3D Visualisation of Tumours and Blood Vessels in Human Liver

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Abstract

One of the treatments of liver cancer is resection or ablation of one or several tumour and of an area of healthy tissue around it. Computed Tomography (CT) scans are generally used to make the diagnostic and to plan the surgery. The objective is to find the number of tumours, their size and the physical and spatial relationship between the tumours and the main blood vessels. The extraction of the essential information from the images is a time-consuming procedure, as the radiologist must trace the contour of the liver manually as well as the tumour and the main vessels. In addition one problem is that blood vessels and liver tissue show similar contrast on the CT scans. In this paper we describe alternative image processing procedures to visualise more effectively the tumour in three dimensions (3D) with respect to the main blood vessels with less human intervention, using OpenDX and MATLAB.

Keywords: 3D visualisation, Computed Tomography, vessel segmentation, liver surgery.

1 Introduction

Treatment of liver cancerous tumours often requires a liver resection. This is a complicated surgical procedure involving the removal of the malignant part of the liver, and currently there are inadequate diagnostic and pre-operative planning tools available. The standard approach involves acquiring 2D image slices through the torso using Computerised Tomography (CT) scans. These are then combined by the radiologist to provide the surgeon with information about the 3D structure of the liver. The liver consists of soft tissue surrounding a branching system of blood vessels. Tumourous tissue in the liver has a very similar density to the healthy tissue and usually appears on a greyscale CT scan image as a slightly lighter or darker patch. 3D reconstructions of the liver, its vascular system and the tumour can enhance precision in preoperative planning. In order to plan the least invasive approach to liver surgery, it is vital for the surgeon to have a good mental model of the 3D spatial relations between the liver, tumour and the vascular system. It is difficult to develop such a model with only 2D images. Improved 3D visualisations are therefore highly desirable. Furthermore, the current approach is time-consuming; therefore improvements in areas such as automatic segmentation and fast visualisation techniques are also required. This paper outlines the first stages of a project, which has started to address these aims, in which improved visualisations are being created using OpenDX and MATLAB.

2 Anatomy of the Liver

The liver is the largest solid organ in the body. Located in the upper right portion of the abdomen, it is protected by the rib cage. 75% of the blood supply to the liver comes from the hepatic portal vein and 25% from the hepatic artery [1]. The blood drains into the hepatic vein. The liver is exceptional in that it can regenerate if part of it is removed. The liver is schematically divided into eight independent segments, which have their own vascular inflow, outflow and biliary drainage [2]. Each segment can be resected without damaging the others. 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.

3 Data Acquisition

3.1 Data

The dataset consists of a sequence of CT scan images taken orthogonally through a torso such as the one shown on Figure 1. It is immediately apparent that the scans

Figure 1: Original CT scan of the thorax

cannot be used without further image processing: the liver area shows little contrast between veins, tumours and the liver tissue. The initial aim of this project is to extract as much detail as possible from these 2D images and to create a 3D visualisation of the liver showing the blood vessels and the location of the tumour.

3.2 Techniques used at the hospital

Once the scans have been acquired the radiologist prepares a visualisation of the liver for the surgeon. The software used in Radiology at the RNS hospital is based on volume and surface rendering. A volume of the whole torso is first produced and is then thresholded to highlight and discard the high intensity voxels produced for instance by the bones. The radiologist then selects portions of the volume to be discarded by drawing curves in the remaining volume: hence the liver is isolated. The radiologist must be very exact in the choice of "cuts" made as otherwise important data may be discarded. It is therefore time-consuming to build a model of the liver. The veins are then extracted by thresholding and segmented manually to differentiate between the hepatic and portal venous systems. The tumourous tissue regions are also selected manually, another time-consuming step requiring exactness.

4 Methods

4.1 Image processing

The data were received in the form of DICOM files and converted to the TIFF format for ease of use. The TIFF images are laterally inverted, possibly as a consequence of the format conversion. The images were cropped and histogram equalised [3], before being used in the visualisation, in order to reduce the image to a convenient size and optimise the contrast. Here we present a set of results using, different visualisation software applications.

