

MANAGEMENT OF REQUIREMENTS FOR DEVELOPED DIAGNOSTIC SYSTEMS

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Summary

This study presents results of a research on the development of methods for supporting design processes of diagnostic systems. One major challenge during the process is the precise description of goals or, in other words, determining the planned functionality of the developed diagnostic system given financial as well as technology constraints. The goals can be presented in the form of a set of requirements that the developed system should meet. Also, one critical task that occurs during the process of requirement acquisition is an appropriate management of the process. Nowadays, methods for requirement management are under intensive development in the field of software engineering in particular. However, their application in the process of diagnostic system design requires an additional treatment in order to account for the domain knowledge on technical diagnostics as well as diagnosed objects. As a solution the authors propose multimodal statement networks.

Keywords: requirement management, diagnostic systems, multimodal statement network.

ZARZĄDZANIE WYMAGANIAMI DLA PROJEKTOWANYCH SYSTEMÓW DIAGNOSTYCZNYCH

Streszczenie

W artykule przedstawiono wyniki badań związanych z poszukiwaniem metod wspomagania procesu projektowania systemów diagnostycznych. Zwrócono w nim uwagę na fakt, że trudnym etapem tego procesu jest dokładne opisanie potrzeb czyli określenie oczekiwanej funkcjonalności projektowanego systemu diagnostycznego przy uwzględnieniu istniejących ograniczeń np. kosztowych czy też technologicznych. Potrzeby te mogą być przedstawiane w postaci zbioru wymagań stawianych projektowanemu systemowi. Ważnym zadaniem występującym w procesie gromadzenia takich wymagań jest odpowiednie zarządzanie tym procesem. Metody zarządzania wymaganiami są intensywnie rozwijane w inżynierii oprogramowania. Ich zastosowanie w procesie projektowania systemów diagnostycznych wymaga jednak dodatkowych działań pozwalających na uwzględnienie wiedzy dziedzinowej dotyczącej diagnostyki technicznej oraz diagnozowanego obiektu. W celu rozwiązania tego zadania autorzy zaproponowali wykorzystanie wielomodalnych sieci stwierdzeń.

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

1. INTRODUCTION

Modern state-of-the-art diagnostic systems are sophisticated systems that register and analyze multiple signals (process variables, residual processes). The signal analysis is carried out by means of advanced tools and techniques, e.g. artificial intelligence methods, and the result of that process is then transferred to appropriate systems of an object as control inputs as well as to end-users in the form of sound signals, light signals and the like.

Designing such systems is often a challenging task. The process incorporates the following: need (goal) recognition (definition of a function that a specific diagnostic system should realize), generation of a set of solutions capable of meeting the specified goals, definition of existing or potential constraints, definition of selection criteria for an

optimum solution, designation of an ultimate solution meeting established criteria. The set of likely solutions can be presented in the form of a morphological table (see Fig. 1) in which specific rows correspond to particular goals (diagnostic system functionalities), and row elements describe possible solutions capable of meeting particular goals. The process of determining the contents of specific rows as well as their elements in the table is not an easy task. Simply, it is required to account for the domain knowledge on an object, diagnostic knowledge, as well as existing constraints, for example, engineering constraints, financial restrictions, etc. Therefore, in order to support the table development it is recommended to use a set of requirements describing the diagnostic system under development.

