DIAGNOSTIC SYSTEMS DESIGN PROCESS WITH USING THE SETS OF REQUIREMENTS

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Summary

The article deals with the problem of designing diagnostic systems. During this process it is possible to use sets of requirements which are very commonly used in the software area. The requirements may influence both on the set of possible solutions of diagnostic system as also on the set of criteria which will be used for evaluation of these solutions. Selecting an optimal solution is not an easy task, especially for given the nature of the diagnostic field. But this process can be improved by using expert system. Knowledge base of this system, which contains possible solutions of designed system can be recorded in the form of multimodal statement networks. During the inference process, it is possible to isolate some subset of preferred solutions. This process should be carry out based on available information about technical object, operational conditions and imposed project limitations. The received subset of solutions should be the basis for further analysis, which leads to get the final solution of a diagnostic system.

Keywords: diagnostic systems, requirements engineering, expert system, optimization process

PROJEKTOWANIE SYSTEMÓW DIAGNOSTYCZNYCH Z WYKORZYSTANIEM ZBIORÓW WYMAGAŃ

Streszczenie

Artykuł opisuje problematykę projektowania systemów diagnostycznych. Zwrócono uwagę, że podczas przeprowadzania takiego procesu możliwe jest wykorzystanie zbiorów wymagań powszechnie stosowanych w obszarze inżynierii oprogramowania. Wymagania mogą mieć wpływ zarówno na postać definiowanego zbioru możliwych rozwiązań projektowanego systemu, jak również na zbiór kryteriów, względem których rozwiązania te będą oceniane. Proces wyboru rozwiązania optymalnego z powodu specyfiki dziedziny jaką jest diagnostyka techniczna nie jest zadaniem łatwym. Może być on usprawniony poprzez wykorzystanie systemu doradczego. Baza wiedzy tego systemu zawierająca możliwe rozwiązania projektowanego systemu diagnostycznego może być zapisana pod postacią wielomodalnych sieci stwierdzeń. W wynik procesu wnioskowania na podstawie dostępnych informacji o obiekcie technicznym, warunkach jego pracy oraz narzuconych ograniczeniach projektowych wyodrębniany jest pewien podzbiór rozwiązań preferowanych. Są one podstawą dalszej analizy, w wyniku której opracowywany jest ostateczny projekt systemu diagnostycznego.

Słowa kluczowe: systemy diagnostyczne, wymagania, system doradczy, optymalizacja

1. INTODUCTION

The exploitation process of technical objects is connected with the possibility of occurrence difference type of malfunctions or faults of these objects. These incidents influence not only on considered object but also on its immediate surroundings. It is extremely important in the case of critical machines. Besides the break in operation of such object, which is associated with the specified financial costs, the adverse influence on object's environment may appear also. As an example of such accidents the Chernobyl (1986) and Fukushima (2011) power plant accident may be recalled. The occurring faults can be result of improper performance of selected elements of the object, bugs in the control program, failure to follow operation recommendations or events of a natural or purely random manner.

[1] The author of this article is a scholarship holder in the project called *DoktoRIS - Scholarship Program for Innovative Silesia Area,* co-financed by the European Union under the European Social Fund.

To minimize risk of failure of particular technical objects it is necessary to equip them with suitable diagnostic systems. In many cases, the process of designing such systems is a very complex task. This applies especially for a new objects, that have innovative solutions. For these cases not exist data which would be describe the possible results of wrong operation of these objects. The development process can be difficult, because it is necessary to take into account many different external factors that affect to technical object operation. In many cases, the operation conditions have crucial impact for correct operation of considered objects. At the same time it is necessary to conduct an advanced processing and analysis of recorded signals, sometimes with using artificial methods and techniques, to acquire reliable estimates of the systems condition.

By joining to the process of designing the diagnostic system it is necessary to choose an adequate design method. This one should be as best as possible take into account all requisite factors that influence on the form of designed diagnostic system.

