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IMAGES AND RULES-BASED DECISION SUPPORT SYSTEM IN ULTRASOUND EXAMINATION OF ABDOMINAL ZONE

LYUDMILA BURTSEVA, CONSTANTIN GAINDRIC and AND SVETLANA COJOCARU

Institute of Mathematics and Computer Science of the Academy of Sciences of Moldova, Chişinău, Republic of Moldova
Chişinău, MD2945, Miron Costin str. 15/2, ap 12;
E-mail: burtseva@math.md, Svetlana.Cojocaru@math.md
Corresponding author: gaindric@math.md

Two main approaches are used in the development of computer-aided decision support systems in medicine: (i) based on the processing of images obtained during medical investigations, (ii) based on rules. At present, various combinations of these two techniques become more adequate and assure a great perspective for this domain.

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

Key words: decision support systems, ultrasound diagnostics.

1. INTRODUCTION

Diagnosis is one of the most difficult task clinicians may face every day. Early detection and diagnosis of suspicious lesions allow earlier intervention, which leads to a better prognosis for patients [13].

Computer-aided diagnosis (CAD) schemes are subject to various researches since 1980, when a number of medicine domains begun to use computer assistance [9]. The research concerned the application of artificial intelligence (AI) techniques and methods as support for the diagnosis process. On the other hand, during these years, huge databases of medical images were created and became a powerful source for decision making. Considering these tendencies, two main approaches to create CAD systems can be distinguished:

(i) Image processing systems. Such systems aim at making the decisions based on the comparison between the newly obtained images and the images taken from a database. These systems classify the new images according to existing classification methods and/or provide the possibility to determine a degree of similarity with the 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.

(ii) Rule based systems. Such systems deal with decision making taking into consideration 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.

The mutual employment of decision making and image retrieval in CAD development shows itself as a profitable research direction. On one side, medical imaging computer systems provide the medical practitioner with imaging techniques, leading to new explicit knowledge. On the other side, the informatics research helps in standardizing the image content, enabling comparisons across populations and facilitating new ways of thinking. The usage of the domain-specific knowledge leads to better results in many applications. Moreover, research in medical image analysis tries to find links between image features and knowledge in order to be able to fulfill quantification tasks and to answer prognostic questions [5].

The ultrasound examination of patients, being non-invasive and not expensive, is a basic technique of medical imaging. 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, using this technique does not always come up to expectations, encountering some difficulties associated with the dependence on the 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, information systems are developed with the purpose to reduce the influence of subjective factors by assisting in the examination process. These systems can be used as a second opinion, helping the physician-ecographist to obtain higher-quality images, and to formulate better interpretations and conclusions.

In this article, the state of the art of the domain of mutual employment of knowledge-based and image-based technologies in the decision support systems design is presented. Some interesting implementations of combination of methods are described in Section 2. Some approaches used to overcome difficulties related to ultrasound images processing are characterized in Section 3. Section 4 contains a presentation of the SonaRes decision support system, designed to assist the diagnostician in the examination process of the abdominal zone - particularly difficult because numerous organs are located in a relatively small space and there is a need to take into account their interaction.

2. DECISION SUPPORT BASED ON THE COMBINATION OF KNOWLEDGE-BASED AND IMAGE-BASED TECHNOLOGIES

In this section, the system architecture solutions using various combinations of knowledge-based and image-based techniques are presented.

The first group of solutions provides the decision support based on classified images using the technologies and methods of AI. The typical system architecture of this type consists of the following steps: pre-processing, features extraction, usage of AI methods for making a decision.

ANALYSIS [14] is a CAD system designed to assist the interpretation of vascular ultrasound images. The role of image pre-processing in this system can be defined as typically for this kind of architecture, as improving the quality of images is very important for the effectiveness of subsequent tasks, like the definition of regions of interest (ROIs) and feature extraction. According to AI technologies, ANALYSIS uses a vector of texture and motion features for fuzzy c-means classification. The selected feature set is fed into a group of neural network classifiers.

The tool for finding visual pathologies artifacts in mammographic images proposed in 2006 in [3] also has the typical architecture. But, for this system, the authors declare a completely automated approach. The AI technologies in this case are represented by ROI characterization using textural features computed from the gray tone spatial dependence matrix, and ROI classification by means of a neural network. This system has wide possibilities for evaluation because of its large database of mammographic images. The automated approach is also proclaimed for the system described in [10], directly aimed at retrieving medical images to support the neurology diagnosis. In this case, the differential diagnosis clinical information related to specific image characteristics is defined by experts.

In the system for the classification of brain tumor in CT scan brain images, proposed in [11], the system architecture is similar to a typical one, but has several AI-related steps. The decision tree classification AI technology (with an association rule classification method) assists the physicians to classify unclear images. For this type of hybrid – imaging & AI techniques construction – is also typical that the association rules for decision trees are constructed on the basis of images themselves, and not on domain knowledge.

IT-CADe system [16] skips the step of features extraction providing a so-called featureless, i.e. information-theoretic (IT), similarity measures. IT-CAD makes decisions by evaluating the queries average similarity. The *random mutation hill climbing* algorithm is applied to select a concise set of knowledge cases, and then a support vector machine is used to derive a decision rule using the relational representation of cases.

