Synthetic Tracked Aperture Ultrasound Imaging: Virtual Fixtures and Force Control

Group 2: Checkpoint Presentation

Kalyna Apkarian and Rodolfo Finocchi
Mentors: Kai Zhang, Dr. Emad Boctor, Dr. Russ Taylor

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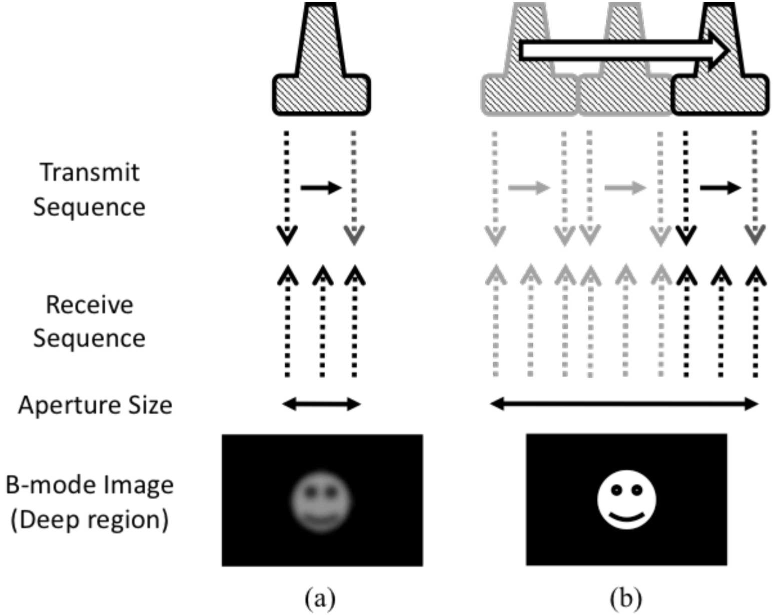
Motivation

- Aperture size of the ultrasound transducer limits image quality
- Synthetic tracked aperture imaging shows improvement
  - Current system is autonomous by robot
    - Difficulty in clinical translation
    - Force control required for anatomy specific imaging and patient safety
- Goal is to bring system from autopilot to co-robotic freehand



Deliverables

Minimum

- Code implementing virtual fixtures ✓
- Code implementing compliance force control ✓
- Comparison of actual trajectory of robot with planned trajectory ✓ **- (minor issue)**
- Demonstration of translational path in water tank using co-robotic control ✓

Expected

- Demonstration of translational path on general US phantom, without contact force control ✓
- Demonstration of translational path on general US phantom, with contact force control – **Next step**

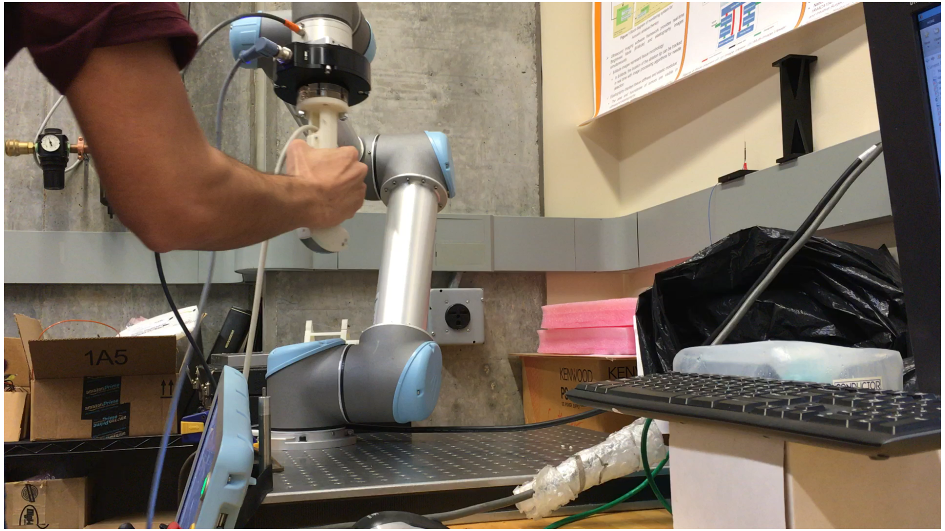
Maximum

- Demonstration of rotational path in water tank using co-robotic control – **Planned**
- Demonstrate control on more anatomically accurate path using rotation and force control on abdominal phantom – **Possible**

