Computational Anatomy: Model Construction and Application for Anatomical Structures Recognition in Torso CT Images

Hiroshi Fujita [#1], Takeshi Hara [#2], Xiangrong Zhou [#3], Huayue Chen [*4], and Hiroaki Hoshi [**5]

[#] *Department of Intelligent Image Information, Graduate School of Medicine, Gifu University*
[*] *Department of Anatomy, Graduate School of Medicine, Gifu University*
[**] *Department of Radiology, Graduate School of Medicine, Gifu University*
Yanagido 1-1, Gifu 501-1194, Japan

[1] fujita@info.gifu-u.ac.jp
[2] hara@info.gifu-u.ac.jp
[3] zxr@info.gifu-u.ac.jp
[4] huayue@gifu-u.ac.jp
[5] hoshi@gifu-u.ac.jp

***Abstract*—This paper describes the purpose and recent summary of our research work which is a part of research project "Computational anatomy for computer-aided diagnosis and therapy: Frontiers of medical image sciences" that was funded by Grant-in-Aid for Scientific Research on Innovative Areas, MEXT, Japan. The main purpose of our research in this project focus on model construction of computational anatomy and model applications for analyzing and recognizing the anatomical structures of human torso region using high-resolution torso X-ray CT images. A CT image database was constructed and a number of CT images were collected and will be used for training and testing of our model constructing approach. We believe our anatomical modes can reduce the complexity and increase the robustness of process flow for anatomical structure recognition and organ segmentation problems in CT images. Furthermore, such models also should be useful for computer-aided diagnosis (CAD) systems by providing a quantitative measuring function for shape, density and spatial location of the target organ and tissues in CT images.**

I. Background

Multi-detector CT scanners have been widely used in clinical medicine. The high performance of such CT scanners can provide detailed information of the whole torso region of human body during a one-time CT scan within 10 seconds. Because the high resolution torso CT images include the entire information of different inner organs, those CT images have been regarded as an important reference for screening, precise diagnosis, and surgery purposes in clinical medicine.

A torso CT scan typically includes 800-1200 axial slices. The large volume of CT data causes a lot of interpretation burdens for radiologists. Computer-aided diagnosis (CAD) can help to reduce the 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]. The traditional approach for lesion detection prepares a pattern for a specific lesion type and searches the lesion candidates in CT images by a pattern matching process. In the case of multi-disease detection from multi-organ, generating and matching a lot of prior lesion patterns from CT images can be tedious and sometimes not possible. Instead of preparing a lot of different lesion patterns, collecting a large number of normal human cases was much easier to do. Generating a normal body model and searching the differences between the current patient and the normal body model may be a realistic way to solve the task of multi-disease detection from multi-organ required by the CAD system.

In previous research works [3]-[8], 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. This system has been tested for 334 cases of torso CT images and used for CT image analysis in emergency medical care. One example of recognized result is shown in Fig.1. However, we found that the robustness and accuracy of this system were not high enough. The anatomical structures in about 30% of CT cases could not be recognized successfully by our system. Especially the proposed process was often fault in recognizing the CT cases that have large distortions in anatomical structures; generally, those distortions were caused by lesions. Automated recognition of human anatomy and organ & tissue segmentations in CT images is still challenging issues that unsolved by our previous research works. We think that anatomical model construction and model-based recognition & segmentation should be the key for solving this problem.