The second group of solutions provides the decision support based on knowledge acquired using image processing and retrieval technologies. The architecture of such system provides 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.

The system for detecting a diffuse lung disease pattern in HRCT lung images proposed in [20] is an extended variant of the systems based on imaging and uses AI technologies as support. This system architecture has an additional step – the decision verification. To perform this step, researchers use the domain knowledge about the lung structure as well as expert knowledge about the appearance of diseases. The domain knowledge is organized as a model for the human lung and there are algorithms which automatically generate visual lung regions, according to the anatomical sense of notions, frequently used in disease reporting.

CADMIUM [1] is a system for diagnosis of mammograms that combines image processing with symbolic representations of clinical decisions. Decision support is provided by mapping between imaging measurements and the symbols in the knowledge base constructed from expert knowledge. Radiological information is represented as a set of arguments, i.e. the amount of information that a radiologist would weigh up, whereas the decision rules define each descriptor in terms of combinations of imaging measurements.

FP6-IST European Project HEARTFAID "A knowledge based platform of services for supporting medical-clinical management of the heart failure within the elderly population" (IST-2005-027107) [7] is a system whose architecture is typical for such solutions. Image processing methods are used in the knowledge representation process for embedding parameters extracted from different data acquisition channels.

The system proposed in [18] is an adaptive knowledge-driven medical image search engine for an interactive quantification of the diffuse parenchymal lung disease. This system is not declared as a decision support system, but has its typical architecture. The knowledge database is initially filled with selected images on which volumes of interest (VOIs) are marked by experts. Then the VOIs are processed and volumetric features are extracted. The parametric statistical models for each disease class along with their optimal feature sets are learned and stored in the knowledge database.

The research in breast cancer grading using a knowledge-guided semantic indexing of histopathology images, described in [17], provide the architecture that is the most successful in the representation of mutual usage of knowledge-based and image-based techniques. The establishment of an association between the meaning and features extracted from the image is done according to the 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 based on criteria rules modeling. The conceptual annotations are rule-based defined in the grading model for every particular frame and globally transmitted for the entire case.

3. OVERCOMING THE DIFFICULTIES OF ULTRASOUND IMAGES PROCESSING

Because ultrasound is widely available and relatively inexpensive to perform, it has become a valuable diagnostic addition [15] to several medical domains. Decision support systems become leaders as perspective tools for reducing operator dependence in ultrasound sonography.

However, application of imaging technologies to ultrasound image processing has significant challenges. The classical image-segmentation techniques lose their performance because of the nature of speckle, tissue related textures and artifacts found in ultrasound images. To avoid losing such a rich information source as the ultrasound images, the enhancement and modification of image processing and segmentation techniques are evaluated by research group all over the world. The review [12], published in 2009, gives a bibliographical survey of the current research efforts in the area of image segmentation on static ultrasound images. Several current trends in the segmentation of ultrasound images are defined, including the use of: quantized neural networks, statistical shape models, discrete region competition approaches, level-set methods, hybrid boundary detection methods using watershed and methods based on texture and shape priors.

The computer-aided system for automated retrieval of similar carotid plaque ultrasound images [8] uses general type classifiers: the neural self organizing map and the statistical K-nearest neighbors. Specifically interesting in this research is the introduction of correlograms along to the histograms, computing not only statistics about the features of the image, but also taking into account the spatial distribution of these features.

Although the research domain of [2] relates to veterinary medicine - automatic cattle rib-eye area estimation, the ultrasound images are not significantly different to human ecographies. To provide automatic segmentation and cover the limitations of ultrasound images, the researchers proposed to use shape priors. Knowledge about the shape is introduced by using a set of images manually segmented by the experts. This knowledge defines a typical shape and its possible variations starting from an initial shape of pathology.

The ultrasound examination is used in mammology and shows even more sensitivity (91%) in comparison to mammography (83%) [12]. In [19], research concentrated on the automatic extraction of the morphologic features of breast lesion on ultrasound images. They use a priori rules, represented by rectangular ROI, segmented by experts, and introduce three new morphologic feature measures based on domain knowledge.

A major stage in the automatic analysis of ultrasound images is to find areas occupied by a specific organ. The paper [4] presents a method for filtering the gallbladder contours on static ultrasound images. Using a wide palette of image processing methods, the system makes the step correction by expert defined initial organ shape.

4. SONARES SOLUTION

The SonaRes decision support system [6] provides a second opinion for specialists, experienced or not so experienced, with necessary explanations and images that are similar to the currently examined case.

SonaRes system combines the two basic approaches of ultrasound diagnostic systems development by assisting the decision making process on the base of both rules and images. So, the SonaRes system collects a set of model images attached to the corresponding rule, with ROIs (region of interest for a particular pathology) defined. 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 correctly interpret 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. 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 definition of the supposed 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 [21]. To provide the integration of knowledge accumulated in SonaRes (rules, annotated images) and algorithms of medical images storage and processing of IRMA the CASAD (Computer-Aided Sonography of Abdominal

Diseases) system of type of data warehouse of standard reference images was developed. The scheme of interaction and data exchange between SonaRes, CASAD, IRMA systems is presented below (see Fig.1).

