Second International Conference
Modelling and Development of Intelligent Systems
Sibiu - Romania, September 29 - October 02, 2011

Ultrasound diagnostics system SonaRes: structure and investigation process

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Abstract

In this paper the recent approaches to development of Diagnostic Decision Support Systems (DDSS) are examined. The solutions used in the SonaRes system, which combines knowledge-based and image-based techniques, are described.

1 Introduction

Diagnostics is one of the most difficult tasks clinicians may face every day. Determination of the correct diagnostics involves a multitude of factors, that characterize the patient's state of health. Omission or misinterpretation of them can lead to mistakes with unpredictable consequences. No less important is to reveal the relationships between these factors, as well as interaction between organs and its manifestation mode. In such activities it is a natural tendency to ask for a help, to make sure we proceed in the right way or to find a solution when we do not know how to proceed. A second opinion, an advice, is useful to any physician, even to an experienced one.

The problem, associated with the medical diagnostics activities, acquires a special relevance in modern circumstances. First of all, it is connected with the fact that physicians have to work with poorly structured and weakly formalized information. Besides, medical diagnosis involves interplay between a vast number of medical knowledge resources in so-called healthcare environment of important patient data, including clinical information, up-to-date status reports, medication and medical imagery.

The ultrasound investigation domain is not an exception. The appearance of new ultrasound devices or the improvement of old scanners doesn't simplify, but even complicates the physicians diagnostic thinking. So far as one has to analyze a number of diagnostic data, the time of diagnostics determination increases and the accuracy sometimes may reduce.

The subject of this study is the Decision Support Systems in ultrasound diagnostics revealing two classes: image-based and knowledge-based systems. Some interesting implementations of combination of these methods are presented. The principles and techniques of knowledge acquisition, structurization, representation and management, aiming to create an efficient logical inference and adaptive user interface, are described. Some aspects of future work are discussed.

As an illustration for the proposed approach serves the SonaRes decision support system, designed to assist the diagnostician in the ultrasound examination process of the abdominal region. It is particularly difficult because of numerous organs are located in a relatively small space, and there is a need to take into account their interaction.

2 Diagnostic Decision Support Systems: general characteristics

DDSS at the early stages were perceived by doctors rather simplistically as: "a machine algorithm that supports the clinician in one or more components of the diagnostic process" [1] or as "a process of definition in the process of investigation of nature and circumstances of the disease formation" [2].

In [3] there are identified three components of comprehensive information needs:

1. currently satisfied information needs (information recognized as relevant to a question and already known to clinician);

2. consciously recognized information needs (information recognized by the clinician as important to know to solve the problem, but which is not known to him); and

3. unrecognized information needs (information that is important for the clinician to know to solve a problem at hand, but not recognized as being important by the clinician).

Establishing the diagnosis is a process preceding the suggestion of therapeutic or surgical treatment. According to [4] "The process of diagnosis entails a sequence of interdependent, often highly individualized tasks: evoking the patients initial history and physical examination findings; integration of the data into plausible scenarios regarding known disease processes; evaluating and refining diagnostic hypotheses through selective elicitation of additional patient information, such as laboratory tests or serial examinations; initiating therapy at appropriate points in time (including before a diagnosis is established); and evaluating the effect of both the illness and the therapy, on the patient, over time".

Diagnosis is a process consisting of separate steps. These steps begin with establishing the certain facts in the examination process 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. Even if the start and end points of the process are identical, the steps followed by two doctors could differ very much, and at the same time, the diagnostician can take various steps in two almost identical cases. Since the investigation is a creative process based on knowledge and experience, different physicians may face the problems in valuation of the same patient. Diagnosis as an interpretation of the results of a number of observations, is potentially recursive and is essentially defined by consistently complicating diagnostic tools.

As a matter of fact, DDSS do not generate a single conclusion (diagnosis) and usually suggest several ones, based both on patient data and knowledge embodied into the system. All these conclusions correspond to the facts, observed in the process of examination. Since the general knowledge, storing in the system about the case under examination, could be supplemented with other one, specific to a given patient, the physician would be allowed to reduce, as far as possible, the number of conclusions generated by the system.

In general case DDSS are not intended to replace the physician, their role being to give clinician recommendation on his request or to draw 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).

3 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).

Besides the difficulties of ultrasound image processing, because of the speckle, tissue related textures and artifacts, this source of information is still significant for diagnosis decision making. 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.

