A01-3 Model Construction for Computational Anatomy: Progress Overview FY2011

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Abstract— **This paper describes the purpose and summary of our recent progress in the research work, which is a part of research project "Computational anatomy for computer-aided diagnosis and therapy: Frontiers of medical image sciences" funded by Grant-in-Aid for Scientific Research on Innovative Areas, MEXT, Japan. The main purpose of our research in this project is to be engaged in model construction of computational anatomy and model applications for automatically recognizing the anatomical structures and analysing the functions of different organs in human torso region using high-resolution X-ray CT images and FDG-PET images. In the 3rd year (2011.4-2012.3, FY2011) of this project, the following progresses have been achieved. (1) proposing a Bayesian framework to modelling the universal organ segmentation approach based on machine-learning and image retrieval techniques; (2) developing a whole body probabilistic model to show the metabolic activities of the normal organs and tissues based on FDG-PET images; (3) constructing a shape model for supporting the abdominal muscle segmentations on CT images; (4) proposing an atlas for supporting the bone structure recognitions on dental panoramic radiographs. The preliminary experiments have shown the efficiency and potential usefulness of these research works.**

I. Background

Modern imaging devices represented by CT, MRI, and PET have been widely used in clinical medicine. The high performance of such scanners can provide detailed information of the whole body region, not only showing real anatomical structures of the patient in 3D, but also being able to visualize the functions of the inner organs within a short time. Therefore, these medical images have been regarded as an important reference for screening, precise diagnosis, and surgery purposes in clinical medicine.

A 3D volumetric image typically includes a large number of axial slices. For example, a torso CT scan generally generates 800-1200 2D axial slices and causes a lot of interpretation burdens for radiologists. Computer-aided diagnosis (CAD) can help to reduce such burden and assist image interpretation [1]. In addition, torso CT images are very suitable for an advanced CAD system that aims at multi-disease detection from multi-organ [2]. In order to realize the aim of the multi-disease detection from multi-organ regions, automatic segmentation/recognition of the detailed anatomical structures and constructing the model of the normal human body are necessary, but it is a still challenging issue. As one of the solutions, modelling the human anatomy and function for normal and abnormal human bodies based on large number of medical images is expected as one of the key techniques [3].

In our previous research works [4]-[9], we developed a system to recognize the anatomical structures in torso CT images automatically and try to construct a normal human body model for detecting the abnormality in CT images. However, we found that the robustness and accuracy of this system was not high enough especially for abnormal CT cases that have a large distortion in anatomical structures; generally, these distortions were caused by existing lesion(s). Automated recognition of human anatomy and organ/tissue segmentations in CT images is still challenging issue that unsolved by previous research works.

II. Purpose And Plan

Our research work centers on the new methodology of anatomical model construction that is an important part of the whole research project. We also join the discussion with the other research groups for model definition and application [10-13]. The straightforward purpose of our anatomical model is to accomplish the robust recognition of anatomical structures and accurate organ segmentation based torso CT images. The basic consideration of our model construction is to integrate human anatomy, medical image processing, and machine learning techniques together. The goal of our research is to realize the multi-lesion detection in multi-organs from multi-modality medical images.

III. Recent Achievements

In our research plan as 3rd year (2011.4-2012.3, FY2011), we have been focused on the following subjects: (1) Modelling the universal organ segmentation approach based on a Bayesian framework by using machine-learning and image retrieval techniques; (2) Building an shape model for supporting the abdominal muscle segmentations on CT images; (3) Generating a whole body probabilistic model to show the metabolic activities of the normal organs and tissues based on FDG-PET images; (4) Constructing an atlas for supporting the bone segmentations on dental panoramic radiographs.

The progress of each part is described in the following section by comparing with the previous results (Figure 1).

