ACQUISITION OF REQUIREMENTS FOR DIAGNOSTIC SYSTEMS

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Summary

Defining the expected functionality of a designed diagnostic system is the most critical stage of the development process. In general, needs that describe such system can be determined by means of a requirement set pursued by the designed system. One important task during the requirement acquisition process is the problem of requirement management. Specific requirements can be defined based on information from multiple sources, and the acquisition process is reduced to that of a negotiation between a customer and a contractor. However, an immediate application of many well-known software engineering methods is impossible in the case of diagnostic systems. Issues arise due to difficulties in defining a customer in the negotiation process. The proposed approach relies on considering a technical object as a virtual customer in the negotiation process. The customer is represented by an expert system with a knowledge base in the form of a multimodal statement network.

Keywords: requirements management, diagnostic system, multimodal statement network, expert system.

GROMADZENIE WYMAGAŃ DLA SYSTEMÓW DIAGNOSTYCZNYCH

Streszczenie

Jednym z najtrudniejszych fragmentów procesu projektowania systemu diagnostycznego jest etap definiowania oczekiwanej funkcjonalności takiego systemu. Potrzeby opisujące taki system mogą być określane za pomocą zbioru wymagań stawianych projektowanemu systemowi. Ważnym zadaniem pojawiającym się w procesie gromadzenia wymagań jest odpowiednie zarządzanie tym procesem. Poszczególne wymagania mogą być definiowane na podstawie wielu źródeł a sam proces ich pozyskiwania zazwyczaj sprowadza się do negocjacji pomiędzy klientem a potencjalnym wykonawcą projektu. Bezpośrednie zastosowanie jednej z wielu znanych metod, rozwijanych w ramach inżynierii oprogramowywania, jest jednak w tym przypadku niemożliwe. Spowodowane jest to przede wszystkim trudnościami w zdefiniowaniu klienta dla procesu negocjacji. Zaproponowano sposób postępowania polegający na rozpatrywaniu obiektu technicznego jako wirtualnego klienta w procesie negocjacji. Klient ten reprezentowany jest przez system doradczy z bazą wiedzy w postaci wielomodalnych sieci stwierdzeń.

Słowa kluczowe: zarządzanie wymaganiami, systemy diagnostyczne i doradcze, wielomodalne sieci stwierdzeń.

1. INTRODUCTION

Modern technology development results in more and more complex systems and technical objects. As their complexity increases, it is necessary to develop diagnostic systems in order to minimize an operational risk. Technical objects under the development are characterized by complexity as well as innovative solutions. With such objects it is possible to observe various signals (process variables and residual processes). At the same time, an advanced signal processing and analysis methods often performed with artificial techniques and methods is critical to acquire reliable estimates of the systems condition. Due to the above, the process of designing diagnostic systems is not an easy task. In a majority of cases the process is multi-stage. It incorporates a need of recognition or a definition of a function that the developed diagnostic system should perform. Next, it is necessary to generate a set of solutions for meeting the defined functions as well as determining existing or likely constraints (limiting criteria). The final phase of this process includes establishing of selection criteria and selecting an optimum solution that meets all accepted criteria. While searching for subsequent solutions of a diagnostic system it is clear that operating principles of a technical object for which the diagnostic system is designed should be accounted for. The issue concerns both the object's internal structure as well as its operating conditions. Moreover, domain specific requirements (technical

