AN INTELLIGENT DECISION SUPPORT SYSTEM FOR SCREENING MAMMOGRAPHY

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Abstract: The paper presents the first results of a Computer Aided Diagnosis (CAD) system development project for automatic detection of breast cancer. The primary aim of the R&D project is to develop an intelligent decision support system for analyzing mammographic images, and to help radiologists in making diagnosis. The paper presents the main goals of the project, the architecture of the advisory system and some general experiments obtained during the system development. The first results show that analyzing individual images can result in good sensitivity values, while the false positive marks/image is rather high. The false positive marks can be reduced only if joint analysis of all four images are done.

Introduction

Breast cancer is the most common form and the second major cause of cancer among women. According to statistics, 8% of women will develop it in her lifetime. Thanks to recent advances in medicine, there are effective methods in the treatment. The sooner the illness is detected, the more effective the treatment is. If detected early, the five-year survival rate exceeds 95%. For early detection of breast cancer currently screening mammography is the most effective way [1]. Women aged 40-49 showed about 17% reduction in mortality 15 years after screening had started and women in the ages of 50-69 showed a reduction of 25-30% [2].

Screening mammography is an X-ray examination. In a mammographic session four X-ray images (two views - typically craniocaudal (CC) and mediolateral (ML) views) of the two breasts are taken. The images are used to detect signs of abnormalities and judge their severity: to differentiate benign and malignant cases.

Most of the mammograms are normal, but an enormous number of images must be evaluated. As an example this means around one million images per year in Hungary, if global screening were done (women over 40 are screened periodically in every second year). The diagnosis of this amount of images takes very long time of skilled radiologists and can produce human errors due to the length and monotony of the process. To reduce miss rate of human diagnosis usually double readings of mammograms are applied, when two radiologists – independently of each other – diagnose all cases. The mammographic advisory system can improve the efficiency of screening either by replacing the second radiologist or by drawing the attention of the radiologists to suspicious areas of the images. A further possibility of utilization of such a system is to support specialists by filtering out normal images. It could save time and could help avoiding (or at least reducing the number of) false diagnoses.

This paper deals with the development of such a system by a consortium of medical doctors, intelligent system researchers and software engineers. In this paper the main architecture of our CAD system (ODR) is presented, and some results of the different steps are introduced.

The importance of the breast cancer problem is well-known for decades, but the theoretical and technical background for supporting the task with an intelligent CAD system are only available for a few years. Our project's main contribution to this area is twofold: we develop intelligent algorithms for automatic breast cancer detection and a large-size mammography image database is being built where each image is stored with diagnosis (by skilled radiologist).

First we introduce the system architecture we set up for supporting the project, then we describe the main parts of the computer aided diagnoses solution. The paper presents the main steps of the information processing and gives the first test results obtained using more hundred cases from the DDSM database [3]. Some details of the detection of abnormalities in mammographic images are given in accompanying papers [4], [5].

The mammographic advisory system architecture

A distributed architecture based CAD system was implemented in the project. This infrastructure was primarily designed to help the development of automatic detection algorithms. The environment supports all parts of the project, starting from scanning X-ray films, offering an enhanced viewer to help radiologists in labeling the images with diagnosis data and offering medical imaging standard DICOM interface for communicating with the automatic diagnosis module.

The main role of the system is to support the development of an automatic mammography diagnostic

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system but it was an important goal to create a system that can work in the future as a standalone mammographic workstation. For developing and testing diagnostic algorithms a large number of qualified cases, a large database is required. In the whole project two large databases were used. The first one is a public database constructed in University of South Florida. This Digital Database for Screening Mammography (DDSM) [3] is a large set of well diagnosed cases which is a collection of images of rather various normal, benign and malignant patients. It contains 2620 cases (each case contains for images).