Robot Control: Constrained Optimization Approach

$$\dot{x}_{des} = Kf$$

$$\dot{q}_{des} = \min_{\dot{q}} \|\dot{x}_{des} - J\dot{q}_{des}\|$$



Robot Control: Constrained Optimization Approach

$$\dot{x}_{des} = Kf$$

$$\dot{q}_{des} = \min_{\dot{q}} \|\dot{x}_{des} - J\dot{q}_{des}\|$$

Subject to:

$$\begin{bmatrix} H_{line} & 0 \\ 0 & H_{jointvel} \end{bmatrix} \begin{bmatrix} J \\ I_{6x6} \end{bmatrix} \dot{q} \leq \begin{bmatrix} h_{line} \\ h_{jointvel} \end{bmatrix}$$

$$H_{line} = \begin{bmatrix} [R[\cos\frac{2\pi}{n}, \sin\frac{2\pi}{n}, 0]']' & 0 & 0 & 0 \\ [R[\cos\frac{4\pi}{n}, \sin\frac{4\pi}{n}, 0]']' & 0 & 0 & 0 \\ \cdots & & & \\ [R[\cos\frac{2n\pi}{n}, \sin\frac{2n\pi}{n}, 0]']' & 0 & 0 & 0 \end{bmatrix},$$

$$h_{line} = \begin{bmatrix} \epsilon \\ \cdots \\ \epsilon \end{bmatrix} - H \begin{bmatrix} [x_p - P_{cl}]_{3x3} \\ \vec{0} \end{bmatrix}$$

$$H_{jointvel} = \begin{bmatrix} -I_{6x6} \\ I_{6x6} \end{bmatrix}, \vec{h}_{jointvel} = \begin{bmatrix} \dot{q}_{lower,6x1} \\ \dot{q}_{upper,6x1} \end{bmatrix}$$

where n = 8, $\epsilon = 0.5$ mm,
$-\dot{q}_{lower} = \dot{q}_{upper} = 0.5$ rad/sec

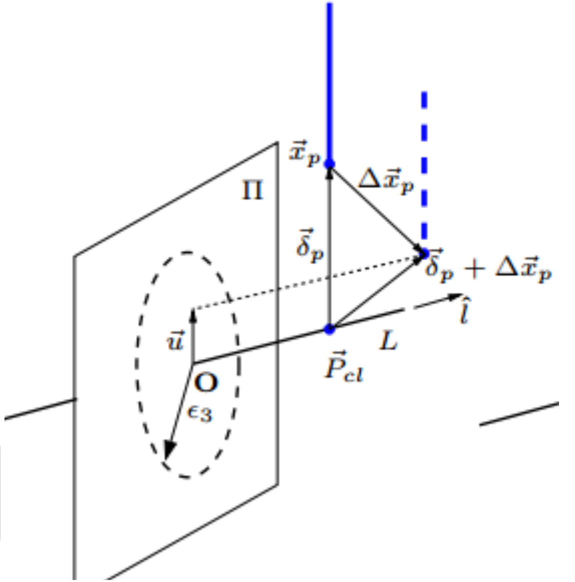
Stay On Line Virtual Fixture

$$\dot{\boldsymbol{q}}_{des} = \min_{\dot{q}} \|\dot{\boldsymbol{x}}_{des} - \boldsymbol{J}\dot{\boldsymbol{q}}_{des}\|$$

Subject to:

$$H\dot{q} \leq \vec{h}$$

$$H_{line} = \begin{bmatrix} [R[\cos\frac{2\pi}{n}, \sin\frac{2\pi}{n}, 0]']' & 0 & 0 & 0 \\ [R[\cos\frac{4\pi}{n}, \sin\frac{4\pi}{n}, 0]']' & 0 & 0 & 0 \\ & \cdots & & \\ [R[\cos\frac{2n\pi}{n}, \sin\frac{2n\pi}{n}, 0]']' & 0 & 0 & 0 \end{bmatrix}, \quad h_{line} = \begin{bmatrix} \epsilon \\ \cdots \\ \epsilon \end{bmatrix} - H \begin{bmatrix} [x_p - P_{cl}]_{3x3} \\ \vec{0} \end{bmatrix}$$