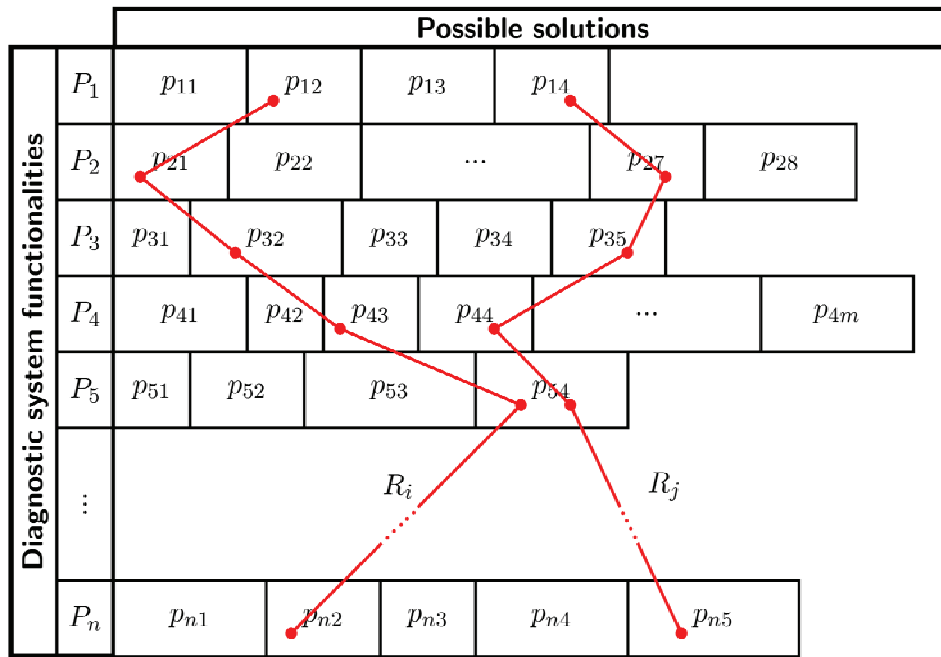


Fig. 1. Morphological table as a set of possible solutions

The size of a designed table depends on characteristics of an object that the system is developed for (number of rows) as well as diagnostic methods and techniques (row elements).

As shown in Fig. 1, specific solutions (R_i, R_j) are developed in the form of a combination of selected solutions for meeting particular goals. In a generic case, it is then possible to develop a set of

$$\prod_i \text{card}([P_i]) \quad (1)$$

diagnostic system solutions, where $\text{card}(P_i)$ is the number of solutions capable of meeting the goal i (i.e. the number of elements in the row i). Initially, the set of solutions may comprise inefficient solutions as well unrealizable solutions. They will be eliminated in subsequent steps of the development process. The application of a morphological table guarantees the considering of all solutions. The process of selecting an ultimate solution out of the solution set is an optimization task and that of a multicriterial optimization in particular.

2. REQUIREMENT ENGINEERING

Requirement based procedures are often used in the area of software engineering. For example, various literature sources [10,13,15,16] have proposed definitions of the term „requirement” in the software engineering aspect. In general, it is assumed that a requirement is a statement describing functions that a specific solution should meet. One

example of a requirement for a condition monitoring (diagnostic) system project can be the following statement: „relative displacement amplitude measurement in the bearing node no. 4 in the range from XX to YY at the accuracy of ZZ”.

One field of science to consider and examine all requirement related aspects is requirement engineering, and its fundamental tasks are revealed in Fig. 2.

2.1. Defining requirements

Defining requirements comprises four fundamental processes, i.e., acquisition, analysis, specification, and verification.

The purpose of the acquisition process is to discover or reveal, emphasize, and to present system requirements. In existing literature sources the process is also called a requirement collection or acquisition, identification, formulation, etc. Each term reflects process-related specific activities depending on object characteristics.

The purpose of the analysis process is to evaluate the set of collected requirements. The requirements are clustered into subject-related groups, pending the removal of possible contradictions, and prioritized.

Also, requirement specification is a process that allows for a translation of a requirement into the form that can be understood by system designers. Possible formats include natural languages, symbolic languages and graphics.

Finally, verification is a process that allows requirements to be tested for correctness, integrity,

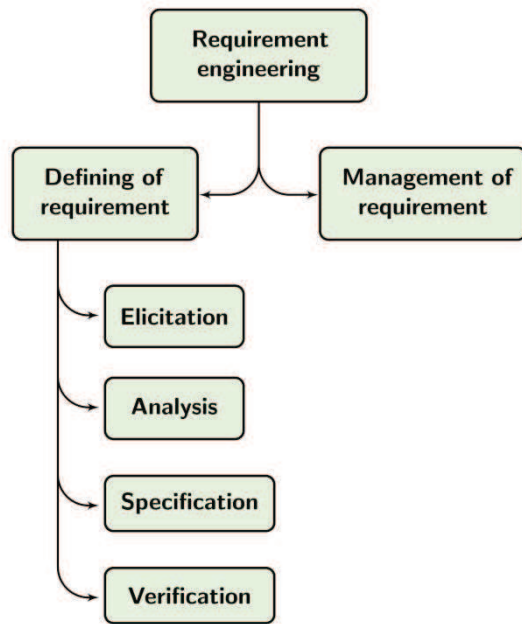


Fig. 2. Requirement engineering tasks

completeness, and importance (ranking). Also, note that the above processes are mutually dependent and often performed simultaneously, and their outputs influence one another.

In a majority of cases there exist three fundamental categories of requirements, i.e., structural requirements, functional requirements and non-functional requirements. The structural requirements describe the structure of designed technical means. The functional requirements report services that a specific solution should deliver.

Moreover, the non-functional requirements allow one to determine the level of compliance of structural and functional requirements with respect to the project goals. They are the result of the technology used, timing constraints, standards and regulations, quality policies, etc. This category of requirements can be then split into appropriate sub-categories, e.g. usability requirements, organizational requirements, performance requirements, operating requirements, safety requirements, legal requirements, design and the like. This sectioning depends on specific features of a project for which requirements should be defined.

In general requirements can be acquired from various sources, e.g.:

- principal customer,
- end-users,
- existing solutions,
- domain experts,
- standards, recommendations,
- knowledge and experience of the project developers,
- prototypes, etc.

