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The Clinical Feasibility of 2-D US and Computed Tomography Registration Technology for Human Liver Imaging

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This paper was to discuss the clinical feasibility of 2-D ultrasound and CT registration technology for the human liver. The 2-D US images and CT images of 20 patients' livers were registered to assess accuracy and stability between the two images. The process included ultrasonic probe calibration, marks registration, image preprocessing, and the simulation experiment. The images could be fully registered between 2-D US and CT. Our results indicate that image similarity improved. After registration, we calculated that the target error of the mean and standard deviation was 4.01 and 0.32 between the US and CT images, respectively; the accuracy and stability were therefore high. The images can be fully registered between 2-D US and CT. There were a few errors, but these results suggest that this method has promising applications.

Keywords: Ultrasound, CT, Registration.

1. INTRODUCTION

Currently, liver surgery such as radiofrequency ablation depends on 2-D ultrasound (US) in preoperative planning and guidance. Surgery techniques also require other medical images during operations, so 2-D ultrasounds are especially inconvenient. Additionally, due to differing imaging techniques, some images may not accurately show lesions that can be clearly shown on computed tomography (CT).[1] In these cases, registration between the preoperative CT and intraoperative US images is necessary. This step can improve the accuracy of the US image, thereby reducing risk and wasted time during treatment.[2,3] The assessment of registration technology according to the qualitative and quantitative between 2-D US and CT of the liver shows its feasibility in clinical application.

2. MATERIALS AND METHODS

2.1. Patients

The publication was approved by all authors and the hospital institutional review board. 20 patients were selected with hepatic tumors from April to October of 2013: 12 men and 8 women between the ages of 26 to 62 (average 44 ± 10.53). The sizes of their lesions varied from 4.24 to 7.56 centimeters (average 5.95 ± 0.99 cm). The patients were examined by an abdominal CT enhancement, followed by a US.

2.2. Equipment and Software

Equipment included ultrasonic diagnostic instruments with a US scanner using a 3.5 MHz convex-array probe (GE E9, MyLab 90, Aloka 4000) and a spiral computed tomography (CT) instrument with 64 rows and 128 layers (GE Lightspeed VCT). Registration software and equipment were property of the Biological Engineering College of Shanghai Jiaotong University. The system used an electromagnetic tracking device, as well as an ultrasonic probe that was bound on 6-D sensors. Software used the Python language and the Visualization Toolkit (VTK), and Compute Unified Device Architecture (CUDA) was used to accelerate the core of the algorithm. Navigation software ran in a Dell Precision computer (Intel Core i5 CPU 2.67 GHz, 2.96 GB RAM, NVIDIA GeForce GTX 260 graphics card, Microsoft Windows XP Professional edition 2002 Service Pack 3). The US images were fed into the computer using the video acquisition card. The electromagnetic navigation system (NDI, Northern Digital, Canada) included a field generator (FG), the air interface unit (AIU), and four sensor interface units (SIU).

2.3. Preparation Before Registration

2.3.1. The Calibration of Ultrasonic Probe

The US images could be incorporated into the software system by calibrating the ultrasonic probe according to the calculation of the coordinate transformation matrix between the US image coordinate system and the sensor coordinate system. We made a water tank containing the ultrasonic calibration panel. The panel

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had 25 cylinders, each with a radius of 1.5 mm and height of 1 mm. The panel and cylinders could be clearly imaged by the US. Ultrasonic calibration was divided into three steps:

(1) A six degrees of freedom sensor fixed on the ultrasonic probes obtained the space position and angle of the probe;

(2) The calibration tank filled with water was used for ultrasonic imaging;

(3) We adjusted the US images to the calibration pane by ultrasonic probe.

The center of the cylinder was obtained in ultrasonic image coordinates and world coordinate systems according to the mouse and the navigation needle in the system. Finally, we obtained a rigid body transformation from the calculation of the two sets of points to minimize Euclidean distance.

2.3.2. Registration of Markers

Markers provided us with the information to complete the process of registration from the hepatic vein and portal vein separated from the CT. Several related points in blood vessel bifurcation were selected as anatomy markers from the CT and US images of the liver. The markers were used to identify data points from US images to complete the ultrasonic calibration and mark registration. US images were integrated to the system and then the initial transformation from mark registration would be prepared for the next image registration.