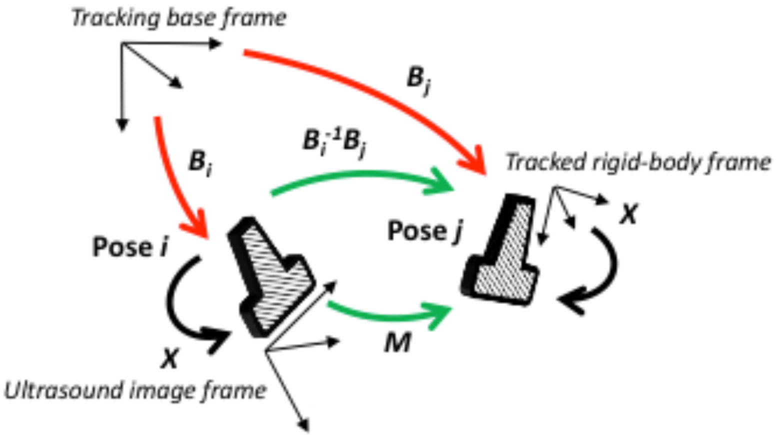


Source:
Li, Ming, Ankur Kapoor, and Russell H. Taylor. "A constrained optimization approach to virtual fixtures." *Intelligent Robots and Systems, 2005.(IROS 2005). 2005 IEEE/RSJ International Conference on*. IEEE, 2005.

Frame Transformation

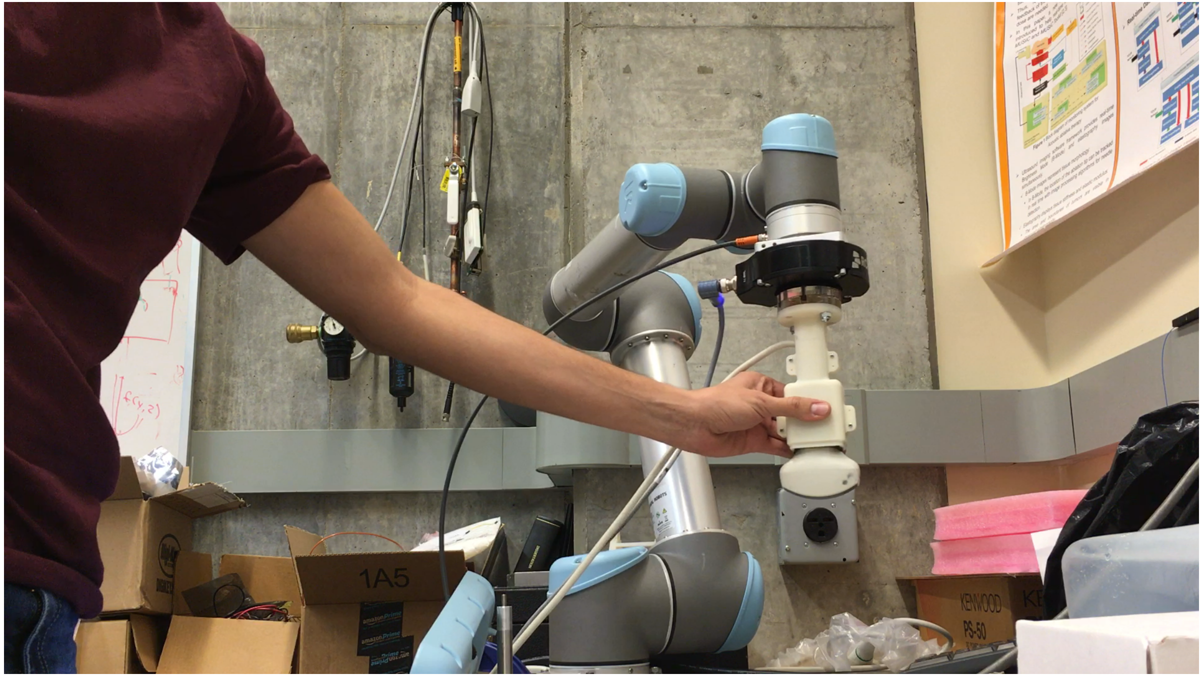
- Used in STRATUS image reconstruction according to: $M=X^{-1}*B_i^{-1}*B_j*X$ for each pose

- Used in “stay on line” to define desired trajectory relative to long axis of probe

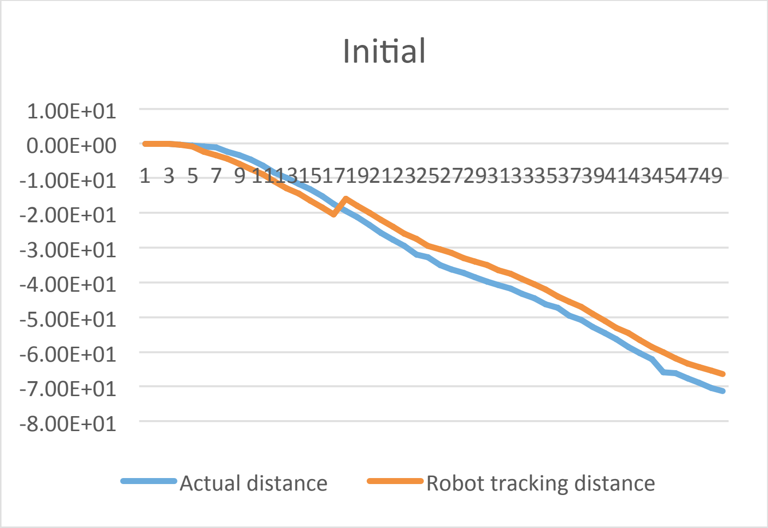


$$X = \begin{bmatrix} 0 & 0 & -1 & 0 \\ -0.9998 & 0.0175 & 0 & 0 \\ 0.0175 & 0.9998 & 0 & 177 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Demonstration of VF