A) A Bayesian framework for universal organ segmentation based on machine-learning and similar image retrieval[14-16]

Our aim was to develop a universal approach that can be used to automatically segment the different massive organ regions on CT images. The traditional approaches for developing automatic segmentation algorithms focus on how to generate a model to show the organ appearances on CT images by the human designers. A model that shows the anatomical structures of a special organ should be constructed firstly and then used as the prior knowledge for supporting the segmentation task. However, generating such a model to present all the possible anatomical structures in both normal

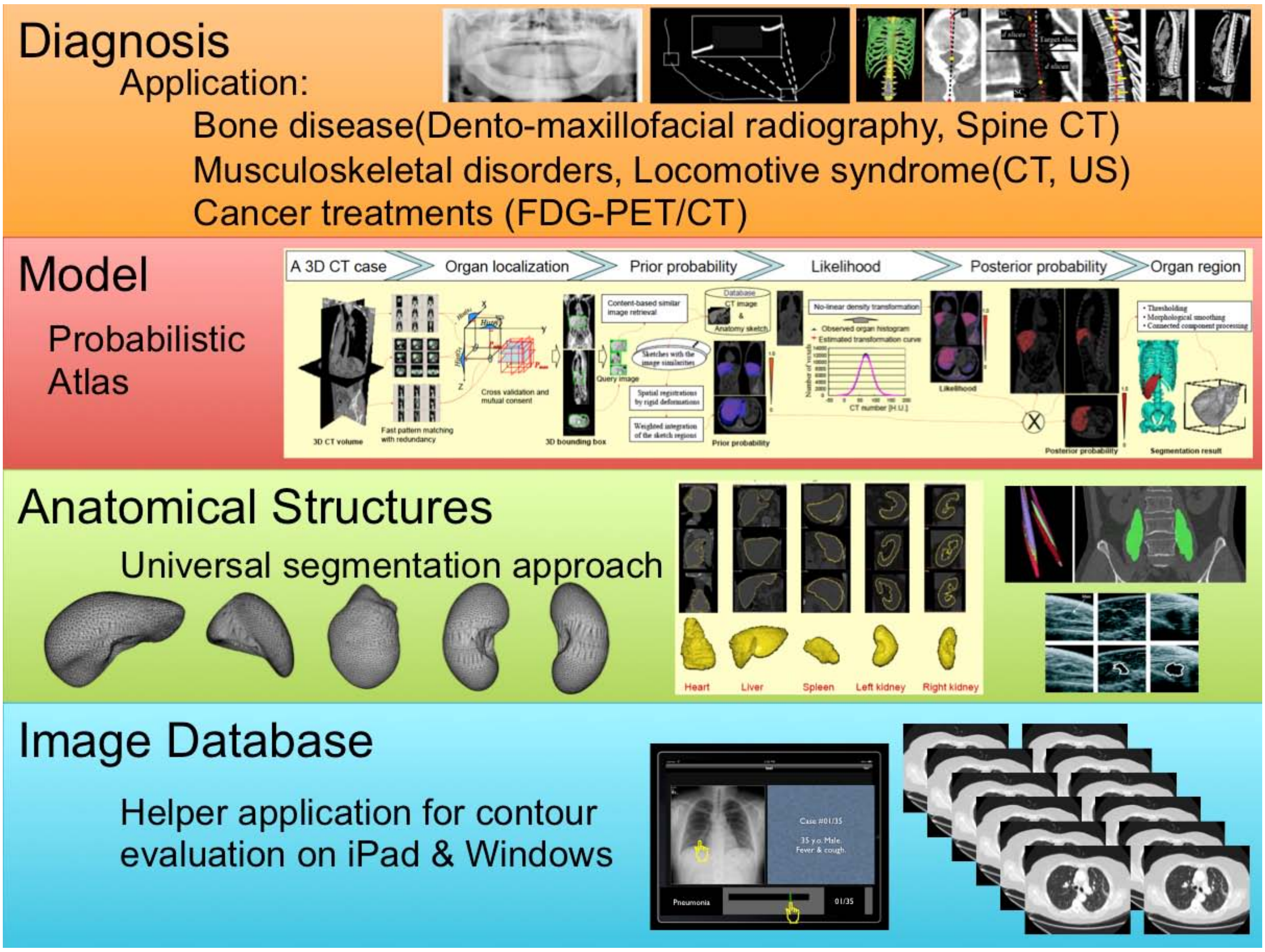

Fig. 1 Overview of our recent achievements

and abnormal CT cases is difficult and sometimes unrealistic, especially in the case that only a limit number of CT images are known during the development. Therefore, the approach that can learn and update the knowledge of the model directly from database and solve the different organ segmentation problems simply and straightforwardly is expected.

