Ultrasound Volume Reconstruction: Open-Source Implementation with Hole Filling Functionality

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Purpose: Ultrasound volume reconstruction is the process by which 3D ultrasound volumes are generated from a series of spatially tracked freehand 2D ultrasound images. Unfortunately, due to hand motion or rotational motion, the spacing between images is often irregular. If the grid resolution of the output volume is not low enough, holes can result from an inadequate image density, thereby rendering the volume unusable. The purpose of this work was to implement hole filling in free software for the reconstruction of high resolution ultrasound volumes that do not have holes.

Methods: We collected image data sets using a SonixTouch ultrasound scanner with L14-5 and EC9-5 transducers electromagnetically tracked with GPS extension (Ultrasonix, Richmond, BC, Canada). Images were inserted into volumes using reverse tri-linear interpolation [1]. For each image set, a ground truth volume was generated from a complete, dense set of images. We created test volumes with holes by skipping images during the image insertion phase, and then applying one of two hole filling methods, or no hole filling at all. The first method, the static size kernel method, filled holes with a weighted average of surrounding voxel intensities. The weight corresponded to a 3 x 3 x 3 voxel truncated gaussian spherical kernel centered on the hole voxel. The second method, the variable size kernel method, first attempted the static size kernel method, except if no voxel intensity information was contained in the 3 x 3 x 3 kernel region, a larger kernel was then tried instead of a 3 x 3 x 3 kernel. Progressively larger kernels would be tried in this fashion until either voxel intensity information was found, or some maximum kernel size was reached. All gaussian kernels in all methods were spherical and truncated such that 95% of the weight was retained. The hole filling was implemented in the free and open-source Public Software Library for Ultrasound (www.assembla.com/spaces/plus).

Results: Ultrasound volume reconstruction was performed on two image data sets – one of a spine phantom (using the L14-5 transducer) and one of a prostate phantom (using the EC9-5 transducer). Voxel intensities in holes from test volumes were compared to those from the ground truth to determine a mean absolute error for that test volume. Any unfilled holes were assumed to be completely black in the resulting reconstruction. A percentage error reduction was computed for test volumes that had holes filled compared against test volumes that did not have holes filled. Error reduction for the spine phantom reconstruction was 85.4% when using the static size kernel method, and 86.5% when using the variable size kernel method. Error reduction for the prostate phantom was 73.3% when using the static size kernel method, and 88.0% when using the variable size kernel method.

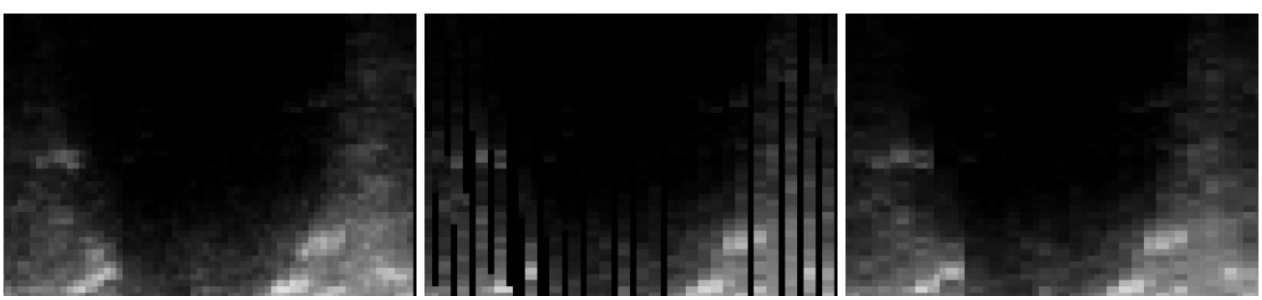

Figure: Spine phantom reconstruction slices; left, ground truth; center, test volume without hole filling; right, test volume with nearest neighbor gaussian kernel hole filling.

Conclusions: High quality ultrasound volume reconstruction methods were implemented and made available for researchers as part of the free and open-source Public Software Library for Ultrasound. Hole filling was shown to greatly reduce the error in holes of reconstructed ultrasound volumes. Our results suggest that using a variable kernel size when there may be limited voxel information in the nearby region improves the accuracy of the final reconstruction.

[1] - Gobbi D. and Peters T. *Interactive intra-operative 3D ultrasound reconstruction and visualization.* Medical Image Computing and Computer Assisted Intervention 2002. **2489:**156-163, Springer.