# ASSESSING THE FEASIBILITY OF DOWNSAMPLING AND WAVELET RESIZING FOR REAL-TIME EXTRACTION OF BONE SURFACES FROM 3D ULTRASOUND

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## INTRODUCTION

In computer assisted orthopaedic surgery (CAOS), ultrasound (US) bone imaging is emerging as a viable intra-operative imaging modality. US imaging offers numerous advantages over the currently dominant radiation-based systems - specifically no use of ionizing radiation, low cost, portability and real-time response. In recent years, ridge detection-based approaches [1, 2, 3] have shown promise in extracting bone surfaces with sub-millimetric accuracy and in biometrics. However, such ridge detection-based approaches are not yet able to be executed in real time; the computational time needed to segment a 3D US volume is 47s using parameter-optimized phase symmetry (PS) [2] and 13s using confidence-based PS (CPS) [1] on a non-GPU-based implementation. While GPU-based implementations can speed up portions of this image processing pipeline [4], in the current study, we aim to reduce the computational time for the bone extraction technique reported in [1]. To reduce computational time, we reduce the scales of wavelets and reduce the sizes of windows used in the proposed ridge detector in [1], hypothesizing that such downsampling will not compromise detection of the ridge-like structures. Essentially, we exploit the property that bone surfaces in an US image appear as thick ridges [5]; thus, we anticipate that these features will still be readily visible even in lower-resolution images.

A second motivation for exploring the accuracy of bone surface detection in downsampled images is that a number of bone-imaging applications may require lower-frequency US transducers that can scan to greater depths, which will decrease the spatial resolution of the images [6]. By analyzing downsampled images, we can emulate lower beam-frequency scans, and check whether the accuracy in bone surface extraction remains acceptable. Since the bone surfaces in downsampled US still exhibit ridge-like structure, we hypothesize that the bone surface extraction accuracy will not be significantly affected.

## MATERIALS AND METHODS

We obtained 'gold standard' bone surfaces from computed tomography (CT) scans (obtained as part of routine clinical care under appropriate institutional review board approval) of 15 patients admitted to Vancouver General Hospital (a Level 1 trauma centre) for pelvic fractures. Further, we collected additional US scans (obtained after informed consent) using a commercially-available real-time scanner (Voluson 730, GE) and a 3D transducer T1 (3D RSP 5MHz-12MHz) from the same patients around the iliac crest region. We used US scans from around the iliac crest region because it is closer to the skin surface. By doing so, we ensure that the US signal from the high beam-frequency transducer T1 (5MHz-12MHz) does not get attenuated beyond a threshold that compromises acquisition of bone surfaces. We also obtained US volumes from a volunteer using another real-time scanner (Sonix RP, Ultrasonix) and two 3D transducers: a lower-beam frequency transducer T2 (4DC7-3/40) and a high-beam transducer T3 (4DL14-5/38). Since the bone surfaces in US images appear as thick ridges with widths ranging from 2-4mm [4], we use phase symmetry-based ridge detection [7] which has been shown to be robust to noise and intensity variance. To differentiate bone boundaries from other boundaries, we incorporated information from attenuation and shadowing features derived from an ultrasound transmission model, resulting in a composite Confidence Phase Symmetry (CPS) feature [1].

To speed-up the extraction of bone boundaries and to study the feasibility of low resolution (low beam-frequency) transducers, we processed US volumes (acquired by T1) downsampled by a factor of 4 in the axial direction and by factors of 2 in the lateral and azimuth directions. Note that we downsample the data after applying an anti-aliasing low pass filter; i.e., we first convolve the image with a Gaussian kernel of size 2*(downsampling factor). Similarly, we reduce the scales of the log-Gabor wavelets used in phase symmetry estimation and also reduce the sizes of windows used in attenuation and shadowing feature estimation by a factor of 4.

## RESULTS

Figure 1 shows US scans from exemplary pelvic bone structures. Note that the iliac crest and the region around it (Fig. 1a) are closer to the skin surface and can be well captured with high frequency transducer. For deeper structures (Fig. 1e), transducers with low beam-frequency (Fig. 1g) capabilities are needed. The US volumes are processed to produce the CPS image shown in Figure 1(c, h), whereas the downsampled US volume with subsequent wavelet and US transmission analysis resulted in Figure 1(d).