We proposed a new approach [14] to simplify the organ segmentation process by finding its location in CT images, searching the image patterns that are similar to the inputted image in a database, and transferring the anatomical structures in the selected image patterns directly to the inputted image as the references to guide the segmentation. This approach is fully based on machine-learning and data-driven methods that use more image data instead of complex algorithms to enhance the robustness and accuracy of the organ segmentation process.

The key point of our proposed approach is to simplify the organ segmentation process as a content-based image retrieval and anatomical structure transformation problem. In order to measure the image similarity between the same kinds of organ regions in different CT cases, the location (bounding box) of the target organ on the CT images should be detected firstly. Furthermore, the post-processing is also needed to compensate the individual variation between the query target (inputted CT image) and query results (image patterns in the DB). Therefore, the approach includes three processing steps: (1) automated target organ localization [15, 16], (2) content-based image retrieval and atlas construction, and (3) atlas-based organ segmentation. Two techniques have been used in this approach; one is fast object localization based on machine-learning, and the other is image retrieval by using a phase-correlation registration based on the fast Fourier transform [14]. The outline of the proposed approach is shown in Figure 2.

In the experiment, a database (DB) that includes 100 cases of 3D volumetric CT cases was used. These CT cases were collected at Gifu University Hospital by two kinds of multi-slice CT scanners (LightSpeed Ultra16 of GE Healthcare and Brilliance 64 of Philips Medical Systems). All of the CT cases imaged with a common protocol (120 kV/Auto mA) and covered the entire human torso region, which consists of 800-1200 axial CT slices with an isotropic spatial resolution of approximately 0.625 mm and a density (CT number) resolution of 12 bits. All of these CT images were taken from patients with certain real or suspicious abnormalities.

The heart, liver, spleen, left kidney, and right kidney were selected as the segmentation targets for evaluating the performance of the proposed approach. One of the authors (A.W.) manually extracted liver region in 38 CT cases, spleen region in 60 CT cases, left kidney in 93 CT cases, and right kidney in 35 CT cases. These regions were used as the ground truth for accuracy evaluation. A leave-one-out cross validation was employed in the experiment. We picked up one CT case from the DB and segmented each target region individually by querying similar image patterns from the other CT images left in the DB. The Jaccard similarity coefficient (JSC) between the segmentation result and ground truth was used as the accuracy measure. Some examples of the segmented results