4.2 Masking

Direct volume rendering is often used in medical visualisation to show the organs in relation to each other [4, 5, 6]. In this case we are primarily interested in the liver and the simplest way to visualise the liver, tumour and blood vessels in 3 dimensions is to use isosurfaces [7]. Isosurfaces, the 3D analogue to contour lines, represent surfaces of equal density. However in medical imaging the non-uniqueness of intensity values in the images make the use of isosurface techniques difficult. A particular intensity value might occur in the liver, the kidneys, and the bones. In fact, the bones contain intensity values ranging across the whole scale. Therefore it is difficult to differentiate features using isosurfaces representing specific densities, as the rib cage obscures the internal organs. In order to solve this problem, we attempted to find a way of isolating the liver from the image. This had to be achieved spatially, as thresholding the image based on intensity values is ineffective. A mask was created for each slice, consisting of ones in the selected section (the liver) and zeros everywhere else. The section was selected by manually by drawing a contour around the liver. Unfortunately there is no automatic method for segmenting the liver from the CT scan slices, as many of the other organs in the image have the same or similar density values. Thus, the boundaries are not well defined as often the organs are pushing up against each other and it is difficult to determine the difference between liver tissue and that belonging to another organ, for example the kidneys. Edge detection algorithms are therefore not useful in this situation. Research is being carried out at the Centre for Medical Diagnostic Systems and Visualisation in Germany on semi-automatic segmentation, but this still requires a certain amount of human interaction [8, 9]. Figure 2a shows an example of an image slice, Figure 2b its mask and Figure 2c the result when the mask is applied. The image shows part of the liver (on the left) and the heart (on the right). The mask extracts the portion of the liver that appears in the slice.

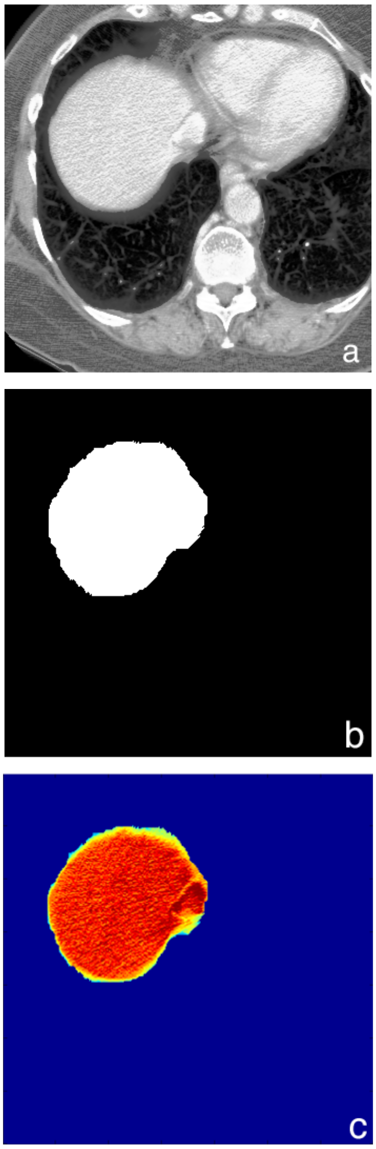

Figure 2: (a) Enhanced CT slice; (b) mask isolating the liver; (c) mask and CT slice.

