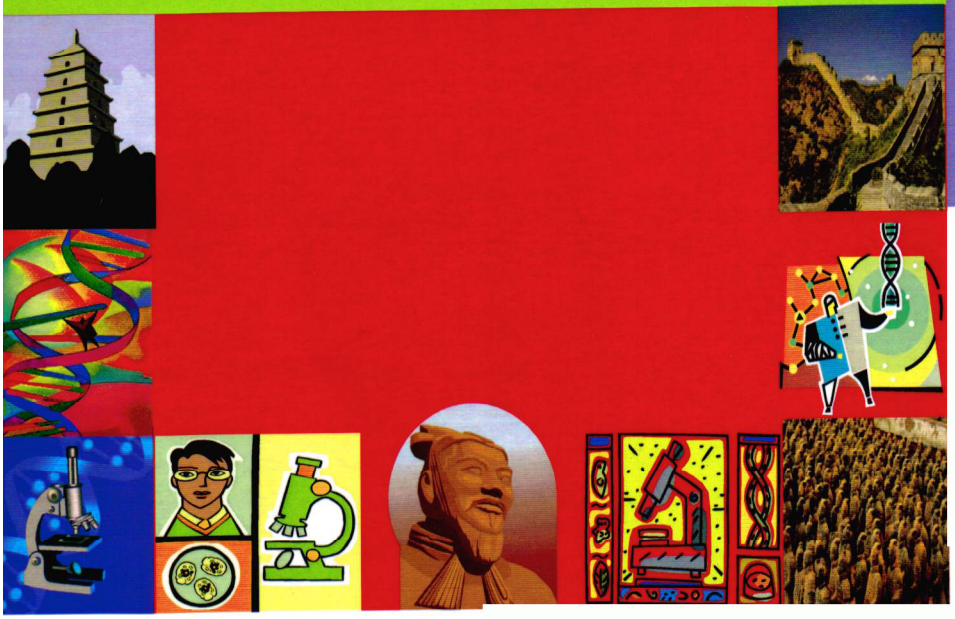
BioMedical Engineering and Informatics: New Development and the Future

Proceedings of the First International Conference on BioMedical Engineering and Informatics

BMEI 2008



Volume I

IEEE computer society

IEEE

Editors: Yonghong Peng and Yufeng Zhang

May 27-30, 2008, Sanya, Hainan, China

A novel method for extraction of spleen by using Thin-plate splines (TPS) deformation and edge detection from abdominal CT images

Xuejun Zhang[a], Hiroshi Fujita[b], Tuanfa Qin[a], Jinchuang Zhao[a],
Yurong Qin[a], Chao Gao[a], Liling Long[c], Zuojun Zhang[c]
[a]*School of Computer, Electronics and Information, Department of Electronics and Information Engineering, Guangxi University, Nanning City, Guangxi 530004, P. R. China*
[b]*Department of Intelligent Image Information, Division of Regeneration and Advanced Medical Sciences, Graduate School of Medicine, Gifu University, Gifu 501-1194, Japan*
[c]*Department of Radiology, The First Affiliated Hospital of Gaungxi Medical University, Nanning City, Guangxi 530022, P. R. China*
E-mail: xjzhang@gxu.edu.cn

Abstract

The spleen is always hypertrophied in the patient with cirrhotic liver, which is regarded as one of complementary features for analysis of cirrhosis. Furthermore, segmentation of an abnormal spleen region based on CT or MR images is a crucial step in surgical planning. However, precisely carrying out this step remains a challenge due to either connectivities of the spleen to other organs or the shape, internal texture, and homogeneity of spleen that maybe extensively affected in case of liver diseases. In this paper, we propose a non-density based method for extracting the abnormal spleen region by edge detection processing. The accuracy of segmentation of spleen in 20 cases is the coincidence ratio 0.96 with the average error rate of 4.3%, and the result showed that our fully automatic method for the segmentation is effective and robust despite the presence of abnormal tissues within the spleen.