Availability of particular sources depends on project specifics. While defining requirements it is recommended to apply multiple sources.

Unfortunately the resulting requirements can be inconsistent or contradictory. The number of requirements to be defined within a projects varies from as low as few hundreds for small projects to well over 300 thousand requirements while designing passenger aircrafts for example [10].

2.2. Requirement specification

As a result of requirement evaluation using appropriate methods and techniques, a subset of fundamental requirements is extracted from the initial set of requirements. The subset ensures that both planned functionality and constraints are met. The requirement set is then recorded in a document – requirement specification. According to the standard IEEE 830 [6] that defines requirement specification for IT (Information Technology) projects, the document should be as follows:

- 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 cost-effective 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.

The process of defining requirements is a challenging and time-consuming task. In general, numerous requirements are collected – they come from different sources and are defined by various individuals. Therefore, the answer to two basic questions may become difficult. Is the developed set of requirements complete? Is it free of contradictions? It becomes clear then that the application of appropriate methods for the process management is necessary and a key to a successful project.

3. MANAGEMENT OF THE PROCESS FOR REQUIREMENT ACQUISITION

The process of requirement management can be supported with dedicated IT systems [7, 14]. Their support capability depends on project specific characteristics. Also, they allow for an assignment of various attributes (author, priority, status, version,

etc.) to defined requirements. They have filtering as well as search capability. Moreover, they incorporate mechanisms for tracking changes in a requirement set and collaborating with external applications, e.g. database systems, MS Office documents and the like. In addition to that, they allow for team collaboration during the requirement development process, establishing various levels of access to the requirement set, developing mechanisms of automated messaging on any potential modifications in the requirement set and the like.

Analyzing the description of numerous projects and IT projects in particular implies that in many circumstances the requirement development process relies on negotiations between a client and a project's engineer. One common methodology is the so-called EasyWinWin whose origin can be tracked to the negotiation model Win-Win, in which the primary objective is a mutual satisfaction of a client and an engineer of formulated requirements [1]. Throughout the course of a negotiation participants formulate requirements, prioritize and evaluate them in order to extract principal requirements describing the designed system.

However, such approach cannot be used directly when designing a diagnostic system. It is indeed rather difficult to define a customer for negotiations in such projects. By a fashion, the so-called customer can be the object end-user. In many scenarios such approach is not optimal – mainly because end-users do not usually have the right domain knowledge and the diagnostic knowledge that allows them to define appropriate requirements.

The essence of the proposed approach for requirement acquisition is the hypothesis that this problem can be solved by assuming that any analyzed technical object is a virtual client in a negotiation process. The object (virtual customer) can be represented by an expert system that is capable of establishing object-oriented requirements to be met by a diagnostic system.

4. STATEMENTS, STATEMENT NETWORKS

An expert system for use as a virtual client in a negotiation process should be capable of operating based on the knowledge it has access to. A knowledge database of the expert system may occur in the form of a multimodal statement network [2, 3, 4, 5].

It is assumed that a statement concerns a sentence (or an expression) on an observed fact or an opinion. The expression (statement contents) can be assigned the value v , in order to inform of its logical value or a belief that the statement is true. In the case of definite statements the value is one element out of the set $\{yes, no\}$. The statement s is an ordered pair

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

where c is a statement contents, and v refers to the statement value. Relationships occurring among statements can be described by developing a statement network (see Fig. 3) in which statements appear in the form of network nodes. The network is a directed graph

$$G = \langle N, E \rangle, \quad (3)$$

in which N is a finite and non-empty set of vertices of this graph, and E is a finite and non-empty set of directed edges linking selected vertices.

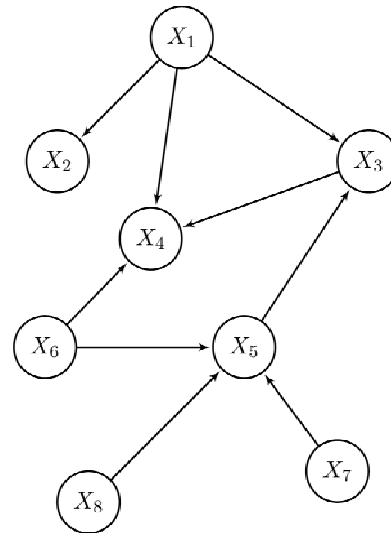


Fig. 3. Multimodal statement network

All statements used for developing such networks should be collected in a set of statements – thesaurus.

Statements that are gathered in a thesaurus include both descriptive statements (on the object's structure, possible failure modes of object's selected components, failure mode probabilities, repair and servicing costs, etc.) and statements (requirements) reporting the expected or demanded functionality of a designed diagnostic system. Both knowledge and requirements that are represented by statements are developed and collected based on available literature incl. object's maintenance manual and documentation, description of similar objects, data from domain experts, designers and end-users, as well as similar existing solutions.