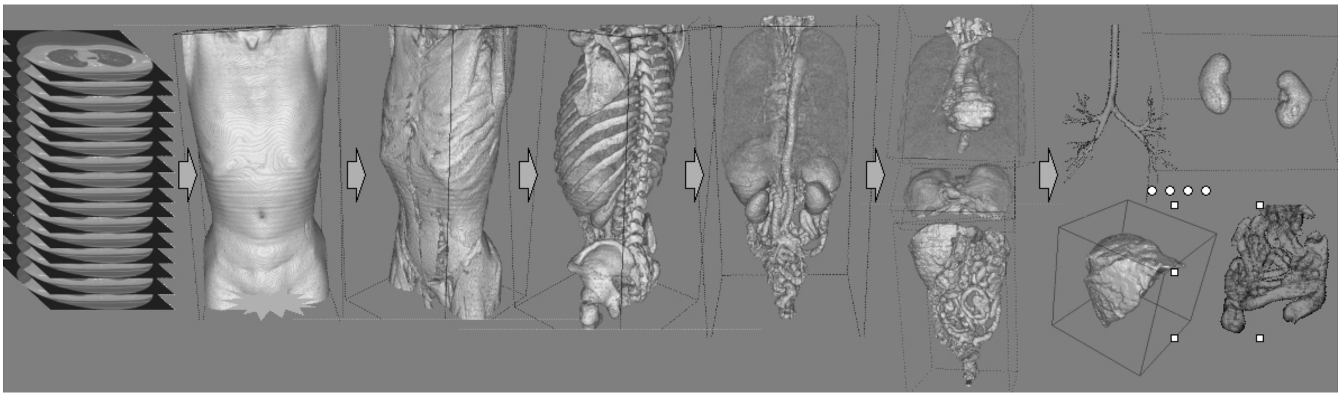

Fig. 1. An example of anatomical structure recognition result from a torso CT case.

II. PURPOSE AND CONCRETE PLAN

Our research work focuses on the new methodology of anatomical model construction that is an important part of the whole research project. We will also join the discussion with the other research groups for model definition and application. The straightforward purpose of our anatomical model is to accomplish the robust recognition of anatomical structures and accurate organ segmentation in torso X-ray CT images. The basic consideration of our model construction is to integrate human anatomy, medical image processing, and machine learning techniques together. The concrete plan of our research is shown below.

A. Research Plan for 2009.9 to 2010.3

The main research plan of the first year centres on data collection, methodology investigation, and computer hardware preparation. The first task in this stage is to construct a CT image database and manually extract anatomical structures in those CT images. Those CT images and corresponding information about human anatomy will act as resource for model construction and training samples for machine learning. The learning-based approach using a large number of CT cases commonly requires the high computing speed and availability of computers. Therefore, we plan to construct a computer cluster system that can manage a large CT image database and can be used for parallel computing task based on message passing interface (MPI).

B. Research Plan from 2010.4 to 2014.3

We will cooperate with the other research groups to accomplish the anatomical model construction and application for robust recognition of anatomical structures and accurate organ segmentation in torso CT images. The experience of our model construction and application will be concluded and integrated as a general methodology that might be beneficial for the other purposes of medical image analysis.

III. RECENT ACHIEVEMENTS

The progress of our research works in this year can be concluded as three parts: (1) CT image database construction, (2) initial study about model construction and machine learning, and (3) development of a computing environment. The current progress of each part is reported in following sections.

A. Database Construction

Our research plan was examined and permitted by Institutional Review Board (IRB) of Gifu University and Gifu University Hospital. A database that includes 559 cases of torso CT images has been constructed. Each patient case includes 800-1200 CT slices and presented as a 3-D volumetric image with an isotropic spatial resolution of 0.63 mm. The database was constructed based on MySQL with a web-based interface that was coded by PHP under Apache Wed Server.

A part of anatomical structures in each CT case was extracted manually. In current stage, we selected the locations of heart, liver, spleen, right and left kidneys, prostate, pelvic bone, left and right heads of femur as the landmarks to present the anatomical structures. The locations of these landmarks in each CT case have been manually indicated and registered into our database.

B. Initial study on model construction

The human anatomy is an explicit definition of different organs and tissues in human body. That definition includes location, spatial relation and shape information of human organ and tissues. Each part of human organ and tissue regions is annotated by a pre-defined name. In general, an anatomical model only focuses on a part of human body and pays attention to a special kind of information due to the requirement of the real application. In our initial study, we tried to construct two models based on some techniques in present state of the art in this research field. One is a probabilistic shape model to present diaphragm upper surface; the other is a learning-based model for detecting the kidney locations.

