State-of-the-Art of Computer-Aided Detection/Diagnosis (CAD)

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Abstract. This paper summarizes the presentations given in the special ICMB2010 session on state-of-the-art of computer-aided detection/diagnosis (CAD). The topics are concerned with the latest development of technologies and applications in CAD, which include brain MR images, fundus photographs, dynamic chest radiography, chest CT images, whole breast ultrasonography, CT colonography and torso FDG-PET scans.

Keywords: Computer-aided detection/diagnosis (CAD), medical imaging, image processing and analysis.

1 Introduction

With the rapid advances in computing and electronic imaging technology, there has been increasing interest in developing computer aided detection/diagnosis (CAD) systems to improve the medical service. CAD is emerging as an advanced interdisciplinary technology which combines fundamental elements of different areas such as digital image processing, image analysis, pattern recognition, medical information processing and management. Although the current CAD systems cannot fully replace human doctors for medical detection/diagnosis in clinical practice, the analytical results will assist doctors to speed up screening large populations for abnormal cases, generate medical records for interdisciplinary interaction on the relevant aspects for proper treatment and facilitate evaluation of treatment for clinical study.

In general, a CAD system consists of four major components: 1) image acquisition and data preprocessing for noise reduction and removal of artifacts; 2) image feature

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extraction and representation; 3) detection of region of interest (ROI) by image analysis based on segmentation and matching; 4) evaluation and classification by an appropriate decision-making scheme. The conventional CAD systems are focused on the applications to diagnosis of breast cancer, lung cancer, colon cancer, prostate cancer, bone metastases and coronary artery disease based on the analysis of X-ray or CT images. The extension of the existing medical imaging technologies and their applications were presented in the special session of CAD at ICMB2010 as reported in this short paper. Section 2 highlights these topics which include brain MR images, fundus photographs, dynamic chest radiography, chest CT images, whole breast ultrasonography, CT colonography and torso FDG-PET scans.

2 State-of-the-Art CAD Topics

This section briefly describes the recent research projects and their results on advanced CAD by 7 teams from Japan, Hong Kong and Australia respectively.

2.1 Brain MR Images

The brain check-up which is also referred to as "Brain Dock" is getting popular in Japan because of increasing average longevity. The aim of the Brain Dock is to detect or classify asymptomatic brain diseases in their early stages, e.g., asymptomatic lacunar infarction, unruptured intracranial aneurysms, early dementia, and to prevent such brain disorders. In particular, dementing disorders such as Alzheimer's disease (AD) and vascular dementia are major public health problems in countries with greater longevity, such as in Japan. The process applies the advanced imaging techniques like magnetic resonance imaging (MRI) and positron emission computed tomography (PET) for preventing various neurological conditions including stroke, dementia, etc.

The computer-aided diagnosis (CAD) systems for brain MR images play important roles in the Brain Dock, because it would be laborious for neuroradiologists to detect the lesions among a great number of images or a small number of patients out of many healthy people [1]. Moreover, it could be possible to miss the lesions of patients, because of their heavy workloads. In addition, the number of images, which neuroradiologists have to diagnose, has increased rapidly, because MRI has shifted from two-dimensional (2D) imaging to 3D imaging, and the resolution as well as signal-to-noise ratio has become higher. In neuroradiological field, the CAD systems are needed for not only the Brain Dock, but also the other brain diseases such as multiple sclerosis (MS). Therefore, in recent years, various types of CAD methods have been developed by many researchers including the author's group in the neuroradiology using brain MR images.

Radiologists expect that CAD systems can improve their diagnostic abilities based on synergistic effects between the computer's and radiologist's high abilities by using the information analysis including the medical images. In this presentation, the author described examples of CAD approaches in brain MR images, including detection of abnormalities, e.g., aneurysms in MRA images [2], lacunar infarction [3], Alzheimer's disease [4], white matter hyperintensities [5], MS lesions [6], and concluded with possibilities in the future of the CAD systems for brain diseases in MR images.

2.2 Fundus Photographs

Images of the ocular fundus, also known as images of the retina, can tell us about retinal, ophthalmic, and even systemic diseases such as diabetes, hypertension, and arteriosclerosis. As a non-intrusive method to screen retinopathy, the colour retinal images captured by digital fundus cameras have been widely used in clinical practice. A fully automated segmentation of colour retinal images can greatly help the management of certain diseases, especially the disease which requires the screen of large populations such as diabetic retinopathy.

