Semi-Automatic Feature Delineation In Medical Images

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Abstract

Resection or ablation of tumours is one treatment available for liver cancer. This delicate operation consists of removing the tumour(s) and surrounding healthy tissues. The surgery is complicated by the fact that major blood vessels are present in the liver: the surgeon must proceed cautiously. Computer Tomography (CT) scans are used to diagnose the presence of tumours in the liver but also to assess whether the patient is suitable for surgery. The surgeon needs to find the number of tumours, their size and the physical and spatial relationship between the tumours and the main blood vessels. Extracting this information from the CT scan is a time-consuming procedure, which requires manual contouring of the tumour and the main vessels and is complicated by the low contrast in the images. In this paper we describe a framework, designed within Matlab, to semi-automatically segment the liver, tumours and blood vessels and create a three dimensional (3D) model of the patient's liver suitable for surgery planning.

Keywords: liver resection, visualisation, Computed Tomography, image segmentation, liver surgery.

Introduction

One of the treatments of liver cancer is resection or ablation of one or several tumours. This complicated surgical procedure involves the removal of the malignant part of the liver and an area of healthy tissue around the tumours. Not all patients are suitable for liver resection. A CT scan is the tool of choice to make a diagnosis and decide whether the patient is suitable for the surgery and if appropriate, to plan the surgery. A CT scan consists of a series of 2D images taken along the lower part of the thorax and the abdomen. The images are then combined by the radiologist to provide the surgeon with the information necessary for the surgery. The liver is made of soft tissues surrounding a branching system of blood vessels. Malignant tumours have a similar density to healthy tissue and appear lighter or darker on a greyscale CT scan image. Blood vessels are also very similar to healthy tissues, resulting in low contrast images. Hence 3D reconstructions of the liver vascular system and tumours are difficult, however they help pre-operative planning. It is therefore imperative to identify the position of the tumour(s) with respect to the blood vessels. Image processing, semi-automatic segmentation of the liver and blood vessels, added to 3D visualisation techniques can address this problem. In this paper we present further work on a pilot project aimed at helping liver surgery planning. The techniques are likely to be more generally useful in biological imaging, where feature detection and segmentation often need to be done by eye and hand.

1 Anatomy of the Liver

The liver is located in the upper right portion of the abdomen and protected by the rib cage. About 1450 ml/min of blood flows through the liver: this represents almost a third of the total blood in the body. 75% of the blood supply to the liver comes from the hepatic portal vein and 25% from the hepatic artery (Grady, Lake and Howdle 2000). The blood drains into the hepatic vein. The liver is the only organ we possess that can regenerate itself if parts are removed. It is divided into eight independent segments, with their own vascular inflow, outflow and biliary drainage (Couinaud 1956). Each segment being independent can be resected without damaging the others. Problems arise when a tumour is located across two segments. A liver resection is a complex procedure and care must be taken next to the important liver blood vessels. As each patient is different, CT scans are an essential imaging tool to "map" the patient's liver and plan the surgery.

2 Related Work

Several groups have been working on an automatic segmentation of the human liver for surgery planning. Most of them are working on the volume made from the CT image slices. Soler et al (1997) combines several image processing techniques such as thresholding, mathematical morphological methods and distance maps to extract 3D-models of the skin, bones, lungs, and kidneys. A 3D reference model of the liver is then embedded in the CT-scan and is deformed to "match" the patient liver contours. This procedure helps in classifying the different organs. The researcher then use a least-square fitting of three Gaussian distributions onto the grey-level histogram to estimate the thresholds corresponding to the liver, tumours and vessels and the automatic segmentation is then done based on these threshold values. Researchers at the Centre for Medical Diagnostic Systems and Visualisation in Germany (Schenk et al. 2000, Selle and Peitgen 2001, Preim et al. 2002, Scheuering et al. 2003) have developed semi-automatic segmentation algorithms based on the calculation of minimal cost paths. The user sets a seed point on the boundary and moves the mouse along the boundary: the algorithm calculates and displays the contour calculated. Most of these algorithms however are proprietary.

3 Data Acquisition

The dataset is made of 128 CT parallel image slices of 512 x 512 pixels. Figure 1 is one of the images in the scan. The image has poor contrast in spite of the dye injected into the patient during the CT scan acquisition. The liver occupies the left side of the image. The tumour appears as a darker circular area, the blood vessels as lighter objects than the liver. Further image processing is thus required to bring more details.