1. Introduction

In clinical interpretation of cirrhosis on CT or MR images, several image findings are very helpful to differentiate cirrhosis from normal liver: enlarged caudate lobe, fiberization, shrunk quadrate lobe, irregular hepatic surface, blunting of left hepatic lobe, hypertrophy of spleen and so on. Analysis on shape, texture or volume of liver is proven as an effective tool on differentiation of cirrhosis [1]. Cirrhosis of the liver is a late stage of progressive liver disease defined as structural distortion of entire liver as well as spleen by fibrosis and parenchymal nodules. As the cirrhosis may increase the risk of hepatocellular carcinoma, early detection and accurate staging of cirrhosis is an important issue in practical radiology. Many related works [2,3] are focus on the investigation of liver status of liver for computer analysis. In fact, the spleen is always hypertrophied in the patient with cirrhotic liver, which is regarded as one of complementary features for analysis of cirrhosis. In other words, radiologists come to a decision of cirrhosis or non-cirrhosis based on a range of global and local information and diagnosis was made with respect to a liver. Therefore, segmentation of an abnormal spleen region based on CT or MR images is a crucial step in a Computer Aided Diagnosis (CAD) system as well as in a surgical planning. However, precisely carrying out this step remains a challenge due to either connectivities of the spleen to other organs or the shape, internal texture, and homogeneity of spleen that maybe extensively affected in case of liver diseases. In this paper, we propose a non-density based method for extracting the abnormal spleen region by Thin-plate splines (TPS) deformation on multi-phase CT images and edge detection processing.

2. Methods

Our method consists of three main steps: I. Registration of spleens in multiphase images; II. Edge detection on subtraction image and finding initial spleen area; III. Eliminating the connectivity and integrating the lesion region.

978-0-7695-3118-2/08 $25.00 © 2008 IEEE
DOI 10.1109/BMEI.2008.206

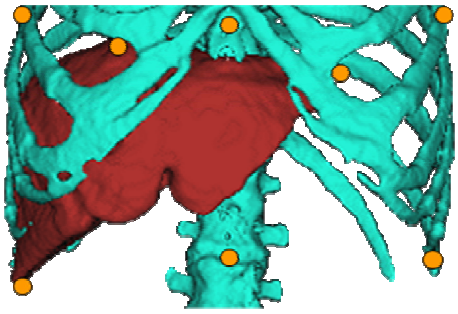


Fig. 1 Eleven landmarks are selected as: one point at the centroid of the liver region that first appeared on the top slice near the heart; four points on the abdominal wall at the above slice axial plane; one point outside the lateral segment on the left lobe; one bottom point at the posterior segment (caudal part) on the right lobe; four points on the abdominal wall at this slice axial plane.

2.1. Registration of multiphase images

We have been developing an automatic method for the segmentation of the liver region on multislice MDCT and MR images [4,5], that gives liver maps on multi-phase images.

The proposed method in this study uses CT images obtained in two or more phases. Therefore, if the patient moves his body or changes the status of breath during the whole scanning time, misregistration might occur between the images of each phase. In our study, thin-plate splines (TPS) were used for the registration. TPS is a technique for transforming the image by moving the control point [6]. The image can be transformed by setting the coordinates of the control point before and after the image moves. Eleven landmarks from liver and bones are selected on the artery phase images to obtain a fixed image (Fig. 1), and the corresponding points in the images obtained in other phases are also selected.

$I(x, y, z)$ is defined as the fixed image and the other as moving image $I'(x', y', z')$, where x, y, and z represent a position in 3D volumes. TPS registration attempts to determine an alignment spatial mapping between two images by moving the control point (x_i, y_i, z_j) on the moving image to the corresponding control point (x'_i, y'_i, z'_j) on the fixed image, where $1 \le i \le n$, $1 \le j \le m$. The moving image obtained after transformation by using TPS can be expressed by the following equations:

$$I(x', y', z') = I(f_x, f_y, f_z) \tag{1}$$

and

$$\begin{cases} f_x(x,y,z) = a_{11} + a_{1x}x + a_{1y}y + a_{1z}z + \sum_{i=1,j=1}^{n} w_{1i} U(\|(x,y,z) - (x_i, y_i, z_j)\|) \\ f_y(x,y,z) = a_{21} + a_{2x}x + a_{2y}y + a_{2z}z + \sum_{i=1,j=1}^{n} w_{2i} U(\|(x,y,z) - (x_i, y_i, z_j)\|) \\ f_z(x,y,z) = a_{31} + a_{3x}x + a_{3y}y + a_{3z}z + \sum_{i=1,j=1}^{n} w_{3i} U(\|(x,y,z) - (x_i, y_i, z_j)\|) \end{cases} \tag{2}$$