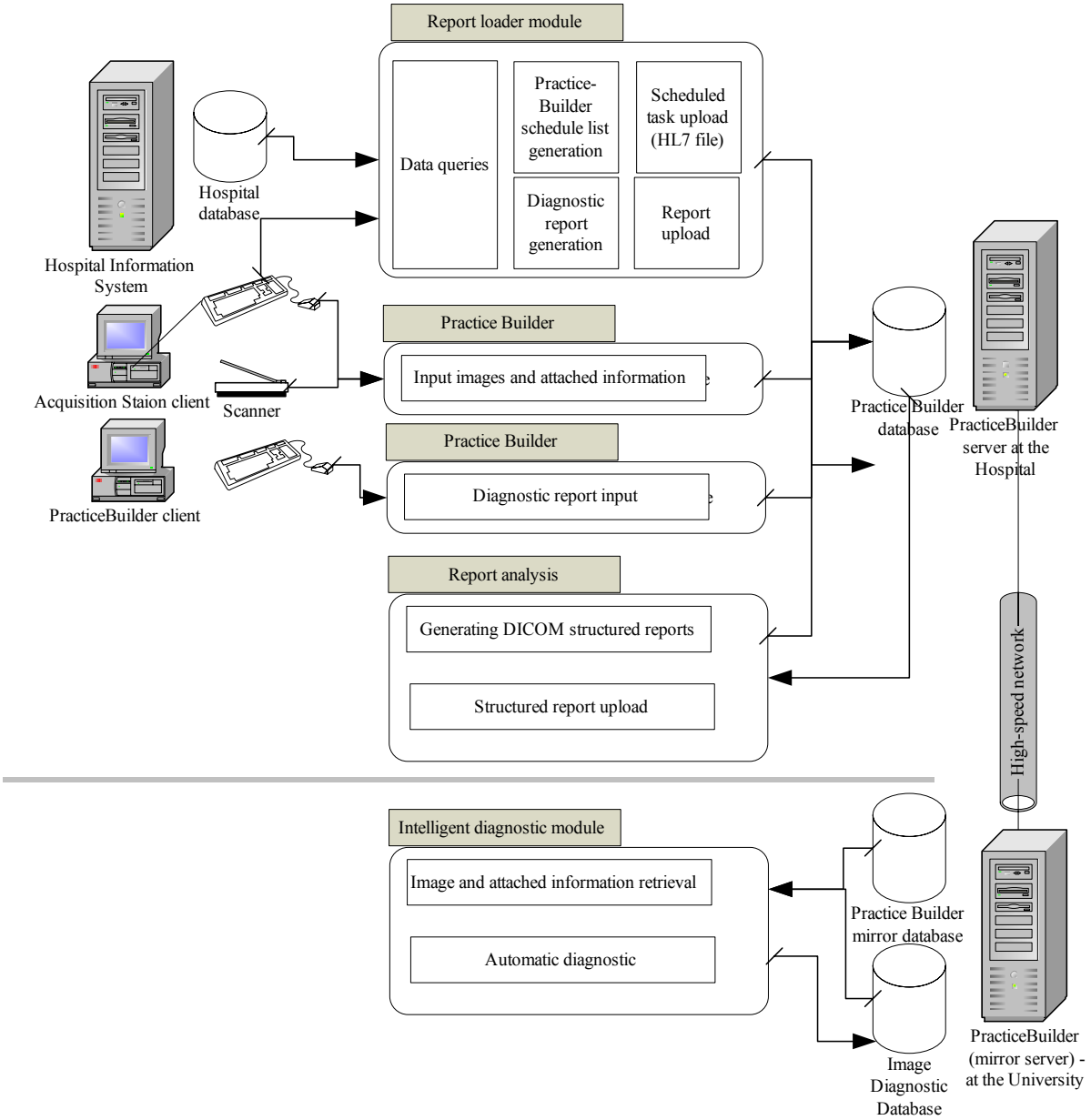

Figure 1: The infrastructure of the project

The second one is constructed by a Hungarian medical doctors' team. It is much smaller than the DDSM database, however it has some special features that are important for the success of the project. The main reason to deal with two large databases is to use different images for developing the system and for the final testing. In the development phase DDSM is used, while the Hungarian database mainly serves testing. In testing it is especially important that the images and all other available information would be similar to the everyday screening mammography examinations done in Hungarian mammography centers.