2. METHODS OF DIAGNOSTIC SYSTEMS DESIGN

Depending on the field which is currently considered, different types of design methods are used for the purpose of design a new technical objects. Traditional design approach assumes that exist four basic stages in each project [8]. In the first of them the description of the project, called also as a need, is formulated. In the next stage the set of possible solutions which can fulfil the need are generated. The possible limitations (e.g. technological, cost etc.) which would be have influence on the final solution are gathering during the next project stage. The possible selection criteria are also defined during this stage. Based on these criteria an optimal solution from the set of possible solutions is selected during the last stage of the design process. This one is compatible with existing limitations as well as the best meets the defined need.

It may be noted, that contemporary diagnostic systems are being made as software systems. So, a good solution would be the attempt to use some techniques directly related to the software engineering. In this area, for describing designed system the sets of requirements are very commonly used. The term requirement is very differently defined in many literature references e.g. [10,13,17]. Most of them assume that requirement describes the function which the final solution should meet or realize. Generally two main types of requirements, functional and non-functional requirements can be distinguished. For describing basic functions (functionalities) of a designed software system functional requirements are used. As an example of this type of requirement the following statement can be given: *the system must provide an access to the database.*

Non-functional requirements are used to describe how to be implemented each of the functional requirements. These type of requirements are related with project limitations (e.g. technological, cost, safety, etc.) as well as some quality expectations which are being formulated by a client. For example, the mentioned earlier functional requirement can be specified by the following non-functional requirement: *connection to the database should be done via an encrypted transmission protocol.*

For the purpose of description of designed software system it is necessary to gather a set of requirements. Standard process consists of two main stages (see in Figure 1). The first one consists in defining of requirements, taking into account existing expectations, limitations etc. Different methods and techniques may be used for this purpose [16]. Analysis of gathered set of requirements is performed during the second stage. Contradictory requirements are removed as well as incorrectly defined requirements are improved. The final result of this stage is a subset of requirements which describes designed software system. In literature this set is called as requirements specification. Only the requirements which are necessary to achieve by the designed system assumed function are included into this document.

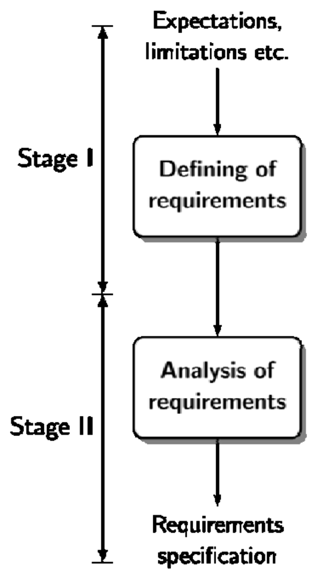

Fig. 1. Stages of requirements definition process

During the previous study [4,5] an author observed that some elements of requirements engineering can be used for describing the proposed diagnostic systems. Traditional design approach can be supported by using sets of requirements. Details of the proposed design approach are presented in the next section.

3. PROPOSED APPROACH TO THE PROBLEM OF DIAGNOSTIC SYSTEMS DESIGN PROCESS

For the purpose of explaining the proposed design approach a certain technical object is considered. This object has structure that is described by its components and it also operates on a certain environmental conditions. Risk given by the formula

$$R = \sum_i P_i c_i \quad , \qquad (1)$$

where: P_i – probability of the *i*-th event occurrence, c_i – cost (loss) connected with of *i*-th event occurrence, is associated with operation of this object. This risk have to be minimize to ensure the correct operation of the considered technical object. In examine case, this task should be recognize as a main project need. This need can be realized by using diagnostic system, which will be used to monitor a technical state of considered object. By joining to the design process of this system some project external limitations (e.g. available technologies etc.) and expectations of potential client (e.g. minimal cost, appropriate reliability etc.), can be elaborated.