2.3.3. Preprocessing of Images

The US image of the liver had a large number of image particles, so it needed to be a smooth processing. Speckle noise[4] in US images could also retain boundary information in denoising.

2.3.4. Simulation Experiment

Based on the principle of ultrasonic physics about the characteristics of CT images simulating US images, an ultrasonic beam model was built with ultrasonic reflection and attenuation characteristics. The process of simulation was divided into two steps:

(1) We obtained the 2-D resampled CT surface data from the probe position and angle of space by the ultrasonic probe binding 6-D sensors;

(2) We calculated the pixel values on the simulation ultrasonic beam and the gradient value to obtain the final value from an iterative update.

An accurate simulation system was established; the parameters of the virtual sensor could be changed arbitrarily and interactively in the process of simulation, including the type of probe (linear or fan), probe position (space position and angle), the original strength of the ultrasound beam, the frequency, the field, the penetration depth, and the speckle noise of the ultrasound beam. As a result of ultrasonic reflection characteristics, histic boundaries were reinforced. At the same time, the bone had been reduced due to high reflectivity on the surface. The simulation results would be used as intermediate images in the following image registration.

2.4. The Process of Registration and the Evaluation of Qualitative and Quantitative After Registration

We established gold standards according to the selected markers and target points in CT and US images. The four vascular bifurcation points were set as benchmarks and the centers of the lesions were set as the target points. After setting benchmarks for the CT and US images, the information was included in the system through the computer. The system automatically found matches between the two images. This allowed us to rotate the registered CT and US images up to 20 degrees, as well as translate 20 to 20 pixels on the x, y coordinates to preliminarily show registration similarity. The error values of the targets between the US images and the CT images were calculated after images registration. We calculated the average error (AVG) and standard deviation (SD) to obtain the accuracy and discrete degree (stability) after registration.

3. RESULT

Registration between the 2-D US images and CT images of the 20 patients achieved a 100% completion rate. It was the CT volume data and US fusion rendering obtained from this method Figure 1. Arrows 1, 2, and 3 mark the anatomical structure of subcutaneous tissue, the spine, and the liver respectively Figure 1. The corresponding structure had been matched. Arrows 1, 2, and 3 mark the hepatic lobe profile, blood vessels, and hemangioma respectively Figure 2, Figures 2(a), (b) shows the full characteristic information including tumor and blood vessels. The characteristics of the structure could be basically matched in accordance by this registration method Figure 2(c). The preliminary qualitative experiment showed that the accuracy of this proposed registration method was more effective. The results shows the error value between the targets of the 20 patients' images, with an average error value of 4.01 ± 0.32.

4. DISCUSS

The different principles of CT and US imaging leads matching errors between the two gray-scales. The boundary of the soft tissue is enhanced and the bones are blocked in the US images, which is very different from CT images. Furthermore, the low quality of US images (low contrast, high noise, and artifacts) make them difficult to be registered with CT images. As a result, enhancing the similarities between the two images can improve registration accuracy.[4]

Due to different imaging principles between CT and US images, it is difficult to establish an effective similarity measure. Also, low US image contrast and signal-to-noise ratio with speckle noise make it difficult to apply the common algorithm to US image registration. This study establishes the framework of CT and US image registration based on the imaging

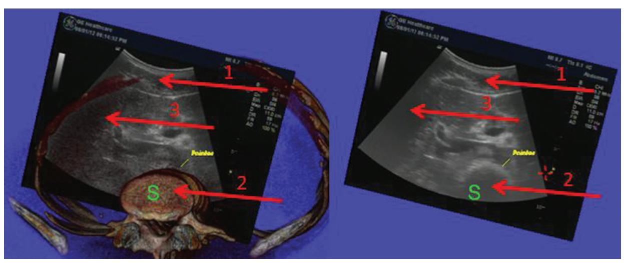

Fig. 1. The fusion in combination of the CT volume data and the US plane image.