Actual vs. Expected Robot Trajectory



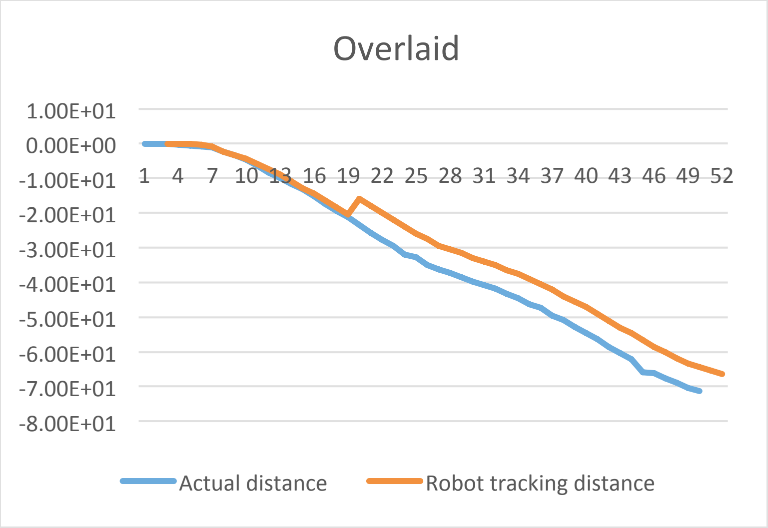
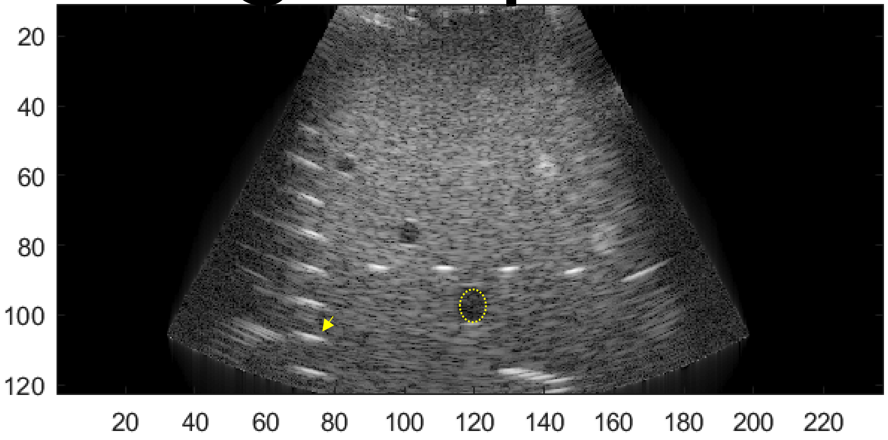
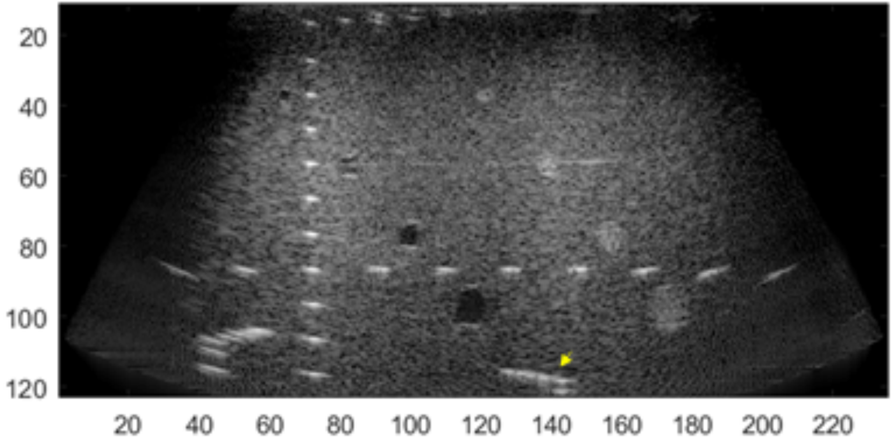


Image Improvement





Left: Single pose B-mode ultrasound image of general US phantom.