During diaphragm shape analysis, we faced a problem that how to solve the shape model construction for an open surface. This basic model of open surfaces can be presented as a traditional point distribution model that generated by principal component analysis (PCA). However, point correspondence between different surfaces is difficult to be decided. We proposed a novel method to solve the point selection and correspondence problem in different patient cases during the model construction [9],[11]. This method maps 3-D diaphragm surfaces to a 2-D plate firstly, and then, decides the correspondence between the points sets in different patient cases by minimizing the bending energy of a non-rigid deformation from different diaphragm instances to the model. Forty-six patient cases have been used for shape model construction. The effect and performance of our shape model construction method were confirmed through the detailed evaluations on compactness, generality, and specificity of generated model [11]. The proposed method is also applicable to construct the shape models for other organ and tissue surfaces. These models can be expected to satisfy the requirement for quantitative measuring the shape changes on a local region that doctors are interested in.

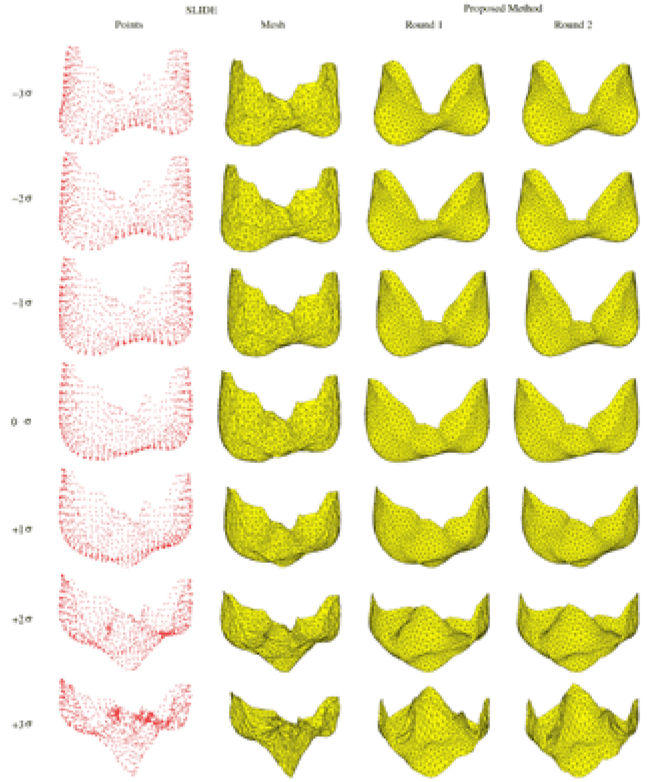

Fig. 2. Comparing the shape models constructed by our proposed method [10] and a previous method [9].

Detecting the location of an interested anatomical target in different patient cases is one of the most important tasks required by medical image analysis. Searching the correct position in medical images by pattern matching in feature space is the most efficient approach. We proposed a machine-learning model to select the proper feature space for searching a specific target and generate the rules for judgment. Comparing to the similar methods that was used in computer vision research field, our learning-based model focuses on how to use a limit number of training cases to generate a scheme with high robustness and accuracy. This approach was applied to design a fast detecting scheme for determining the left and right kidney locations in CT images. We generated a detecting scheme using less than 100 CT cases by our leaning-based approach and tested detector's performance by using the other 2000 CT cases. The experimental results showed that both left and right kidney regions have been detected correctly in more than 80% of CT cases. One example of kidney detection results is shown in Fig.3. The computing time was less than 15 seconds/case using a conventional personal computer. The proposed model will be used to construct multiple detectors for searching the multiple land markers and getting the position of the interested anatomical structures in specific CT cases.