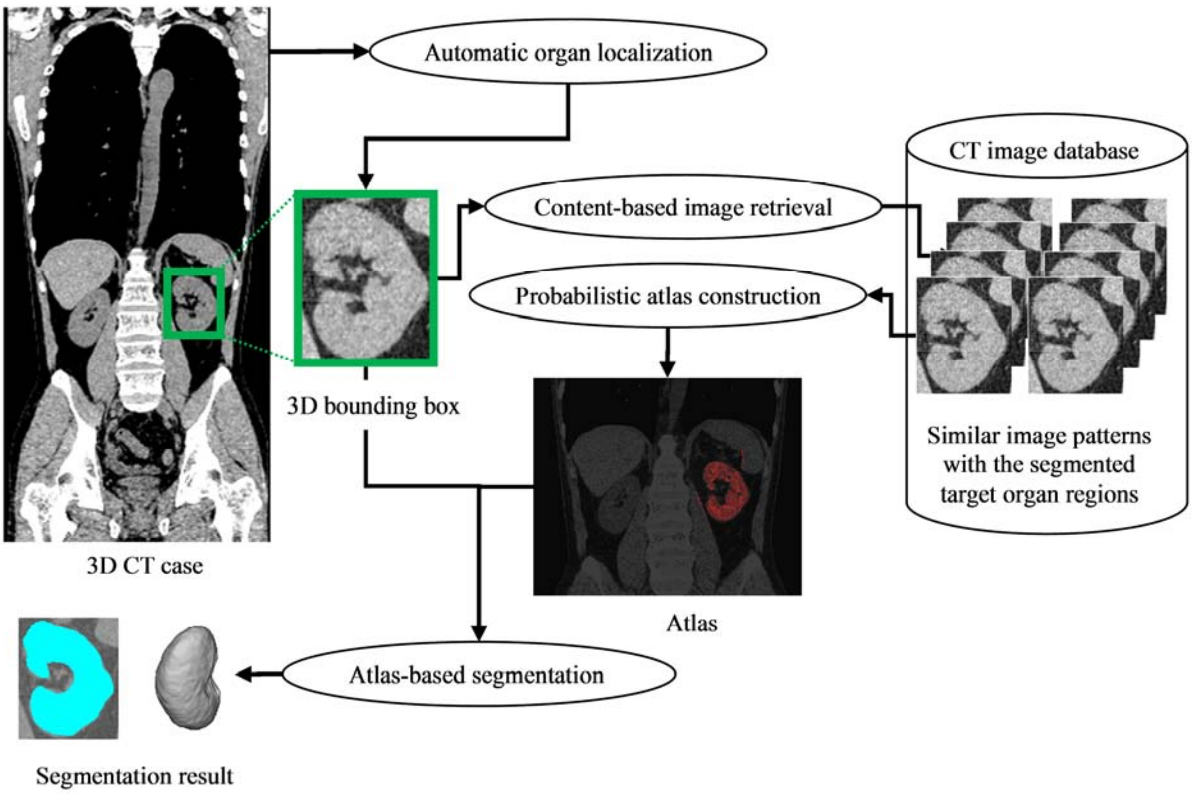

Fig. 2 Outline of the proposed approach for organ segmentation.

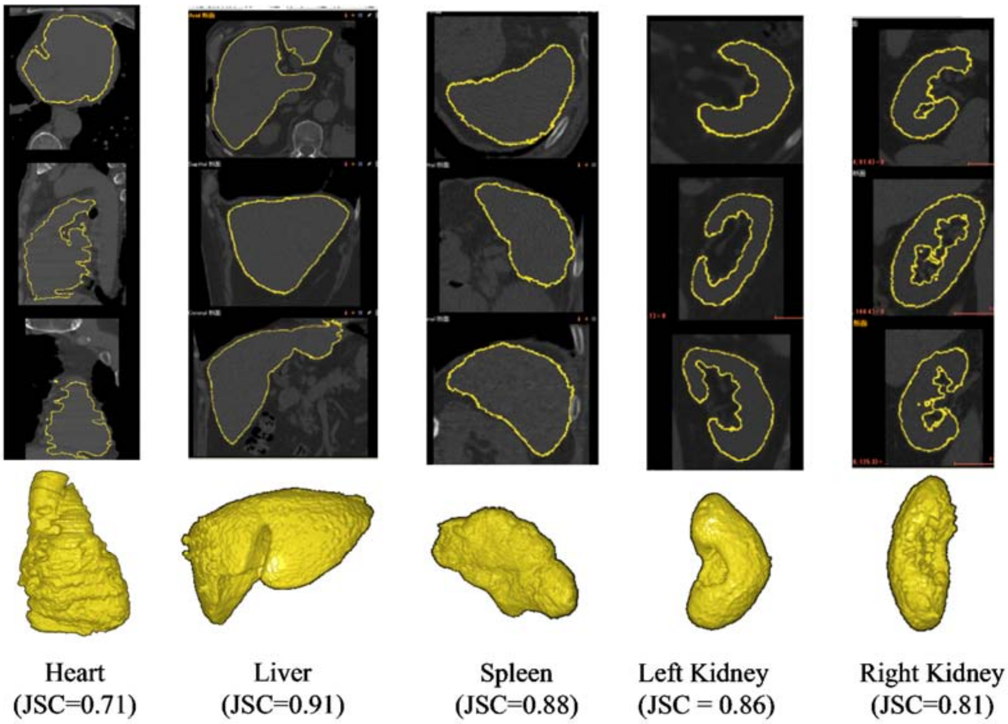

Fig.3. Examples of the segmentation results of heart, liver, spleen, left kidney, and right kidney. Each of the segmented organ regions is shown as 3 typical 2D image slices along with a 3D surface rendering, where the yellow lines indicate the contour of the segmented regions. (JSC: Jaccard similarity coefficient between the segmentation result and ground truth).

are shown in Figure 3 as 2D and 3D with the original CT images.

