ENHANCEMENT OF SPINE BONE SURFACES FROM ULTRASOUND DATA USING IMPROVED LOCAL PHASE TENSOR FILTER

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INTRODUCTION

In recent years, there has been a growing interest to incorporate ultrasound (US) into computer assisted orthopaedic surgery (CAOS) procedures in order to provide non-ionizing intra-operative imaging alternative to traditional fluoroscopy (Penney 2006, Kowal 2007). However, a challenging problem in all of these applications is the identification and interpretation of bone surfaces from noisy US data. Furthermore, the quality of the collected US images is dependent on the orientation of the US transducer with respect to the bone surface (Jain 2004) and the complexity of the imaged anatomy. To overcome some these problems, intra-operative US images have been registered to a pre-operative plan developed from computed tomography (CT) or magnetic resonance imaging (MRI) data. Fast, accurate and automatic registration is important for successful US-guided CAOS procedures. Due to the rigid nature of bones and providing a faster solution to the registration problem surface based registration methods have gained popularity. Methods, based on intensity and local phase information, were developed for automatic segmentation of bone surfaces from US data (Kowal 2007, Foroughi 2007, Beitzel 2012, Hacihaliloglu 2012). Although successful results were reported difficulty in acquiring US images with high intensity bone boundaries is an ongoing limitation of current US guided CAOS procedures. For spine interventions this is especially problematic due to the complex shape of the vertebrae and surrounding ligaments which complicate the proper orientation of the US transducer.

Recently we have proposed a new fully automatic US bone surface enhancement filter in the context of spine interventions. The method is based on the use of a Gradient Energy Tensor (GET) filter to construct a new feature enhancement metric, which we call the Local Phase Tensor (LPT) (Hacihaliloglu 2014). In our previous work we have shown that a multi-vertebrae statistical shape model can be registered to the enhanced spine US images, obtained from 120 *in vivo* scans, with a mean target registration error (TRE) value of 2 mm (±0.4 mm).

The goal of this study is to provide further improvements to the proposed filtering method by incorporating a-priori knowledge about the physics of US imaging and salient grouping (object that are distinct and representative) of enhanced bone features.

MATERIALS AND METHODS

Investigating Figure 1-(a), a typical US scan of the spine, we can see that there is a large soft tissue interface present close to the transducer surface with high intensity values similar to those of the bone anatomy response. Typical US image segmentation or enhancement methods will be affected by this thick soft tissue response. In order to weaken this soft tissue interface intensity response and improve the intensity values of the bone features present in the images we exploit the knowledge about the physics of US image formation. We calculate a new transmission map where features deeper in the US image have higher transmission

values and shallow features have lower transmission values (Figure 1-(b)). The calculation of this new US transmission/attenuation map allows the proposed image enhancement method to mask out erroneous regions, such as the soft tissue interface, and improve the accuracy and robustness of the spine surface enhancement. The masked US images were used as an input to the LPT image enhancement method (Hacihaliloglu 2014). Investigating Figure 1-(d) we can see that the bone surfaces in the enhanced LPT images are pre-attentively outstanding and create some form if immediate significance. In order to provide a more compact spine surface representation and further reduce the typical US imaging artifacts and soft tissue interfaces (Figure 1– (d) white arrows) we calculate saliency LPT features. The saliency images are computed using Difference of Gaussian (DoG) filters (Achanta 2009).

The proposed method was validated on 3D US volumes captured by an expert sonographer using a SonixTouch US machine (Ultrasonix, Medical Corp, Richmond, BC, Canada) with a curvilinear 3D transducer (4D C7-3/40), operating at 3.3 MHz with depth of 7 cm. 10 patients with informed consent were included in the study. For each volume, 80 frames over a 600 field of view were captured. US volumes were acquired with each subject in the prone position. In total, twelve 3D US volumes were acquired for each patient.