Statements that are selected out of a thesaurus can appear as nodes in various developed statement networks. Particular statement networks can be formulated based on various aspects of an available knowledge on the object's structure, functionality, object characteristics, etc., thus forming a set of statement networks over a common set of nodes. Such a set of statement networks is called a multimodal statement network.

Well designed and developed statement networks reflect relationships between the knowledge on

objects and requirements describing the diagnostic system of interest. Statement networks utilize various methods for representing node-to-node relationships. One widely used statement network type is a Bayesian network (belief network) [8, 9, 11], in which the relationships are expressed with conditional probability tables assigned to specific nodes. Also, it is possible to utilize approximate networks in which node-to-node relationships are described with necessary and sufficient conditions [3, 4].

Statement networks allow then to realize reasoning processes in which unknown values of certain nodes (conclusions) are determined based on known values of other nodes (reasons and premises). One advantage of a statement network is its ability for carrying out a reasoning process based on incomplete, uncertain, and partially inconsistent knowledge.

5. REQUIREMENT MANAGEMENT USING MULTIMODAL STATEMENT NETWORKS

The morphological table that is described in Section 1 allows for representing a set of likely solutions of a diagnostic system. The process of defining such tables incorporates two stages. In the first stage table row captions (titles) are assumed. In other words, this stage determines functionalities referring to subsequent rows of the table. The second stage goal (that should be established independently for each row) is to identify row elements. It becomes apparent that a clear distinction of both stages emphasizes that in order to accomplish the first stage a detailed knowledge on both the structure and substance of object operation principles as well as a generic diagnostic knowledge are needed. At the same time it is clear that the second stage goals can be accomplished with a detailed in-depth diagnostic knowledge as well as a generic high-level knowledge on a particular object.

One component of a morphological table that is particularly important is a set of table rows for determining various approaches to ensure required functionalities of a designed diagnostic system are met. The functionalities should reflect the knowledge on a given object, and the object structure, specific sub-systems and components in particular. The domain knowledge should be incorporated there as well.

By acquiring a certain amount of knowledge on a given object and recording it in the form of a set of statements, it is then possible to develop a multimodal statement network to define captions (titles) of morphological table rows. In this network statements describing an object and object operation conditions are input nodes, whereas requirements (for determining the proposed functionality of a diagnostic system – morphological table rows) are output nodes.

As a result of a reasoning process specific requirements are given so-called belief levels (assuming the examined multimodal statement network is a Bayesian network) to describe their capability of meeting a goal function by a designed diagnostic system. It is also possible to extract a subset of requirements out of a requirement set for which a belief level is greater than a specified threshold level. The subset will contain the assumed description of a diagnostic system functionality.

Next, it is required to determine elements of specific rows of a morphological table. In this case a diagnostics-related knowledge is accounted for. Statement networks are developed at this state in order to reflect relationships among functionalities (morphological table rows) and diagnostic methods. The outcome of the reasoning process is a set of diagnostic methods and techniques to ensure specific functionality is met for an assumed functionality and existing constraints.

Note that the result of a process of collecting requirements to describe a diagnostic system is a numerous set of requirements. It incorporates all requirements that can be formulated during the development process. However, some of the formulated requirements can be contradictory or incapable of meeting assumed goals. As such, with multimodal statement networks the requirement set is limited to a rational subset of requirements to describe the required functionality of a diagnostic system (morphological table rows) and related diagnostic techniques and methods (table row elements).

Multimodal statement networks can be formulated e.g. with the dedicated software platform REx [5, 12]. The package was developed based on the well-known language R. An installation package is available as well [12]. It allows for formulating statement sets, grouping of selected statements into thematic subsets with assigned keywords, and using them for the development of multimodal statement networks. Finally, it allows one to carry out reasoning processes assuming that dependencies between particular statement networks are expressed with conditional probability tables (Bayesian networks) and/or with sufficient and necessary conditions (approximate networks).

6. SUMMARY

In this paper the authors described issues concerning requirement management in the development of diagnostic systems. Specifically, the needs for representing a set of possible solutions of a diagnostic system project with a morphological table were analyzed and emphasized. The process of determining particular rows of such a table (representing assumed functionalities of a diagnostic system) and row elements (describing possible variants of diagnostic methods and techniques) may be supported by an expert system delivering

appropriate requirements. Simply, the essence of this requirement acquisition approach is the assumption that the problem can be solved by claiming the examined diagnosed system is a virtual client in a requirement negotiation process. Here, the client is represented with an expert system whose knowledge base is written down as multimodal statement network.

Finally, determining morphological table elements with multimodal statement networks is reduced to a reasoning process in which requirements describing a developed diagnostic system are resolved based on known facts on a technical object and a domain in which the diagnostic system is applied.

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