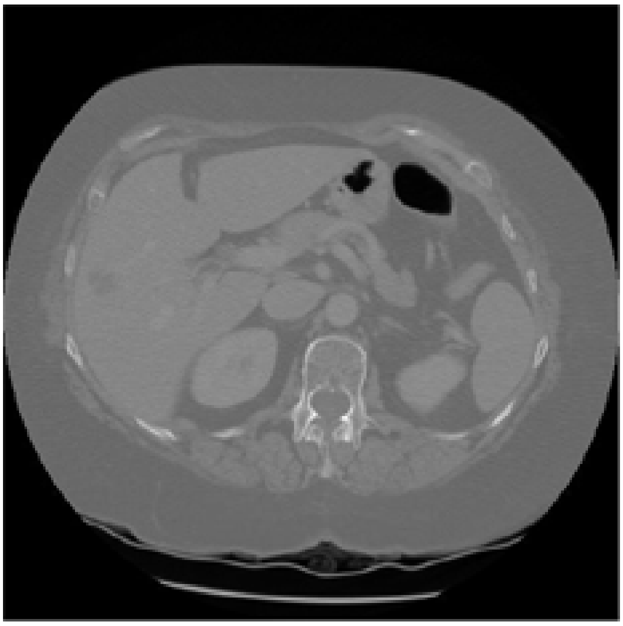

Figure 1: Original slice from the CT scan: the tumour is visible a darker object and the blood vessels as lighter objects.

At the hospital the medical technician prepares the data for the surgeon. The process is lengthy: a volume of the whole torso is first produced. Thresholding operations highlight the high intensity voxels such as those produced by the bones. They are "discarded". The medical technician proceeds then to manually discard other organs by drawing lines around them; the liver is hence isolated. The veins and arteries are extracted by thresholding and segmented manually. They are annotated in order to differentiate between the hepatic and portal venous systems. Finally the tumour(s) are also selected manually. All these steps render the process time-consuming.

4 Methods and Results

Matlab is a computing-visualisation environment, which "integrates numerical computation, advanced graphics, visualisation, and a high-level programming language" (Mathworks 2003), and is supplemented now by a large array of toolkits. Most of the algorithms used in this project were developed within the Matlab problem-solving environment; they could have been produced as stand-alone codes, but not as readily.

4.1 Image Processing

The images were originally in the dicom format, an image format commonly used in medical imaging (DICOM). They were converted to tiff format (TIFF), to make the dataset anonymous: patient's name, machine settings were thus omitted during the conversion. In the process the tiff images became laterally inverted. The CT images were first cropped to enclose the liver area. This reduction in size of the images decreases the computation time and the file size. The images were cropped at row 30, column 90 and row 360 and column 420, the resulting size being 330 x 330 pixels. The CT images are homogeneous in intensity due to poor contrast and noise in the images. We first used standard image processing techniques in order to enhance contrast and details (Gonzales and Woods 1992) before attempting the 3D reconstruction. A low pass gaussian filter reduced the noise and smoothed the features in the images. A high pass filter sharpened the edges of the organs however increased the noise in the image thus offering no improvement. The intensity between slices is not uniform, especially between the "top" and "bottom" slices: this is due to the acquisition process. Histogram equalisation (Gonzales and Woods 1992) was then performed on each slice to adjust these intensity values and improve the contrast by stretching the intensity distribution. These pre-processing steps were applied to figure 1 and are illustrated in figure 2. The

Figure 2: A low pass filter followed by histogram equalisation was applied to the image shown in figure 1 after it was cropped: tumour and blood vessels become apparent.

tumour and the blood vessels are now apparent and the organs better defined. Such image processing techniques are quick to perform. In order to create a 3D model of the patient's liver a mask isolating the liver from the other organs needs to be created. In previous work this was done manually (Doherty et al 2003). The liver is malleable and does not have a specific shape. The organs touch each other and the boundaries are not well defined. The density values are similar on the scan. For instance the heart and the liver seem to belong to the same organ: an edge detection algorithm is difficult to use. We developed a region-growing algorithm to create the mask. The user first selects a seed point by clicking in the liver region and then constrains the search area in the image by defining the physical limits of the liver, which vary from slice to slice. This provides the stopping conditions for the growing region algorithm and speeds up the computation. The algorithm tests the neighbouring pixel: if it belongs to the liver, the pixel in the mask at the corresponding position is set to 1, if it does not, it is set to 0. This test is based on a proximity and intensity test: the pixel has to be adjacent to the growing region and its intensity must belong to a threshold range. It is possible to grow several regions and add them to the mask: in some images, the liver does not form a continuous area. The seed values were not constant over the scan: they varied slightly between images, as the intensity value tends to increase towards the top. This suggests that a complete automation of the process is not possible. The algorithm worked reasonably well on this dataset as shown in figure 3. However the algorithm includes areas adjacent to the liver where the intensities are similar. Within the user interface a tool is provided to add or remove areas that should belong or not belong to the liver. The tool works in a similar way to the lasso tool in Photoshop: the user points and clicks to define the area that needs to be added to or removed from the mask and click on the "cut" or "add" buttons on the interface. Sometimes the region-growing algorithm omits pixels that clearly belong to the liver area. A function using morphological operations, specifically dilation and erosion, (Gonzales and Woods 1992) was created to remove this "noise". A four-pixel square was passed over the image to "close" these pixels. A series of masks was then created for each slice consisting of ones in the selected section (the liver) and zeros everywhere else. The image and corresponding mask were then multiplied together element by element, to isolate the liver. The resulting segmented image was then saved.

