Synthetic Tracked Aperture Ultrasound Imaging (STRATUS): Virtual Fixtures for Co-Robotic Control

Computer Integrated Surgery II
Spring 2016
Kalyna Apkarian and Rodolfo Finocchi
Mentors: Kai Zhang, Dr. Emad Boctor, Dr. Russell Taylor

Introduction

• We have developed a way to improve image quality in ultrasound imaging by implementing constraints in the form of “virtual fixtures” in the STRATUS system.
• Accomplishments include the successful demonstration of co-robotic control for in-plane and rotational motion on various phantoms, and an overall increase in US image quality.
• These accomplishments allow for ease of use by the sonographer, increased patient safety, and higher quality images.

The Problem

• Conventional ultrasound image quality is limited by the aperture size of the transducer, especially in deep tissue.
• STRATUS has been shown to improve image quality, but has only been used as an autonomous system.
• Co-robotic control would bridge the gap between an autonomous robot and unconstrained control, allowing for clinical translation.

The Solution

• Virtual fixtures are a way to augment motion commands from the user, thus enhancing precision, stability, and patient safety. We use virtual fixtures to allow for co-robotic control.
• It takes the form of a constrained optimization problem, according to

\[ \mathbf{q}_{\text{des}} = \mathbf{q}_{\text{des}}^* \]

Where \( H \) and \( h \) are geometric constraint matrices that define the desired robot behavior
• Behavior specified by user through GUI, based on 3 options
  1. Move along a line in 3D space
  2. Move in plane (with/without contact force control)
  3. Rotational motion in plane (with/without contact force control)

\[ \mathbf{H} * \mathbf{q}_{\text{des}} \leq \mathbf{h} \]

Outcomes and Results

• The implementation of virtual fixtures accurately constrains the probe motion as desired.

Figure 2. Trajectory of probe being guided by the user under constraint (a) move along a line, (b) move along a plane, (c) rotational. Error specified to be ±0.5 mm in each direction.

• Constraining the motion of the probe results in an overall improvement in image quality.
• Comparing a single pose image to a STRATUS image with co-robotic control results in an improvement in FWHM from 3.87 mm to 2.37 mm, contrast from -7.14 to -10.67 dB, and SNR from 25.01 dB to 29.35 dB.

Figure 3. Demonstration of improvement in image quality from (a) single pose ultrasound image to (b) STRATUS image with “move along a line”.

Future Work

• Work will be continued by another MSE student
• Next steps include:
  • Calibration of frame transform for rotational motion
  • Refining system to image on realistic abdominal phantom with contact force control

Lessons Learned

• The importance of documentation
• How to critically read a piece of literature and apply it to a project
• Real-world application of our robotics coursework

Credits

• Admittance control and 1 Euro filter from Rodolfo’s Thesis
• Original image reconstruction code from Kai
• All other work done jointly

Publications

• Submitted paper to Medical Image Computing & Computer Assisted Intervention (MICCAI) International Conference
• Submitted abstract to IEEE International Ultrasonic Symposium conference

Acknowledgements

• Thank you to our mentors Kai, Dr. Boctor, and Dr. Taylor