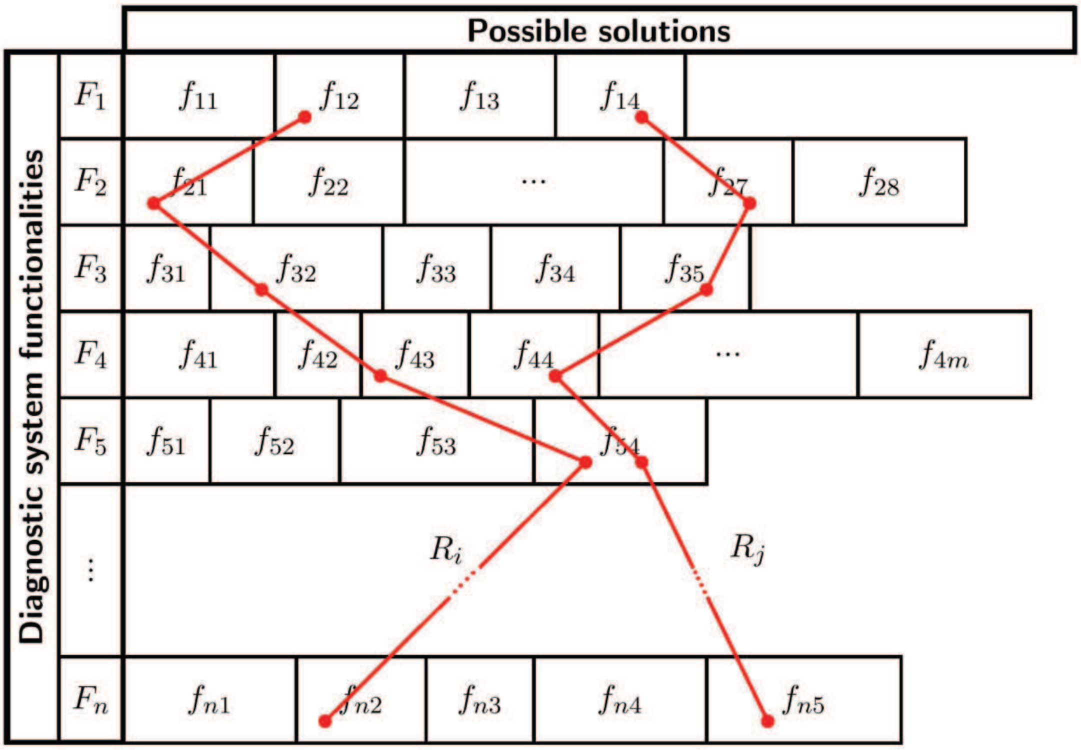

Fig. 1. Morphological table as a set of possible solutions

diagnostics) should be taken into account.

In general, a set of possible solutions of a diagnostic system can be represented using various techniques and methods. One such approach is the so-called morphological table [18] that is a common tool in the process of designing machinery and hardware. The morphological table concept is illustrated in Fig. 1. The successive rows of this table refer to the expected functionalities of the designed system. They incorporate row elements – variants of solutions to meet the expected functionality. The table size depends on two factors. Object characteristics for which the diagnostic system is developed influences the number of rows in a table whereas potential diagnostic methods and techniques determine the number of elements in particular rows.

Having a complete morphological table one may generate solutions of a diagnostic system (as shown in Fig. 1, for example) in the form of a combinations of selected variants of solutions to meet particular needs. In a generic scenarios and provided the table does not included repetitions it is possible to develop a set of solutions of the size

$$\prod_i card(F_i) \quad , \qquad (1)$$

where $card(F_i)$ is the number of elements of the row i of the table - i.e. the number of possible solution to meet the functionality i. Briefly, application of a morphological table guarantees that all possible solutions of a diagnostic system project will be included in the design process. However, note that the set of possible solutions may include solutions that would be technically infeasible, incomplete or simply irrational. They should be eliminated in subsequent stages of the design process e.g. by using the cross consistency assessment method (CCA) [14].

The process of selecting a final solution out of a general set of all solutions is an optimisation problem and a multicriterial optimisation one in particular. Given the k-dimensional vector of criteria, the optimum solution is searched for in a set of possible solutions (to be determined by the morphological table). The range of key criteria to be examined in the design process includes [6]:

- economic criteria (e.g. minimum cost, minimum risk),
- operational criteria (e.g. minimum response time),
- ergonomic criteria (e.g. personnel's maximum safety),
- manufacturing criteria (e.g. application of available materials and technologies), etc.

The process of defining a morphological table is a challenging task. It can be aided using a set of requirements that describe designed diagnostic systems.