It should be stressed that consecutive losses of the information accuracy are inherent to the process of ultrasound examination. An analog signal transmitted by the probe is converted into a digital one and used to construct an image that quite subjectively (depending on qualification and experience) is interpreted by the operator. To overcome such shortcomings the information systems are developed with the purpose to reduce the influence of subjective factors by assisting in the examination process [5], [6], [7]. These systems can be used to get a second opinion, helping the physician-ecographist to make better interpretations, to deduct conclusions, and to obtain higher-quality images.

Computer-aided diagnosis schemes has been subject to various research since 1980, when a number of medicine domains began to use computer assistance [8]. 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. Such systems are aimed at making the decisions based on comparison between the newly obtained images and the images taken from a database. These systems classify new images according to existing classification methods and/or provide the possibility to determine a similarity degree with images stored in the database. In case of an acceptable resemblance with an image, this is considered as a precedent and the current decision is based on the existing decision for this particular precedent.

- Knowledge-based systems. Such systems deal with decision making based on a description given by the user, and data and rules provided by the system. Most of these systems are informational-instructive with (or without) an additional diagnosis component.

A joint realization of decision making and image retrieval in DDSS development shows itself as a fruitful research direction. Usage of the domain-specific knowledge leads to better results in many applications, in medicine as well. On the one hand, medical imaging computer systems provide the medical practitioner with imaging techniques, leading to new explicit knowledge. On the other hand, informatics research helps in standardizing the image content, enabling comparisons across populations and facilitating new ways of thinking. 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 [9].

4 Decision support based on combination of knowledge-based and image-based techniques

In this section the system architecture solutions, which use various combinations of knowledge-based and image-based techniques, represented.

The first group of solutions provides decision support based on classified images, using the technologies and methods of artificial intelligence (AI). The typical system architecture in this case consists of the following steps: preprocessing, features extraction, usage of AI methods for decision making.

Setting of regions of interest (ROIs) [10] is an aspect that is actively used and should to be noted. ROIs concept helps to facilitate the process of medical knowledge acquisition. ROIs marked by expert can be associated with some domain knowledge instances, for example, the image subjects in the ontology.

ANALYSIS [11] is a CAD system designed to assist in the interpretation of vascular ultrasound images. The role of image preprocessing in the system can be defined as a typical one for this kind of architecture. Improvement of images quality is very important for the effectiveness of subsequent tasks, such as definition of ROIs and feature extraction. According to AI technologies, ANALYSIS uses a vector of texture and motion features for fuzzy c-means classification. The selected features set is fed into a group of neural network classifiers.

A tool for finding of visual pathologies artifacts in mammographic images was proposed in [12]. It also has the typical architecture. But, the authors of this system declare a completely automated approach. The AI technologies in this case are represented by ROI characterization using textural features, computed from gray tone spatial dependence matrix, and ROI classification by means of a neural network. The system has wide possibilities for evaluation because of its large database of mammographic images.

An automated approach is also proclaimed for the system described in [13], directly aimed at retrieval of medical images to support neurology diagnosis. In this case, the differential diagnosis information related to specific image characteristics is defined by experts.

A system for classification of brain tumor in computed tomography scan brain images is proposed in [14]. The system architecture is similar to a typical one, but has several AI-related steps. The decision tree classification assists the physicians to classify unclear images. For this hybrid system (imaging and AI techniques) it is also typical, that the association rules for decision trees are constructed basing on images themselves, but not on domain knowledge.

The second group of solutions gives the decision support based on knowledge, acquired using image processing and retrieval technologies. The architecture of such systems provide a kind of parallel work of image processing/retrieval and AI-based techniques. After all required information is obtained during these parallel steps, the decision engine interprets the results and offers advice to the user.

A system for detecting a diffuse lung disease pattern in high resolution computed tomography lung images, proposed in [15], is an extended variant of the images-based systems, and uses AI technologies as a support. The architecture of this system has an additional step verification of the decision. To perform this step researchers use domain knowledge about the structure of lung, as well as expert knowledge about the appearance of diseases. A model for human lung is created basing on domain knowledge. The algorithms automatically generate visual lung regions according to the anatomical sense of notions, frequently used in disease reporting.

EchoCardio Lab [16] of the European HEARTFAID Project is an infrastructure providing integrated management of different type data of echocardiography workflows. Decision support services and image analysis facilities interaction is implemented in the frame of this infrastructure.