The structure of the two databases is different. In DDSM the ratio of the cancerous cases to all cases is much higher than in the normal screened population, while the Hungarian database is developed from the cases obtained during the everyday activity of a mammographic screening center.

An important characteristic of the data store is that the size of a single image is some megabytes itself, so

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the infrastructure should be able to work with some hundreds of gigabyte data that needs special considerations in designing data archive and communication services of the system.

As a result of the mentioned requirements the built system infrastructure (Figure 1) supports the following main tasks:

- digitalization and upload of mammography images from films, attaching relevant patient and image data,
- graphical interface for viewing and analyzing the images,
- marking, inputting and storing diagnostic information
- and providing services for searching, filtering and using selected images.

The system can be reached by users at two locations in parallel. Image upload and providing diagnosis were performed at the hospital participating in the project, meanwhile the development of automatic diagnostic algorithms was done in the Technical University. The development work is supported with a mirror server that is connected through high-speed network to the server in the hospital. The whole system is used by multiple users at the same time that is served by the web client/server solution based on the PracticeBuilder application of ImageMedical Inc. [6].

The tasks of the CAD system in mammography

The computer-aided diagnosis for mammography is a rather hard task because of the great variability of the mammographic images. Suspicious lesion detection is an ill-defined problem. In several cases the pictures are taken from such breasts, where the breast tissue is very dense and no details or only a few details can be observed in the mammographic images. These cases are hard to diagnose even for skilled radiologists. A study of more than 27.000 patients showed that (traditional) mammography missed up to 50% of cancers for dense and 36% in moderately dense breasts; only the fatty breasts can be diagnosed by skilled human radiologists with as low as 2% of miss rate [2].

A further problem is that there are many patterns in the images caused by normal breast tissues, which are very similar to patterns of malignant areas. These patterns can be differentiated only if both local information gained from the pattern, and global information obtained from all four images of a patient are taken into consideration. A further difficulty may come if the quality of the images is poor.

So far many reports, papers have been published about mammographic CAD systems (e.g. [7]-[11]). Some of these systems are applied for traditional screen-film mammography [8], [9], but the real advantages can be achieved if they are used for full-field digital mammography [10]. Digital mammography uses digital detectors that produce electrical signals when exposed to an X-ray source. Digital mammography has the potential to improve breast cancer and breast lesion characterization. For traditional screen-film mammography a CAD system can be applied only after the images are scanned, but scanning may result in degradation of image quality (contrast, spatial resolution dynamic range, etc.). Our system has been developed for screen-film mammography, however it is believed that the system can be applied for digital mammography as well.

The goal of our project is to develop a complex system to relieve radiologists from lots of monotonous tasks. The logical architecture of the system developed is shown in Figure 2. The role of the different boxes are explained as follows:

Current Images: In each mammographic session four pictures are taken. In the first processing steps each image is investigated separately. After some steps the localization and classification of the suspected abnormalities are improved using the two images (CC and ML) of the same breast. At the end asymmetry of the left and right breasts is investigated using e.g. texture analysis.

Archived Images: If the images of a previous mammographic examination for the same patient are available, then the change of suspected abnormalities is checked.

Anamnesis Data: Several personal parameters of the patient influence the probability of breast cancer development e.g. the family records (were similar diseases in the family or not), the profession etc. Therefore in the final evaluation the diagnosis depends on that data as well.

Preprocessing: There are several important tasks before the diagnostic evaluation of the images can start. Because some of the pictures are of poor quality image enhancement methods should be applied [12]. Histogram equalization, filtering, denoising, edge enhancement, etc are the most important preprocessing steps. The parenchymal patterns are patient dependent and probably different methods are optimal for the diagnosis of different basic patterns. Therefore in the preprocessing step the basic parenchymal type is determined.