Right: STRATUS images synthesized in the range of 60 mm motion data; field-of-view expanded by 65.5 mm.

	Single	STRATUS: 60 mm
FWHM (mm)	3.87	2.37
Contrast (dB)	-7.14	-10.67
SNR (dB)	25.01	29.35

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Additional Accomplishments

- Paper submitted to 2016 MICCAI Conference
  - "Co-Robotic Synthetic Tracked Aperture Ultrasound Imaging with Virtual Fixture Control"

Dependencies & Problems

Original

- Access to mentors ✓
- Access to water tank & phantoms ✓
- Access to STrAtUS real-time visualization system ✓
- Deeper understanding of virtual fixtures and implementation ✓
- Access to UR5 robot and force sensors- **minor issue, addressed**
- Access to Sonix Touch ultrasound system- **minor issue, addressed**

Management Updates

- Weekly meetings with Kai ✓
- Bi-weekly team meetings ✓
  - Design documentation
  - Working code
    - Updated after every meeting via shared folder
  - Experimental data

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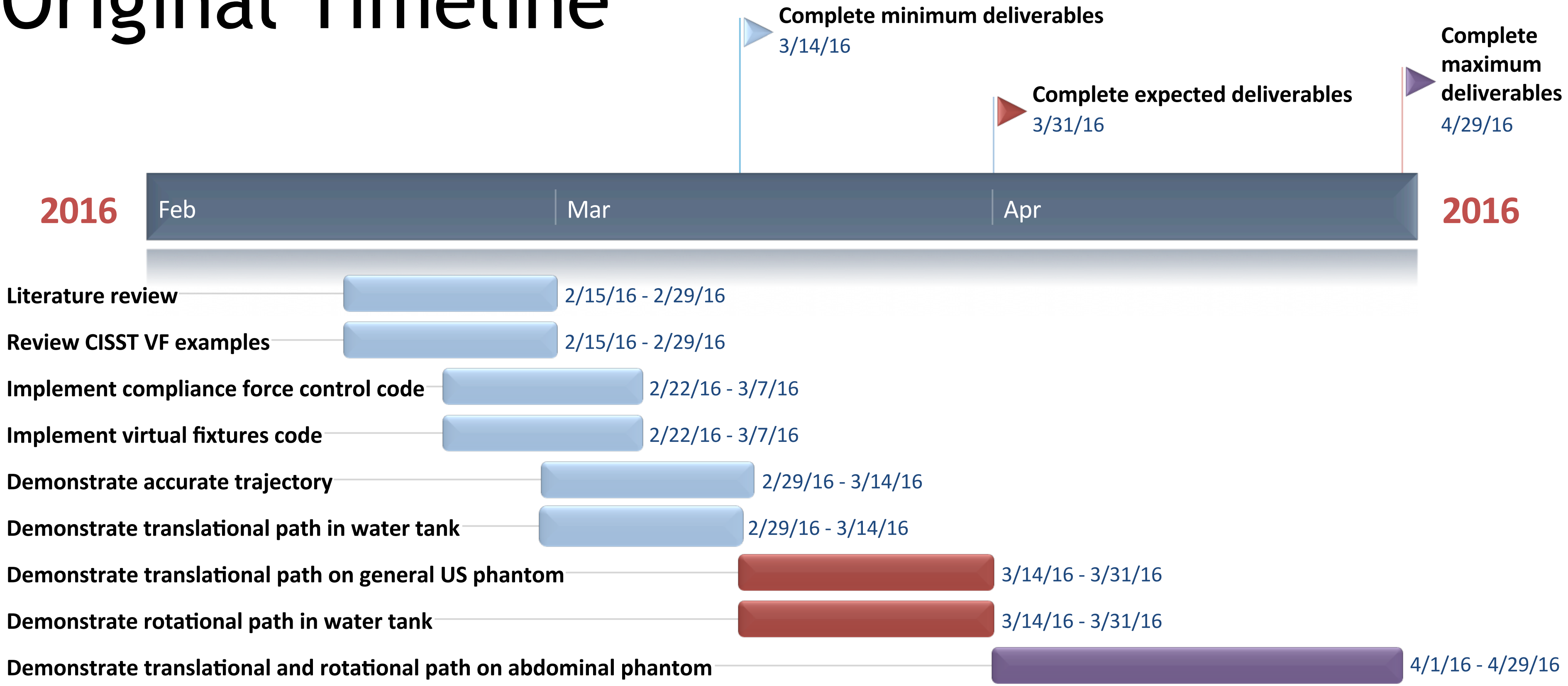
Original Timeline



Updated Timeline