of the corresponding parameters. After obtaining the information, SMA generates the corresponding $IP_i$ for the model $TM_i$. The transfer of
The use of text models in the formation of heuristics to solve tasks of diagnosing technical objects

IP; into TM; is implemented at the end of the current system work cycle or the work cycle of a monitoring model (SMO), because it may become necessary to make changes in the descriptions of certain parameters in TM. If the current parameter values changed at the amount which foresees the change of interpretation description used in TM, the system SMA activates the transfer of generated IP; into the corresponding model TM;. Synthesis of IP; and TM; is implemented corresponding to synthesis algorithms (Korostil, 2012). In the third case, when changes in STO are caused by an influence from external factors on the system, it can eventuate that there are no interpretation descriptions for these factors, which are necessary to describe the corresponding changes, in the S; vocabulary system. In this case, system SMA, using text model systems (STM), S; vocabulary systems and systems of text description output, implements the extension of the corresponding S; with new components for which a text description has been deduced.

In the instance of detecting parameters with values not within the acceptable threshold, or which fail to meet the specified requirements, a diagnostic model (MD), solves the task of detecting, localizing and recognizing malfunctions to the extent of its capabilities. This is necessary because in these cases an effective reaction on detected unacceptable deviations is needed. Obviously, in these cases some processes may have to be blocked.

Using logical methods in tasks of heuristics generation

Because diagnostic tasks can be solved on the basis of using heuristics \( \mathcal{E}_r \), and the latter are a system of rules that are used while making decisions in a process of implementing a diagnostic algorithm, or for its preparation, it is reasonable to use methods of mathematical logic to generate them (Slupiecki, Halkowska & Pirog-Rzepecka, 1999).

Mathematical logic, in this case, is used to describe methods for implementing links between the system of text models \( STM(TM; , SMA; , Sc;) \), diagnostic models and other models used for the control and maintenance of STO in general. To implement these methods, the following tasks must be considered:

- tasks of transition from text fragments \( tm_i \in TM; \) to logical formulae describing \( tm_i \) with corresponding adequacy, which would provide effective usage of deduced heuristic rules;
- determining methods for choosing necessary \( tm_i \in TM; \);
- proving consistency or absence of contradictions \( L(\mathcal{E}_r) \) with the system of logical formulae describing the solutions of tasks implemented in MD(STO);
- developing methods for the extension of logical formulae \( L(\mathcal{E}_r) \) interpretation to the interpretation of tasks solved in MD;
- if the result of MD functioning is obtained data for which there is no corresponding interpretation in MD, then it is necessary to solve the task of output for corresponding interpretative extensions and their transfer to the corresponding TM; and MD.

Transformation of fragments \( tm_i \in TM; \) to a logical form is based on methods of using semantic parameters \( \sigma; \), as stated previously (Korostil, 2013). Considering this, to form \( L(\mathcal{E}_r) \), limitations in the interpretation of corresponding variables must be taken into account, and modal logic used. For this reason, logical formulae of deduced heuristics can be consistent within the limited boundaries of the definition of variables. This is implemented due to the use of modal logical operators. One example of logic that includes these operators is non-monotonous logic with defaults (Reiter, 1980). An example of one output rule which is called a default is \( (\alpha; \& M\beta;) \rightarrow \gamma; \), which has the following interpretation. If we believe in \( \alpha; \) and if \( \beta; \) is true, then we take for granted that \( \gamma; \) takes place, where \( M \) is a default operator. In this case, extensions of the output system is used with the corresponding interpretations, listed below.

1. A modal rule of output by observability, or introspection is: \( p \rightarrow Lp \), and its interpretation lies in the following: «\( p \) has to be correct», provided \( p \) is correct.

2. A scheme of knowledge axiom: \( Lp \rightarrow p \), which means «something that is known to be true».

3. A scheme of positive introspective axiom is described by the following relation: \( Lp \rightarrow LLP \), where operator L means «known». Then, the mentioned scheme asserts that «if I know \( p \), then I know that \( p \) is known to me».

Similarly, interpretation for a scheme of negative introspection axiom is introduced. Introspection, within the scope of this paper, is used to interpret limitation conditions for the definition range of the corresponding logical variables (McDermott, 1982). Using non-monotonous logic allows us to prove that a certain statement is possible or can be deduced on the basis of using the corresponding logic. This logic indirectly allows us to accept the deduced formula as true, and using the corresponding operators \( L \) and \( M \), gives a non-monotonous
nature to the corresponding logic. Modal operators do not affect the interpretation of logical functions. According to a classic axiom system, modal axiom schemes and output rules, generating an output of formulae \( L(\varepsilon r) \) does not lead to inconsistencies within the scope of the subject area of interpretation. This means that within the logical approximation, description of \( \varepsilon r_i \) as \( L(\varepsilon r_i) \) will not lead to inconsistencies with the logical interpretation of processes implemented in MD.