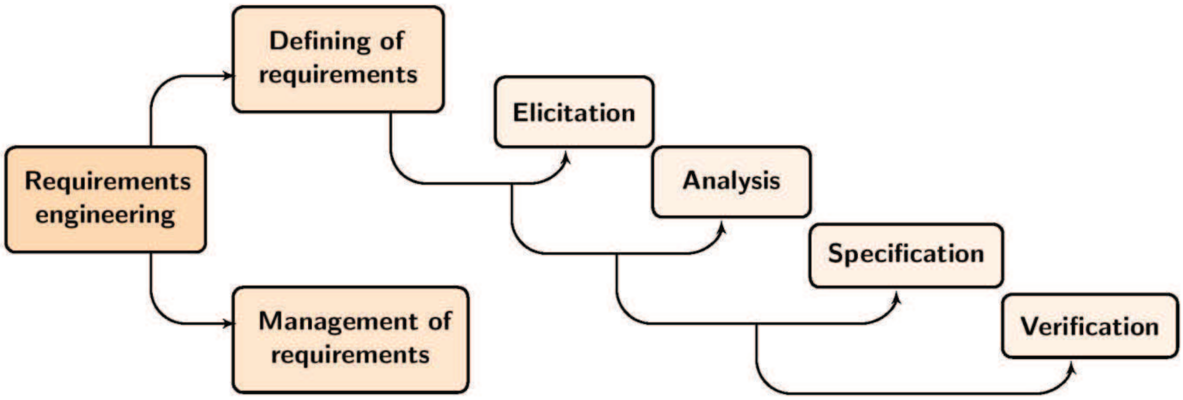

Fig. 2. Requirement engineering tasks

2. REQUIREMENT ENGINEERING

The concept of a "requirement" is defined in various ways in the available literature [8, 12, 16, 17]. The definitions are usually related to a specific branch of science, e.g. software engineering in which the concept is widely used. In order to generalize, a requirement is a statement that describes selected functions to be realized/performed by a solution that is a result of a project's implementation. Exemplary requirements for diagnostic system needs can be the following statements:

- *temperature field acquisition in an environment of the object's element X is necessary to positively determine a technical condition of the object,*
- *it's necessary to measure pressure in a pipeline supplying a working medium to the control valve ZR03.*

Defined requirements should not include any description of a specific problem solution but the description of a particular need only. However, at the same time it should be emphasized that the concept of a requirement is not identical to the term "need". In general, one need can be described with a numerous set of requirements, or different needs may results in identical or similar requirements.

1.1. Defining requirements

One domain that specializes in requirements is requirement engineering (see Fig. 2). The scope of requirement engineering incorporates two fundamental tasks (processes), i.e. requirement definition and requirement management. The process of requirement definition includes then four fundamental stages, i.e. acquisition, analysis, specification and verification of requirements.

One purpose of the requirement acquisition stage is the development of a set of requirements that describe properties of a designed system. In literature the stage is often called an accumulation, identification, formulation, determination or disclosure of requirements. Each term reflects the character of the acquisition process which depends on properties and characteristics of an object that it is designed for. Eliminating of conceivable contradictions occurring in a set of acquired requirements is carried out during the analysis stage. Next, one important stage in the requirement definition process is the specification of requirements that incorporates all actions related to recording and documenting of requirements into a form that is adequate for system designers. Possible format include natural languages, symbolic, graphics, etc. Finally, the last stage of the acquisition process includes a verification of a set of requirements involving tests for correctness, completeness and, e.g. importance of all acquired requirements.

Note that the described stages are often mutually dependent and realized simultaneously in a majority of cases. Effectively, the results influence each other [12, 16].

In a majority of projects requirements are often acquired from various sources which may include, e.g. project's team, end user, existing solutions, rules, standards, domain experts, law, final product prototypes, knowledge and experience of people executing a specific project, etc. The level of accessibility of particular sources of requirements depends on specifics of a domain in which a project has been realized. The acquired requirements should account for all operational aspects of technical means ranging from fundamental functional requirements describing principal characteristics of a designed object to specific requirements related to, e.g. safety, appearance, usability, etc. The size of the final requirement set depends on the object scale. Small-scale projects will involve hundreds of requirements whereas large-scale projects will utilize a huge set of requirements incorporating hundreds of thousands of requirements [12].

1.2. Specification of requirements

The process of defining requirements involves numerous requirements. In many circumstances they may not meet the accepted or imposed constraints or they are contradictory. Therefore, they should be rejected or modified at one of the requirement definition process stages (analysis and/or verification). The requirement set is then recorded in a document – requirement specification. According to the standard IEEE 830 [7] that defines requirements specification for IT (Information Technology) projects such document should be:

- correct – each requirement is a requirement to be met by a designed system,
- unambiguous – each requirement must be interpreted in only one possible manner,
- complete – the document contains a set of all possible and essential requirements,
- consistent – the set of requirements cannot contain contradictory elements,
- ranked for importance and/or stability – each requirement should have a granted priority (importance level) for a better management of the requirement set,
- verifiable – there must exist a (funded) process to determine whether specific requirements can be accomplished in a timely and realistic manner,
- modifiable – the specification document structures should allow for changes in the requirement set,
- traceable – the origin of each requirement as well as their mutual relationships should be identifiable.