Coefficient a, w, and $U(r)$ are calculated as stated below:

$$\begin{bmatrix} \mathbf{w} \\ \mathbf{a} \end{bmatrix} = \begin{bmatrix} \mathbf{V} \\ 0 \end{bmatrix} \begin{bmatrix} \mathbf{K} & \mathbf{P} \\ \mathbf{P}^T & 0 \end{bmatrix}^{-1} \tag{3}$$

and

$$U(r) = |r|, \tag{4}$$

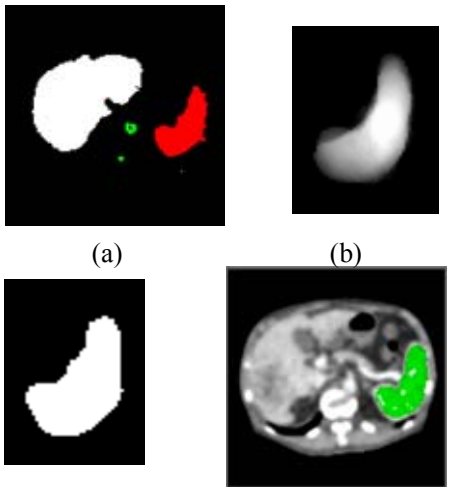
where

$$\mathbf{P} = \begin{bmatrix} 1 & x_1 & y_1 & y_1 \\ 1 & x_2 & y_2 & z_2 \\ \dots & \dots & \dots & \dots \\ 1 & x_n & y_n & z_n \end{bmatrix}, \quad \mathbf{V} = \begin{bmatrix} x_1' & x_2' & \dots & x_n' \\ y_1' & y_2' & \dots & y_n' \\ z_1' & z_2' & \dots & z_n' \end{bmatrix},$$

$$\mathbf{K} = \begin{bmatrix} 0 & U(r_{12}) & \dots & U(r_{1n}) \\ U(r_{21}) & 0 & \dots & U(r_{2n}) \\ \dots & \dots & \dots & \dots \\ U(r_{n1}) & U(r_{n2}) & \dots & 0 \end{bmatrix}.$$

2.2. Edge detection on subtraction image

The spleen tissues in the edge image derived from Sobel and LoG [7] filters are always turned into black and only remain a closed contour along spleen surface. In order to attenuate the affect of fibrosis region, we propose a new method by using subtraction image of two phases. Because the intensity of spleen and fibrosis regions are always lower in non-contrast phase image *Gpre* than in portal venous phase image *Gpor*, subtraction value of *Gsub*=*Gpre*-*Gpor* in spleen region will be under zero. In this case, *Gsub* is regarded as 0. However, things are changed outside these areas. *Gsub* can be over zero as the signals show to be different in the two phase images. As a result, the spleen with fibrosis region is equal to 0 on the subtraction image while leaving white points along the surrounding area



(a) (b)

(c) (d)

Fig. 2 (a) edge map of a subtraction image after edge detection (b) frequency of spleen points (c) average shape of spleen (d) the slice with a largest spleen region

after edge detection. Areas with gray value 0 are shown in Fig. 2(a).

2.3. Extraction of initial spleen region and finding the slice with a largest spleen

The initial spleen region, which is separated into one of the red labels on edge map, can be picked up as the first largest 3D label from the left abdominal wall (near left lobe of liver) except for the background as shown in Fig. 2(a). An iterate 3D morphology with labeling processing is employed for deleting the unwanted connectivity. In order to automatically select one of the slices with largest spleen region as a start point, we first generate a frequency image of the spleen by a range of 3D initial spleen. A range of 75-mm-thick 3D spleen slices are selected with 25 mm distance from the start slice and the frequency of spleen points are calculated as in Fig. 2(b). Binerization of this frequency image derives the average shape of spleen as shown in Fig. 2(c). Error images are generated from every initial spleen to average spleen, and the slice with the minimum error is selected as the slice with a largest spleen region *S0* in Fig. 2(d).