Let us review the ways of implementing solutions to the above-stated tasks, which occur while using logical formulae in diagnostic tasks. A choice of \( tm_i \in TM_i \) is performed on the basis of text descriptions of the diagnostic system \( TM_i(MD) \). This description represents processes implemented in MD. Thus, \( TM_i(MD) \) contains descriptions of all known parameters which are related to the class of diagnostic parameters.

Within the \( TM_i(STO) \), diagnostic parameters are also described, because they represent, on the level of functional parameters, the functioning processes of the corresponding fragments of \( STO \). However, from the point of view of functioning process description \( Pr_i(STO) \) they can be redundant. Their description in \( TM_i(STO) \), unlike the description in \( TM_i(MD) \), besides the identifiers, contains a description of interpretation of their current values. A simple example of \( \varepsilon r_i \) could be heuristics of threshold analysis type, which is formally described by this relation:

\[
\varepsilon r_i(p_i^d) = \left\{ \left[p_i^d(\xi_i) < \Delta^d_i(\xi_i) \rightarrow \left[ Pr_i(S_i), p_i^d(\xi_i) \right] \right] \right\}
\]

(4)

Let us examine how, based on the semantic analysis of \( TM_i \), implicit functional links between different parameters are detected. Implicit functional links can only exist in instances when the corresponding parameters in \( TM_i \) are described in the different sentences, \( \psi_i \) and \( \psi_j \). The system of semantic analysis \( SMA \) establishes an implicit link between the parameters \( p_i^d \) and \( p_j^d \), if in the corresponding \( tm_i \in TM_i \) and \( tm_j \in TM_j \), the values of these parameters are changed synchronously. Synchronisation in this case means that during two consequent cycles of analysis of \( TM_i \), the corresponding parameters would be changed by the values described by a certain known functional dependency. In most cases, a linear function is chosen as this dependency.

If the generated \( \varepsilon r_i \), has not led to, for example, the shortening of a monitoring cycle, then \( SMA \) system implements an extension \( \varepsilon r_i \), that lies in continuing additional analysis of implicit links between \( p_i^d \) and \( p_j^d \). This would allow a shortened time of implementation of the cycle of diagnostic process strategy of \( St(MD) \).

**Organising the process of diagnostics of a technical object**

Let us examine the process of forming and implementing strategy for \( STO \) parameter monitoring. A monitoring strategy \( St(SMO) \), implemented within the corresponding methods or the model \( SMO \), is defined by the following parameters and characteristics of strategy \( St_i \):

- time interval \( \tau_i \), when the monitoring process is implemented;
- number of parameters \( p_i^d \), chosen for control, where \( i \) is a monitoring cycle number, \( j \) is a corresponding parameter index, written as \( (\lambda_i) \);
- way store act, or reaction discipline of \( St_i \) on the value of parameter under check \( (Dr_i) \);
- controllability measure of the strategy \( (Mu_i) \).

Time interval \( \tau_i \) is a parameter of \( St_i \) and its value can be defined for the current time point, including using the corresponding heuristics \( \varepsilon r_i(\tau_i) \). Obviously, during the operation of a diagnostic model \( MD(STO) \) the value of \( \tau_i \) can decrease or increase.

Parameters \( p_i^d \), controlled by the monitoring system \( SMO \), can also be chosen on the basis of using certain heuristics \( \varepsilon r_i(p_i^d) \). This is caused by the fact that the check-up of all \( p_i^d \) each time \( SMO \) is activated is not reasonable, because certain \( p_i^d \) can remain unchanged during the current check-up period. A check-up period in this case is understood as a value \( \Delta t_i = \tau_i + t_i \), where \( t_i \) is an interval duration between regular check-up cycles. Within the scope of processes \( Pr_i(S_i) \), the way of reaction of \( St_i \) on changes of certain parameter values is determined. Because the value of \( t_i \) can vary, a task appears to determine the conditions of activation for the next monitoring cycle. Solutions for this tasks can be based on using data regarding the current level of system safety, taking heuristics \( \varepsilon r_i(\tau_i) \) into consideration as well. A measure that determines the strategy controllability is defined by the following features:

- possibility to change, during implementation of the strategy \( St_i \), the tactics determined when it was prepared, which means that the influence of external factors can change the sequence of parameter monitoring and one or another analysis depth of a certain parameter within the acceptable range;
- monitoring processes can change the trajectory of the search for data sources that characterise the
corresponding events, appearing during the system functioning and caused by external factors.

