

Dual-robotic Arm For Prostate Ultrasound Tomography

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INTRODUCTION

Clinical motivation

- **Prostate cancer** is the most dominant than other cancers (180,890, 21% in total cancer diagnosis) and the second leading cause of cancer-related deaths in men (26,120, 8%).
- The current diagnostic approach involves **PSA testing and TRUS, followed by mpMRI** if there is a high suspicion of cancer..
- TRUS has limitations, including a low detection accuracy and positive predictive value.
- Quantitative imaging via **USCT** has the potential to enhance the accuracy of TRUS.

About USCT (Ultrasound Computed Tomography):

- USCT emits ultrasound waves through the body and records echoes from tissue structures.
- Process the data to create a 3D image of tissue structures, including the prostate.

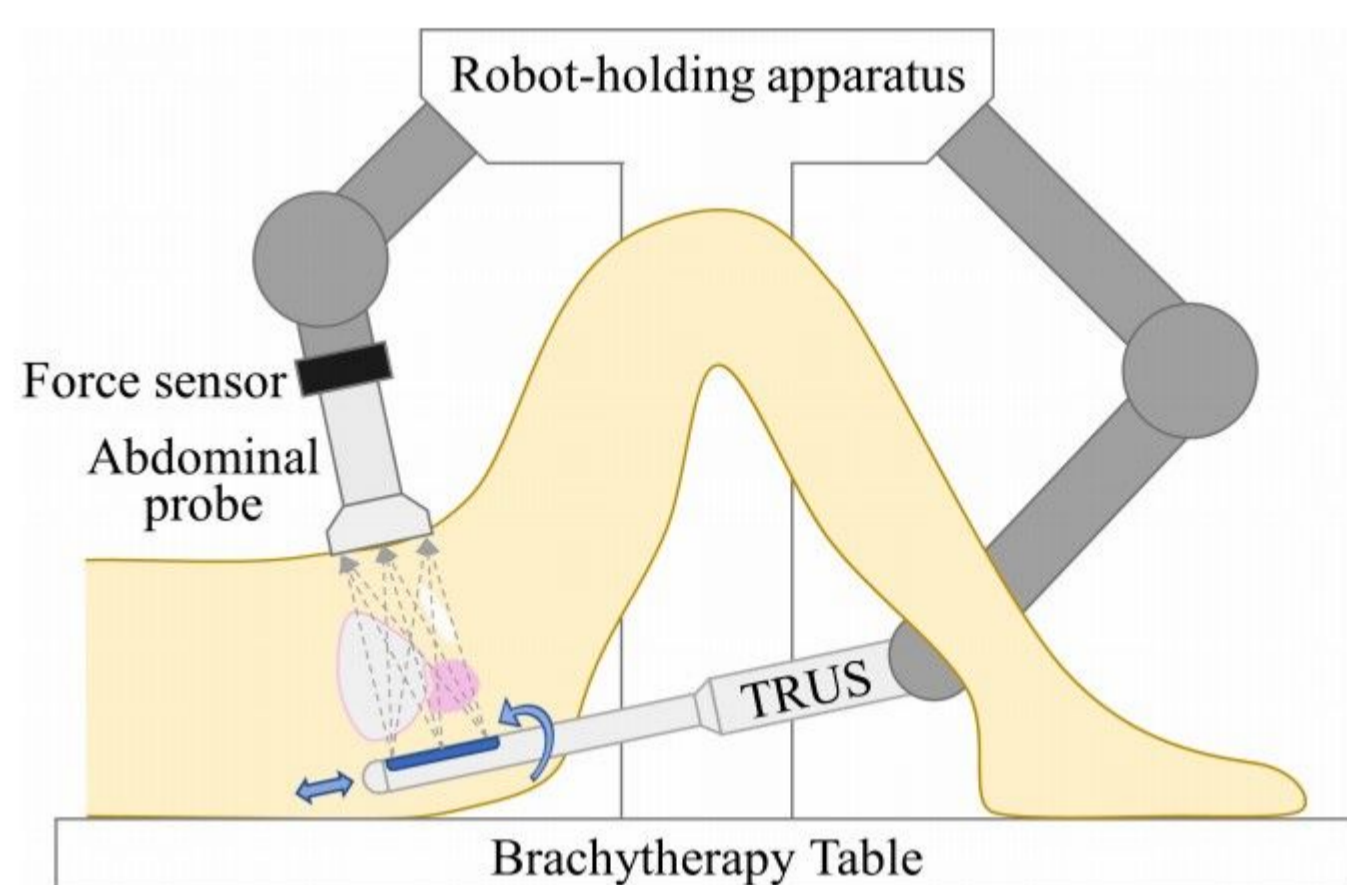


Fig. 1 General approach to dual-robotic USCT [1]

To enable the USCT:

- **Step 1:** Trus probe inserted into the patient's body
- **Step 2:** Abdominal probe moves to an aligned position.
- **Step 3:** Abdominal probe touches the patient abdomen.
- **Step 4:** Trus probe starts rotating and abdominal probe follows the rotation and keeps alignment with Trus probe.
- **Step 5:** Ultrasound image reconstruction.

PROJECT OBJECTIVE

- A demonstration of proper dual-robotic setup and equipment connectivity.
- Robot base-to-base registration and end-effector-to-ultrasound calibration.
- Real-time motion planning of dual arms for ultrasound image acquisition where two ultrasound transducers are automatically aligned.
- Integration of virtual fixture to limit robot arms' workspace to ensure the safety for in vivo imaging (for Abdominal probe)
- Enhanced path planning to achieve smoother and steadier motion.