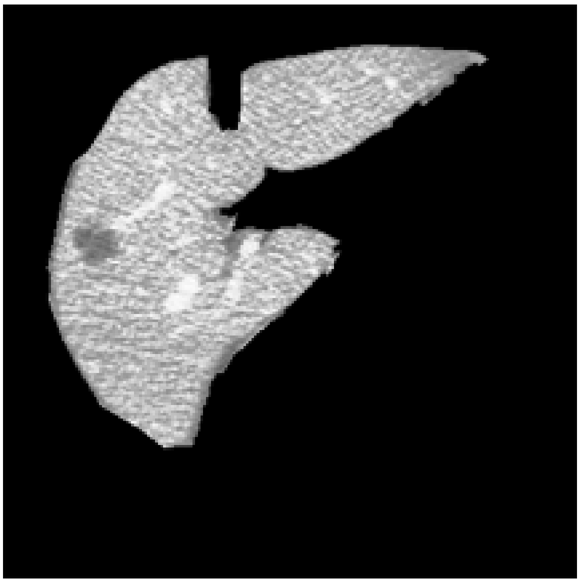

Figure 3: Semi-automatic delineation of the liver by region-growing.

4.2 3D Visualisation

Two ways of visualising the liver are available: direct volume rendering and isosurfacing. Volume rendering is a powerful method often used in medical visualisation

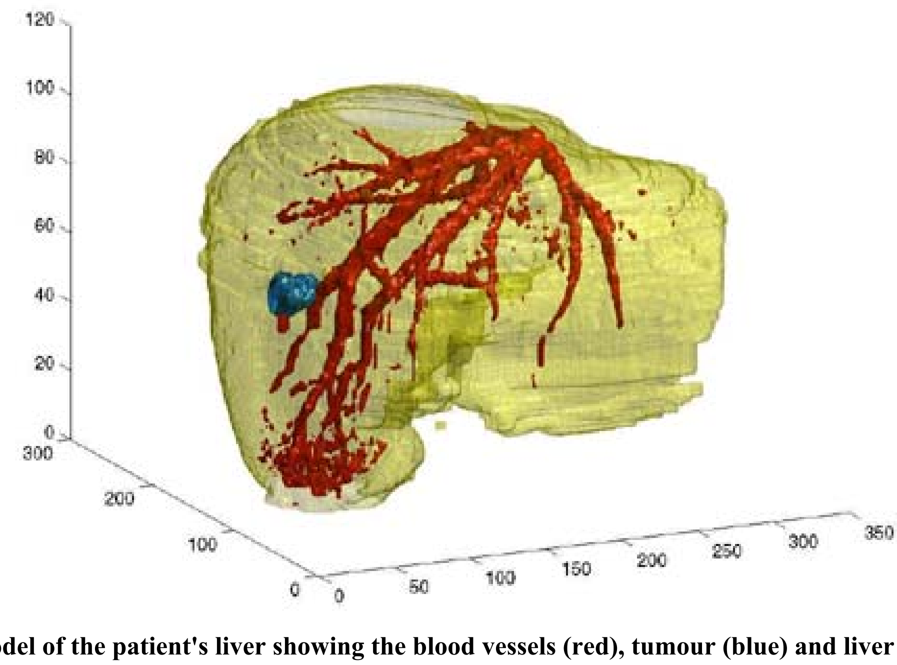

Figure 4: 3D model of the patient's liver showing the blood vessels (red), tumour (blue) and liver (yellow). The x- and y-axis corresponds to pixels and the z-axis to the slice number.

(Kaufman 1991 and Kaufman et al. 1993, Elliot et al. 1996). All pixels (or voxels) contribute to the final image and this technique works well to show the organs in relation to each other. Isosurfaces are the 3D analogue of contour lines: they represent surfaces of equal values or density in the case of the CT scan (Lorensen and Cline 1987). The latter technique was chosen to visualise the liver, tumour and blood vessels in three dimensions. The segmented images were then read as a volume. The density values corresponding to tumours, veins and liver were determined by checking the pixel intensities of theses features using a simple colourmap. The liver was first visualised as an isosurface shown in semi-transparent yellow. The blood vessels were added and then finally the tumour, shown in blue. The blood vessels are clearly visible as well as their 3D relationship to the tumour as shown in figure 4. The 3D interrelation of these features provides one set of essential information required by the surgeon, while designing a surgical procedure to remove the tumour.