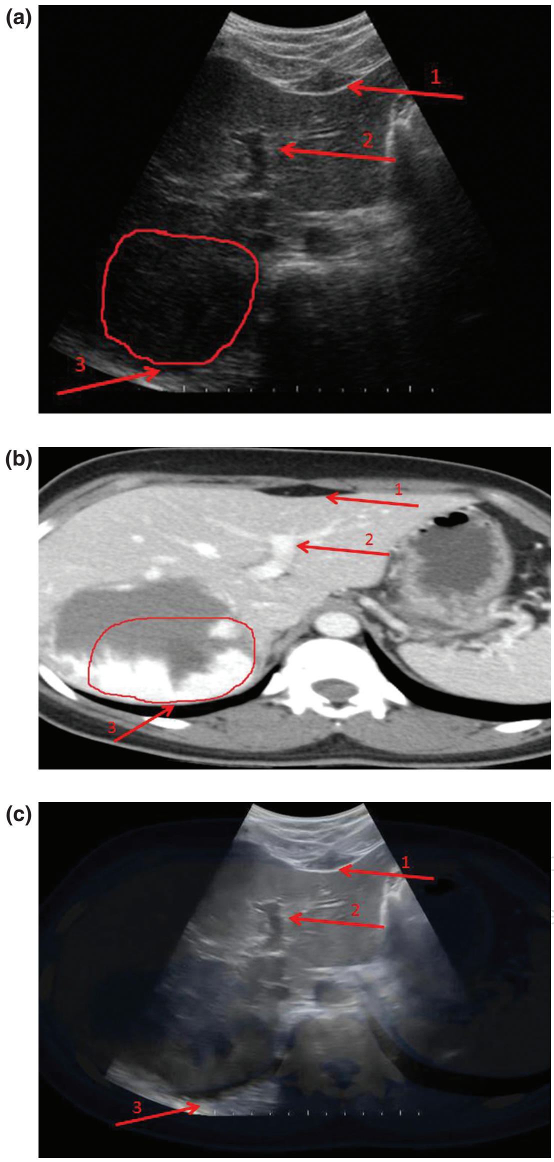

Fig. 2. The fusion combined with CT slice and US plane images. They matched feature information including the border, blood vessel, and tumor.

characteristics of CT and US images, which establishes a new similarity measure combined with the information of the gray-scale and geometry.[5] The algorithm framework strengthens two modes of similarity to preprocessing CT and US images. The spots in the US images are eliminated while the boundary information is retained. A US simulation model is established. The simulation of US reflection and attenuation characteristics as well as US characteristics from CT images can increase the similarity of these two modes, which is prepared for further registration. After simulation, the histic boundary is enhanced because the US reflection characteristics and the bone is fully eliminated due to the high reflectivity between the interfaces. As a result, these features from the emulation are consistent.[6,7] We propose a similarity measure that integrates spatial information and the gray-scale to register the emulation US images from CT images and real US, a new measure of image gray-scale and the combination of the spatial information is completely different from previous method. The preliminary experimental results show a higher accuracy of the new measurement than that of only using image gray-scale information, especially for low resolution US images. This study therefore promotes a method with higher overall accuracy.[5]

There is still an unanswered question regarding the automated registration between the CT and 2-D US images. As far as we know, there are few fully automated registrations of CT and US images regarding clinical cases with human livers. Accurate registration depends on good initial transformation, which requires clinical doctors to select benchmarks on the patients' skins or images. The methods of matching benchmarks are combined with image registration to improve the accuracy and stability of the registration. Computational benchmark registration has high efficiency but poor stability.[8,9] Image registration can mitigate manual operation and improve registration accuracy. However, it is easy to fall into a local minimum point, which results in a failure in parameter optimization.[10,11] It is more effective to combine the two registration methods to maintain accuracy and stability. In this study, the average error value of the quantitative evaluation after the registration is 4.01 ± 0.32, which shows high accuracy and stability. This research can therefore be applied to clinical diagnosis and interventional therapy.

Navigation system of clinical intervention can be established by the fusion of CT and US images. Due to the complexity and poor image quality of US images, relying on US images for real-time navigation can often limit doctors' abilities to treat patients. The electromagnetic navigation and the fusion of CT and US images in our system can help clinicians accurately determine target areas for surgery.[5]

5. CONCLUSION

It is possible that 2-D US and CT registration can have clinical applications. But because of the difference between the CT and US medical images, it is difficult to build an ideal similarity measure between the two images. This paper used a small sample size, so more clinical experiments are necessary to verify the proposed method.

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