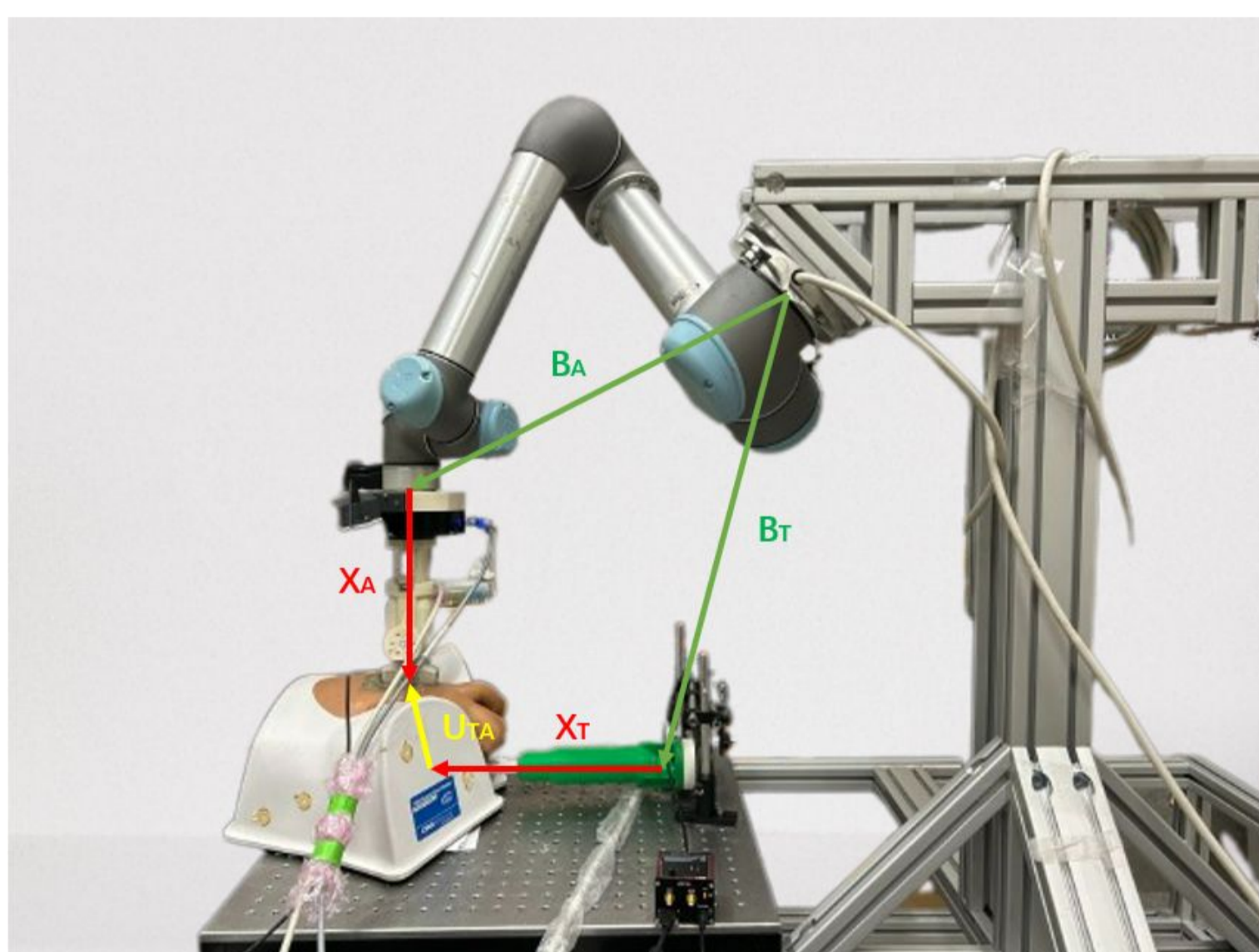


Fig. 2 Transformation loop of the dual robot [1]

- A rotation stage is used (step motor with encoder) for the Trus Probe instead of a UR5 robot arm..

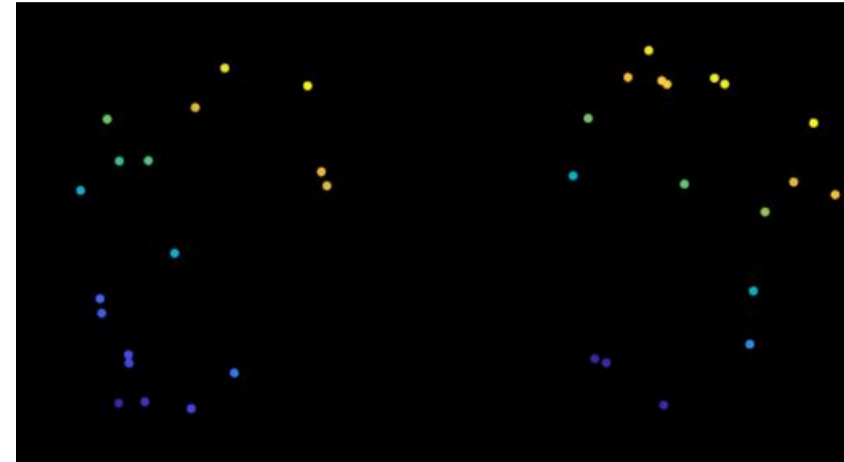
REFERENCES

- [1] Gilboy, Kevin Michael. ROBOTIC ULTRASOUND TOMOGRAPHY AND COLLABORATIVE CONTROL.
- [2] Ming Li, A. Kapoor, and R.H. Taylor. A constrained optimization approach to virtual fixtures. In 2005 IEEE/RSJ International Conference on Intelligent Robots and Systems, pages 140

Calibration and Registration of the Robot

Point Cloud Registration

- Use Point Cloud Registration (ICP Algorithm) to find the yellow transformation between the robot base and the Trus frame.
- Use both probes to find the same fixed point in 3D space . collect 20 points for registration



Ultrasound Probe Calibration

Use Bxp Algorithm to find X_A (transformation between end effector to abdominal probe) shown in figure 2.

$$\operatorname{argmin}_{X \in SE(3)} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \|B^{(i)} X p^{(i)} - B^{(j)} X p^{(j)}\|_2^2$$

The error is approximately from 1mm to 3mm.