Several model-based applications are also under the development. An automated scheme has been developed for abdominal muscle recognition and segmentation in CT images based on shape and location models [10],[12]. A system that can be used to quantitatively measure BMD values in each of vertebral bone regions has been developed [13]. A cancer detection system using FDG-PET images has been also proposed by generating normal SUV score distribution models under the anatomical structures of human torso region. The effects have been validated in [14].

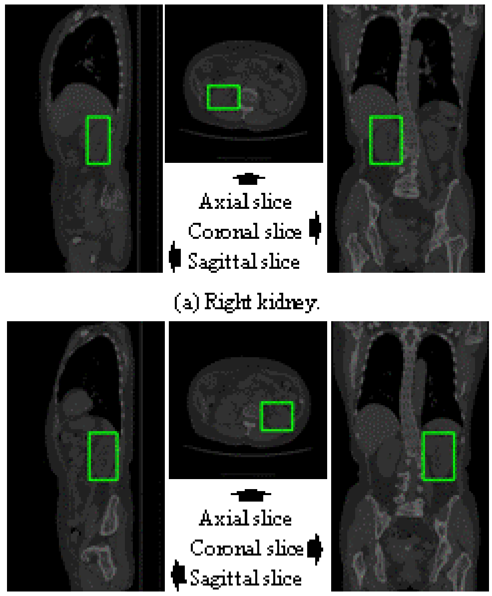

Fig. 3. An example of kidney detection results. Three slices that pass through the detected center position of kidney in a CT image are shown. Green box indicates the detected kidney location (minimum bounding rectangle of kidney region).

C. *Preparation of Computing Environment*

The anatomical model construction needs a lot of CT cases and machine-learning generally requires a powerful computing environment. We developed a system to manage the CT image database (Fig.4). This system can convert the CT images from DICOM-format data into raw data collected from PACS system in Gifu University Hospital and transfer the raw data to our research library. This system used two workstations and two RAID systems that have the capacity to store and manage 10,000 torso CT cases. Implementation of this system efficiently saves time and burden of our CT image collections.

A computer cluster with 8 workstations was also constructed for supporting the model construction (Fig.5). Each workstation is with a Core i7 3.33 GHz CPU and 12 GB memory. The cluster has total 64 CPU cores that can be used for parallel computing based MPI library under a Linux operating system. This computing environment can be expected to assist our model construction through a machine-learning approach by using a large number of CT cases.

Fig. 4. A system developed for CT image collection and database management for our research work in Gifu University Hospital.

Fig. 5. A computer cluster system developed for supporting anatomical model construction in Fujita Lab. of Gifu University.

IV. CONCLUSION

We described our consideration for anatomical model construction in torso CT images. According to our research plan in 2009, we constructed a CT image database and manually extracted a part of anatomical structures in those CT images firstly, and then, we attempted to propose two model-based approaches for analyzing the shape of diaphragm surfaces and searching kidney locations. The experimental results showed the effect and usefulness of the proposed models. We also developed a computer cluster that will strongly support our further research works.

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

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REFERENCES

[1] K.Doi, "Computer-aided diagnosis in medical imaging, *Historical review, current status and future potential*", Computerized Medical Imaging and Graphics, vol.31, pp.198–211, 2007.

[2] H.Kobatake, "*Future CAD in multi-dimensional medical images - Project on multi-organ, multi-disease CAD system*", Computerized Medical Imaging and Graphics, vol.31, pp.258–266, 2007.

[3] X.Zhou, T.Hara, H.Fujita, R.Yokoyama, T.Kiryu, M.Kanematsu, and H.Hoshi, "*Preliminary study for automated recognition of anatomical structure from torso CT images*", Proc. of the 2005 IEEE Engineering in Medicine and Biology 27th Annual Conference, Shanghai, China, paper#340, 2005.

[4] X. Zhou, T. Hayashi, T. Hara, H. Fujita, R. Yokoyama, T. Kiryu, and H. Hoshi, "*Automatic segmentation and recognition of anatomical lung structures from high-resolution chest CT images*", Computerized Medical Imaging and Graphics, vol.30 (5), pp.299-313, 2006.