The experimental results showed that proposed scheme can solve the segmentations of the five different inner organs by using one algorithm. We confirmed that these five target organs were segmented automatically and correctly in all CT cases. The coincidence ratios determined by the JSC values were centered on 0.67 for heart, 0.78 for spleen, 0.83 for liver, 0.77 for right kidney, and 0.73 for left kidney. It was indicated that our proposed method was very robust for different organ segmentations in both normal and abnormal CT cases. The segmentation results were approximate to the manual inputs of the human operators.

Content-based image retrieval is used as the key solution for different organ segmentations by providing the references of the anatomical structures for the inputted CT case. We found that the phase correlation method can output the similarity measure efficiently and correctly for two CT cases with a very similar organ appearance. However, the output of phase correlation function decreased quickly with the increasing of the dissimilarity between two images. In order to ensure the usefulness of the query results, a DB including a large number of CT cases is necessary.

The deterioration on the JSC values of the final segmentation results was caused by the difference of the definitions of the target regions between the automatic segmentation and manual inputs. The segmentation process assumed that the target organ region should be homogenous in CT number and the human operators tended to sketch a smoothing contour surrounding the organ region and ignore some other tissues (for example vessel region) inside the organ regions. This problem can be solved by adding the shape information to refine the segmentation result from this method.

In conclusion, we proposed a universal scheme for the segmentation of different massive-organ regions automatically in 3D CT cases. Machine-learning-based organ localization, content-based image retrieval, and atlas-based organ segmentation techniques have been combined in this scheme to accomplish segmentation for the different organ regions by using the same algorithm. This scheme was applied to the segmentations of heart, liver, spleen, left and right kidneys in 100 cases of CT cases, and its efficiency and accuracy were shown in preliminary results. This scheme can be used for the model construction for understanding and commuting the human anatomy based on medical images [17].

B) A shape model for automated recognition of abdominal muscle region using in X-ray CT images [18-20]

In our previous work, anatomical shape model has been proposed and applied to the psoas major muscle. In FY 2011, we applied it to additional 80 cases for recognizing muscle region. The result was reported in the paper [18]. The progress in FY 2011 is twofold.

Firstly, we proposed a new method for constructing the anatomical shape model of the rectus abdominis muscle (Figure 4) [19], and it has been integrated into an automated recognition for rectus abdominis muscle. In Figure 4, red and yellow colour parts indicate the area on the left and right

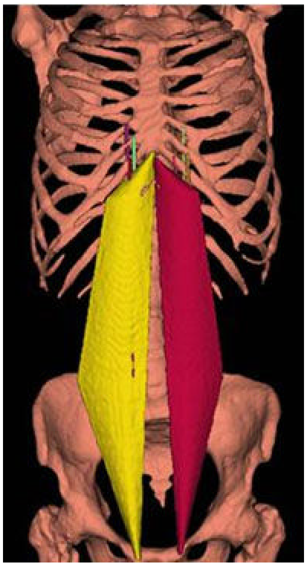

Fig. 4 Anatomical shape model for rectus abdominis muscle.

regions of the muscle, respectively. The muscle region was recognized using this model.

Secondly, we proposed a new medical care system based on the usage of interactive communication tool as shown in Figure 5 (a) [20]. Patients might have a trend not to understand the doctor's image diagnosis completely, so we have produced this system, by which the patient can observe cross-sectional views from the tomographic images virtually in a real-time. This system can be used with the iPad, and understanding of the doctor's diagnosis may become deeper. Figure 5 (b) shows the simple screen interface in the iPad application.

C) A whole body probabilistic model to show the SUV values in the normal organs and tissues based on FDG-PET images[21-23]

2-deoxy-2-fluoro-d-glucose (FDG) - Positron Emission Tomography (PET) scans has been used to detect metastasis in cancer diagnosis in whole body. The FDG-PET image indicates the metabolism of radioactive glucose. Standard Uptake Value (SUV) is one of the important measures to represent the degree of the metabolism, but the value often depended on the patient condition, the dose of FDG, the measurement terms, and the methods for the radioactivity of FDG when the medicine was injected.

