SonaRes - Computer-Aided Approach for Advanced Ultrasound Medical Diagnostics

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Abstract **– Ultrasound image is the primary (input) information for every ultrasound examination. Despite the difficulties of ultrasound image interpretation, this source of information is still significant for diagnosis decision making. This paper describes the experience of SonaRes diagnostic decision support system (DDSS) for ultrasound examination development. Considering two-layer structure of the information contained in ultrasound images, two main approaches in DDSS creation may be distinguished: Image-based systems and Knowledge-based systems. In the SonaRes the advantages of both are combined. In the process of any DDSS development there are three points of major importance, influencing essential the success: i) knowledge acquisition and formalization; ii) image processing and search for similar ones, and iii) interaction with user [1]. SonaRes – represents one of the possible solutions to these problems aimed at increasing the DDSS functionality, user attitude and, as a result, adequacy of generated conclusions.**

Index Terms **– computer-aided approach, knowledge, ultrasound image, decision support, medical diagnostics.**

I. INTRODUCTION

Diagnosis is a process consisting of separate steps. These steps begin with establishing the certain facts in the process of examination and lead to the inference that the obtained facts correspond to some conclusion or begin with some preliminary diagnosis achieving the conformity of the set of objective facts of the patient state to confirm the presumptive diagnosis or reject it, if the facts do not correspond to or contradict the assumption.

In general case DDSS medicine are not intended to replace the physician, their role being to give clinician recommendation on his request or draws automatically his attention to the special cases (cases of alerts).

Obviously, DDSS are targeted on a specific area, which may be more or less broad, and the domain of their applicability is defined by a pathology (a group of pathologies) or a diagnostics method, which in its turn is oriented to certain pathologies (group of pathologies or organs). The subject of our work is development of decision support systems for diagnostics based on ultrasound examination.

II. DECISION SUPPORT SYSTEMS IN ULTRASOUND DIAGNOSTICS

The ultrasound examination of patients, being non-invasive and not expensive, is a basic technique of medical imaging.

Ultrasound image is the primary (input) information for every ultrasound examination. The main characteristic of these images is two-layer structure of the information contained in it. The first layer is the image itself (graphical features), and the second layer is its textual description in medical terms (medical features).

However, utilization of this technique does not always come up to expectations, encountering some difficulties associated with the dependence on operator, which affects the quality of the obtained images, and the way the results are differently described and interpreted by several specialists. Besides the difficulties of ultrasound image interpretation, because of the speckle, tissue related textures and artifacts, this source of information is still significant for diagnosis decision making.

Computer-aided diagnosis schemes has been subject to various research since 1980, when a number of medicine domains began to use computer assistance [2]. During these years, huge databases of medical images were created and became a powerful source for decision making. Taking into consideration these tendencies, two main approaches to create DDSS systems can be distinguished:

- Image-based systems;
- Knowledge-based systems.

A joint realization of decision making and image retrieval in DDSS development leads to new explicit domain-specific knowledge and better results in many applications. Moreover, research in medical image analysis tries to find links between image features and knowledge in order to fulfill quantification tasks and to answer prognostic questions.

There are three points of major importance, influencing essential the success of DDSS, are the following:

- Knowledge acquisition and formalization;
- Image processing (with extraction of knowledge from the images, if possible) and search for similar ones;
- Interaction with user.

The way these issues are resolved determines the functionality, user attitude and, as a result, adequacy of generated conclusions.

In what follows, we will discuss these points, basing on solutions realized in the SonaRes – a Diagnostic decision support system for ultrasound examination of the abdominal region.

III. KNOWLEDGE ACQUISITION IN ULTRASOUND DIAGNOSTICS DOMAIN

There are 5 main stages in the development of knowledge-based systems [3]:

1. Problem identification;
2. Knowledge acquisition;
3. Knowledge structurization;
4. Knowledge formalization;
5. Prototype development.

The phase of knowledge acquisition and formalization is considered as the key one for the development of medical computer-assisted systems (decision support, adaptive training, learning, etc.).