1.3. Requirement management

One important task in the requirement definition process is its management. The course of this task warrants a final success (a correct form of the requirement set). The requirement management process can be aided with dedicated IT commercial as well as open-source systems [9,15]. They provide system designers with various methods and techniques for supporting of the definition process of requirement whose application depends on specific needs of a project team.

Such tools are mainly used in supporting the process of requirement acquisition during the development of IT projects. In the IT industry in numerous cases the process of requirement definition reduces to negotiations between a customer and a contractor. One common technique is the EasyWinWin methodology having its origin in the negotiation model called WinWin. The purpose of customer-contractor negotiations is to generate an equal level of satisfaction on either side (customer's and contractor's) [1]. According to the methodology, participants in the negotiations define successive requirements, assign them priorities, and then estimate the set of developed requirements in order to extract a subset of requirements describing designed objects or systems.

2. VIRTUAL CUSTOMER IN THE REQUIREMENT FORMULATION PROCESS

The EasyWinWin methodology assumes that the customer is competent and has a sufficient knowledge to allow him/her to formulate requirements.

This assumption can be difficult to fulfil with complex systems, and diagnostic system in particular. The end-user (customer) may not have a sufficient knowledge on the object it operates. In addition to that, he/she may not know technical diagnostics specifics. Therefore, in many cases customer are not able to formulate correct requirements. In an attempt to get out of this problem, it is possible to assume that a technical object takes the role of a virtual customer in the negotiation process. In order to enable such assumption, the technical object (virtual customer) can be represented by a formalized system - a knowledge carrier with the ability to generate requirements describing the diagnostic system under consideration. One viable possibility is the application of an expert system in which its knowledge base is represented by a multimodal statement networks [4].

2.1. Requirement management

By definition, a statement is a predicative sentence that describes observed facts or expresses an opinion. Each statement can be assigned a value that informs on the sentence's recognition.

Each considered requirement can be then interpreted as a statement. Therefore, they can be written down in the form of the following pair

$$s = \langle c, v \rangle, \qquad (2)$$

where c is the requirement's (statement's) contents, and v is the assigned value that can be interpreted as a belief measure on the purpose of considering the examined statement or as a preference of a requirement for application in a designed diagnostic system.

Defined statements (and requirements) can be combined into sets of statements (thesauri). Having such statement set, it is possible to present existing relationships between the statements with a statement network (see Fig. 3). A statement network is formally a directed graph

$$G = < N, E >, \qquad (3)$$

where N is a finite and not empty set of vertices (nodes) of this graph, and a E is a finite and not empty set of directed edges connecting selected vertices. Selected statement networks can span over shared vertices, thus developing a so-called multimodal statement network [3, 5]. Relationships between particular nodes of statement networks can belong to different classes. Acyclic Bayesian networks (belief networks) have been widely used in that regard [10, 11, 13]. In such networks the relationships between selected nodes are expressed with conditional probability tables (CPT) assigned to all nodes of the networks. It is also possible to use necessary conditions and sufficient conditions for the purpose of describing relationships between selected nodes of the network (approximate networks) [2]. Having defined a statement network, it is possible to perform a reasoning process. During the process and based on known values of selected nodes (reasons) unknown values of the remaining nodes (conclusions) are determined. One important advantage of using statement networks is the possibility of carrying out a reasoning process with an incomplete, inaccurate and partly contradictory knowledge.

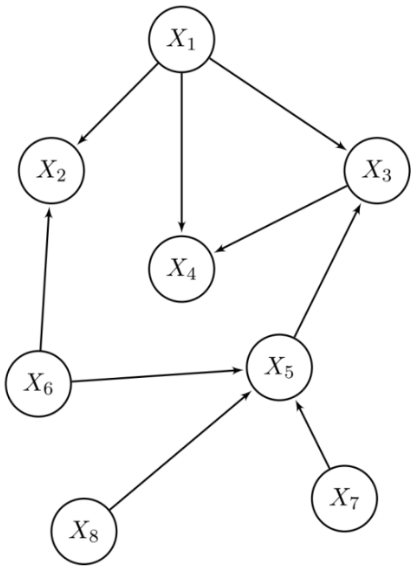

Fig. 3. Statement network

3. MANAGEMENT OF REQUIREMENTS USING MULTIMODAL STATEMENT NETWORK

While designing a diagnostic system it is necessary to possess an appropriate set of statements (requirements) describing examined task problems. The acquired set of statements includes two sorts of statements. One group of statements contains a requirement describing an expected or a required functionality of a designed diagnostic system. The other group includes statements describing a technical object, i.e. structure, components, possible inefficiencies and faults of selected components of the object, fault likelihood, repair and servicing costs incl. temporary lay-offs due to faulty components and subsystems, implementation costs of chosen solutions of a diagnostic system, etc. The statements describe the so-called project knowledge.

