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

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Introduction

Motivation

Volume Reconstruction is the combination of many tracked 2D Ultrasound (US) images to create a 3D US volume. It has clinical applications, such as cross-modality registration. However, reconstruction quality can be affected by holes that result from inadequate sampling.

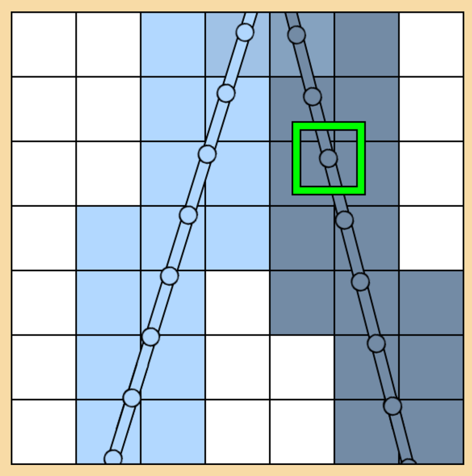

Figure 1: The distribution of a pixel into a volume is shown by a green box. Holes are shown in white.

Objective

We aim to create freely-available, open-source volume reconstruction software that features hole-filling capability.

Methods

Hole Filling Algorithm

- Distribute pixels into the volume using reverse tri-linear interpolation [1]
- Fill holes with a Gaussian weighted average over a cubic kernel region [2]

$$V_{hole} = \frac{\sum(D_i * V_i)}{\sum(D_i)}$$

D **= Gaussian Distance Weight**

V **= Voxel Intensity**

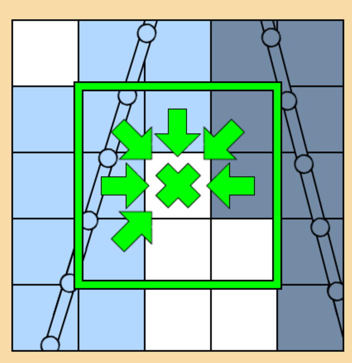

Figure 2: The hole is filled with an interpolated value

- Determine kernel size based on available input

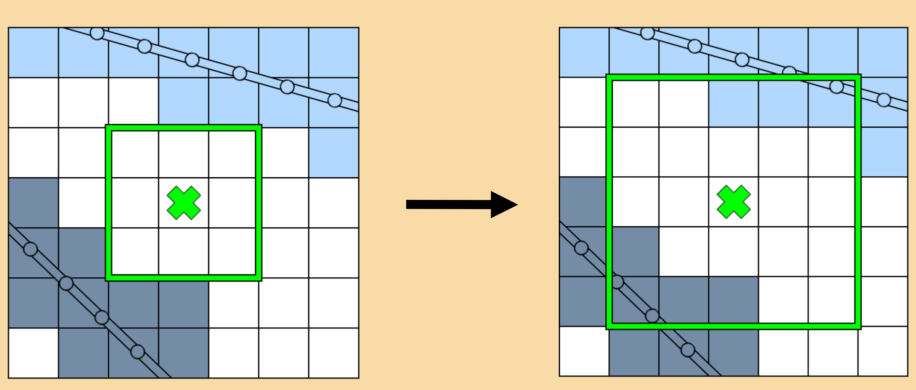

Figure 3: *Left* – There is not enough information in the kernel region for interpolation, *Right* – The hole can be filled using a larger kernel region

- Implemented as free, open-source software in the Public software Library for Ultrasound (PLUS)

Evaluation

- Generate a Ground Truth by inserting a dense set of tracked US images directly into the volume
- Introduce holes by using only every 4th slice – this simulates uniformly faster probe movement
- Compare the results of using a static kernel size (diameter 3 voxels) against those of using a variable kernel size (diameter of 3, 5, or 7 voxels)
- Qualitative Analysis:
  - Visual comparison, but there is potential bias
- Quantitative Analysis:
  - Calculate the Mean Absolute Error (MAE) of hole voxel intensities [3]

$$MAE = \frac{\sum|V_G - V_H|}{N}$$

V_G = Ground Truth Voxel

V_H = Hole Voxel

N **= Number of Hole Voxels**

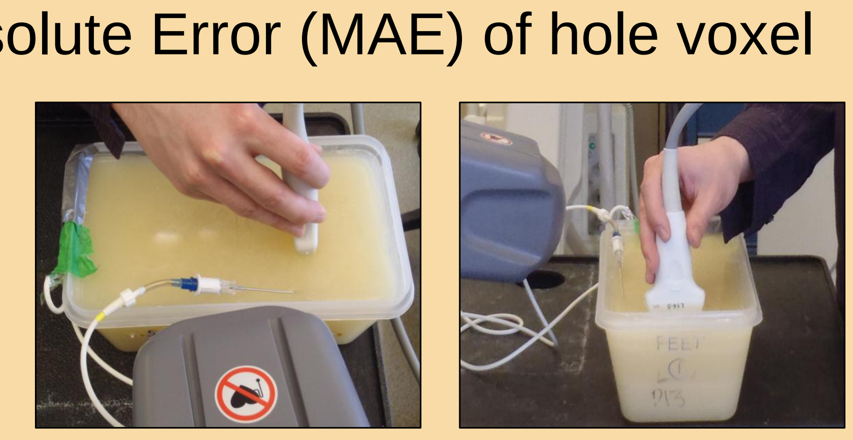

Figure 4: US data being collected on a spine phantom

Results

Qualitative Analysis

- Hole filling makes images easier to interpret
- Large holes are filled only when the kernel size is variable
- Large holes are not filled continuously