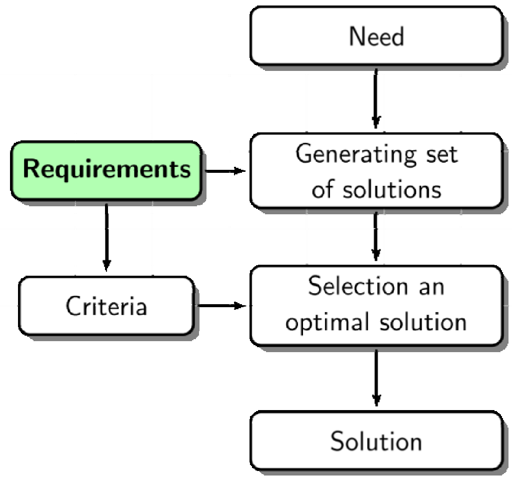

Fig. 2. The process of defining possible solutions of diagnostic system

Proposed by an author the design approach base on traditional model of designing which was presented in section 2. It is possible to modify this approach by using sets of requirements. Requirements can be related with the set of possible solutions of the diagnostic systems and also with the set of criteria (see Fig. 2). As mentioned earlier, in every sets of requirements it is possible to distinguish two type of requirements i.e. functional and non-functional requirements. Assuming according to [12], that technical state is a function of faults, it should be assumed that the functional requirements are related with possible faults of considered object. Thus, they affect to the character of defined set of solutions. On the other hand, the non-functional requirements are related with the set of criteria which is defined.

In order to simplify further analysis, it was assumed that in the rest part of the article, the term requirement will be related only with the functional requirements. Simultaneously non-functional requirements will be considered as criteria.

Inclusion into the design process the sets of requirements forces the need to carry out entire process according to a closely specific order. In order to carry out this process can be assumed that functional requirement is an expression built with expected functionality fu_i as well as the set of criteria c_o, c_s. It can be written as:

$$req_i = \langle fu_i, c_o, c_s \rangle \qquad (2)$$

where: c_o – sets of optimization criteria, c_s – sets of selection criteria. Each functionality can be realized by using a subsystem $subs_i$ which has a structure defined by its elements and connections between them and perform some actions, i.e.

$$subs_i(fu_i) = \langle elem, con, act \rangle \qquad (3)$$

Optimization criteria describe the conditions that have to be met by a potential solutions of individual functionalities. One example of an optimization criterion can be the following statement: cost of the solution below 500$. Selection criteria are used during the evaluation process of gathered set of requirements. Assignment to the requirement of a specific selection criterion, such as minimum weight, indicates that the solutions of the functionality will be characterized by a low mass.
When the minimal weight solution of a diagnostic system will be searched then it is necessary to choose these requirements to which is assigned an adequate criterion.

Process of finding solution of diagnostic system can be illustrated by scheme which is shown in Figure 3. In overall procedure it is possible to distinguish the following main steps:
- defining the project need,
- decomposition of object (only for complex technical objects),
- defining of requirements for separated components of considered object,
- defining of functionalities for particular requirements,
- defining of subsystems for particular functionalities.

The result of implementation of listed above steps is a set of requirements and connected with them sets of functionalities and subsystems which describe the designed diagnostic system. These sets can be presented in the form of morphological table. Example of this table is shown in Figure 4. By plotting the paths between selected elements of this table it is possible to highlighted the potential solutions of a designed diagnostic system. Particular solutions do not have to contain all requirements or functionalities (e.g. solutions R_2 and R_4 in Fig. 4), because a certain requirements can be fulfilled by the same functionalities and particular functionalities can be realized by the same subsystems e.g. the same measurement system.

In many cases, the process of defining subsequent elements of morphological table can be a very time consuming. Sets of requirements, functionalities and subsystems that are used to describe the possible solutions of diagnostic system can be defined based on many different sources. It is possible to use e.g. literature data, technical documentations, operation and maintenance manual, standards and recommendations, experts' knowledge and diagnostic simulators [1].

Unquestionable advantage of proposed approach is the possibility of defining the set of potential solutions of diagnostic system without necessity to take exactly into account a considered technical object. It is possible to elaborate sets of requirements, functionalities and subsystems which are related with typical components of technical objects e.g. bearings, gears, heat exchangers etc. Created independently sets of requirements, functionalities and subsystems can then be used in the design of a wide variety of diagnostic systems.