During the second stage of the development of knowledge-based systems – *knowledge acquisition* – the expert competence and knowledge should be transferred to "knowledge engineer", aiming the "knowledge engineer" to obtain the fullest subject domain representation. The process of knowledge acquisition in ultrasound investigation domain on an example of separately taken organ (gallbladder) is described in details in [4].

The necessary knowledge about ultrasound investigation of gallbladder was acquired from the experts-physicians:

- Gallbladder localization information (including methodology of visualization in typical location, objective conditions of non-visualization or difficult visualization in typical location, causes of non-visualization in typical location);
- Information about the gallbladder pathologic states (chronic cholecystitis, compressed gallbladder, scleroatrophic gallbladder etc.);
- Principal characteristics of gallbladder description (dimensions/volume, shape, tonicity, gallbladder contour etc.);
- Gallbladder anomalies and pathologies information, every anomaly or pathology being determined by changes in principal characteristics of gallbladder description (dimensions anomalies, shape anomalies etc.).

IV. ASPECTS OF KNOWLEDGE STRUCTURIZATION IN UNSUPERVISED EXPERT'S WORK

At the third stage of the development of knowledge-based systems – *knowledge structurization* – the structure of the subject domain acquired knowledge (the list of the basic concepts and their attributes, the relationships between them, the structure of the input/output information, decision-making strategy, etc.) should be defined. The aim is to obtain the informal knowledge description of the subject domain as a graph, a table, a diagram or a formatted text.

In the beginning, the loss in knowledge acquisition dialogue was considered the most essential drawback at the interaction expert-"knowledge engineer", when the volume of information, possessed by the expert, differs from the remembered and communicated one, that is much more than information, listened by "knowledge engineer", and finally, essentially differs from knowledge volume, formalized and stored in knowledge base. Moreover, the information received from the expert can be apprehended incorrectly by the "knowledge engineer" that will cause mistakes in knowledge base. So, the time-consuming procedures of the explanation and additional control are necessary, leading the time, spent for interaction between the expert and the "knowledge engineer", to influence terms of knowledge base creation. Therefore, was created an expert environment – knowledge base generator, accessible to expert with intuitively clear graphical interface – ExpShell [5]. In this case the expert himself had to supervise the process of knowledge base filling from the beginning up to the end, but the "knowledge engineer" only defines the method of data storage and representation.

ExpShell allowed expert to describe the subject domain in a free form. The expert has possibility to work simple and clear only in two routines: 1. filling the list of facts, used in gallbladder ultrasound investigation domain; 2. selecting already introduced facts and establishing in graphical interface the existent relationships between the facts – connections of type →, & and ¬. As the result a decisional graph that describes a diagnostic feature / pathology / anomaly of gallbladder is obtained. Using this ExpShell, expert knowledge considered the most important (58 facts and 30 decisional graphs) was acquired.

The analysis of the acquired knowledge has shown that its further use for decision-making process is very difficult because of its weak structurization. Since there was no clear distinction between the facts and rules, the additional verification of acquired knowledge was required (often the same diagnostic feature, participating in different pathologies, was described by different sets of facts). Therefore, the tactics of knowledge structurization was changed.

Since the quality of acquired knowledge is the determinant factor in successful realization of any knowledge-based system, the decision was to turn to the traditional method of knowledge acquisition (with participation of "knowledge engineer") [6].

V. KNOWLEDGE REPRESENTATION SCHEMES

At the forth stage of the development of knowledge-based systems – *knowledge formalization* – the representation form (language) for acquired and structured knowledge should be selected. The formalized representation of problem domain concepts is created basing on of the chosen knowledge representation form.

The fundamental goal of knowledge representation is to represent knowledge in a manner to facilitate drawing conclusions (inference) by the computer-assisted systems.

We distinguish two approaches – single and hybrid knowledge representation schemes.