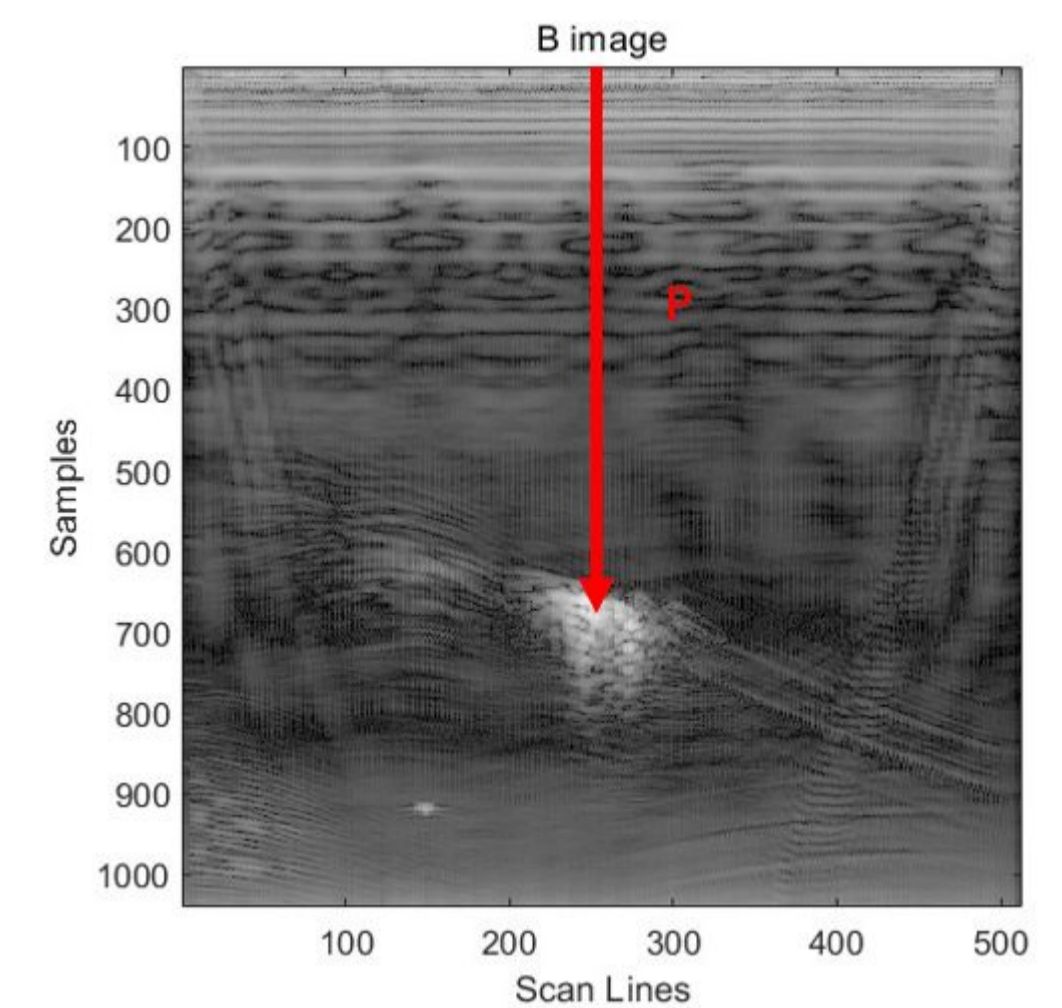