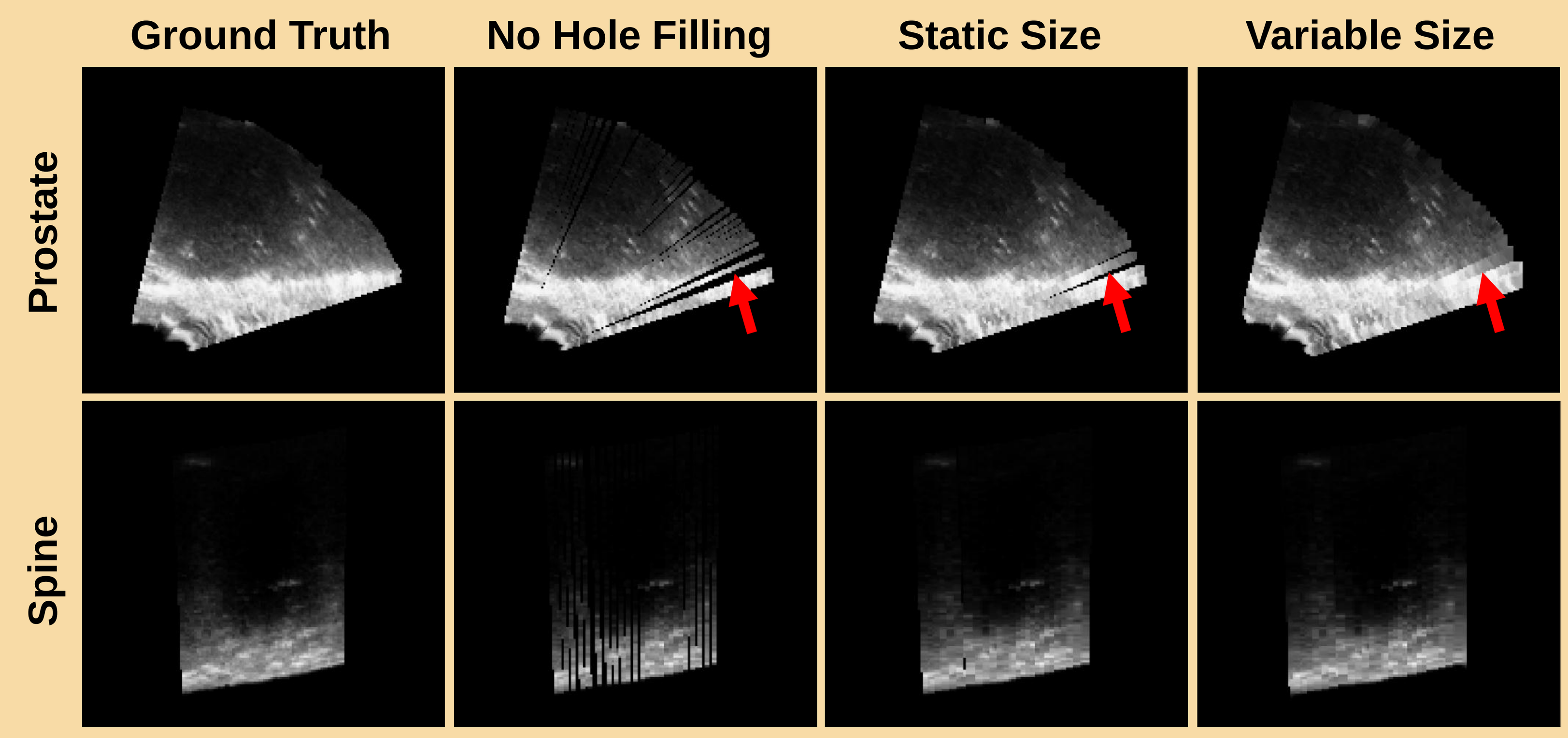

Figure 5: Images are shown for volume reconstruction without hole-filling, with hole filling using a static kernel size (3 voxel diameter), and with hole filling using a variable kernel size (7 voxel diameter maximum). All images are compared to the Ground Truth on the far left. The red arrow shows a larger hole that was not filled continuously.