To acquire such statements it is possible to look up in available literature sources on an exploitation process of such an object and similar objects. Moreover, necessary statements can be formulated based on the knowledge and experience of domain experts as well as object's end users. Aside from the content and its assigned value, all statements can possess additional attributes, i.e. statement's author, priority, status, versions, notes, etc.

Using a developed statement set, it is then possible to deploy subsequent statement networks. The networks will contains an information reflecting a relationship between a possessed project knowledge and requirements describing a designed diagnostic system. The project knowledge is represented by nodes whose values are known, whereas nodes of unknown values are requirements describing the system. As a result of the reasoning process specific requirements (nodes whose values are unknown) are assigned estimates that are a result of research for an equilibrium condition in a specific statement network.

3.1. Defining of morphological table

Statement networks can support the process of defining a morphological table. The table development process can proceed in a two-step manner. At first, captions (titles) of subsequent rows of the table are determined. They describe required functionalities of a designed diagnostic system. Then, diagnostic methods and techniques are determined that are needed to meet a given need (functionality). Separating these two stages of the development process emphasizes the fact that a detailed knowledge on the object's structure and operating principles as well as a generic diagnostic knowledge are needed for the first stage. At the same time, only a generic knowledge on the object and a detailed diagnostic knowledge are necessary to complete the second stage.

Each stage involves developing necessary statement networks to determine selected elements of a morphological table, i.e. row captions and row elements. The number of considered statement networks depends on the project specific characteristics as well as the acquired knowledge quality. It is assumed that in order to establish elements of particular rows separate statement networks may be developed for each row of the table. While developing particular statement networks, various aspects of one's knowledge on a given object should be accounted for, i.e. operating principles, structure, diagnostic system functionality, etc. As a result of the reasoning process, nodes whose values are not known (requirements) in statement networks are assigned determined values (preference factor). The values can be interpreted as usefulness measures of a specific requirement that has to be taken into account by a diagnostic system to achieve assumed goals. Assuming that particular requirements correspond to specific functionalities of a diagnostic system it is then possible to obtain a full morphological table incorporating all possible solution variants of the system. The process of defining a morphological table is illustrated in Fig. 4.

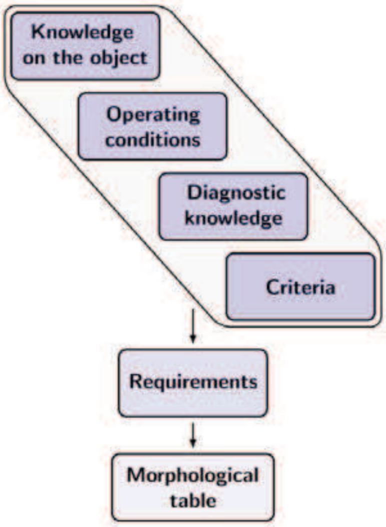

Fig. 4. Process of defining a morphological table

While developing a morphological table using a requirement set, it should be taken into account that the process usually involves a large set of requirements. It contains all requirements that may appear through the development process. However, quite often many of the collected requirements are contradictory to the assumed constraints. Therefore, during the reasoning process a full set of requirements is limited to a rational subset of requirements describing a required functionality of the system (morphological table rows) and related diagnostic methods and techniques (elements of table rows).

3.2. Searching for an optimal system

A morphological table allows for representing possible solutions of a diagnostic system. Their maximum number can be determined using Equation (1). One single solution of a diagnostic system can be considered an element in the *n*-dimensional solution space (multi-dimensional box, OLAP box), where *n* is the number of rows (expected functionalities) of a morphological table. In an exemplary morphological table shown in Fig. 5a, the solution is represented by a single element in the 3-dimensional box illustrated in Fig. 5b. The highlighted solution comprising the partial solutions *{x1,y2,z2}* is only one of the 60 possible solutions of a diagnostic system defined by a morphological table.

a)