This presentation consists of two fundamental parts of our work. The first part is on the segmentation of blood vessels. The appearance of blood vessels is a critical feature for diagnosis. Automated segmentation of blood vessels in retinal images can help eye-care specialists screen larger populations for vessel abnormalities which caused by retinal diseases or systemic diseases. The segmentation of retinal vessels is attracting lots of researchers but the effects are still not very satisfied. In this thesis, the major difficulties in vessel segmentation are analysed and two novel vessel segmentation methods are proposed. The second part of this presentation describes the proposed system to segment main regions and lesions of colour retinal images obtained from patients with diabetic retinopathy (DR). There are thousands of retinopathies affecting human being's vision. In this presentation, we focus our research area on DR which affects very large populations. It is one of the most common causes of blindness. Diagnosing DR as early as possible is critical to protecting patients' vision. Our segmentation system is designed to segment the main regions of retina and the major lesions caused by DR. This system is helpful to screen diabetic retinopathy in large populations so that DR can be found earlier.

Retinal vessel segmentation: Many works have been done on vessel segmentation these years [7]. However, automated retinal segmentation is difficult due to the fact that the width of retinal vessels can vary from very large to very small, and that the local intensity contrast of vessels can be weak and unstable. It is still very hard to detect the vessels of variant widths simultaneously and the weak, small vessels effectively. In this presentation, we will present a simple but efficient multiscale scheme to overcome this difficulty by using Multiscale Production of the Matched Filter (MPMF) responses as the multiscale data fusion strategy [8]. Considering that the vessel structures will have relatively strong responses to the matched filters at different scales but the background noises will not, multiplying the responses of matched filters at several scales will further enhance the vessels while suppressing the noise. The vessels of variant widths can be detected concurrently because the MPMF can incorporate the multiscale information. And the MPMF can detect the small and weak vessels which can not be detected by other methods because the weak vessels could be better enhanced (while the noise being significantly suppressed) in the scale production domain. Another difficulty of vessel segmentation is from the affection of lesions. For example, if we need to find the dark lines in an image, the edges of bright blobs will be the major source of false line detection. Consequently, some blobs (bright lesions and the optic disk) in the retinal image may cause false detection of vessels. In this thesis, we propose a modified matched filter to suppress the false detection caused by bright blobs. Instead of subtracting the local mean from the response for removing background and then thresholding to detect vessels as in the traditional matched filter, we first enhance the retinal image by using Gaussian filters and then analyze the local structures of filtering outputs by a double-side thresholding operation. The proposed modified matched filter could avoid responding to non-line edges so that false detection of vessels will be reduced significantly.

DR image segmentation: The objects useful for DR diagnosis include retinal lesions such as red lesions (intraretinal haemorrhages, microaneurysms), bright lesions (hard exudates and cottonwool spots) and retinal main regions such as vessels, optic disk, and fovea. Colour retinal image segmentation to assist DR diagnosis has attracted many researchers these years. But few works have been designed on extracting all above objects in one efficient scheme. The major disadvantages of current colour retinal image segmentation works are (1) the affections among different objects are insufficiently considered so that the false positives of segmentation are relative high; (2) the algorithms are too time-consuming so that the online application is impossible. In this presentation, we propose one efficient scheme to segment all useful objects for DR diagnosis. With sufficiently considering the affections among different objects, our segmentation scheme organized one efficient working flow to segment all objects. This scheme can suppress false positives effectively and improve segmentation speed. And the segmentation speed is further improved by algorithm optimizing and keeping the algorithm as simple as possible.

2.3 Dynamic Chest Radiography

The Background: X-ray translucency of the lungs changes depending on contented air and blood volume. The changes can be observed as changes in pixel value on dynamic chest radiographs obtained with a flat-panel detector (FPD). Thus, the decreased ventilation is observed on dynamic chest radiographs as small changes in pixel values. However, these changes are very slight making their detection by the naked eye difficult, and their correct interpretation requires specialized knowledge of respiratory physiology. Therefore, we have developed a computer-aided diagnosis (CAD) system for dynamic chest radiographs, which quantifies pulmonary ventilation and circulation based on slight changes in pixel value, resulting from respiration and heartbeat. In this presentation, we demonstrate imaging procedures (Exposure conditions, patient positioning, breathing method), quantifiable features from dynamic chest radiographs, image analysis procedures, relationship between the quantified parameters and pulmonary physiology, display methods, and the results in the primary clinical study.