The purpose of this work was to develop a quantitative measurement method to show a normality of the metabolism of FDG and to confirm the fundamental technique for CAD approach of whole body scanning using FDG-PET. A typical quantitative measurement approach is a scoring method, in which the interval of values from normal groups was determined by the mean (M) and the standard deviation (SD) and the Z-score for value P is defined as (P-M)/SD. The scoring approaches in PET scans were well employed in functional MRI and PET for brain imaging.

A whole body probabilistic model takes very important roles in the estimation of normal activities from FDG materials in every organs and tissues [21]. The accuracy of the probabilistic models was measured by employing normal PET/CT scans as a progress in FY 2011 [22]. The CT images from PET/CT scans were used to verify the organs locations after the registration technique was applied. Miss-registrations were confirmed around the lung apex and upper-liver contours. Another progress in FY 2011 is in the automated registration method between previous and current FDG-PET scans to enhance the temporal changes of SUVs [23]. The differences of SUV and Z-score were obtained after the body region was deformed to fit the model. This method includes automated region tracking technique between two time series scans to compare the activities and the volumes of abnormal spots.

Figure 6 shows the interface of the temporal subtraction system with lung cancer. Yellow circles show the abnormal regions in lung. The SUV in previous scan was 0.66, but the one in current scan was 2.73 with 19.71 of Z-score. The differences between the two images were well depicted. Figure 7 indicates the region tracking results during chemotherapy. The activities of colon cancer regions were decreased as the treatments were carried out. In the latest scans, the system could not detect any regions because the region was disappeared. These results were reported in two international conferences and one Japanese meeting.

D) Automated scheme for measuring mandibular cortical thickness on dental panoramic radiographs for osteoporosis screening [24,25]

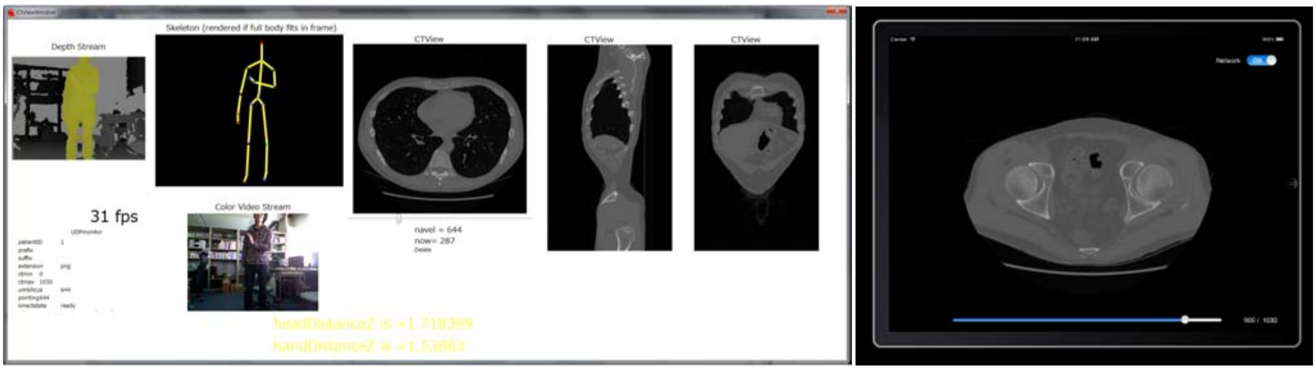

Fig. 5 Interface of the new medical care tool (left) and screen interface of the iPad application (right).

Findings of dental panoramic radiographs (DPRs) have shown that the mandibular cortical thickness (MCT) was significantly correlated with osteoporosis. Identifying asymptomatic patients with osteoporosis through dental examinations may bring a supplemental benefit for the patients. However, most of the DPRs are used for only diagnosing dental conditions by dentists in their routine clinical work. We developed a CAD scheme that automatically measures MCT to assist dentists in screening osteoporosis. First, the inferior and posterior border of mandible was detected by use of an active contour method. Second, the locations of mental foramina were estimated on the basis of the inferior and posterior border of the mandible. Finally, MCT was measured on the basis of the grayscale profile analysis.