		Solutions				
Functionalities	X	x_1	x_2	x_3		
	Y	y_1	y_2	y_3	y_4	y_5
	Z	z_1	z_2	z_3	z_4	

b)

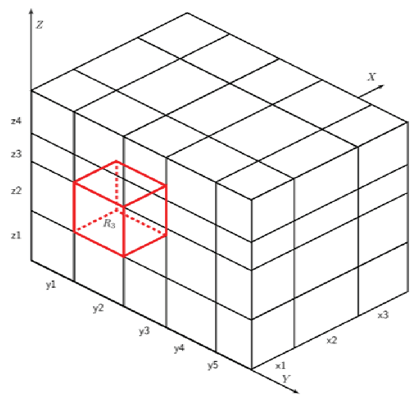

Fig. 5. a) Morphological table, b) corresponding 3-dimensional box of solution variants

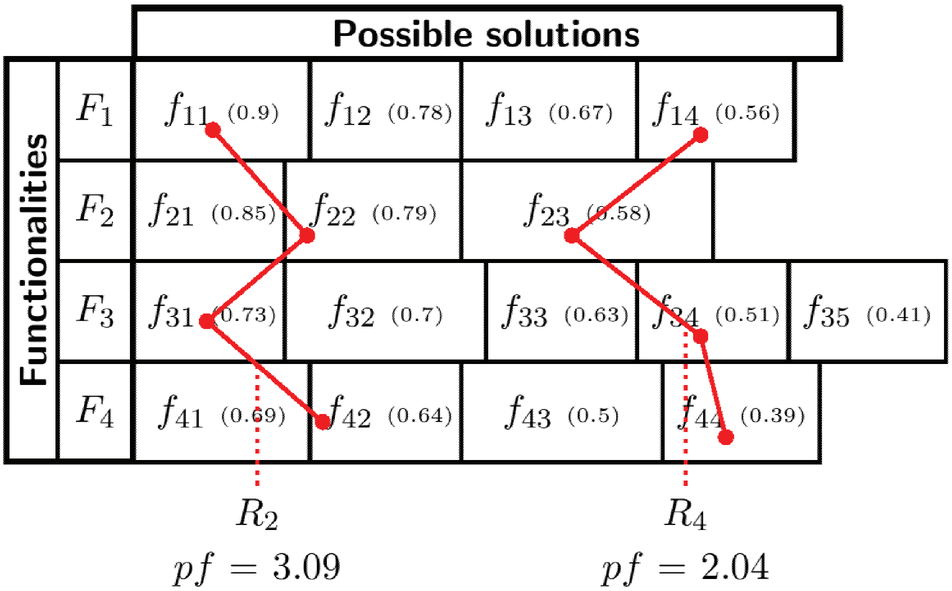

Fig. 6. Exemplary preference factors of particular elements of a morphological table (values in brackets) and selected solutions of a diagnostic system, pf – preference factor

While defining elements of subsequent rows of a morphological table, note that it permits repeated row elements between specific rows if it is used for a diagnostic system. Some of the defined functionalities can be realized using identical diagnostic methods, tools, sensors, etc. At the same time it is apparent that different diagnostic techniques (located within the scope of different functionalities) can be realized with one measurement system. Effectively, it leads to a reduction in the number of all solution of a diagnostic system project.

Each element of a morphological table (rows, row elements) can be assigned a preference factor (importance) that is determined during a reasoning process with statement networks. As such, it is then possible to order selected elements of the table according to the parameter value. At the same time it is possible to assign preference factors to particular solutions of a diagnostic system based on preference factors of specific elements of a solution. The obtained value can be then used for evaluating the solution quality. One example of such a procedure is illustrated in Fig. 6.

It is also possible to assign additional parameters (solution cost, risk, etc.) to particular elements of a morphological table. The parameters can be used in multicriterial optimization.

4. SUMMARY

The paper describes issues of requirement acquisition process for designed diagnostic systems. The authors explore the possibility of representing a set of possible solution of a diagnostic system with a morphological table. The process of defining such a table, i.e. defining of rows representing expected functionalities of a diagnostic system and row elements corresponding to possible methods and techniques can be carried out in two independent stages. To support it, a set of requirements describing the system can be used.

The approach that the authors propose relies on the assumption that a considered technical object takes on the role of a virtual customer in the requirements negotiation process. The virtual customer can be represented by an expert system in which a knowledge base takes the form of a multimodal statement network. Morphological table elements can be determined based on the outcome of the reasoning process performed on defined statement networks.

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