[5] X. Zhou, T. Kitagawa, T. Hara, H. Fujita, X. Zhang, R. Yokoyama, H. Kondo, M. Kanematsu and H. Hoshi, "*Constructing a probabilistic model for automated liver region segmentation using non-contrast X-ray torso CT images*", Proc. of 9th International Conference for Medical Image Computing and Computer-Assisted Intervention - MICCAI 2006, Part II, vol.4191, pp.856-863, Springer Berlin/Heidelberg, 2006.

[6] X. Zhou, H. Ninomiya, T. Hara, H. Fujita, R. Yokoyama, H. Chen, T. Kiryu, and H. Hoshi, "*Automated estimation of the upper surface of the diaphragm in 3-D CT images*", IEEE Transactions on Biomedical Engineering, vol.55 (1), pp.351-353, 2008.

[7] X. Zhou, M. Han, T .Hara, H. Fujita, K. Sugisaki, H. Chen, G. Lee, R. Yokoyama, M. Kanematsu, and H. Hoshi, "*Automated segmentation of mammary gland regions in non-contrast X-ray CT images*", Computerized Medical Imaging and Graphics, vol.32, pp.699-709, 2008.

[8] X. Zhou, T.Hayashi, H.Chen, T.Hara, R.Yokoyama, M.Kanematsu, H.Hoshi, and H.Fujita, "*Automated measurement of bone-mineral-density (BMD) values of vertebral bones based on X-ray torso CT images*", Proc. of the 31st Annual International Conference of the IEEE Engineering in Medicine and Biology Society, pp.3573-3576, 2009.

[9] P.Dalal, B.C.Munsell, S.Wang, J.Tang, K.Oliver, H.Ninomiya, X.Zhou, and H.Fujita, "*A fast 3D correspondence method for statistical shape modeling*", Proc. of IEEE Conference on Computer Vision and Pattern Recognition (CVPR) 2007, pp.1-8, 2007.

[10] N.Kamiya, X.Zhou, H.Chen, T.Hara, H.Hoshi, R.Yokoyama, M.Kanematsu, and H.Fujita, "*Automated recognition of the psoas major muscles on X-ray CT images*", Proc. of the 31st Annual International Conference of the IEEE Engineering in Medicine and Biology Society, pp. 3557-3560, 2009.

LIST OF ACCEPTED AND PUBLISHED PAPERS SINCE 1ST SEPTEMBER 2009

[11] P.Dalal, L.Ju, M.McLaughlin, X.Zhou, H.Fujita, and S.Wang, "*3D open-surface shape correspondence for statistical shape modeling: Identifying topologically consistent landmarks*", Proc. of 2009 IEEE 12th International Conference on Computer Vision (ICCV), pp.1857-1864, 2009.

[12] N.Kamiya, X.Zhou, H.Chen, T.Hara, H.Hoshi, R.Yokoyama, M.Kanematsu, H. Hoshi, and H.Fujita, "*A model based method for recognizing psoas major musclesin torso CT images*", Proc. of SPIE Medical Imaging 2010, in press, 2010.

[13] T.Hayashi, X.Zhou, H.Chen, T.Hara, K.Miyamoto, T.Kobayashi, R.Yokoyama, M.Kanematsu, H. Hoshi, and H.Fujita, "*Automated extraction method for the center line of spinal canal and its application to the spinal curvature quantification in torso X-ray CT images*", Proc. of SPIE Medical Imaging 2010, in press, 2010.

[14] T .Hara, S. Ito, T. Katafuchi, D. Fukuoka, H. Fujita, K.Doi, and X. Zhou, "*Quantitative analysis of FDG-PET scans by use of a statistical model for normal cases*", Proc. of RSNA2009, CODE: SST14-05, p. 694, 2009.