The overview of our proposed method is illustrated in Figure 8. Our proposed scheme consists of the five steps. Canny edge detector and active contour method were used to extract the mandibular contour in the first (Step 1) and the second step (Step 2), respectively. Positions of mental foramina, which exist both on left and right sides, were estimated automatically on the basis of the result from the mandibular contour extraction in the third step (Step 3), and the grayscale profiles in a direction perpendicular to the extracted mandibular contour were obtained at both sides separately in the fourth step (Step 4). Finally, MCTs on the both sides were determined by the analysis of the grayscale profiles (Step 5).

One hundred DPRs were used to evaluate our proposed scheme. Experimental results showed that the sensitivity and specificity for identifying osteoporotic patients were 92.6 % and 100 %, respectively. We conducted multi-clinic trials, in which 223 cases have been processed in a month period. Our scheme succeeded in detecting all cases of suspected osteoporosis. Therefore, in summary, our scheme has a potential to identify osteoporotic patients at an early stage.

IV. CONCLUSIONS

Our recent progresses for anatomical model construction based on torso CT images are described. According to our research plan for previous year, we proposed a universal solution for automatic organ segmentation and confirmed its usefulness and efficiency based on the experimental results by using a large database. This work is beneficial to the further anatomical model constructions by providing a possible way to extract a large number of anatomical structures quickly and automatically from the CT images.

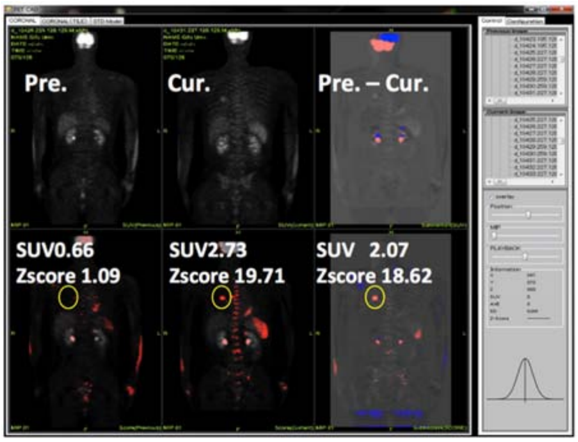

Fig. 6 Interface of temporal subtraction system for FDG-PET scans.

We also generated a whole body probabilistic model to show the metabolic activities of the normal organs and tissues based on FDG-PET images. This work showed the potential possibility of our consideration that detecting the lesions by comparing the patient image to a normal human body model under the consuming that the anatomical structures in the images can be recognized firstly. The consideration was proposed by our group for solving the problem of the multi-lesion detection in multi-organs.

We also applied the models to the muscle and bone segmentation scheme and confirmed its good performances.

Our research group has been collaborated with several research groups of the same research project. Especially, we have been working together with the Kido Lab. of Yamaguchi

