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.

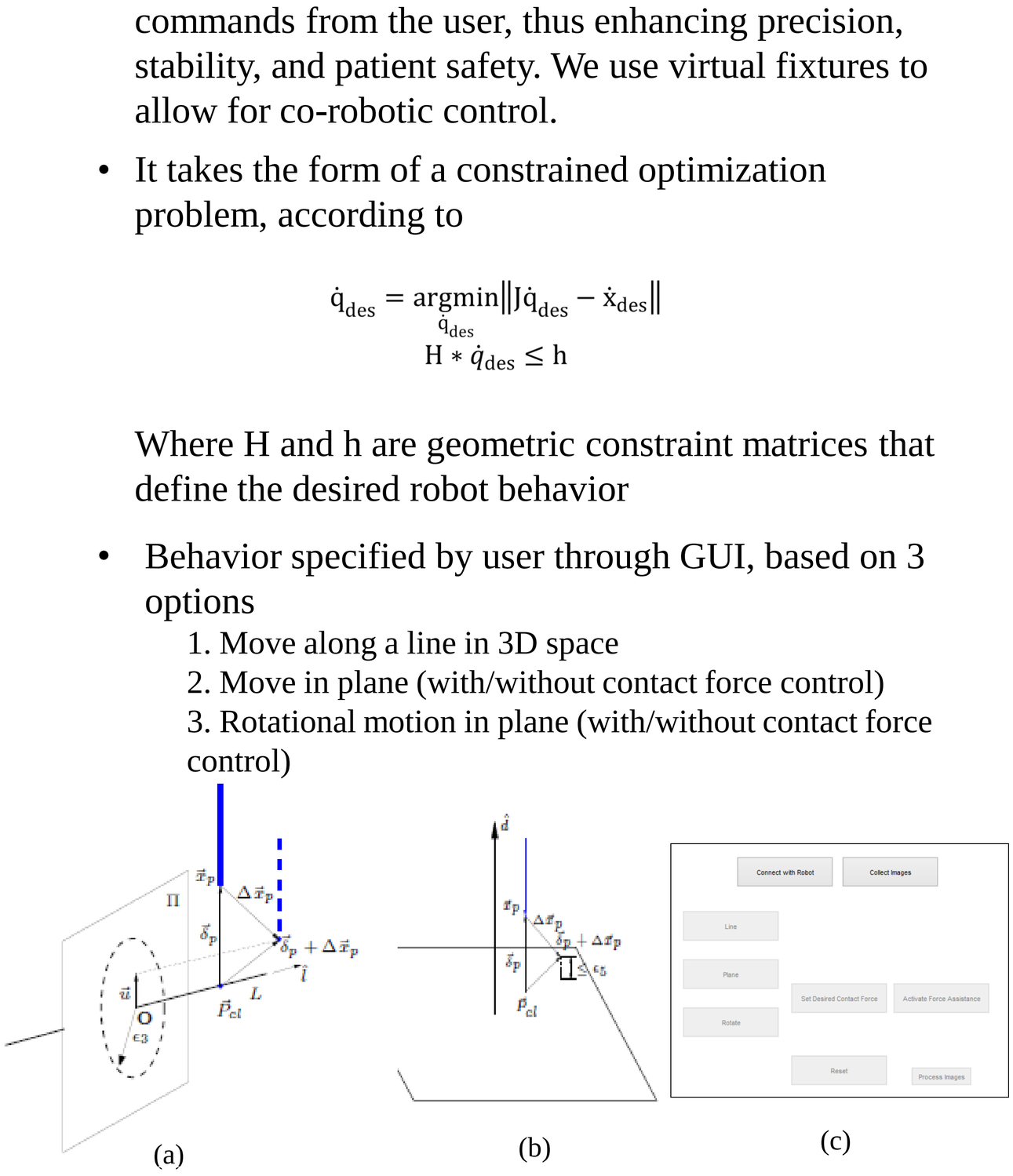
The Solution

- 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

$$\dot{q}_{des} = \underset{\dot{q}_{des}}{\operatorname{argmin}} \left\| J\dot{q}_{des} - \dot{x}_{des} \right\|$$
$$H * \dot{q}_{des} \leq h$$

  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)



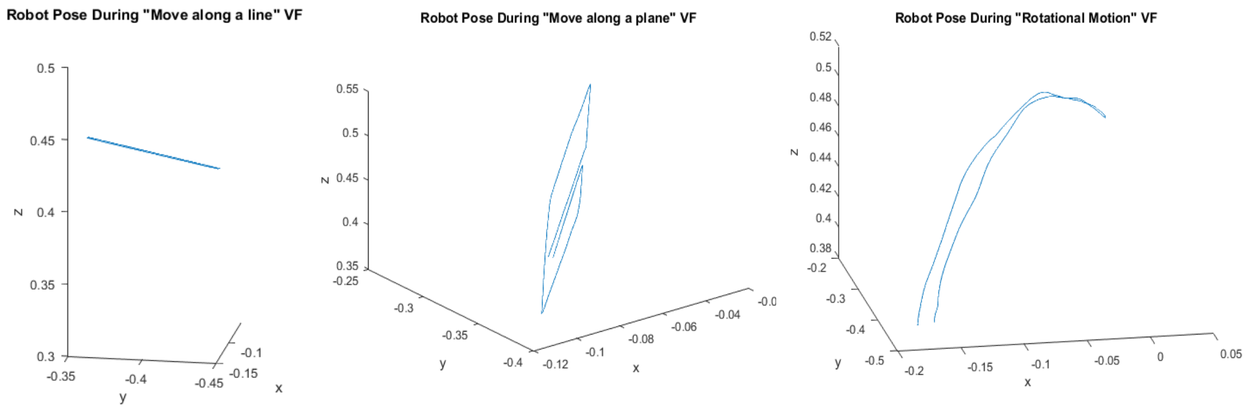
(a) (b) (c)

Figure 1. Depiction of geometric relationships for (a) move along a line, (2) move in plane and rotate in plane (image source: 1) (c) Custom GUI

[1]M. Li, A. Kapoor, and R. H. Taylor, "A constrained optimization approach to virtual fixtures," in IROS, 2005, pp. 1408–1413.

Outcomes and Results

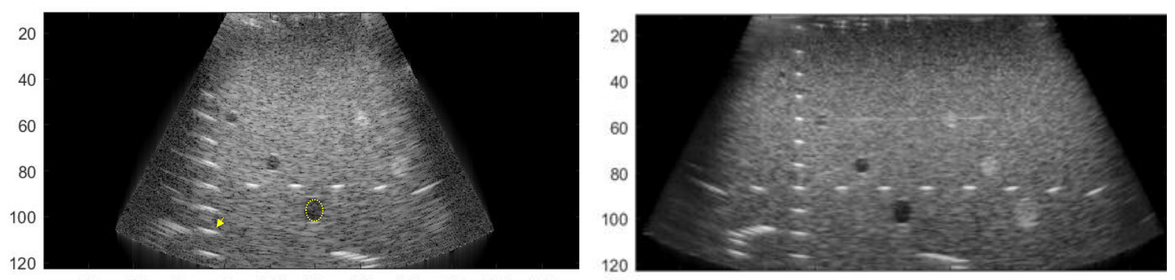
- The implementation of virtual fixtures accurately constrains the probe motion as desired.



(a) (b) (c)

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.



(a) (b)

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