An Efficient Platform for Freehand US Calibration

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Abstract. Freehand three-dimensional ultrasound system allows intra-operative imaging of pathologic tissue for image-guided injection. Accurate registration of ultrasound image for injection navigation requires calibration that is time-consuming and tedious. We present an efficient calibration system based on a clinical injector. The injector equipped with an optical tracking sensor is moved in the vicinity of an ultrasound imaging plane taken by a fixed ultrasound probe also equipped with an optical tracking sensor. The ultrasound images, ultrasound probe’s and injector tip’s physical coordinates are recorded simultaneously. For each ultrasound image, the injector tip is recognized and the image coordinates are identified automatically. A point registration between the injector tip image and physical coordinates is performed to estimate the calibration matrix. Experiments are performed to verify the accuracy of the calibration system. Results suggest that the calibration system is applicable to the calibration of freehand ultrasound for image-guided injection.

1 Introduction

One of the major challenges in image-guided injection procedure is the three-dimensional (3D) anatomic visualization of pathologic muscle in the procedure. Compared with two-dimensional (2D) ultrasound (US), 3D US is particularly well suited for this application. The major advantages of the technique come from target muscle visualization, flexibility in injection orientation and muscle belly localization. In this paper, we focus on freehand US imaging system for image guided injection, which offers a flexible method to construct an US visualization with image acquisition with unconstrained movement. The key to freehand 3D volume reconstruction is the initial calibration, which computes the transformation between the coordinate frames between the sensor mounted on the probe and the imaging plane. There are two kinds of calibration: phantom and tracked pointer. Most calibration methods use an object known as a phantom with known geometric properties. These geometric properties are identified in the imaging plane. Their physical positions are also located by the tracking system. A relation between image and physical positions is built to estimate the transformation. A simple phantom is a small spherical object or two intersecting wires. The point target or wire-crossing is aligned to US imaging plane and imaged from several viewing angle [1-3]. To shorten the calibration time, multiple point targets are introduced [4-6]. Similar to multiple point phantoms, 2D shape alignment phantoms are designed. The corners of the structures are imaged [7, 8]. Other wire crossing
phantoms include the three-wire phantom, Z-fiducial phantoms and so on [9, 10]. Compared with point target techniques, the wall phantom images a line on the US image. The line produces more redundant image characteristic than points. Single wall phantom [11], membrane technique [12, 13] and Cambridge phantoms are designed [10]. A detailed classification of calibration methods are discussed by Mercier et al. [14]. All of these methods need a complicated phantom with precise known geometries for a better accuracy and precision. Another method without phantoms is tracked pointer. The tip of a tracked pointer is aligned to the US beam by hand. The image position of the pointer tip is obtained with manual segmentation. A point registration is performed for estimating calibration matrix [15, 16].

In this paper, we present a calibration system with a tracked pointer. A clinical injector, which tip can be tracked by an optical tracking system, is imaged by US. Our method differs from the previous ones [15, 16] in the following aspects: (1) a general clinical injector is employed. No other addition tool is needed. (2) A full automatic method is proposed for the tip alignment to the US image. The automatic method is more convenient than manual one in previous studies. (3) After collecting the image and physical coordinate points, a point-to-point registration procedure is performed. RANSAC [17] is applied to minimize the residual error between the mapped image points and physical points. This paper is organized as follows. In Section 2, the calibration system is discussed. The experimental results and discussion are elaborated in Section 3. The conclusions obtained from this study are stated in Section 4.

2 Method

In this section, the proposed system configuration and method are described. The system hardware configuration includes: (1) An US scanner (Pt10, Mindray, China) is equipped with a 2D linear probe operating at central frequency 10MHz (which we used throughout our study). (2) An optical tracking system (Vicra, NDI, Canada) includes two lens providing the physical coordinate system. Two 6 degree of freedom (6DOF) tracking sensors are employed. One is mounted on the US probe and the other is mounted on an injector to track its tip. (3) A computer (Intel Core i3 3.30GHz, 4G Ram, Windows7) equipped with a video digitizer (MV-U2000, MicroVision, China) that receives the video output of the US scanner at a resolution of 640×480 pixels, 25FPS. The US probe is fixed, and the acoustic signal is projected into a water tank. The tracked injector tip passes through various places of the US beam. US images are digitized in real time in the computer along with the tracking information with the same time stamp is acquired. All data are processed using programs written in Visual Studio (Version 2008, Microsoft, USA).
**ROI extraction.** The US image showing the injector also contains artifacts due to the reflected echoes from the tank bottom. So it is difficult to localize the injector tip by comparing the intensities between them. In order to recognize injector from background, a ROI of the injector is extracted by a digital subtraction imaging method. The method is depicted as following.

\[ I^b_x = I^b - I^b_p \]  \hspace{1cm} (1)

\[ I^c_u = I^b_u \cap I_j \]  \hspace{1cm} (2)
Fig. 2. Localization of injector tip in imaging plane
**Injector tip recognition.** To localize the tip from the injector ROI, a kind of US image feature is used. When the injector is imaged, incident acoustic signals travel along the injector shaft and reflect from its tip. The tip produces a particularly strong intensity and can be distinguished from the shaft in the ROI by detecting intensity distribution [18].

### 3 Conclusions

This paper demonstrates an efficient system for freehand US calibration. Instead of a phantom, a tracked injector is used as the calibration target. An automatic injector tip recognition method is proposed. After a simple mathematical linear algebra matrix operation is derived to solve the calibration matrix, a point-to-point registration method is implemented between the image and physical positions of the tip. A RANSAC algorithm is employed to minimize the registration error. This system was evaluated by experiments. In all cases of our calibration process, the injector tip could be accurately identified from the background of tank. The employed RANSAC could filter out outliers and produced an accurate estimate than the conventional method SVD. These results suggest that this system is applicable to the calibration for freehand US imaging system for image-guided injection.

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