Synthetic Tracked Aperture Ultrasound Imaging: Virtual Fixtures and Force Control

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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
Goals

• Bring system from autopilot to co-robotic freehand using a guidance virtual fixture
• Implement compliance force control for ease of use by the physician
• Ensure patient safety using virtual fixtures
Proposed System Architecture

- Virtual fixture
- Compliance control
- Contact force control
Main Constraints

(a) Phantom: Front view
Forbidden region virtual fixture

(b) Phantom: Top view
Forbidden region virtual fixture (out of plane)
Guidance virtual fixture
Technical Approach: compliance control

**Task level control**
\[ \dot{x}_{des} = K \star f \]

**Motion level control**
\[ \Delta q = \text{argmin}_{\Delta q} \| J \Delta \dot{q} - \Delta \dot{x} \| \]

**Subject To:**
- Joint Limits: \( q_L \leq q \leq q_R \)
- Motion, orientation, or force limits imposed by VF

**Inputs:**
- Safety constraints
  - Input by operator

**Dependencies**
- Sensor values
- Motor currents

**Position control**
Deliverables: Summary

Minimum
- Code implementing virtual fixtures
- Code implementing compliance force control
- Comparison of actual trajectory of robot with planned trajectory
- Demonstration of translational path in water tank using co-robotic control

Expected
- Demonstration of rotational path in water tank using co-robotic control
- Demonstration of translational path on general US phantom

Maximum
- Demonstrate control on more anatomically accurate path using rotation and force control on abdominal phantom
Detailed Summary of Approach

Minimum deliverable

- Code implementing virtual fixtures
  - Finding correct CISST libraries and gaining a deeper understanding of algorithm
  - Implement virtual fixture algorithm
    - Guidance type and forbidden region type

- Code implementing compliance force control
  - Implement compliance force control algorithm

- Comparison of actual trajectory of robot with planned trajectory
  - Calculate forward kinematics of desired trajectory
  - Collect end effector pose data of the robot using commands from UR5 library
  - Compare actual end effector pose data with desired

- Demonstration of translational path in water tank using co-robotic control
  - Compare with image generated on autopilot using FWHM
Detailed Summary of Approach

Expected deliverable

• Demonstration of rotational path in water tank using co-robotic control
  ▫ Compare with image generated on autopilot using FWHM
  ▫ Ensure better quality than translational path

• Demonstration of translational path on general US phantom
  ▫ Implement contact force control algorithm
  ▫ Compare actual force exerted with desired force exerted
Detailed Summary of Approach

Maximum deliverable

- Demonstrate control on more anatomically accurate path using rotation and force control on abdominal phantom
  - Demonstrate integration of virtual fixtures with compliance force control and contact force control
  - Compare actual force exerted with desired force exerted over a varying path
Dependencies

• Access to UR5 robot and force sensors - MUSiiC Lab Google Calendar
• Access to Sonix Touch ultrasound system – Done
• Access to STrAtUS real-time visualization system - Done
• Access to mentors - Weekly meeting with Kai
• Access to water tank & phantoms - Available in lab space
• Deeper understanding of virtual fixtures and implementation- Ongoing
• Familiarity with CISST libraries- Ongoing
Management Plan

- Bi-weekly team meetings: Mondays and Thursdays
- Weekly meetings with Kai: Mondays
- Use Git for version control

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Project Timeline

2016

Feb | Mar | Apr | 2016

- Literature review: 2/15/16 - 2/29/16
- Review CISST VF examples: 2/15/16 - 2/29/16
- Implement compliance force control code: 2/22/16 - 3/7/16
- Implement virtual fixtures code: 2/22/16 - 3/7/16
- Demonstrate accurate trajectory: 2/29/16 - 3/14/16
- Demonstrate translational path in water tank: 2/29/16 - 3/14/16
- Demonstrate translational path on general US phantom: 3/14/16 - 3/31/16
- Demonstrate rotational path in water tank: 3/14/16 - 3/31/16
- Demonstrate translational and rotational path on abdominal phantom: 4/1/15 - 4/29/16

Complete minimum deliverables: 3/14/16
Complete expected deliverables: 3/31/16
Complete maximum deliverables: 4/29/16
Reading List

- sawConstraintController and Constrained Optimization JHU-saw library page on Virtual Fixtures