4.3 The user interface

The graphical user interface (GUI) is the vehicle for the interaction between the user and the computer. Matlab was originally command-oriented and, as such, would have been a bad choice for a general user. However for the past few years Matlab has provided excellent GUI capabilities, which have been used for this project. MATLAB implements a GUI as a figure window, which contains various objects, such as buttons, text boxes, sliders, etc. The user programs these objects to perform a certain task. All this programming is performed with GUIDE, the Matlab GUI development environment.

Our interface allows the user to compare the result of the image segmentation technique to the original image and modify it, and to reject it as required. Files can be loaded and saved in sequence. The histograms, corresponding to the two displayed pictures, are presented as an aid to assist the user to select the intensity value; alternatively the user can point and click the mouse in the image and determine the pixel intensity.

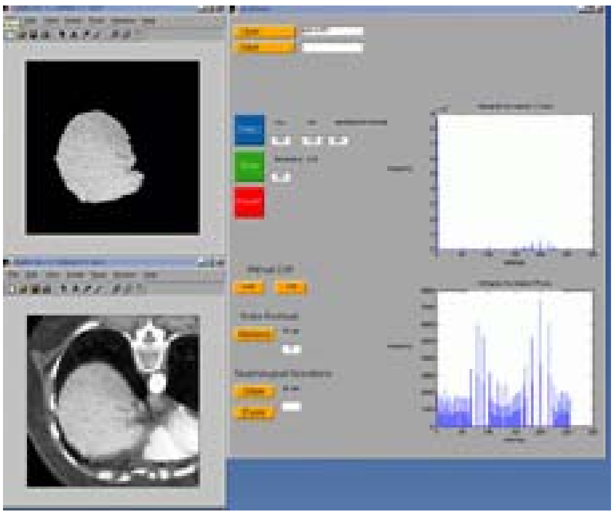

Figure 5: Graphical user interface showing the segmented image (top) and the original image (bottom) and associated histograms.

4.4 Discussion

The performance of today's computers, the availability of powerful graphics cards and the existence of problem-solving applications such as Matlab, make the analysis of medical images, and the extraction of critical information, possible without resorting to expensive hardware and software, or to exotic techniques. We were able to process the CT scan and create a 3D visualisation of the liver within the Matlab environment. The region-growing algorithm was effective, however computation time could be improved by rewriting the function in C and calling it as an external executable from Matlab. We specifically worked on each image slice in sequence. Currently we are investigating whether it would be more efficient to work on the volume itself although the region-growing algorithm would need to be generalised and re-implemented in three dimensions. The 3D model is created in about four minutes on a Sun workstation. The model can be rotated and viewed from different angles, providing spatial information and insights to the surgeon. The semi-automatic segmentation of the liver reduces the time required to prepare the 3D model. Isosurfacing techniques that rely on the selection of density values were more accurate and faster than the manual selection process currently used by the medical technician.

The visualisation is useful to the surgeon; however more work is required. For instance the different blood vessels need to be visually identified: this has to be implemented as a post-processing step in the user interface.

Although Matlab is not frequently used in the medical community, this software application provides an inexpensive, widely used and powerful prototyping, visualisation and image analysis environment. The ability to create a graphical user interface is also a bonus for people who are not used to assembling and writing instructions at the command line. Finally the ability to program new algorithms within Matlab, or to call C programs from Matlab, makes it a flexible and scalable tool.

5 Conclusion and Future Research

The major problem in creating a 3D model of the liver from CT scans with minimum intervention resides in the ability to delineate the liver boundaries and the blood vessels. We implemented a semi-automatic method based on region-growing to isolate the liver. Although the algorithm can sometimes miss or add areas to the liver, the user interface allows the user to add or remove these areas. We are currently investigating other techniques, such as morphological operations as an alternative to region growing. We also need to test our system with other datasets in order to evaluate and refine the method. With the exception of the segmentation that requires some intervention, the creation of the isosurfaces is automatic once the isosurface values are determined. Before this system can be used in a hospital setting, the following work needs to be done:

- as mentioned earlier, we need to test these techniques on different CT scans.

• the efficiency of the algorithms needs to be evaluated. As higher resolution images become available, Matlab's performance will probably not scale. This can be solved by writing the relevant routines in C for instance, and interfacing them with Matlab.

• a usability study needs to be done to evaluate the design of the user interface.

• the surgeon needs to be able to measure the distances between tumour(s) and main blood vessels as well as to identify portal veins and hepatic arteries. This needs to be addressed.

The ultimate goal is to display the visualisation, interactively, in the operating room for ready reference by the surgeon.

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