Chapter 21

An Improved Olympic Hole-Filling Method for Ultrasound Volume Reconstruction of Human Spine

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ABSTRACT

Hole-filling in ultrasound volume reconstruction using freehand three-dimensional ultrasound estimates the values for empty voxels from the unallocated voxels in the Bin-filling process due to inadequate sampling in the acquisition process. Olympic operator, as a neighbourhood averaging filter, can be used to estimate the empty voxel. However, this method needs improvement to generate a closer estimation of the empty voxels. In this paper, the authors propose an improved Olympic operator for the Hole-filling algorithm, and apply it to generate the volume in a 3D ultrasound reconstruction of the spine. The conventional Olympic operator defines the empty voxels by sorting the neighbouring voxels, removing the n% of the upper and lower values, and averaging them to attain the value to fill the empty voxels. The empty voxel estimation can be improved by thresholding the range width of its neighbouring voxels and adjusting it to the average values. The method is tested on a hole-manipulated volume derived from a cropped 3D ultrasound volume of a part of the spine. The MAE calculation on the proposed technique shows improved result compared to all tested existing methods.

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INTRODUCTION

The use of three-dimensional ultrasound (3DUS) imaging in clinical applications has contributed to more extensive information for medical diagnoses. Significant improvements in the generation of structural volumetric representation enable better visualization and more accurate measurement and analysis (Fenster & Downey, 2000; Solberg, Lindseth, Torp, Blake, & Nagelhus Hernes, 2007; Brunner, Obruca, Bauer, & Feichtinger, 2003; Scharf, Ghazwiny, Steinborn, & Sohn, 2000; Manini, Burton, Meixner, Eckert, Callstrom, Schmit, El-Youssef, & Camilleri, 2009). One of the advanced developments is the generation of 3DUS imaging out of two-dimensional ultrasound (2DUS) system. In this regard, this 3DUS system employs mechanical or freehand scanning techniques (Fenster & Downey, 2000; Campani, Bottinelli, Calliada, & Coscia, 1998; Candiani, 1998). The mechanical sweeps the region of interest by mounting the probe to a stepper motor to move the probe in a predefined manner where the relative position and angulation of each frame can be determined precisely. In contrast to the mechanical system, the freehand scanning acquires the region of interests by mounting a position tracking system to the probe. In this system, the scanning geometry is not predetermined (Fenster & Downey, 2000; Solberg, Lindseth, Torp, Blake, & Nagelhus Hernes, 2007; Gee, Prager, Treece & Berman, 2003; Huang, Zheng, Lu, & Chi, 2005). However, both have their own advantages and drawbacks.

In the evaluation of the spine, ultrasound imaging has been proven to capture spinal features from the reflection of the ultrasound signal (Suzuki, Yamamuro, Shikata, Shimizu, & Iida, 1989; Brendel, Winter, Rick, Stockheim, & Ermert, 2002; Purnama, Wilkinson, Veldhuizen, van Ooijen, Sardjono, Brendel, & Verkerke, 2006). In the study of Suzuki et al. (1989), ultrasound is capable of outlining the spinous process and the laminae to measure axial rotation of the vertebrae. This method, however, only applies 2DUS scanned to the marked skin of the back. In fact, what can be seen in the ultrasound images is not the bony structure, but only the reflection of some parts of the bone surface as investigated by Brendel et al. (2002). Purnama et al. (2006) has shown that the ultrasound signal reflects on the processi transversi and proved that such imaging system is an appropriate system to determine the shape of the human spine. Furthermore, to obtain the 3DUS volume of the spine, freehand scanning technique can be a good choice due to its flexibility to reach the whole spinal surface. However, imaging the spine using freehand 3DUS still suffers from an inadequate sampling process and speckle noise problems that may obscure the visibility of the spinal features causing inaccuracy in the extraction of the acquired vertebral features.

Figure 1 illustrates one 2DUS frame from the thoracic vertebra part taken in axial plane using a linear probe with the frequency of 10 MHz, multiple focusing range of 3.5 to 5 cm, and imaging depth of 7 cm. From this example, the surface of the spinous process appears prominent as borderline between soft tissue structures. A dark shadow appears after the spinous process. Other features such as laminae, transverse processes, superior articular processes, ribs, and even pleura are also visible as reflected surfaces depending on the probe direction to certain locations of the vertebrae and their surroundings. The primary procedure in obtaining a 3DUS volume out of these 2DUS frames consists of two-step processes, acquisition of the ultrasound frame and position information, and reconstruction of the 3D volume (Solberg, Lindseth, Torp, Blake, & Nagelhus Hernes, 2007). The acquisition process grabs echo data based on the sweeping transducer arrays (an ultrasound probe) and information of a position-tracking system which determines the position of a sensor mounted on the ultrasound probe. This can be performed either from an integrated positional sensing device or from an external system. Since the spine has an elongated area of scanning and slanted parts

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