Chapter 44
A Freehand 3D Ultrasound Imaging System Using Open-Source Software Tools with Improved Edge-Preserving Interpolation

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ABSTRACT

Ultrasound imaging is widely employed in various medical procedures. Most ultrasound procedures are performed with conventional 2D ultrasound systems, but visualizing the 3D anatomy using 2D ultrasound images is often challenging. This paper describes the use of open-source software tools to develop a freehand system for synthesizing high-quality 3D ultrasound volumes using electromagnetic tracking. In the proposed system, the spatial transformation between the 2D ultrasound images and the electromagnetic sensor attached to the ultrasound transducer was performed using an accurate spatial calibration method. A new interpolation method, called the edge-preserving distance-weighted (EPDW), is employed to reconstruct the 3D ultrasound volumes. The performance of the system is evaluated by performing a set of phantom experiments. The results showed that the reconstructed 3D ultrasound volumes have sub-millimeter accuracy. Moreover, the ultrasound volumes synthesized using the EPDW method demonstrated improved edge preservation compared with a previous interpolation method.

INTRODUCTION

Ultrasound imaging is commonly used in various medical diagnosis and procedures, such as cancer screening (Liao et al., 2011) and image-guided intervention (Daoud et al., 2011; Unsgard, 2009). Compared with other imaging modalities, such as computed tomography (CT) and magnetic resonance imaging (MRI), ultrasound offers the advantages of low cost, noninvasiveness, portability, and real-time imaging

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capability. The majority of conventional ultrasound imaging systems is equipped with two-dimensional (2D) transducers that cannot provide three-dimensional (3D) volume data of the tissue. Using 2D ultrasound imaging, the user is required to perform mental analysis and integration of several 2D ultrasound images to obtain a 3D impression about the scanned anatomy. Moreover, conventional 2D ultrasound systems do not support the acquisition of 2D images parallel to the skin. To overcome these limitations, 3D ultrasound imaging systems have been developed to enable 3D volume data acquisition (Wen et al., 2013; Scheipers et al., 2010).

Several methods have been proposed for enabling 3D ultrasound imaging (Bax et al., 2008; Wen et al., 2013; Oralkan et al., 2003). In general, these methods can be classified into three groups (Fenster et al., 2011). In the first group, ultrasound volume imaging of the tissue is performed using a 3D transducer that is composed of a 2D array of transducer elements. The transducer elements are controlled to electronically steer the ultrasound beam across a volume of interest (VOI) to acquire a 3D ultrasound volume in real time (Oralkan et al., 2003). In general, these 3D ultrasound systems involve high-costs and are not commonly available.

In the second group of 3D ultrasound imaging systems, a motorized mechanical apparatus is employed to rotate, translate, or tilt a 2D ultrasound transducer along a predefined path to acquire a sequence of 2D ultrasound images across a VOI. This motorized motion of the 2D transducer is precisely controlled, and hence the 3D position and orientation of each acquired 2D ultrasound image can be determined with high accuracy. A 3D ultrasound volume can be reconstructed by processing the acquired 2D ultrasound images along with their 3D positions and orientations (Bax et al., 2008). One limitation of these 3D ultrasound imaging systems is the size of the reconstructed ultrasound volume, which is restricted by the motion range of the motorized mechanical apparatus. In addition, the ultrasound probe employed in these 3D systems integrates both the 2D ultrasound transducer and the motorized mechanical apparatus, and hence such a probe is considered bulky and its use in some clinical procedures might not be convenient.

The last group of 3D ultrasound imaging systems is based on freehand ultrasound imaging. In this approach, the capability of a conventional 2D ultrasound imaging system is expanded to enable the reconstruction of 3D ultrasound volumes (Wen et al., 2013). In particular, the 3D motion of the conventional 2D ultrasound transducer is monitored using a tracking system. The operator freely moves the conventional 2D ultrasound transducer in unrestricted manner over the target anatomy to acquire a sequence of 2D ultrasound images. The 3D positions and orientations of each acquired 2D ultrasound image are computed based on the tracked motion of the transducer. Finally, a 3D ultrasound volume is reconstructed by interpreting the acquired 2D ultrasound images along with their computed 3D positions and orientations.

Freehand ultrasound is considered a cost-effective technique for 3D ultrasound imaging. Moreover, freehand ultrasound offers several advantages, including the flexibility of visualizing the anatomy from different views and the ability to increase the density of the acquired ultrasound images in important areas (Gooding et al., 2008). Due to these advantages, freehand ultrasound has gained increasing popularity in both diagnostic and therapeutic procedures.

This paper describes the use of open-source software to develop a freehand 3D ultrasound imaging system for synthesizing high-quality 3D ultrasound volumes. In this freehand ultrasound system, an electromagnetic sensor is attached to a conventional 2D ultrasound transducer to track its motion with six degrees of freedom (6DoF). In order to estimate the 3D positions and orientations of the 2D ultrasound images based on the tracked motion of the transducer, spatial calibration is performed to transform the coordinate system of the 2D ultrasound images to the coordinate system of the electromagnetic sensor.