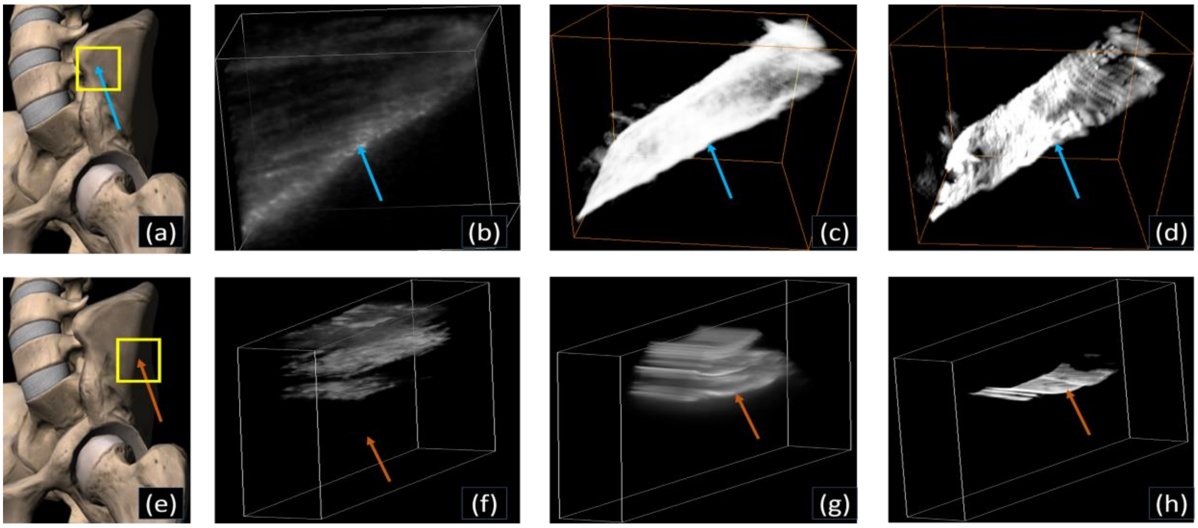


Figure 1. Qualitative results: (a), (e) pelvis anatomy with approximate locations of US transducers (yellow box). (b), (f) US volumes acquired using high beam-frequency transducer and (g) using low beam-frequency transducer. (c), (d) Extracted bone surfaces (CPS) from US volume of (b) and its downsampled (low-resolution) volume. Bone surface in (h) is extracted from (g). Qualitatively, similar extraction accuracies are seen in (c), (d) and (h), which have been extracted from different types of US volumes, i.e., high beam-frequency US volume, emulated low-resolution US volume and low beam-frequency US volume respectively.

To quantify the accuracy of segmentation, we used automatic Gaussian mixture model (GMM)-based registration [8] to align the CT- and US-derived bone surfaces (datasets collected from the 15 trauma patients) and computed the corresponding surface fitting error (SFE). Results are summarized in Figure 2(a). Computation times of the standard CPS method and the proposed method with downsampling are summarized in Figure 2(b).

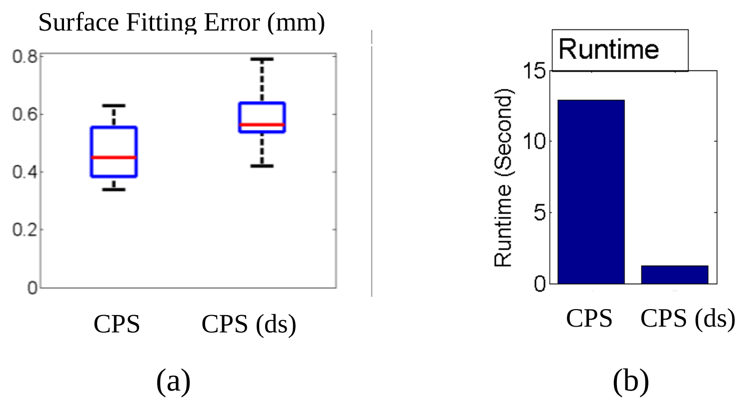


Figure 2. Performance comparion between of CPS and downsample-based CPS. (a) Surface fitting error (mm) of localized bone surface with ground truth CT, (b) runtime for a 128x128x128 B-mode US volume.

## DISCUSSION

In this study, we have proposed a novel method to reduce computation times involved in ridge detection-based bone imaging methods, based on downsampling the input volumetric image, reducing wavelet scales and reducing window sizes. We validated the algorithm on *in-vivo* clinical pelvic data. We found that the computation time was reduced approximately ten-fold, with modest increases in the surface fitting error (from ~0.45mm to 0.57mm). Thus, accuracy results suggest that CPS processing may be feasible in near-real-time bone imaging with low beam-frequency transducers. However, this tentative conclusion would need to be reassessed using real low beam-frequency transducers. In future, we will do a more extensive accuracy assessment and will reassess the algorithm using a version of the code that we have implemented on a graphical processing unit (GPU) to further reduce computational time.

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## DISCLOSURES

No relevant disclosures.

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