Detection: Several methods of determining the location of suspected abnormalities were suggested in the literature, but none of them gives solution for every type of abnormalities in every tissue. Two types of abnormalities are of primer importance; reliable detection of microcalcifications and lesions must be solved. Several methods were suggested especially for microcalcification detection e.g. classical image processing algorithms, morphological operations, neural network based methods, texture analysis, heuristic methods, wavelet transform based methods, etc. Some of these procedures (e.g. neural nets) can be used for lesion detection as well. Of course there are some special algorithms for suspicious mass localization like image segmentation based on different approaches (e.g. edgeflow algorithm [13]), AFUM algorithm [14], etc. The details of microcalcification and mass detection algorithms are presented in accompanying papers [4], [5].

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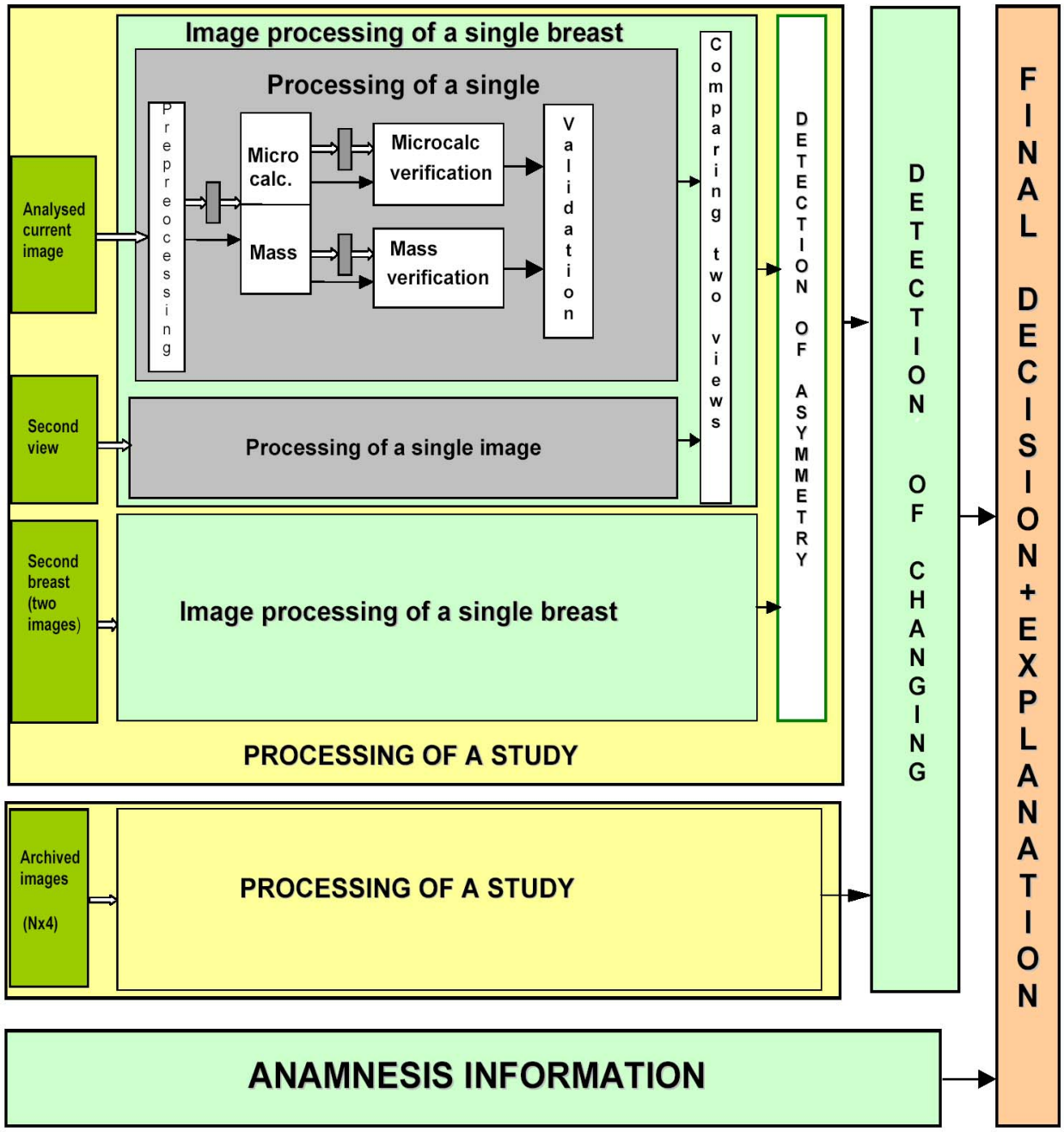