Using heuristics in diagnostic tasks is based on the analysis of conditions generated on the basis of the following rules:

- heuristics gives a binary result regarding the making of the corresponding decision;
- heuristics can use logical variables that are not present in the diagnostic model but characterise \( W_i \);
- variable values are determined on the basis of setting up thresholds for parameter values identified by these variables;
- current values of diagnostic parameters, if they have gone from one value range to another one, are written in the vocabularies \( S_p \) in the data register mode;
- activation of recording the value of the next parameter is performed by each single source of corresponding information, based on their priorities.

An important element of \( MD \) is the task of localizing the malfunction. This task is closely related to recognizing the malfunction. In this case, recognizing the malfunction corresponds to detecting the reasons that caused it, which is the final goal of \( MD \). In this case when an unacceptable change of a diagnostic parameter value is directly related to the reason of its deviation from normal values, \( Z_r \) and \( Z_v \) are the same. These cases are grouped in a separate malfunction class. In most cases, sensors of diagnostic parameters \( p_i^d \) are not directly related to the reasons of occurrence of the corresponding deviations. In a general case, the change of a parameter \( p_i^d \) into an unacceptable value range is caused by known reasons, unknown reasons, or a combination of known and unknown reasons.

In all cases, the localization task lies in determining one possible reason for the occurrence of the deviation. For this to occur, additional tools must be used, namely heuristics. Because heuristics are out of range of \( MD \), it becomes possible to extend data regarding possible unknown malfunctions. In general, reasons for malfunction occurrence will be considered for certain events, occurring within the diagnostic object.

If we accept that an event \( y_i \) is the diagnostic parameter \( p_i^d \) going outside the acceptable range because of some reason, or \( p_i^d > \delta (p_i^d) \), the corresponding event is described by a logical formula \( L_i (p_i^d) \). This formula, together with the logical formula of the corresponding heuristics \( L_i (E_i) \), or \( L_i^f \), must ensure the possibility of detecting reasons for the occurrence of \( p_i^d > \delta (p_i^d) \). If a possible reason for the occurrence of \( p_i^d > \delta (p_i^d) \) from \( [L_i (p_i^d) \& L_i (E_i)] \) cannot be determined, it means that from the system \( [L_i (p_i^d) \& L_i (TM)] \) a new heuristics formula \( E_i \) has to be deduced, which would ensure the necessary output: \( [L_i (p_i^d) \& L_i (TM)] \rightarrow L_i (E_i) \). Solving this task on a basic level is performed on the basis of implementing the following processes.

1. Modification of \( TM_i \) is implemented by the system of modification and analysis \( SMA \) using semantic vocabularies \( S_i \), \( TM_i \rightarrow TM_i^* \).
2. In the modified \( TM_i^* \) a semantic analysis of description for the corresponding \( STO \) components is implemented. On the basis of this analysis, indirect links between reasons of malfunction occurrence \( N_i \) and diagnostic parameters \( p_i^d \) are established, described by the relation:

\[
F \{\sigma^d_i (TM_i^*) \rightarrow \sigma^d_i [j(p_i^d, \ldots, p_i^d) * j(p_i^d, \ldots, p_i^d)] \}
\rightarrow \{E_i [P(p_i^d, \ldots, p_i^d) * P(p_i^d, \ldots, p_i^d)] \} = \{E_i (N_i)\}
\]

3. \( \{[L_i (p_i^d, \ldots, p_i^d) * E_i (N_i)] \rightarrow L_i^f (E_i) \rightarrow S_i (L_i) \) is generated.
4. From the system \( S_i (L_i) \) the formula \( L_i^f (p_i^d, \ldots, p_i^d) \) is deduced, from which the reason of \( N_i \) occurrence is determined.

**Conclusions**

The approach given in this paper is proposed to be used to organise a diagnostic system based on using text description models for technological processes of \( STO \) system functioning, and it is oriented towards use in a system complex enough with regards to its structure, as well as the number of functional processes implemented in such an object. This approach is especially effective for \( STO \) which have a big service life, which provides a great number of functioning cycles.

By using text models, it is possible to detect malfunctions which arise, because the data from the text models allows the detection of implicit relations between parameters, if they exist.

Since heuristics are formed not only on the basis of data possessed by the diagnostic model of a technical object, but also on the basis of data of the text model that describes a technical object in general, it becomes possible to extend the conditions which can be used by diagnostic algorithms. This extension ensures the correct decision is made by the diagnostic algorithm, if an ambiguous situation arises during its functioning.
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