A research in breast cancer, grading using a knowledge-guided semantic indexing of histopathology images, is described in [17]. Its architecture is the most successful one in representation of joint usage of knowledge-based and image-based techniques. The creation of association between the meaning and features, extracted from the image, is done according to domain knowledge (the domain knowledge modeling is provided, starting with the domain ontology). The algorithm performs a segmentation of images and processes the object recognition phase (features extraction step) as an input for the semantic classification step. The conceptual annotations are rule-based defined in the grading model for every particular frame and globally transmitted for the entire case.

From the above analysis (that does not purport to be a comprehensive one) we can conclude that three points of major importance, influencing essential the success of DDSS, are the following:

- Knowledge acquisition and presentation;
- Image processing and search for similar ones (with extraction of knowledge from the images);
- 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 system.

5 SonaRes solution

The SonaRes decision support system [7] provides a second opinion for specialists, experienced or not, with necessary explanations and images that are similar to the currently examined case.

SonaRes system combines two basic approaches of ultrasound diagnostic systems development by assisting the decision making process on the base of both rules and images.

The main components of the SonaRes system are:

- Module of knowledge acquisition and validation;
- Integrated database (of knowledge, images, annotations, examination reports templates) and tools for its management;
- Tools for the examination process support;
- Image processing module, including algorithms for fast retrieving of similar images;
- Generator of examination reports.

Here is a brief presentation of the SonaRes components.

The first module – knowledge acquisition and validation – is designed to support effective communication with experts in the development of the knowledge base. It is created as an expert shell. The main stages of the development are: problem identification, knowledge acquisition, structure definition, formalization and implementation. The experience of experts and the medical specialty literature served as the main sources of knowledge.

In order to develop the methodology and technology, which can be extended to the whole abdominal region, the gallbladder and pancreas were selected. The necessary knowledge for the examinations of these organs was obtained from physicians who have vast experience in ultrasound diagnostics, consisting of:

- Structured information about organ localization, including the method of visualization of typical areas, objective conditions for visualization, considerations about possible non-visualization, objective conditions for a difficult visualization;
- Descriptors of the main characteristics of organs (number, size or volume, shape, contour, etc.);
- Structured information about pathologies and anomalies, each of them being determined by the characteristics of organ modifications (anomalies of shape, size, quantity, etc.).

The knowledge obtained from the experts is stored in the knowledge base and presented as a tree structure.

The second component is the integrated database of images, annotations and examination reports.

The tools aimed to support the examination process, included into the third component, allow to select one of the main ways of examination, corresponding to the physician usual methods of work:

- Step by step, i.e. studying the obtained image, the physician selects the attributes from a list and sets their values. Depending on the values of selected attributes, one or more conclusions are proposed, corresponding to the rules from the knowledge base. The conclusion may be accompanied by an image, in which ROIs are highlighted, if the diagnostician thinks that this is necessary for the physician who administrates the treatment. Following a special request, the annotated images from the integrated database, similar to the one obtained in the current examination, are retrieved and presented, that allows validation of the diagnosis on the base of similar cases solved by experts. This method allows to reduce the time required to obtain a conclusion, i.e. an examination result, raises the diagnosis quality, promotes the formation of correct actions and mentality in the field of ultrasound diagnostics. This is a very important point in professional training, encouraging use of correct terminology.
- From the presumed pathology to its confirmation or refection. In this case the physician determines if the rules marked by the system as appropriate for the currently examined case correspond or not to the presumed pathology. This way can be used by more experienced physicians.
- Mixed way, which allows the clinician to alternate in the examination process both procedures.

To assist in the examination process, a thesaurus has been developed. A sufficient number of terms should be contained in this thesaurus, providing a clear picture of the full spectrum of clinical concepts. It can be used autonomously as an encyclopaedic reference book, but also for the help function that is integrated in the examination interface for a quick access to explanations of terms that appear in the examination process. For each term its definition is given, along with synonyms and translations (for national and international users). The encyclopaedic reference book is also supplied with videos (remember that in ultrasonography the organs can be seen dynamically). Queries of the thesaurus can be made through various criteria: key words, combinations of words, search by topic.

The fourth component performs image processing (preprocessing) and search of similar images. Because of the shortcomings of ultrasound images mentioned above, for the beginner in ultrasound examination or for a physician with lack of experience it is difficult to identify the organ pathology based only on one image. Thus, it is useful to provide a quick search for images similar to one obtained in the examination process.