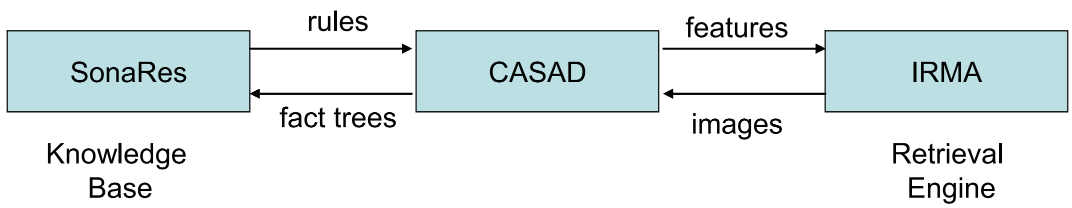

Fig. 1 - Scheme of three systems interactions

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.

The meaning of both of these functions is image classification. In the case of new image adding function classified image is added to warehouse. In the case of the system output is the set of images belonging to the same class that the pattern image was classified.

Summing implementation necessities of both rules and image based techniques the SonaRes system architecture was designed.

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 for 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 entire abdominal zone, the gallbladder and pancreas were selected. The necessary knowledge for the examinations of these organs was obtained from physicians who have extensive 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 physicians' usual methods of work:

(i) 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 which correspond to the rules from the knowledge base satisfying the obtained values. The conclusion may be accompanied by an image, in which regions of interest 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 that are similar to the one obtained in the current examination, are retrieved and presented, which allows the validation of the diagnosis on the base of similar cases solved by known experts. This method allows the reduction of 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, which is a very important point in teaching, encourages the use of a correct terminology.

(ii) From the presumed pathology to its confirmation or denial. Following this path, 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 path can be used by more experienced physicians.

(iii) Mixed path, which allows the clinician to alternate in the examination process both the procedure starting from pathology and the one taken step by step.

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 encyclopedic 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 process of examination. For each term its definition is given, along with synonyms and translations (for national and international users). The encyclopedic 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 the search of similar images. Because of the shortcomings of ultrasound images mentioned above, for the beginner in ultrasound examination, and even 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 that obtained in the examination process.

First, all the images from the database are classified (clusterization I), depending on the organ diagnosis – if there is any pathology or an organ normal state description. The organ diagnosis is based on the qualitative and quantitative values of the descriptors – characteristics of the organ, which are defined by a physician-ecographist in the examination process. Further clusterization (clusterization II) is carried out depending on the image statistics. It is necessary to identify regions of interest by calculating the difference between the investigated image and images from the database.

Therefore, some statistical descriptors (e.g. histograms, mean and standard deviation of the intensity of the image, the average standard deviation of the intensity of the zone) were calculated for each image. The advantage of these statistical descriptors, compared to the others mentioned above, is that they are independent from the experience of the physician and refer to a particular image.

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 usage of image retrieving was described above as a part of SonaRes web-interface. For obtaining a more precise result, the user has to set his own ROI on uploading the pattern images. After the retrieval process is finished, the web-gallery of similar images is shown. The image 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 and its annotation. This annotation can be used as a description for pathology diagnosis on the pattern image.

The last component of the system is the generator of examination reports. Traditionally, the medical conclusion of the examination consists of data about patient, the 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, while 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, especially the procedure of knowledge acquisition. As a result, 54 decision rules for the gallbladder and 37 decision rules for the pancreas were formulated. The analysis of the 54 rules obtained for the gallbladder 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 25 help files.

The SonaRes image database consists of 166 representative graphical resources concerning the gallbladder and pancreas examination, mainly stored in ‘jpg’ and ‘bmp’ files formats. 224 of ROIs were marked out on static images, being associated with 127 distinct nodes of the knowledge pyramid.

Finally, we obtain a system with the following characteristics:

- guidance of the examination process, adapting it to different levels of physician's experience;
- support for reporting, assuring common standards;
- prevents possible errors in the process of examination (such as omitting the examination of some important aspects, skipping some characteristics or admitting some inaccuracy in the formulation of conclusions, etc.);
- offers the possibility to use experts' experience, which is collected in the database of the system, in the form of annotated images, similar with the one under examination;
- processes captured images in order to increase their quality or to better distinguish some special zones or characteristics;
- offers the possibility to be used for training;
- stores investigations as records in electronic format (to have the possibility to observe the disease dynamics, to collect statistics etc.).

The 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.

5. CONCLUSIONS

The practical testing of the SonaRes system, which combines the two basic approaches of ultrasound diagnostic systems development, assisting to the decision making process on the base of both rules and images, proves the advantages of such a system. Further research will be aimed to implement more complex ways of mutual correlation between decision making and image retrieval techniques. Applying advanced methods of image processing and retrieval in ultrasonography opens the opportunity to acquire new inner medical knowledge. A special attention will be paid to the organ interaction, which can be reflected in specific pathologies.

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