There is no single or hybrid scheme to satisfy end-users preferences and/or all the requirements of knowledge-based systems developers. So, taking into account only the system requirements on the knowledge acquisition stage, one can say that semantic nets, decision trees, frames and description logics are more suitable to represent medical knowledge [7].

For SonaRes system we have chosen the decision tree as a model of acquired knowledge representation. Basing on the principles of the decision tree scheme, the knowledge base of gallbladder ultrasound examination domain has been established.

VI. KNOWLEDGE STRUCTURIZATION AND FORMALIZATION DURING EXPERT-"KNOWLEDGE ENGINEER" INTERACTION

The information obtained from the experts-physicians was structured, formalized and introduced by the "knowledge engineer" in knowledge base (a pyramid of meta-concepts, and a set of rules created on its basis), marking out 9 main characteristics for gallbladder ultrasound investigation, representing principal nodes. Other nodes are connected to principal ones by hierarchical links, forming a tree structure of "attribute" and "value" nodes. The knowledge pyramid has 335 nodes with at most 9 deep levels.

Using obtained knowledge pyramid, 54 decision rules for gallbladder pathologies and anomalies determination were created. The analysis of 54 rules obtained for gallbladder shows, that in addition to the normal state and anomalies, we also embraced all basic groups of pathologies. Moreover, creation of the rules with a simple structure gives possibility to describe diagnostic of some simple structures and solitary lesions, as well as of any complex pathology, which consists of several separate pathologies: for instance, acute gangrenous lithiasic cholecystitis associated with solitary adenomatous polyp and focal cholesterosis. Description of the complex pathologies can be obtained by combining the existing rules. The obtained knowledge base describes completely the ultrasound investigation process of gallbladder.

Common work of the "knowledge engineer" and experts has shown that in ultrasound investigation domain the reasoning with metaconcepts (facts) and knowledge representation as a pyramid completely corresponds to the experts' mentality and thinking. However, the division of metaconcepts up to the level of objects, concepts and their attributes, and construction of further reasoning on their base is not always clear to the experts, especially, if we demand this at the initial stage of knowledge acquisition.

VII. KNOWLEDGE MANAGEMENT TECHNIQUES

The development of the user's interface for the medical computer-assisted systems basing on the decision tree can lead to various problems and inconveniences. The main lack is the fact that the user's interface does not correspond to the daily work and habits of the end-user – physician. Moreover, the discrepancy of the user's interface of the medical computer-assisted systems and with the form of physician's diagnostic thinking may become the reason of different mistakes or may lead the user to reject its utilization in his medical practice.

To organize an effective dialogue with end-users and to eliminate the mentioned deficiencies an alternative representation scheme of the knowledge base was created in the SonaRes system.

The source of information for the alternative representation scheme is the knowledge base, described as a decision tree. It was necessary to propose such a representation of the acquired knowledge in order to have the opportunities to realize an adaptive user interface with the following features:

- The interface should be simple and understandable. The dialogue with the end-users should take place in its usual rhythm and form, and should not require the changes in his reasoning.
- The interface should correspond to the end-user's daily work and preferences. The end-users should have possibility to influence the dialogue form.
- The interface should be "transparent". The solution proposed by the inference of medical computer-assisted system should be easily to verify.
- The dialogue with the end-user should not have a linear structure. The end-user always should have the opportunity to return to the appointed step back.
- The interface should be adaptive. It should change, depending on time available to the end-user to make a decision. In addition, the interface should conform to the basic forms of end-user diagnostic thinking.
- The interface should not restrict unnecessarily the end-user's actions.
- The interface should be oriented on the restricted screen space and on limited decision making time. The end-users often have to use the system in an emergency or in a network mode.

The dialogue is the most common form of communication and information transfer. Therefore, the organization of the user interface as an ordered set of questions is justified.

The essence of the proposed new representation approach is the separation of knowledge into one, used in the inference, and other, used only in the interface [7].

At the first step of the creation of the alternative representation of the knowledge base there were determined those facts of the decision tree, which are involved in the inference.