4.3 MATLAB

MATLAB is a computing environment, which "integrates

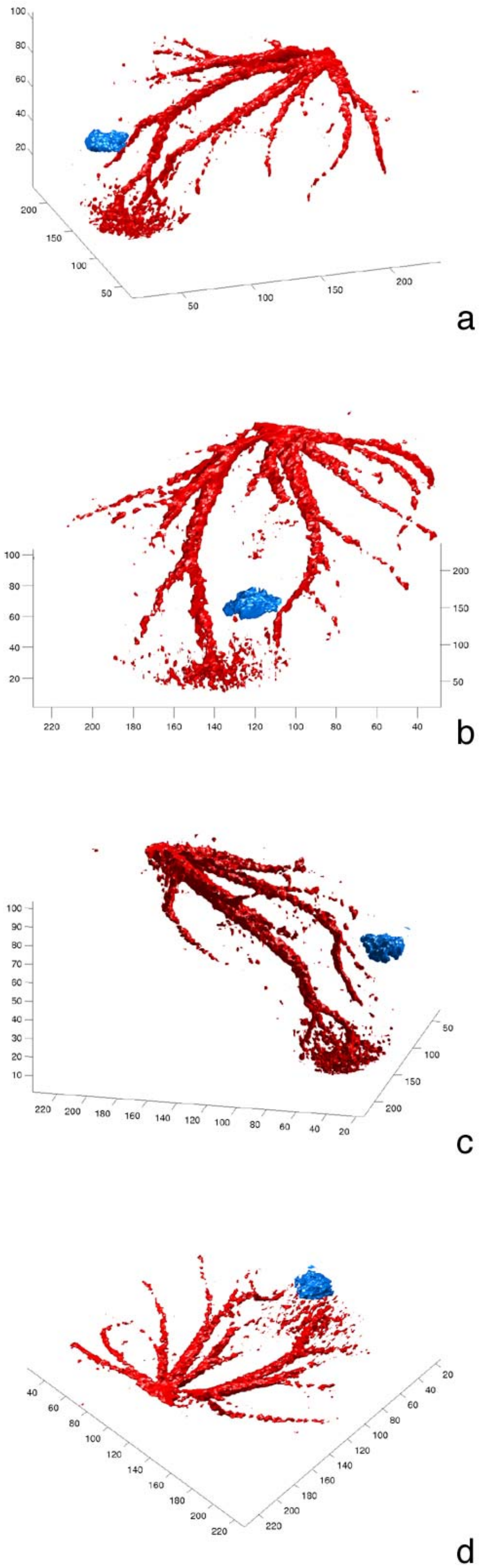

Figure 3: (a-b-c) Different views of the major blood vessels with respect to the tumour and (d) top view, obtained using MATLAB

numerical computation, advanced graphics, visualisation, and a high-level programming language" [10]. To visualise this data set in MATLAB, we firstly read in the images as a volume. The mask set was read in as a separate volume, normalized to one and then the two volumes were multiplied together element by element, to isolate the liver as described above. We then used a simple isosurface method to display the vein structures. Thresholding was used on several slices to find the density values corresponding to certain features, such as the veins. There was a small difficulty in visualising the tumour, as it has the same density as the outer liver tissue. We therefore specified a subset of data, or sub-volume, around the tumour and created an isosurface for this sub-volume, superimposing it on the same axes as the veins. The results are shown in Figure 3a-c, at different viewing angles. We can clearly see the 3rd order veins relative to the tumour. To put the visualisation in Figure 4 into the context of the liver shape, another isosurface was added, at the value of the outer liver tissue and the whole object was made transparent. This is shown below in Figure 4a-b. Ideally it would be more effective to make just the outer isosurface transparent and the others solid.

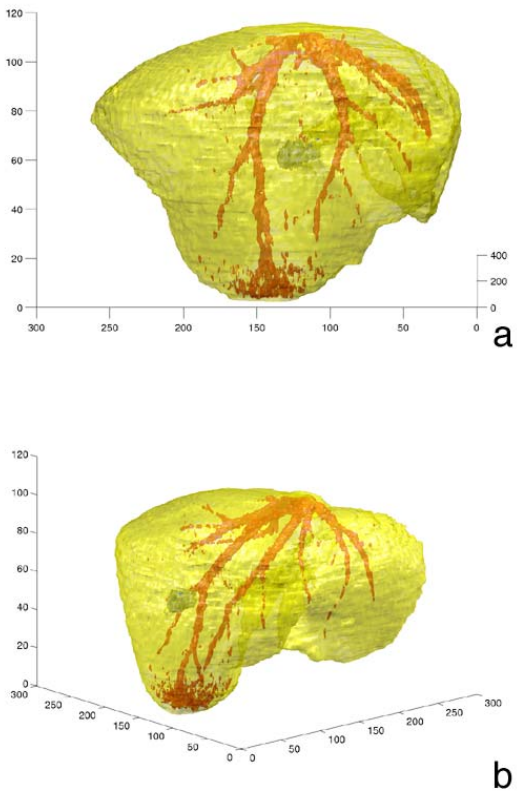

Figure 4: (a-b) Different views of the major blood vessels with respect to the tumour and the liver.

