3D $\alpha$-Expansion and Graph Cut Algorithms for Automatic Liver Segmentation from CT Images

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Abstract. Abdominal CT images have been widely studied in the recent years as they are becoming an invaluable mean for abdominal organ investigation. In the field of medical image processing, some of the current interests are the automatic diagnosis of liver pathologies and its 3D volume rendering. The first and fundamental step in all these studies is the automatic liver segmentation, that is still an open problem. In this paper we describe an automatic method to segment the liver from abdominal CT data, by combining an $\alpha$-expansion and a graph cut algorithm. When evaluated on the data of 40 patients, by comparing the automatically detected liver volumes to the liver boundaries manually traced by three experts, the method achieves a symmetric volume difference of 94%.

Keywords: Computed Tomography, Liver Segmentation, energy minimization, $\alpha$-expansion, graph-cut algorithm.

1 Introduction

Computed tomography (CT) images are nowadays the standard instruments for diagnosis of liver pathologies (e.g. cirrhosis, liver cancer, fulminant hepatic failure) for they provide accurate anatomical information about the visualized structures, thanks to their high Signal-to-Noise ratio and good spatial resolution. This motivates the great deal of research work, in the digital image processing field, aimed at the development of computerized methods for the automatic detection of liver pathologies [16,10], and the 3D liver volume measurement [13] and rendering [6], which have been shown to be helpful for surgical planning prior to living donor liver transplantation or to hepatic resection.

Whatever the aim of the system, the first and fundamental step is always the liver volume segmentation, that is usually done by expert radiologists who either manually trace the liver contour on each slice of the CT data, or employ semi-automated techniques [15]. Since both manual and semi-automatic procedures require the user interaction time, and they are affected by his/her errors and biases, a lot of research work has been devoted to the development of fully automatic liver segmentation techniques. Nevertheless the problem is still open due to several factors. First of all, neighboring organs (e.g. liver, spleen and stomach) might have similar gray levels, since the gray tones in CT images are
related to their (sometimes similar) tissue densities. Besides, the same organ may exhibit different gray levels both in the same patient, due to the administration of contrast media, and in different ones, for varying machine setups. As a result, methods relying on simple thresholding [4,11,12], where thresholds are set based on a priori knowledge or statistical analysis of manually segmented samples, are likely to fail when processing patients whose liver gray level characteristics are not captured by the analyzed sample.

Moreover, due to the partial volume effects resulting from spatial averaging, patient movement, beam hardening, and reconstruction artifacts, the acquired images have low contrast and blurred edges. Consequently, methods employing simple gray level dependent edge detectors (e.g. Sobel, Roberts) do not produce satisfactory results [9].

In addition, the liver presents significant anatomical variation in different image slices of the same patient; even at the same slice position, its shape may vary widely from patient to patient. This fact makes model fitting techniques [5,18], statistical shape models [8], and probabilistic atlases [14,17] not easy to be used, since they require a huge amount of training examples to capture as much shape variability as possible. Furthermore, when dealing with complex shapes, these techniques might require too much computation time before a good match between the model and the image data is obtained.

In [2] we reviewed the most relevant automatic liver segmentation works, and we noted that a comparison among them would not be meaningful due to the lack of a common dataset with its gold standard, i.e. a commonly accepted manual segmentation, and a unique measure of the discrepancy between the automatic and the manual segmentation. Besides, the private datasets employed by most authors are too small (less than 10 patients).

In this paper we propose our liver segmentation method (section 3), that has been evaluated on a set of 40 abdominal CT images (section 2) and achieves results comparable to the intra and inter-personal variability of manual segmentation by experts (section 4).

2 Materials

Our dataset is composed of 40 abdominal contrast enhanced CT images of the third phase. They have been acquired at the Niguarda Ca’ Granda hospital in Milan, with a Siemens multi-detector spiral CT, after the injection of 2 Ml/Kg contrast material. The images, stored into a PACS system in DICOM format, have been exported by AGFA IMPAX software as a set of 2D axial slices in JPG format. For each patient a set of 80 axial slices with a 3 mm interval is acquired; each slice has a 1024 × 1024 pixel size, and a 0.165 × 0.165 mm pixel resolution. To expedite the computation they have been reduced to 256 × 256 pixels, and a 3 × 3 median filter has been subsequently applied to remove impulsive noise. The 3D coordinate system used in this work has the Z axis parallel to the body axis and oriented from the topmost to the bottommost slice, while the X and Y axis are oriented respectively along the width (from left to right) and the