RESULTS

Qualitative results obtained by processing *in vivo* scans are shown in Figure 2. Investigating the B-mode US images we can see that some of the lamina bone surfaces appear blurred or with low contrast. There is also a thick high intensity soft tissue interface present in all of the scans close to the transducer surface. The bone surfaces in the enhanced LPT images appear sharper and with higher contrast. Furhtermore, intensity variations present in different US scans are not affecting the outcome of the proposed method. Saliency image features result in further enhancement of the US images by further reducing the extracted false positives (Figure 2-fourth column). Normalized scanline profiles extracted from B-mode US, transmission masked B-mode US, LPT image and the Saliency LPT are presented in Figure 3. Investigating the scanline profile of the B-mode US image we can see that there are many edge features that correspond to the soft tissue interfaces and imaging artifacts which have similar intensity values as the expected bone surface (pointed with the red arrows). Masking the B-mode US image with the transmission map results in the reduction of the high intensity values which do not belong to the bone surfaces (Figure 3. blue dotted scanline profile). The LPT and Saliency LPT scanline profiles show the further improvement achieved in terms of highlighting the expected bone surfaces and supressing the intensity values belonging to the soft tissue interfaces and imaging artifacts (Figure 3.).

DISCUSSION

Enhancement and extraction of bone surfaces from US data is a challenging task that continues to hamper the embodiment of US imaging modality in orthopaedic surgery applications (Jain 2004). This concern becomes more evident while imaging irregular shaped bone anatomy such as the vertebrae. The high variability of the reflected US signal from the vertebrae surface results in low contrast, blurred and disconnected bone features. Furthermore, the surrounding ligaments also attenuate the US signal and degrade the appearance of spine bone surfaces. In a recent work we have proposed a solution towards this problem by proposing a new approach for enhancing spine bone surfaces from 3D US data (Hacihaliloglu 2014). In this paper we provide further improvement to this new technique by incorporating physics of US image formation and saliency based image compactness measures to the enhancement process.

Qualitative results, obtained from *in vivo* scans, show a strong correspondence between enhanced features and the actual bone surfaces present in the US scans. Since the proposed method is not a bone localization/segmentation method we do not provide comparison results against the state-of-the-art US bone segmentation methods (Kowal 2007, Foroughi 2007, Beitzel 2012). However, the enhanced image features could be used as an input to a bone segmentation algorithm or intra-operative US image registration algorithm.

The total processing time for the proposed enhancement method is 0.55 second for a 340×480 2D B-mode US slice. The method was implemented in MATLAB which is typically an order of magnitude slower than a C++ implementation. Further improvements in computation time could be achieved by implementing the proposed method on multi-processor graphic processing unit (GPU) (Amir-khalili 2013). Future work will include the extension of the proposed method to 3D and validation of the method in the context of intra-operative US image registration in CAOS applications.

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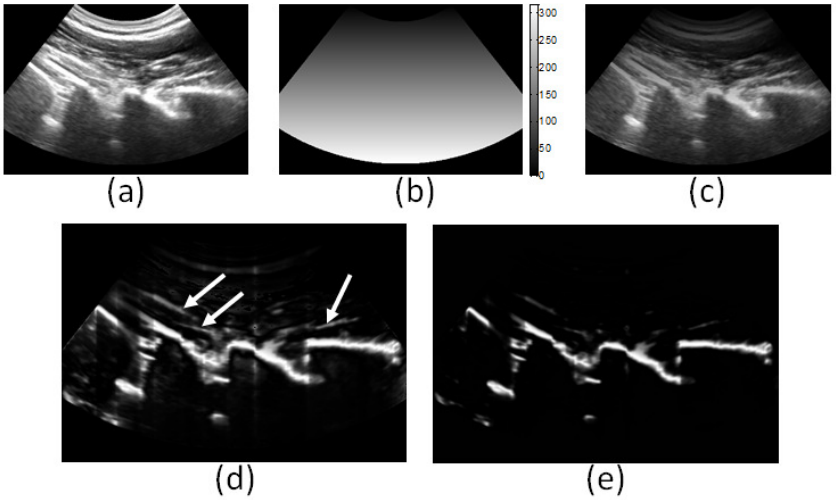

Figure 1. (a) B-mode US image of multi-vertebrae. (b) Transmission map calculated from (a). (c) Masking of B-mode image with the transmission map, (d) LPT image calculated from (c) white arrows point to the extracted soft tissue interfaces. (e) Saliency LPT image where soft tissue artifacts are reduced.