Methods: Dynamic chest radiographs of patients were obtained during respiration using an FPD system. Sixty images were obtained in 8 seconds on exposure conditions as follows: 110 kV, 80 mA, 6.3 ms, SID 1.5 m, 7.5 fps, 2 mm Al filter. Total exposure dose was approximately 1.2 mGy, which was less than those in lateral chest radiography determined as guidance level of the international atomic energy agency (IAEA) (1.5 mGy). The lung area was determined by edge detection using the first derivative technique and iterative contour-smoothing algorithm. For use as an index of respiratory phase, the distance from the lung apex to the diaphragm was measured throughout all frames and then calculated excursion of diaphragmatic movement. Respiratory changes in pixel value in each local area were measured tracking the same area. To visualize changes in pixel values, inter-frame differences were obtained and then mapped on an original image as "Ventilation mapping images" and "Perfusion mapping images". Abnormalities were detected as a deviation from the right–left symmetry of the resulting images. The results were compared with findings in CT, PFT, and pulmonary scintigraphic test.

Results: In normal controls, ventilation and perfusion mapping images showed a normal pattern determined by the pulmonary physiology, with a symmetric distribution and no perfusion defects throughout the entire lung region. Left-right correlation was observed ($r=0.66\pm0.05$). In patients, abnormalities were indicated as a reduction of changes in pixel values on the mapping image. In addition, in many abnormal cases, the mapping images lost its symmetry and abnormalities could be detected as a deviation from the right–left symmetry of respiratory changes in pixel value. There was good correlation between the distribution of changes in pixel value and those of radioactivity counts in scintigraphic test ($r=0.6\pm0.2$).

Conclusions: Dynamic chest radiography using a FPD combined with a real-time computer analysis is expected to be a new examination method for evaluating pulmonary function as an additional examination in daily chest radiography. Our system can thus aid radiologist to interpret kinetic information on dynamic chest radiographs. In addition, the present method has potential for application to cone beam CT or 4DCT, as an optional function.

2.4 Chest CT Images

CAD has become one of the mainstream techniques in the routine clinical work for detection and different diagnosis of abnormalities in various examinations by using multimodality images. Prototype CAD systems demonstrated by academic institutions and commercial systems are becoming available. However, there are technical problems that prevent CAD from becoming a truly useful tool to assist physicians to make final decisions in the routine clinical work. We will accelerate the innovations in practical CAD systems by blending the outcomes of diverse, rapidly developing basic research in lung microstructural analysis and respiratory lung dynamics, and computational anatomy, and by prompting a smooth bridge for their application on the frontline of medical care. The main target diseases are lung cancers, chronic obstructive pulmonary disease (COPD), and osteoporosis.

The following main technical challenges to be overcome were discussed throughout the presentation:

(a) Technology development for integrating digital diagnostic environment with a large amount of database combination of multimodal radiological images with diagnostic results,

(b) Establishment of computational anatomy based on quantitative analysis of the database,
(c) Development of basic technology to practical CAD system for lung cancers, COPD and osteoporosis,
(d) Development of technology to integrate CAD into the clinical work flow and large-scale, multicenter, prospective clinical trials to prove that CAD system can improve the diagnostic performance substantially.

2.5 Whole Breast Ultrasonography

Breast cancer is one of the leading causes of cancer death in women. The lifetime breast cancer risk for women is about 1 in 9 in Western countries such as the United States, the United Kingdom and Australia, whereas that for Japan and some other Asian countries is significantly lower, but on the rise. Early detection is the key to better prognosis with simpler treatment and lower mortality rate. As we know, mammography is the routine technique used in breast cancer screening. The technique is very effective in screening population of age 50 years or above. However, it is less sensitivity in detecting breast cancer in younger women or women with dense breasts. With the increase in breast cancer incident rate in younger women and in countries where women generally have dense breast, a more suitable modality is needed to provide breast health care for these groups of women.

Breast ultrasonography has a long history in detecting and diagnosing breast diseases. It is widely considered as a valuable adjunct to mammography. In the past, breast ultrasound was limited by poor image quality, low image resolution and limited detail recognition. Recent years have seen many advances in ultrasound technology. Image quality has improved remarkably and the modality has been greatly enhanced. On the issue of detecting breast cancer in dense breasts, breast ultrasound does not have the same limitation as mammography, hence, more suitable to be employed in breast cancer screening in Asian countries, like Japan, where a significant proportion of the screening population has dense breast and in clinics that provide breast health care for younger women.

Currently, breast examination is routinely performed by medical staff who has special training in ultrasonography. During an examination, a small hand-held probe about 4 cm in size is used and the ultraonographer/ ultrasonologist runs the probe over the entire breast or pre-identified regions. The technique can provide very valuable information in the hands of experienced examiners but is generally time-consuming. Results are operator independent and reproducibility is poor. Furthermore, the acquired 2-dimensional scan images contain limited views of sections of the breast. Location and orientation of the scan images are only loosely recorded. Due to the lack of precise location and orientation information, image registration is difficult, if not impossible, hindering longitudinal studies and multi-modalities diagnosis.