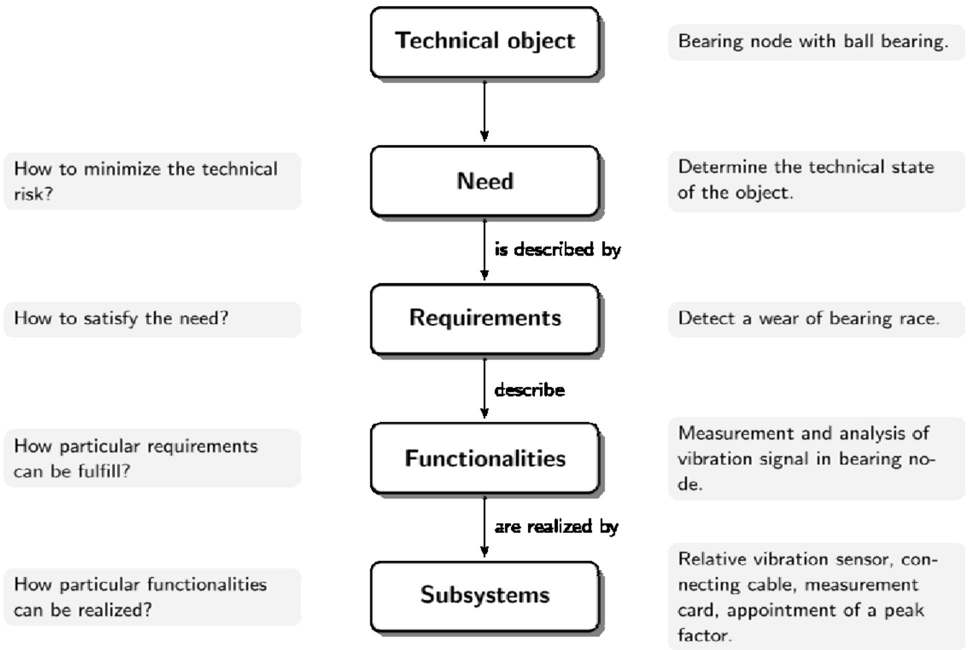

Fig. 3. Main steps of defining process of possible solutions of a diagnostic system

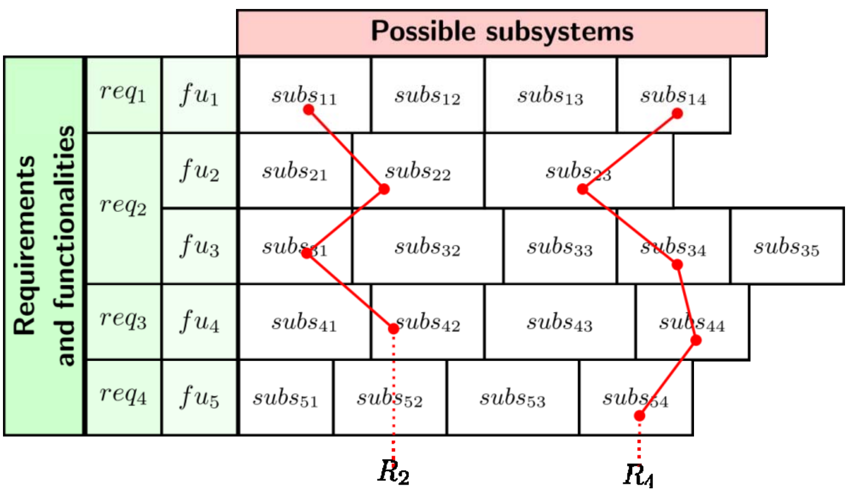

Fig. 4. Morphological table with marked exemplary solutions of a diagnostic system

The application of the proposed approach makes that among of the possible solutions of a diagnostic system some contradictory as well as solutions which are unrealizable due to the technical problems can be occurred. It is therefore necessary to analyze created set of potential solutions and extract from it a subset of preferred solutions. These solutions should be correct and compatible with accepted criteria and limitations.