Quantitative Analysis

- Intensity range: 0 - 255
- Hole filling reduces the Mean Absolute Error of hole voxel intensities
- Hole filling is best with a variable kernel size

Dataset	No Hole Filling	Static Size	Variable Size
Spine	16.98	2.52	2.30
Prostate	64.47	17.09	7.70

Table 1: MAE of hole voxel intensities are presented for reconstructed volumes

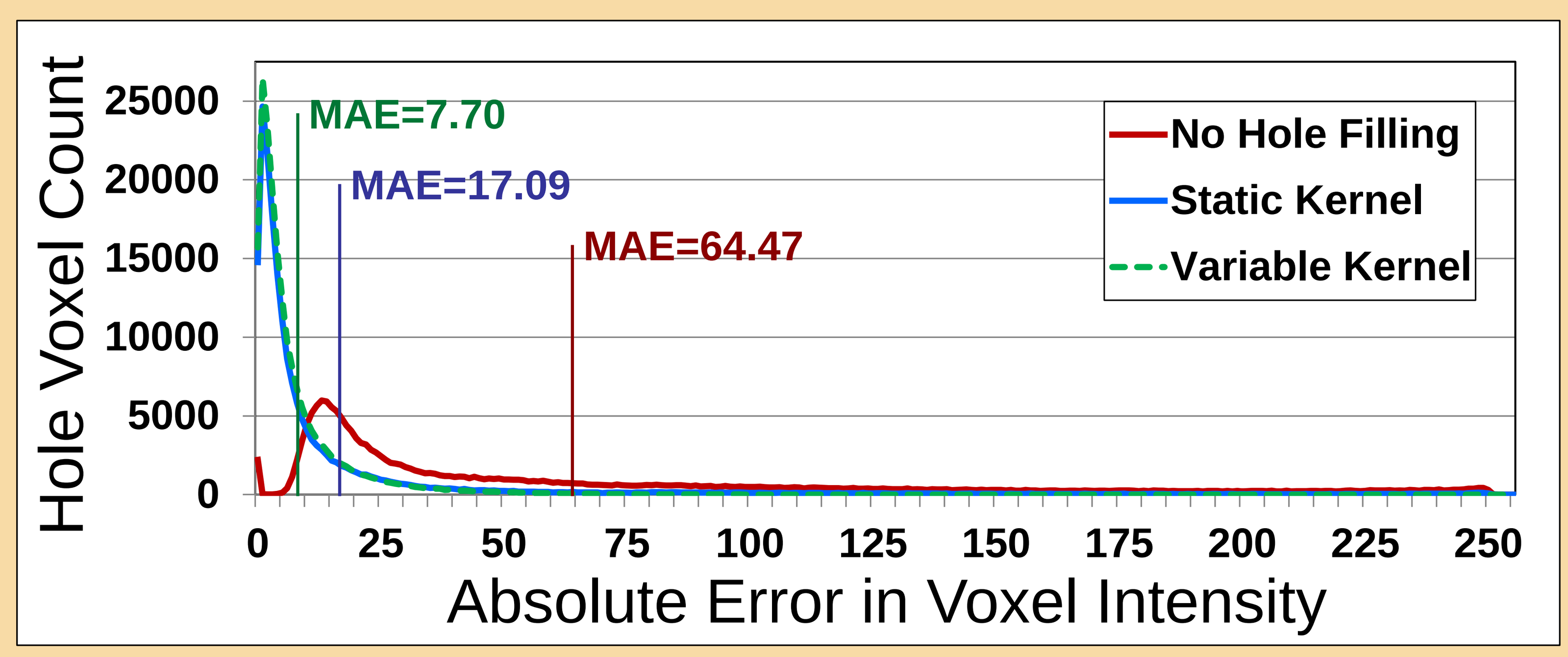

Figure 6: The Absolute Error distribution in hole voxel intensities is shown for the Prostate volume reconstructions. The MAE are marked.

Conclusions

- A volume reconstructor was implemented as free, open-source software available at: **https://www.assembla.com/spaces/plus/**
- The software continues to be tested on data from the University of British Columbia and Queen's University
- Using a variable kernel size enhances the accuracy of reconstructed volumes.

References

1. D. Gobbi, and T. Peters. (2002) "Interactive intra-operative 3D ultrasound reconstruction and visualization." Paper presented at MICCAI 2002. Proceedings of the 5th International Conference on Medical Image Computing and Computer Assisted Intervention Sep 25-28; Tokyo, Japan.
2. P. Caballero-Martinez, C. Alberola-Lopez, and J. Ruiz-Alzola (2003), A theoretical framework to three-dimensional ultrasound reconstruction from irregularly sampled data. Ultrasound in Medicine & Biology. 29(2) pp. 255-269.
3. R. Rohling, A. Gee, and L. Berman (1999), "A comparison of freehand threedimensional ultrasound reconstruction techniques." in Medical Image Analysis, 3(4), pp. 339-359.

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