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3D Ultrasound Reconstruction Based on Free Hand Acquisitions with Motion Estimation

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Summary:
Within the research project POIR.01.01.01-00-1462/19 we developed a method to reduce motion artifacts during 3D volume reconstruction of free hand 2D ultrasound sequences. Additionally, two 3D visualization algorithms were implemented using OpenGL shader language allowing real-time data rendering on an embedded class GPU device.

Keywords: 3d ultrasound, image stabilization, motion estimation, volume rendering

Introduction

Ultrasound imaging is a safe and relatively cheap diagnostic modality. 3D reconstruction and visualization may constitute an additional value to a regular examination workflow. The most common application is OB/GYN for fetal diagnostics [1]. Other use cases are also cardiology [1], surgical navigation [2] or vascular imaging. This modality requires that a system is able to collect 3D volumetric data. This can be done using either: a 2D array probe, a 1D mechanical swing array probe, a 1D array probe with a tracking device or a regular 1D array probe with assumed movement trajectory [3]. Each technique is a trade-off between data quality and system complexity and price. The latter method called also the free-hand technique requires least technical resources but is also definitely more prone to reconstruction errors.

Background, Motivation an Objective

The presented work has been conducted within a NCBiR research project no. POIR.01.01.01-00-1462/19 with the goal of development a high channel ultraportable ultrasound scanner for veterinary and human medicine applications. One of the system components was 3D imaging mode and given the project requirements and assumptions the free-hand approach was the only option. Within our work we developed 3D volume reconstruction based on following predefined ultrasound probe movement trajectories: linear, swing and rotational [3]. The objective was to deliver image quality comparable with high class standalone devices. To improve the reconstruction quality we developed an algorithm for image stabilization and motion estimation. Next steps were data filtering and visualization. Embedded system performance had to be considered, still allowing for real-time data rendering.

Workflow Description

As mentioned before, the first step is 2D image sequence acquisition by moving the probe on a predefined trajectory by operator's hand. For linear movement we have to assume a certain distance travelled, for the swing pattern we need a angle range and the rotational pattern assumes 180° rotation around the probe's axis. For human operator it's very hard to keep constant speed and movement confined only to a given trajectory. The deviations are clearly seen as artifacts in the reconstructed volume.

To improve data quality we developed a novel algorithm for image stabilization and motion estimation. To correct movement deviation in the imaging plane we run an optimizer that finds affine transform that maximizes similarity between patches of consecutive frames. The similarity measure of choice is normalized cross correlation (NCC). It's value after in-plane movement correction is then used to estimate motion in the elevation direction. We approximate the shift with squared logarithm of NCC multiplied by a constant [4].

After the movement correction 3D volume is reconstructed and filtered. For filtering a lowest variance filter [5] is used. The result is visible in the visualization stage: one gets smoother surfaces while preserving structure details.

Finally the data is visualized by an algorithm of choice. Within the project we implemented two volume rendering methods: maximum intensity projection (MIP) and surface rendering. The algorithms were implemented using OpenGL shader language and adjusted to available GPU to reach real-time objective.

Results

The test data used were 2D sequences of bovine ovary recordings. 3D surface rendering was used to visualize ovarian follicles. 3D imaging allows for fast follicle count and morphology assessment.

Summary and Conclusions

Motion estimation algorithm improves imaging quality by reducing out of trajectory movement artifacts. OpenGL GPU optimized programming allows real-time imaging and thus leading to quicker and more accurate assessments of the ultrasound exams.

Sample Images

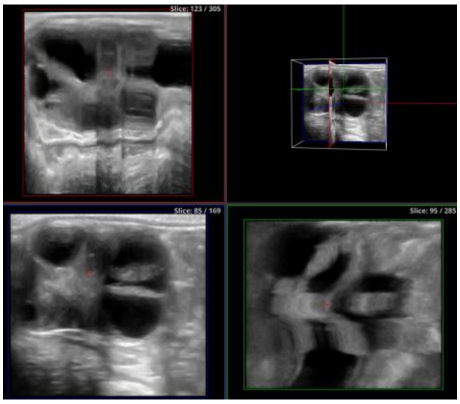

Fig. 1. Cross-sections of 3D reconstruction without motion estimation.

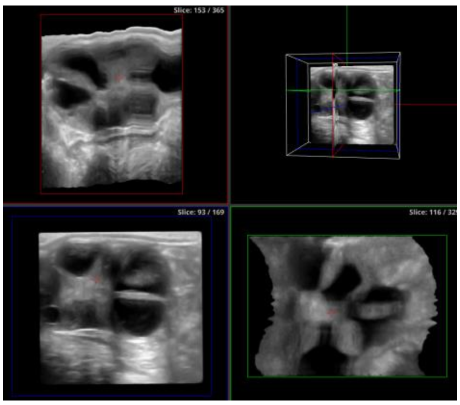

Fig. 2. Cross-sections of 3D reconstruction with motion estimation.

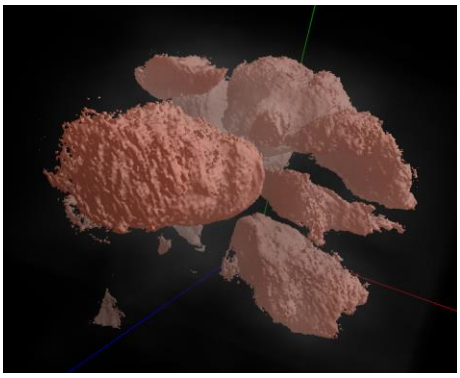

Fig. 3. 3D surface rendering of ovarian follicles, no motion estimation in 3D reconstruction.

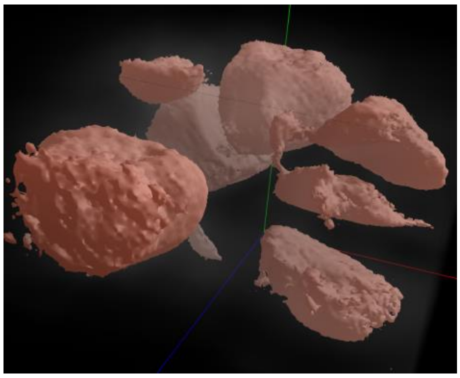

Fig. 4. 3D surface rendering of ovarian follicles, motion estimation enabled in 3D reconstruction.

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