4. OPTIMIZATION PROCESS

The collection of a large set of requirements entails the necessity to their evaluation. Useful requirements are distinguished during this process. In software areas this one is conducted as negotiation between client that ordered the project and potential developer. EasyWinWin methodology (type of Win-Win negotiation) is used very often [9]. Each participant of this negotiation process should be completed them in the feeling of victory and achieves the intended purpose which is expected and accepted by both sides of negotiation process the set of requirements.

In considered case direct use of negotiation in the evaluation of collected set of requirements cannot be usually possible. This is due to the specificity of the field which is the technical diagnostic. Theoretically as the client a supervisor of technical object or domain experts can be considered. However, in many cases they do not have sufficient knowledge about the whole technical object or about the conditions under which such object operates. Therefore, they not be able to define the correct requirements. This problem can be solved by assume that in negotiation process a certain virtual customer will be considered. This customer can be represented as an expert system, which will have sufficient knowledge about analyzed problem (e.g. information about technical object, operation conditions, project limitations etc.). A properly designed expert system will enable to the formulation of necessary requirements for considered design process. Each expert system has three main elements i.e. knowledge base, database and inference mechanism. In considered case, the defined sets of requirements, functionalities and subsystems will be a knowledge base of expert system. Knowledge will be stored in the form of multimodal statement networks. Their basic elements are statements. Each statement can be recorded as pair

$$s = < c(s), b(s) > \qquad (2)$$

where $c(s)$ is a statement content and $b(s)$ is a statement value. Statement content is a sentence that declares about observed facts or expresses a certain opinion. A some values that indicate about truthfulness of this content can be assigned to it. Causal relationships between the selected statements can be imitated by building statement network, which are considered as one type of graphical models. Relationships between particular statements can belong to different classes. Acyclic Bayesian networks also called belief networks are commonly used [11]. The necessary and sufficient conditions [3] and intuitionistic logic [2] can be used also. Particular statement networks can be built taking into account different aspects [14] or context [15]. Separate models for subsequent subsystems of technical object or models for different points of view can be built. Additionally selected models can be built by independent domain experts. Separate models can be combined together through an occurrence a common statements. This structure is called a multimodal statement network [7]. In considered case, the individual requirements, functionalities and subsystems are examined as contents of subsequent statements. Inference process is conducted based on collected data. There are an information about technical object (components and elements of structure), operation conditions (e.g. adverse external factors) and existing limitations (cost, available technology etc.). During the inference process certain values are assigned to the particular statements. These values indicate the degree of preference of the considered cases (requirement, functionality and subsystem) in the final design of the diagnostic system. From the overall set of all defined requirements, functionalities and subsystems are extracted their subsets which contain the most desirable items. It is possible to sort these items according to their preference factor. Orderly set of possible solutions of the diagnostic system will be created by this action. It should be noted that some of the solutions will be very similar to each other, consequently they will be have a very similar, total preference factor. Selection of the optimal solution should be carried out based on the elaborated set of preferred solutions after the additional analysis.

The specialized environment can be used to design and carry out a reasoning process with multimodal statement network [6].

5. EXAMPLE OF USING PROPOSED APPROACH

On simple example the process of elaboration solutions of a diagnostic system with using a proposed approach will be shown. Bearing node with ball bearing is being considering. For this object it is possible to define the need given as follows: *it is necessary to determine the technical state of the considered object*. This need can be realized by a diagnostic system which will be operated with analyzed object. The first step of the design process consists on defining of set of possible solutions of a designed diagnostic system. The sets of requirements, functionalities and subsystems should be defined. Based on the possible faults of ball bearing the set of requirements can be elaborated. Exemplary requirements for considered case can be the following statement:

req_1 – it is necessary to detect a wear of the bearing race,

req_2 – it is necessary to detect a crack of the bearing race,

req_3 – it is necessary to detect plastic deformation of the rolling elements,

req_4 – it is necessary to detect corrosion of elements of the bearing.