For each fact a question concerning the existence or non-existence of this fact was formulated. For instance, for the fact F1=<gallbladder volume, normal> there was formulated the question Q1="Is the volume of gallbladder a normal one?", for the fact F2=<gallbladder volume, enlarged> – the question Q2="Is the volume of gallbladder enlarged?", and for F3=<gallbladder volume, reduced> – Q3="Is the volume of gallbladder reduced?".

As a result, 203 questions were formulated. Answering to some of these questions, the user can describe the case from gallbladder ultrasound investigation domain. All of 54 pathologies and anomalies of this domain were described in terms of these questions.

At the second step we have stored all existing relationships between the facts. So, we have elaborated an interconnection system between all formulated questions.

There are two types of relationships between facts in the decision tree. The first one indicates the position of a given fact in the knowledge base hierarchy. The second type of relationships indicates the existence of interdependence between the facts.

These relations do not depend on the form of visualization of the facts or the whole user interface, but represent the basis of the system's knowledge base and inference.

Separation of the existing relationships between the questions in two groups – those, used in inference, and those, used only in the interface, allows us to create a high-quality adaptive interface based on the individual characteristics and habits of the end-user. It is achieved because the user can define himself the subject and the form of dialogue (by changing the visualization relationships between the questions), without any fear to influence the inference.

Additionally, the questions grouping will allow to diversify the form of dialogue.

This approach allows realization of different versions of the user interface with restricted screen space and limited time for the decision making (for instance, medical computer-assisted systems used in emergency cases).

VIII. CHALLENGES AND SOLUTIONS IN UTILIZATION OF ULTRASOUND IMAGES. IMAGES RETRIEVAL

As mentioned above, ultrasound images have a dual nature considering information they hold. A part of this information is related to visual representation and can be managed by computer graphics techniques. But the most specific feature of this type of images is their medical content. To manage this type of information the *content-based image retrieval technology* is usually used.

SonaRes system collects a set of "model" (representative) annotated ultrasound images. The acquiring of the "model" ultrasound images represents a continuing process, where the experts-physicians play a leading role, providing the ground truth. Experts associate these images to the corresponding rules. On static images the regions of interest (ROIs) are marked out. These ROIs are associated to particular characteristics of the organ – facts (nodes of the knowledge pyramid).

The "model" ultrasound images are stored in SonaRes image database. These are gray-scaled images, mainly, of *.jpg and *.bmp storage formats. It is supposed that the future additions can also be represented in non-DICOM formats.

To provide the ROIs marking, association between ROIs and nodes as well as between images and rules, the special tools for work were developed. These tools help experts to realize of the following actions:

- ROIs management – allowing marking out the ROIs (as a contour of connected points) as well as other operations: addition, deleting and viewing ROIs;
- visualization of all ROIs corresponding to the selected node on different images;
- visualization of all ROIs (corresponding to different nodes) on the chosen image.

In SonaRes system the role of annotated images in decision making process is to be a correct helpful illustration, if the physician is not sure how to interpret an ultrasound image. Since the results of SonaRes images retrieval serve mainly as help for the user, the corresponding tool was placed in the part of SonaRes web-interface.

The retrieving process starts with pattern image uploading and optionally setting an own ROI (as a restriction to avoid time-consuming and to increase retrieval accuracy). After the process is finished, the web-gallery of similar images is shown.

The images preview thumbnails are clickable. If one of these images is selected by the user – a new window is opened, showing the full size view of the image, matched ROI and its annotation.

The most fruitful method for retrieving similar ultrasound images seems to be the application of both medical features (obtained from a knowledge base) and visual features (obtained from images). Retrieving based on medical features allows confirmation of the diagnosis assumption by obtaining a gallery of images containing the supposed pathology or fact.

Retrieving based on visual features allows user to select the most appropriate image from obtained list of similar ones. The combined retrieval, using medical and visual features, makes possible to search a visual representation for textual description of medical feature and conversely to find the textual explanation for visual feature.

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