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A hybrid semi-automatic method for liver segmentation based on level-set methods using multiple seed points

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ABSTRACT

The present study developed a hybrid semi-automatic method to extract the liver from abdominal computerized tomography (CT) images. The proposed hybrid method consists of a customized fast-marching level-set method for detection of an optimal initial liver region from multiple seed points selected by the user and a threshold-based level-set method for extraction of the actual liver region based on the initial liver region. The performance of the hybrid method was compared with those of the 2D region growing method implemented in OsiriX using abdominal CT datasets of 15 patients. The hybrid method showed a significantly higher accuracy in liver extraction (similarity index, SI = 97.6 ± 0.5%; false positive error, FPE = 2.2 ± 0.7%; false negative error, FNE = 2.5 ± 0.8%; average symmetric surface distance, ASD = 1.4 ± 0.5 mm) than the 2D (SI = 94.0 ± 1.9%; FPE = 5.3 ± 1.1%; FNE = 6.5 ± 3.7%; ASD = 6.7 ± 3.8 mm) region growing method. The total liver extraction time per CT dataset of the hybrid method (77 ± 10 s) is significantly less than the 2D region growing method (575 ± 136 s). The interaction time per CT dataset between the user and a computer of the hybrid method (28 ± 4 s) is significantly shorter than the 2D region growing method (484 ± 126 s). The proposed hybrid method was found preferred for liver segmentation in preoperative virtual liver surgery planning.

1. Introduction

The liver volume (LV) information of a patient is needed to prepare a preoperative plan for safe liver surgery. The safety of hepatectomy can be predicted by relative residual LV (%RLV), the ratio of residual to total functional LV (TFLV = entire liver volume − tumor volume) [1,2]. For example, Schindl et al. [2] identified that postoperative serious hepatic dysfunction is likely to occur if %RLV < 26.6% based on an ROC analysis for 104 patients with normal synthetic liver function. Ferrero et al. [1] also reported that hepatectomy can be considered safe if %RLV > 26.5% for patients with healthy liver and %RLV > 31% for those with impaired liver function based on an analysis of 119 cases.

The LV of a patient can be estimated by regression and image processing approaches, which have their own strengths and weaknesses in terms of ease of use, efficiency, and

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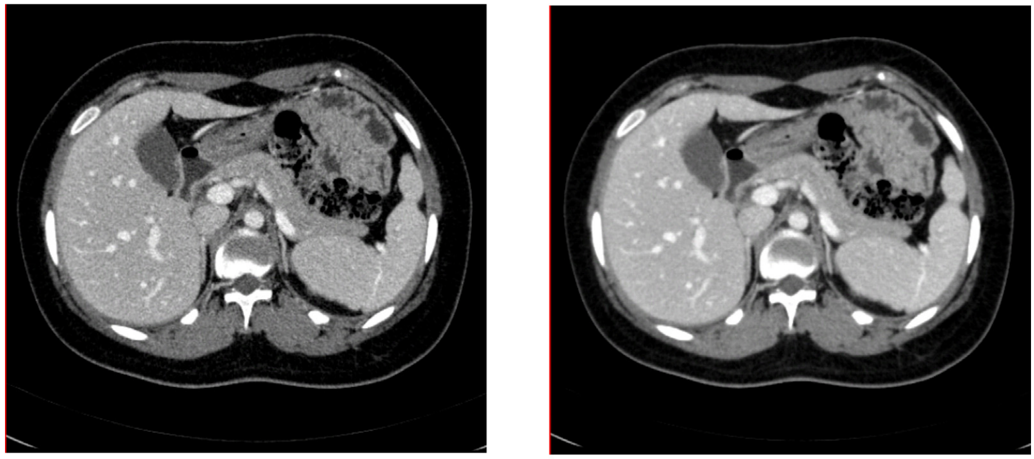

Fig. 1 – Denoising of a CT image: (a) original and (b) denoised. Slices are displayed with a window of 400 and a level of 70.

accuracy. The regression method uses a regression equation which explains the statistical relationship between LV and anthropometric dimensions such as height and weight for LV estimation [3–5]. The regression method is simple and easy to use, but sacrifices accuracy in LV estimation. Yu et al. [5] reported that the standard deviation of LV estimation error ranged from 275.4 to 289.4 ml when various LV regression equations were applied to 652 Korean cases. On the other hand, the image processing approach measures a patient's LV with liver images extracted from the patient's abdominal CT images by using image processing software such as Rapidia (Infinitt Co., Ltd., South Korea), Voxar 3D (Toshiba Co., Japan), Syngovia (Siemens Co., Germany), and OsiriX (Pixmeo Co., Switzerland). The image processing approach is more time demanding for liver extraction but more accurate in LV estimation than the regression approach.

Various automatic and semi-automatic methods have been developed to improve the performance of the image processing approach in liver extraction in terms of time efficiency and accuracy. Automatic liver extraction methods identify the boundary of the liver using a morphological image processing method [6] or a histogram analysis of CT image intensity data [7,8]. However, the automatic methods commonly sacrifice the accuracy of liver extraction because their algorithm cannot completely discriminate the liver from the neighboring organs due to the similarity of image intensity between the organs [9]. Ruskó et al. [8] reported that their automatic liver extraction method based on a histogram analysis resulted in an average overlap accuracy of 89.3% with an average processing time of 56 s per CT dataset with a thickness of 1 to 3 mm on a computer with an Intel Pentium 4 CPU 3 GHz processor. Li et al. [10] proposed an automatic liver segmentation method using probabilistic atlas and reported an average overlap accuracy of 92.9% for low-contrast CT images. On the other hand, semi-automatic methods consist of interactive identification of seed points or regions and extraction of the liver boundary from the selected seed points or regions [11,12]. Dawant et al. [11] proposed a semi-automatic liver extraction method which took 10 min for manual extraction of the liver on 20–30 CT slices seleced with an approximately equal interal from a CT dataset and 10 min for extraction of the rest of the liver using a level-set method and an interpolation method on a computer with a Pentium D 3.2 GHz processor and 2 GB of memory, resulting in an average overlap accuracy of 90.2% for 10 CT datasets with a thickness of 1–3 mm.

The present study was intended to develop a novel hybrid semi-automatic method for better accuracy and time efficiency in liver segmentation. The accuracy and time efficiency of the proposed hybrid semi-automatic method for liver segmentation were compared with those of the 2D region growing method implemented in OsiriX (Pixmeo Co., Switzerland). The liver regions manually extracted by a radiologist using Rapidia (Infinitt Co., Ltd., South Korea) were considered as gold standard for accuracy evaluation. Furthermore, an onsite evaluation of the proposed hybrid method was performed using the public database provided by the SLiver Grand Challenge of the MICCAI 2007 workshop [13].

2. Hybrid liver segmentation method development

A hybrid semi-automatic method which incorporates a fast-marching level-set method [14] and a threshold-based level-set method [15,16] was developed in the present study. The proposed hybrid liver segmentation method consists of five steps: (1) pre-processing of CT images, (2) selection of multiple seed points, (3) formation of an initial liver region, (4) extraction of the liver region based on the initial liver region, and (5) post-processing of the extracted liver region.

2.1. *Preprocessing of CT images*

Abdominal CT images of a patient are denoised (Fig. 1) in the preprocessing stage. Liver extraction without denoising is difficult since the intensity distribution of the liver is irregular due to noise [9]. An anisotropic diffusion filter [17] implemented in ITK [18] was employed in the present study to