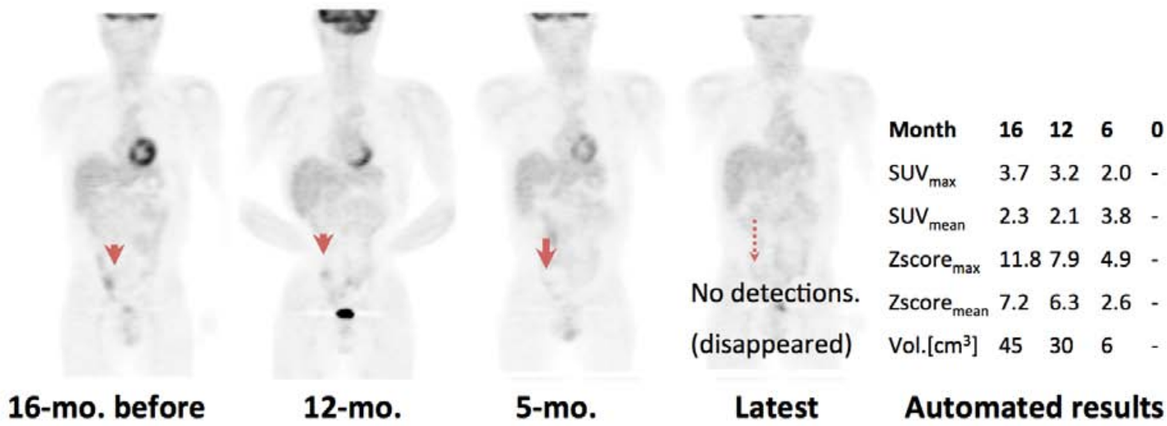

Fig. 7 Examples of automated region tracking system with colon cancer (60 y male).

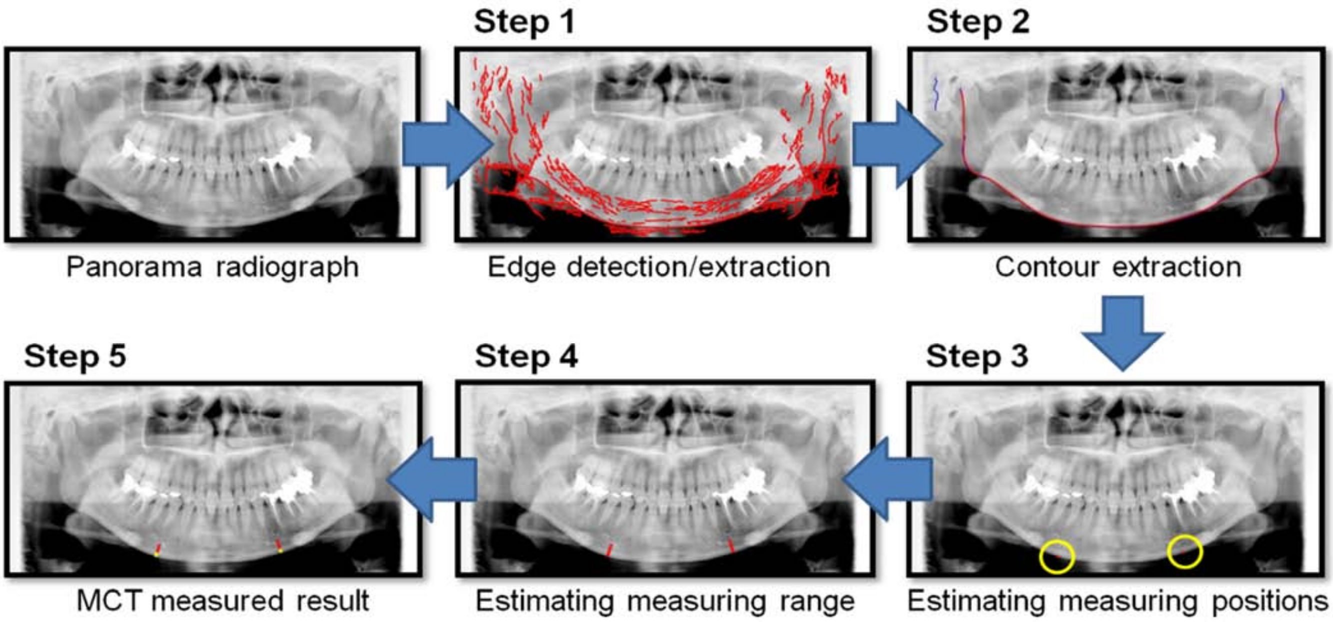

Fig.8. Overview of the proposed method for measuring MCT.

University, and shared the image database and source codes of the programs each other for shape model constructions. The results of these research works have been presented in [10-13].

In addition to these mentioned studies, we have been investigated on CAD developments on chest PET/CT imaging, brain MR imaging, CT imaging for emergency medical care, breast ultrasonography (2D and 3D) and mammography, retinal fundus photography, and some of successful publications are listed at the end of this paper.

As the future works, we will continue to working on the developments, improvements, and the collaboration with the other groups in this research project to accomplish the anatomical model definition, construction, and applications.

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LIST OF PUBLISHED AND ACCEPTED PAPERS

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