Each of the defined requirements describe the possible functionalities of the designed diagnostic system. For example the requirement req_1 describes the following functionalities:

fu_1 – measurement and analysis of vibration signal in the bearing node,

fu_2– measurement and analysis of temperature field in bearing node.

Whereas, the requirement req_3 describes the following functionality:

fu_3 – measurement and analysis of vibration signal in the bearing node.

In the same way it is possible to define the functionalities for the remaining requirements. If it will be necessary the elaborated sets of requirements and functionalities can be expanded by additional requirements or functionalities. A certain criteria can be assigned with particular requirements. The set of possible criteria is given as follows:

c_{s1} – minimal cost of the solution,

c_{s2} – minimal mass of the solution,

c_{o1} – accuracy of the measurement less than 5% of the measuring range,

c_{o2} – simplicity of the solution.

Respective criteria can be associated with the selected requirements according to the following scheme:

$$req_1 = < fu_1, c_{o2}, c_{s1} > \quad (4)$$

$$req_1 = < fu_2, c_{o1} > \quad (5)$$

$$req_2 = < fu_2, c_{o2}, c_{s1} > \quad (6)$$

For the remaining requirements selected criteria will be associated also. During the next step of a design process the sets of possible subsystems are generated. A part of list of possible subsystems for functionality fu_1 can contain the following items:

$subs_1$ – relative vibration sensor, connecting cables, measuring card, appointment of a peak factor,

$subs_2$ – relative vibration sensor, connecting cables, measuring card, appointment of a kurtosis,

$subs_3$ – relative vibration sensor, connecting cables, measuring card, spectral analysis and determination of characteristic frequencies.

Whereas, the list of subsystems for functionality fu_2, can contain such items as:

$subs_4$ – resistive sensor, connecting cables, measuring card, recording of temperature,

$subs_5$ – infrared camera, connecting cables, measuring card, recording and analysis of the temperature field.

In the same way it is possible to define the functionalities and subsystems for the remaining requirements. The complete sets of requirements, functionalities and subsystems will be gathered by this approach. Subsequent elements of these sets can be recorded on the morphological table which will be contained a possible solutions of a diagnostic system.

The next step of a design process consists on evaluation of possible solutions of a diagnostic system. The set of criteria will be used for this purpose. Because the simple example is considered, it was abandoned of public building network model based on a defined collection of requirements, functionalities and subsystems. For the purpose of selection an optimal solution it is possible to assume that sought diagnostic system is characterized by criteria:

c_{s1} – minimal cost of the solution,

c_{s2} – simplicity of the solution.

When the criterion c_{s1} will be considered, it is possible to assume that the best functionality for requirement req_1 will be the measurement and analysis of vibration signal in the bearing node. Next for this functionality, the best subsystem is searched taking into account the criterion c_{o2}. In this case it is possible to assume that subsystem $subs_1$ will be the best one. In the same way it is necessary to carry out the choice of functionalities and subsystems for the remaining requirements. Finally the best solution of a diagnostic system consists of functionality fu_1 for requirement req_1. Because for the requirement req_3 the set of possible functionalities takes also this functionality, so for both requirements the same functionality and subsystem will be used.

When the inference process will be started for different criteria the another solutions will be obtained. The presented example is relatively simple, but it presents the essence of the definition and selection of the best solution of diagnostic system by the proposed method. For more complex object will be necessary to build an appropriate graphical models for the purpose of properly take into account the all dependencies between requirements, functionalities and subsystems.