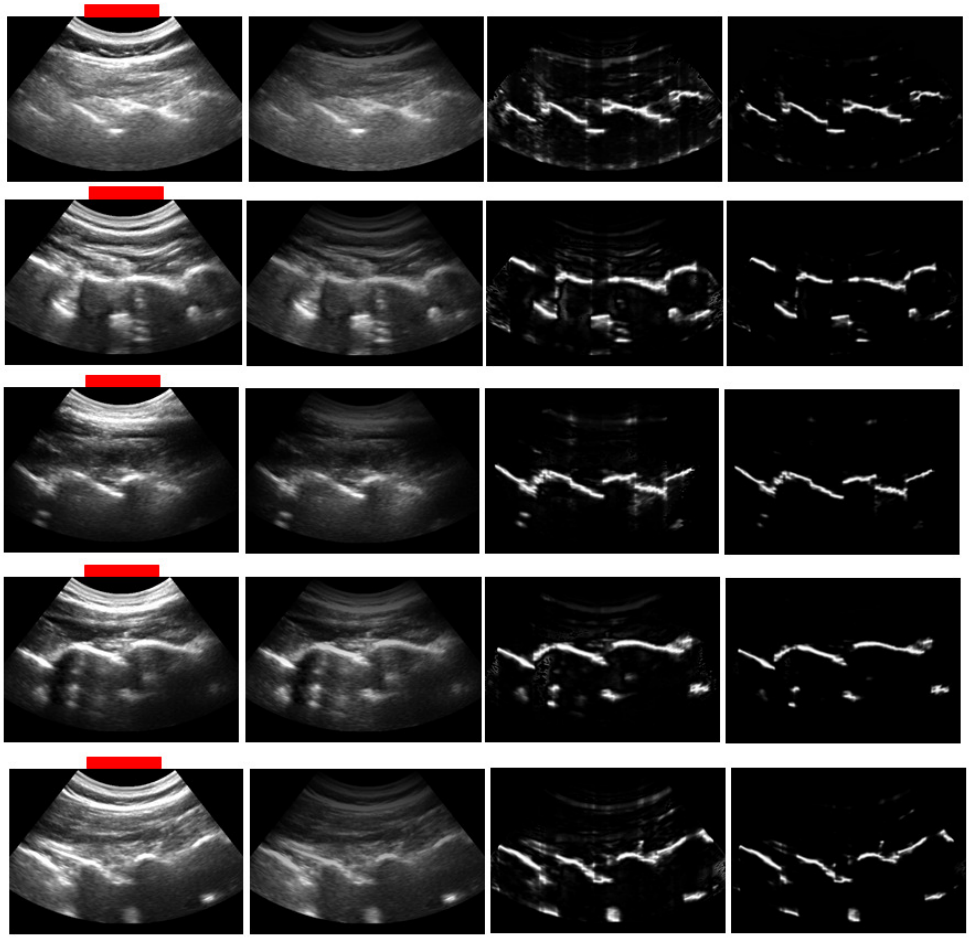

Figure 2. Qualitative results obtained from clinical scans. First column: B-mode US image. Red rectangle representing the US transducer. Second column: Transmission map masked B-mode US image. Third column: LPT image of second column. Fourth column: Saliency LPT image.

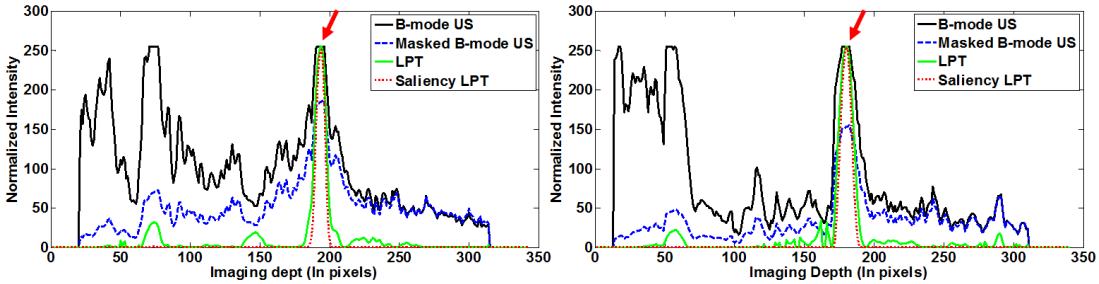

Figure 3. Normalized scanline profiles extracted from two different *in* vivo scans. Red arrows point to the expected bone surface location.