To provide the ROIs marking and attaching of the rules to the images, several special tools, which are part of the SonaRes toolkit for experts, were developed. These tools implement three types of visualization for the ROI-related expert actions: (i) setting the correspondence of ROI with the node of the knowledge tree for an organ; (ii) review of the all ROIs that correspond to the chosen node, on different images; (iii) review of the all ROIs (for different nodes) corresponding to the chosen image.

The SonaRes system collects a set of model images attached to the corresponding rule, with ROIs defined for a particular pathology. The role of annotated images in decision making is to provide help by illustration, in cases when the medical specialist is not sure how to interpret correctly the images.

In the case of ultrasound images, the most fruitful method for retrieving similar images seems to be the application of both medical features (obtained from a knowledge base) and visual features (obtained from images). In this case formalized knowledge is used to classify the images and reduce the retrieval. Medical similarity allows the confirmation of the diagnosis assumption by obtaining a gallery of images marked by experts as containing the supposed pathology or fact (for example: is this a stone in the kidney?). Visual similarity allows the determination of pathology or fact by presenting the list of rules in the knowledge base that correspond to graphical features found in images.

The general-purpose methods of Content-Based Image Retrieval (CBIR), used in SonaRes, are developed and tested in the frame of Image Retrieval in Medical Application (IRMA) project [18]. To provide the integration of knowledge accumulated in SonaRes (facts, rules, annotated images) and IRMA algorithms of medical images storage and processing the CASAD (Computer-Aided Sonography of Abdominal Diseases) system was developed [19]. It represents a data warehouse of standard referenced images. The scheme of interaction and data exchange between SonaRes, CASAD, IRMA systems is presented below (see Fig.1).

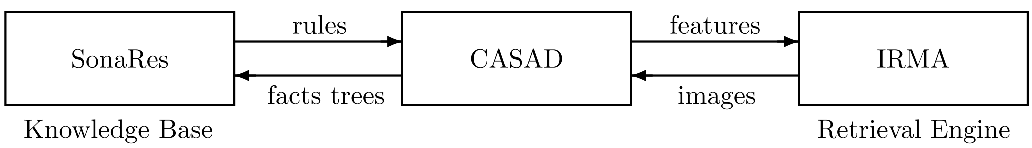

Fig. 1 – Scheme of three systems interactions

The CASAD as data warehouse supposes two main functions:

1. to add new image to warehouse;

2. to retrieve images similar to the pattern image uploaded by user.

Both functions are based on image classification criterion. In the case of new image adding classified image is added to the warehouse. In the case of image retrieval the set of images belonging to the same class that the pattern image is presented.

The last component of the system is generator of examination reports. Traditionally, the medical conclusion of the examination consists of: data about patient, image, quantitative measurements in the examination, and the physician conclusion in an arbitrary form. The examination report given out by the SonaRes contains structured data, obtained during the examination, and the conclusion consists of the rules corresponding to the measured values. Data that can not be obtained during the investigation session, and bearing a specific nature (requiring biochemical or other analysis), are recorded by the physician in his usual free form.

The process of system development was an iterative one. As a result, 54 decision rules for the gallbladder and 52 decision rules for the pancreas were formulated. The analysis of the obtained rules shows that, in addition to the normal state and anomalies, we also embraced all basic groups of pathologies. The specific of pancreas required additional information for 34 help files.

6 Conclusion

The concept of the SonaRes system was described for the first time in [7]. Further research, described in this article, has allowed to improve characteristics of all modules of the system and to create the prototype with the following peculiarities:

- guidance of the examination process, adapting it to different levels of physician's experience;
- support for reporting, assuring common standards;
- prevention of possible errors in the examination process (e.g. omitting of some important aspects, skipping some characteristics or admitting some inaccuracy in the formulation of conclusions);
- possibility to use experts' experience, collected in the SonaRes database, in the form of annotated images, similar with the one under examination;
- processing of captured images in order to increase their quality or to better distinguish some special regionas or characteristics;
- possibility to be used for professional training;
- storage of investigation records (having possibility to observe the disease dynamics, to collect statistics, etc.).

This prototype has been tested by the group of experts-physicians and can be recommended for dissemination.

The SonaRes system can be widely used by all categories of physicians as a support for the examination process. Also, the system can be used by experienced physicians when examining some difficult cases, by physicians practicing in isolated areas or those with limited access to experts, as well as by novices and those studying the ultrasound diagnosis domain.

Acknowledgement: This paper is partial founded from the research Grant 10.820.08.06/RoA, the common project of the Academy of Sciences of Moldova and the National Authority for Scientific Research of Romania.

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