2.4. Elimination of overextraction

(a) Gray level elimination

The final spleen is extracted on the portal venous phase images. The mean intensity *Gavr* and standard deviation *SD* of the spleen within the initial spleen region *S0* that is derived by edge detection is calculated as a reference threshold value for binarization within the range of *Gavr* - *SD* and *Gavr* + *SD*. By reconfirming the whole spleen and generate the gray map, some connectivity caused by the open edge can be easily eliminated by this processing. Starting from the *S0* region, a smaller spleen region is extracted by using the result of the previous slice, and this procedure stops automatically depending on the area of spleen.

(b) Neighbor shape comparing method on axial plane

Since the spleen shape changes gradually slice by slice in the axial direction, connectivities with a large area can be eliminated by comparing the shape to the region of its neighboring slice. Starting from the slice with largest liver region, this procedure is applied in the direction on the upper and lower side. Some organs such as the liver, kidney, or pancreas can be eliminated by this 2D-based processing which sometimes is impossible to realize in a 3D method.

(c) Reference to other phase image

Some tissues or organs like the liver, pancreases, and stomach are often connected with spleen and can be hardly distinguished from each other because their intensity overlaps with the liver. Elimination of these types of connectivity is very difficult when only portal venous image is used. However, these connectivities always have different grey values as compared to the spleen on arterial phase image, and investigation of these components facilities elimination of ambiguous region. Within the spleen region extracted from portal venous image, all the pixels with different intensity from liver are selected as the overextracted candidates. To identify if the candidate is outside the liver region, we investigate its surrounding pixels *S* on portal venous image. If the mean grey value of *S* is near *Gavr*, then it is regarded as the vessels or tumor in spleen, otherwise it is regarded as overextraction.

3. Experiments

A multi-detector row CT (MDCT) scanner (UltraSpeed of GE Healthcare) was used to scan a quadruple-phase protocol that included unenhanced, hepatic arterial, portal venous, and delayed phase images. Each patient received the contrast/bolus agent (Oypalomin370 or Optiray320) via a power injector at a rate of 3 ml/s, and the final average volume of contrast material was 100 ml (range, 110–182 ml). Four complete acquisitions of the entire liver were obtained in a craniocaudal direction during one breath hold with the following parameters: slice interval,

0.625–1.25 mm; bits stored, 16 bits; pixel-spacing, 0.50–0.625 mm; spatial resolution, 512 × 512; 165 mAs; and 120 kVp. In all patients, non-contrast scanning (i.e., the first pass) was performed. The final average start time for the hepatic arterial phase was 37 s (range, 35–40 s). The portal venous phase and the equilibrium phase (i.e., the third and fourth passes, respectively) scans were acquired at 65 s (range, 60–70 s) and 180 s, respectively, after contrast material injection.

12 normal liver cases and 8 cirrhosis cases were used in experiment. The ground truth of spleen region (gold standard) in each CT case was instructed by two experienced radiologists (authors L.L. and Z.Z.) using a semi-automatic segmentation method for evaluating the segmentation accuracy of the results. The coincidence ratio between the segmented spleen region and the ground truth of spleen region was used to evaluate the accuracy of the spleen segmentation method.

4. Results and discussion

Segmentation of a 3D spleen region costs 5 minutes in average running on a PC (Pentium M 1GHz with 512M RAM). The surface rendering technique is used in the 3D visualization preference study. Figure 3 shows an extracted spleen by our new method. The performance of segmentation was with the coincidence ratio 0.96 with the average error rate of 4.3%.

In the whole 20 cases in our experiment, it was found that the spleen regions were successfully segmented without losing any part of spleen tissues.

The result also showed that our fully automatic method for the segmentation is effective and robust despite the presence of abnormal tissues within the spleen.

TPS can realize the non-rigid registration in a reasonable time but requires the high accurate position of landmarks, while in the mutual information registration [8] no landmark and user interaction are required; however, it is an extremely time consuming method. Therefore, TPS appears to be more practical in clinical use but more sophisticated and robust algorithms have to be developed to improve the extraction accuracy of the landmarks in the next step.

Our program can be used with a single phase or multi-phase mode, which implies that the flexibility and utility of our system for the clinical uses as the number and time series of scanning varies in different hospitals. The multiphase mode allows subtraction process and thus improves the accuracy of segmentation than using only one-phase image.