4.4 OpenDX

OpenDX was originally developed by IBM as Data explorer (DX), and is now open source. OpenDX is a multi-purpose visualisation software, which provides a suite of visualisation techniques and uses a visual data flow-programming paradigm [11]. In order to compare the MATLAB results, a similar process described earlier was carried out in OpenDX. The resulting images are shown in Figure 5. Two isosurfaces are shown, with the

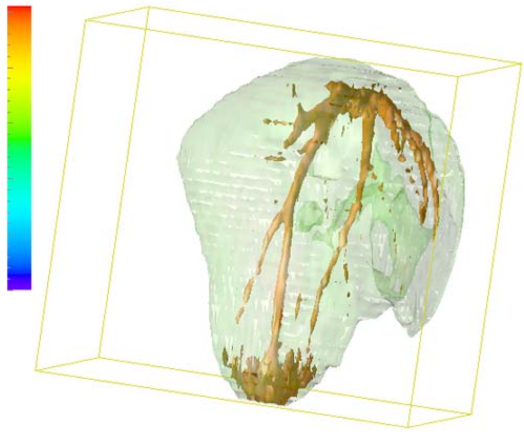

Figure 5: Visualisation of the liver, major blood vessels with respect to the tumour using OpenDX.

outer surface transparent in order to show the inner vein surfaces. The images have not been pre-processed, only histogram equalised. The isosurfaces created here contain triangular "holes", an artefact of the surface rendering. The tumour is visible in these images, in the same colour as the isosurface representing the liver, as it has the same tissue density. However, the isosurface representing the liver was made almost transparent in order to render the tumour is visible.

5 Discussion

Currently the only visualisation techniques available to surgeons are expensive specialised packages. We aimed to determine whether a useful 3D visualisation of the liver could be produced using general visualisation packages such as OpenDX and the visualisation tools in MATLAB.

Initial progress has been made in extracting the tumour and blood vessels and visualising these in perspective to each other and the overall context of the liver. This was achieved using similar methods, in both MATLAB and OpenDX. Good 3D models, which can be rotated and viewed from different angles were constructed and were helpful in aiding the surgeon to study the spatial relations of the tumour to the major blood vessels in the liver. Although it is necessary to create manually a mask for each CT slice to extract the liver, there is however less human interaction involved in this method than is required for the current techniques used in Radiology. The visualisation of the liver and the vessels using isosurfaces based on density values is therefore faster and more accurate than the selection processes involved in creating the images currently used by the surgeon.

The two similar visualisations produced in MATLAB and OpenDX allow us to make a comparison of the capabilities offered by the two packages in producing this type of visualisation. MATLAB is emerging as a powerful visualisation and simulation tool. The MATLAB visualisation holds several advantages over that of OpenDX. Firstly, it is easier to visualise the tumour clearly, using the technique of sub-volumes, as coordinates can be easily specified within MATLAB. Secondly, MATLAB is more convenient for scientific visualisations, for example it creates axes and labels automatically, whereas OpenDX is not optimised for this.

OpenDX generally creates smoother isosurfaces, although in large surfaces cracks start to appear in the surface rendering. It has however a lot more flexibility in the specification of colours and transparency. Both visualisations were compute intensive: MATLAB seemed to be faster but this would have to be assessed formally.

6 Conclusion

By applying a mask on each CT slice to isolate the liver and using isosurfaces, we have been successful in visualising the spatial relations between the liver, main blood vessels and tumour. However, we need to test this technique on several data sets in order to refine the method. Although the masking technique employed here to isolate the liver is time-consuming, the rest of the procedure is automatic and rely on selecting the density values associated to the tumour and the blood vessels., There is currently no way of segmenting the liver automatically as the boundaries between organs are not well defined in many of the image slices.

Although these first results are encouraging there is much work to be carried out on this project before it can be useful for pre-operative planning.

1) we need to apply this method to different CT scans obtained from different patients and refine the accuracy of the tumour location.

2) a method of directly measuring the distances between the tumour(s) and the main blood vessels is also required.

3) another requirement is that the surgeon needs to be able to quickly distinguish between the hepatic and portal systems, the two main branches of the vascular system.. A method therefore needs to be found to segment these two vascular branches separately and plot them as different colours.

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

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8 References

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