6. CONCLUSIONS

Diagnostic system design process was being presented in this article. It was noted that the traditional approach to the design of machines and equipment can be modified by the sets of requirements commonly used in the software engineering. Proposed approach can be successfully used to define a set of potential solutions of a diagnostic system. Elements of this set should be evaluated and the subsets of preferred solutions should be extracted. In many cases this task could be

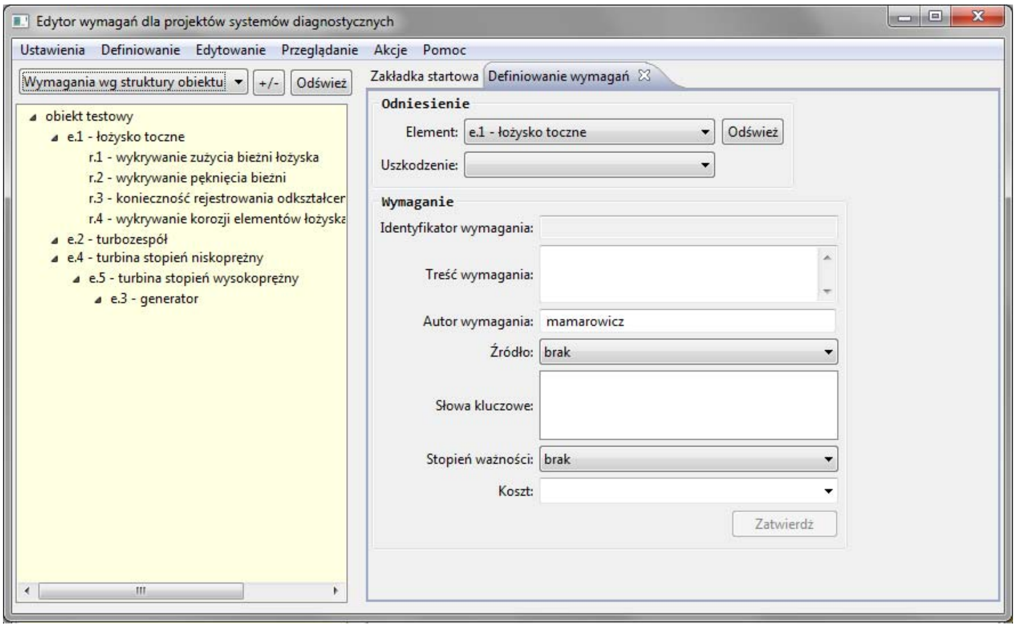

Fig. 5. Exemplary window of application for defining of requirements, functionalities and subsystems that describe the possible solutions of diagnostic system.

a very difficult. Expert system can be used for solve this problem. Knowledge base of this system will be the set of defined possible projects of a diagnostic system. Set of preferred solutions will be extracted during the inference process. These solutions will be the best fulfill the assumed goal function. Based on this set, the final solution of a diagnostic system is elaborated as a result of further analysis. Proposed approach enables to defining of particular part of expected solutions by an independent users. Also exists the possibility of using a certain previously elaborated conception in considered case.

For the purpose of implementation of the presented in this article the diagnostic system design approach the specialized software is being developed. An example window of this application is shown in Fig. 5. Gathering the set of possible solutions of a diagnostic system and evaluation of these solutions will be possible to carry out with use this software. The system consists of two main modules. These modules realize two main stages of defining requirements process which was shown in Fig. 1. At the moment, the module that is responsible for collecting required sets of requirements, functionalities and subsystems is almost completed. At the same time, the work connected with development of a module intended for analysis and evaluation of the collected sets of requirements, functionalities and subsystems are started.

It is assumed that a full verification of the proposed approach will be carried out during the design of a diagnostic system for the power plant with Organic Rankine Cycle system. The plant will be have power about 1MW and is being developed in the framework of a strategic program entitled „Advanced technologies of generating energy".

AKNOWLEDGEMENTS

Described herein are selected results of study, supported partly from the budget of Research Task No. 4 implemented under the strategic program of The National Centre for Research and Development in Poland entitled "Advanced technologies of generating energy".

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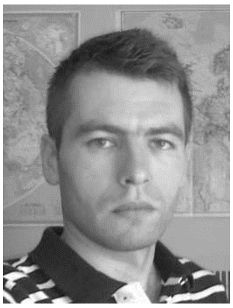

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