Figure 2: The logical architecture of computer-aided diagnosis

Besides calcification clusters and masses there is a third type of abnormalities, which should be detected by a CAD system. This abnormality is called architectural distortion. The special feature of this abnormality is that it is hardly detectable in one image. It can be detected only if the corresponding images of the left and right breasts are analysed together. The main characteristic of architectural distortion is some kind of asymmetry [15]. Perhaps this is the most difficult task in mammographic image analysis. The system in its present state is not able to detect these cases; only some preliminary results are obtained that are based on the detection of some "fuzzy" asymmetry. Fortunately architectural distortion is not a common symptom, so the general hit rate of the whole system is not decreased significantly because of the lack of this capability.

As plenty of algorithms are available and no single algorithm solves even one of the detection problems perfectly, in the final system several methods are applied parallel and the results of them are integrated to get a final qualification of a case. An important feature of the final system (although this will be implemented only in the near future) is that it will give explanation about the detected lesions, to help radiologists to form the final diagnosis.

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Justification: When suspicious locations are detected in a mammogram, some different algorithms are used to justify or reject the hypothesis. This step is needed because the detection algorithms tend to give even in an absolutely normal mammogram 2-5 suspicious locations. Several parallel methods are used in that step - heuristic methods, some shape description and evaluation procedures for lesions, joint analysis of the 4 images of the two breasts, comparison of the current images to previous ones etc.

Classification: In the classification step a diagnosis is established based on the images only. The diagnosis consists of the findings, and some probability-like measure estimating the reliability of the diagnosis.

Decision: In this final step the anamnesis data are integrated to the information extracted from the images and the best possible diagnosis is determined.

The present status of the system

The proptotype of the system is developed and the first test results have been obtained. These tests were used to validate the different algorithms for calcification cluster and mass detection using single images only. Validation means that both the hit rate and the miss rate of the different algorithms are estimated. The goal is to reach high sensitivity value, (to detect almost all true positive cases) while keeping the number of false positive findings/image as low as possible. These two requirements are against each other: increasing sensitivity will increase the false positive rate as well. During the validation process some parameters or features of the individual algorithms have been adjusted in such a way that sensitivity is around 90%. As a consequence the value of false positive marks per normal image is in the range of 2-5, which is relatively high. (see Table 1.)

The reduce this value joint analysis of the two views were applied. This joint analysis is a "2.5 D" reconstruction of the 3D breast from the two (MLO and CC) views. The details and the results are presented in [16].

Table 1: Test results of the ODR system

	No. of cases	**Detected by ODR**	**Sensi-tivity**	**False positive marks /image**
Mass cases	362	320	88.5%	4.6
Micro-calcifi-cation cases	141	129	91,5%	2.3
All cases	**503**	**449**	**89,3%**	**3.95**

Conclusions

The paper describes the main goals of a mammographic project. These are: to develop an infrastructure for getting scanned images which were diagnosed by human experts, to develop algorithms (using different approaches) for detecting abnormalities in mammographic images and to develop a whole advisory system for screening mammography, where all available information is utilized. The first part is required only if traditional film/based screening is used, however the second part, the CAD system can be used for both traditional and full-filed digital screening mammographies.

The first phase of the work is finished: the whole infrastructure has been developed, and it has been used for building the Hungarian database. The second and most important phase, to develop a prototype advisory system is also finished. The system is under extensive testing and according to the test results refinement and extension are under way. The first results show that the sensitivity of the system is comparable to other similar CAD systems (see e.g. [176]), while the false positive marks/image value should be decreased further. From the whole project it can be concluded that because of the nature of this task only hybrid solutions - where the combination of entirely different approaches is applied - can promise results. The results achieved with these procedures are encouraging for building a mammography workstation.

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