In view of the above, an automated breast scanning system that can acquire data of the whole breast systematically (with exact information of location and orientation of the image) and present it in a panoramic view will be of great advantage.

In this presentation, a novel whole breast ultrasound system for auto-acquisition of volumetric breast ultrasound data will be introduced[9] . The main features of the system includes a prototype scanner for automated acquisition of ultrasound images of the whole breast and a image visualization and computer-aided-detection and diagnosis (CAD) platform developed in the Department of Intelligent Image Information, Graduate School of Medicine, Gifu University, Japan [9-14]. The volumetric ultrasound data consists of a stack of two-dimensional images, each depicting a panoramic view of a cross-section of the whole breast. Using the purpose-built visualisation platform, the whole breast data can be displayed in a number of ways such as visualization in axial, saggital and coronal views and synchronized bilateral display to facilitate radiologists' interpretation. The specialized CAD algorithm was purposely developed to handle and analyse ultrasound images acquired with the prototype scanner. The system was able to detect and diagnose suspicious lesions in the whole breast ultrasound data.

2.6 CT Colonography

Computer-aided detection (CAD) in CT colonography (CTC) provides the automatic detection of lesions protruding into the lumen by digitally perceiving the lumen surface in the colorectal tracts[15]. The potential of CAD has been actively investigated in the West countries since the era of single-slice CT, and the utility of CAD systems for detecting colorectal polyps has achieved a clinically applicable level. However, the problem is that the target of CAD for CTC in the West is colorectal polyps because of the respect for the adenoma-carcinoma sequence[16].

Recent recognition of the importance of flat lesions based on development of colonoscopic examination will demand CAD in CTC that can reliably detect the lesions in Japan[17]. Our Center is presently engaged in formal joint research with London University through a British corporation, Medicsight PLC, to develop CAD for CTC. This research focuses specifically on clarifying the characteristics of flat lesions on CTC and developing detection algorithms. We evaluated the current CAD performance regarding 92 early-stage cancers with submucosal (SM) invasion. Colorectal lesions destroying muscularis mucosae and invading the SM layer are more dangerous than intramucosal adenoma or cancer, because these invasive lesions are considered likely to develop into advanced carcinomas. Therefore, we believe that SM cancers are clearly more important than colonic adenomas as a target for early diagnosis.

It is essential to clarify the characteristics of the CTC images and reliably detect them in CTC examinations. Eighty of 92 lesions (86.9%) were detected as well as 100% of protruded lesions and nearly 80% of flat lesions, which was a favorable result beyond our expectation. CAD succeeded in detecting flat lesions that are also challenging for colonoscopy, which suggests the great potential for CTC diagnosis with CAD. To detect a flat lesion, CAD captures some small focal elevations or small nodules in the flat lesion. We are further planning to develop a high-precision CAD algorithm that is applicable to flat lesions to be used clinically for colorectal CTC screening in Japan [18].

2.7 Torso FDG-PET Scans

Objectives: The definition of SUV normality derived from many normal cases will be a good atlas in interpreting FDG-PET scans when suspicious regions with high uptake would appear in high uptake background. The purpose of this study was to develop a new method for determination of SUV of FDG-PET scans to examine the normality by use of a score that is based on the range of SUV on normal cases [19].

Methods: We retrospectively collected normal FDG-PET cases of 143 male and 100 female to determine the normal range of SUV. After all of normal cases in each gender were registered into one model, we configured a normal model which indicates the normal range of SUV voxel by voxel with statistical information of the mean (M) and the standard deviation (SD) that estimate the confidence interval of SUV. The normal models in each gender were stored in iPhone/iPod touch to convert patients' SUV of suspicious regions into abnormal scores defined as deviations from normal SUV where the regions were existed when readers indicate locations on PC and iPhone/iPod touch screen with patients' SUV.

Results: Four hundred thirty two abnormal regions from cancer cases were extracted to measure the SUVs and the abnormal scores. The SUVs in 49 of 432 regions were less than 2.0, but the scores of them were larger than 2.0. Although the SUVmax in 299 of 432 regions were less than 5.0, the scores were larger than 2.0 in 285 of 299 regions.

Conclusions: We have developed a computerized scheme on PC and iPhone/iPod Touch to estimate the abnormalities by the score of SUV using the normal model. Our computerized scheme would be useful for visualization and detection of subtle lesions on FDG-PET scans even when the SUV may not show an abnormality clearly.

3 Conclusions

The presentations given in the special session of CAD/ICMB2010 covered the latest research and technology development in multi-disciplinary areas, which will have long-term significant impact and immediate beneficial to the community on the aspects of medicare, telemedicine and multimedia information processing. These applications will not only increase efficiency and productivity in the business environment, but also enhance the health service for the public.

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