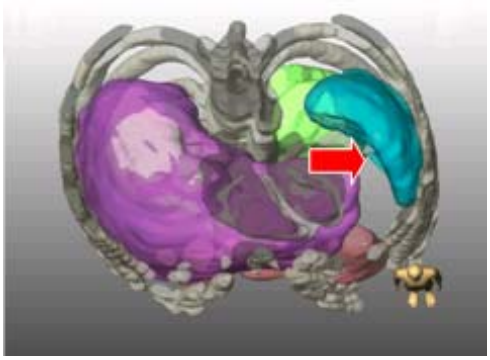


Fig. 3 An example of extracted spleen (arrow) is shown together with other organs and bones to demonstrate its anatomical position.

Furthermore, this method will be modified to enable the use on MRI.

We can expect that the additional information such as volume, irregularity of surface or texture of spleen may be helpful to improve the accuracy of diagnosis of cirrhosis.

5. Conclusion

We proposed an automatic method for the extraction of the spleen region with fibrosis tissues on multi-slice MDCT. It has been proven that our non-intensity based edge-detection and subtraction method can function effectively on the datasets from different modalities with different image quantities despite the presence of lesions within the spleen. The result demonstrates that our program is promising and effective in the segmentation of the spleen region, and it is expected to be useful in the clinical examination of an in vivo hepatic radiographic image.

Acknowledgments

This research was supported in part by the National Natural Science Foundation of China (No. 60762001); in part by the Program to Sponsor Teams for Innovation in the Construction of Talent Highlands in Guangxi Institutions of Higher Learning; in part by the National creative plan for undergraduate student of Guangxi University (No. 200707); and in part by a research foundation project of Guangxi University (No. X071036). The authors would like to thank Takeshi Hara, Xiangrong Zhou, Masayuki Kanematsu, Ryujiro Yokoyama, Gobert Lee, Hiroki Kato, Tetsuji Tajima, and Teruhiko Kitagawa for their helpful former works of this study, as well as the students in Zhang's lab for their assistance in a part of research.

References

[1] Kato H., Kanematsu M., Zhang X., Saio M., Kondo H., Goshima S. and Fujita H., : Computer-aided diagnosis of hepatic fibrosis: Preliminary evaluation of MRI texture analysis using the finite difference method and an artificial neural network. *American Roentgen Ray Society*. **189** (2007) pp.117-122

[2] C.R. McNeal, W.H. Maynard, R.A. Branch, T.A. Powers, P.A. Arns, K. Gunter, J.M. Fitzpatrick and C.L. Partain. "Liver volume measurements and three-dimensional display from MR images," *Radiology*, vol.**169**, pp.851-864, 1988.

[3] H. Awaya, D. Mitchell and T. Kamishima, "Cirrhosis: Modified caudate-right lobe ratio," *Radiology*, vol. **224**, no.3, pp.769-774, 2002.

[4] Zhang, X., Tajima, T., Kitagawa, T., Kanematsu, M., Zhou, X., Hara, T., Fujita, H., Yokoyama, R., Kondo, H., and Hoshi, H.: "Segmentation of liver region with tumorous tissues". *Proc. of SPIE Medical Imaging 2007*: Image Processing, pp.651235-1-651235-9

[5] Zhang, X., Li, W., Fujita, H., Kanematsu, M., Hara, T., Zhou, X., Kondo, H., and Hoshi, H.: Automatic segmentation of hepatic tissue and 3D volume analysis of cirrhosis in multi-detector row CT scans and MR imaging. *IEICE Trans. Inf. & Syst*. **E87-D** (8) pp. 2138– 2147, 2004

[6] Bookstein, F. L.: Principal warps: Thin-plate splines and the decomposition of deformations. IEEE Trans. on Pattern Analysis and Machine Intelligence. **11** (1989) pp.567– 585

[7] D. Marr and E. Hildreth, "Theory of edge detection," *Proc. Royal Society of London*, B207, pp. 187–217, 1980.

[8] W. Wells, P.I. Viola, H. Atsumi, S. Nakajima and R. Kikinis, "Multi-modal volume registration by maximization of mutual information", *Medical Image Analysis*, Vol. 1(1), 35–51, 1996.

Published by the IEEE Computer Society
10662 Los Vaqueros Circle
P.O. Box 3014
Los Alamitos, CA 90720-1314

IEEE Computer Society Order Number P3118
BMS Part #: CFP0893D-PRT
Library of Congress Number 2007943152
ISBN 978-0-7695-3118-2