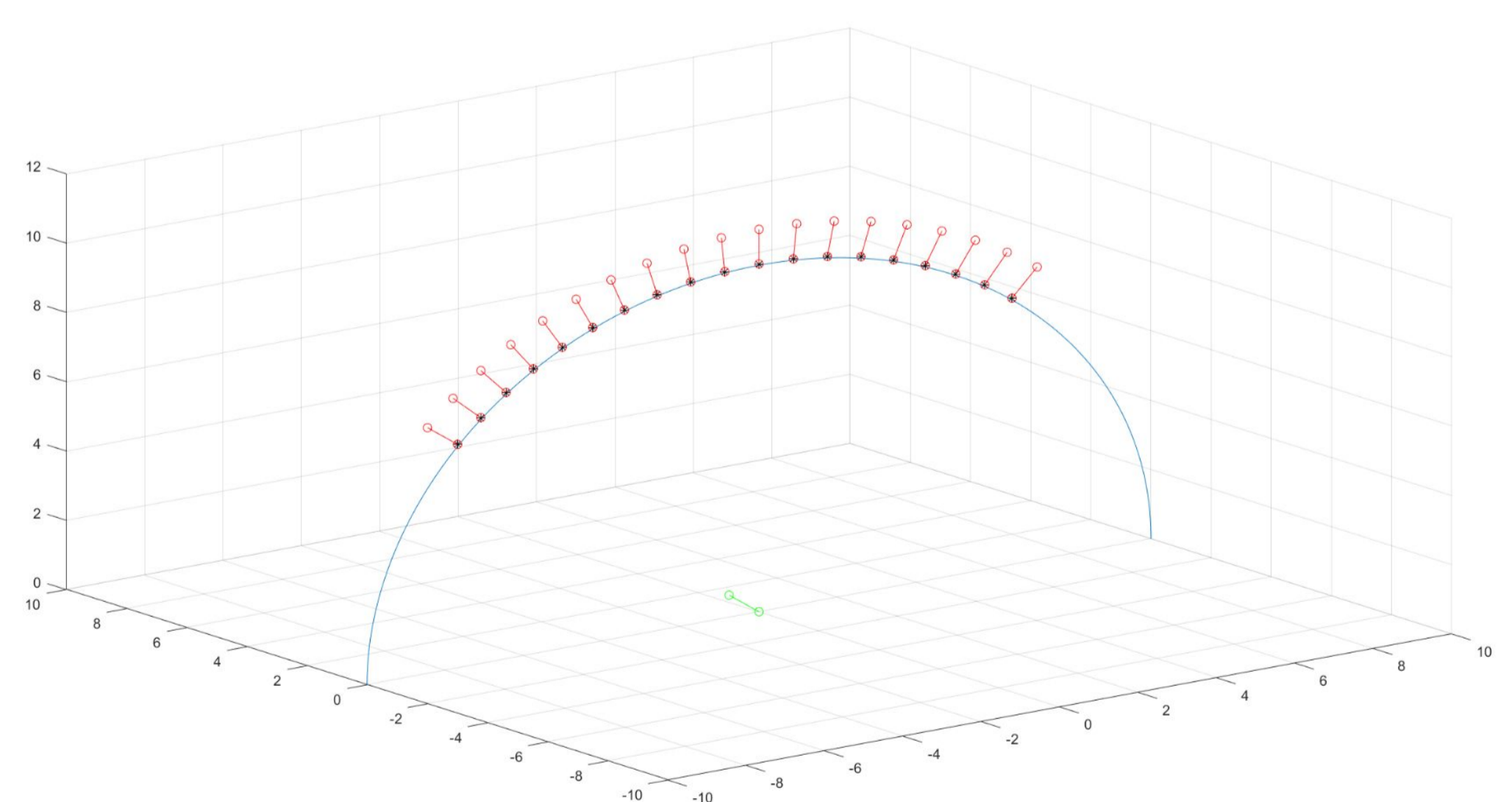
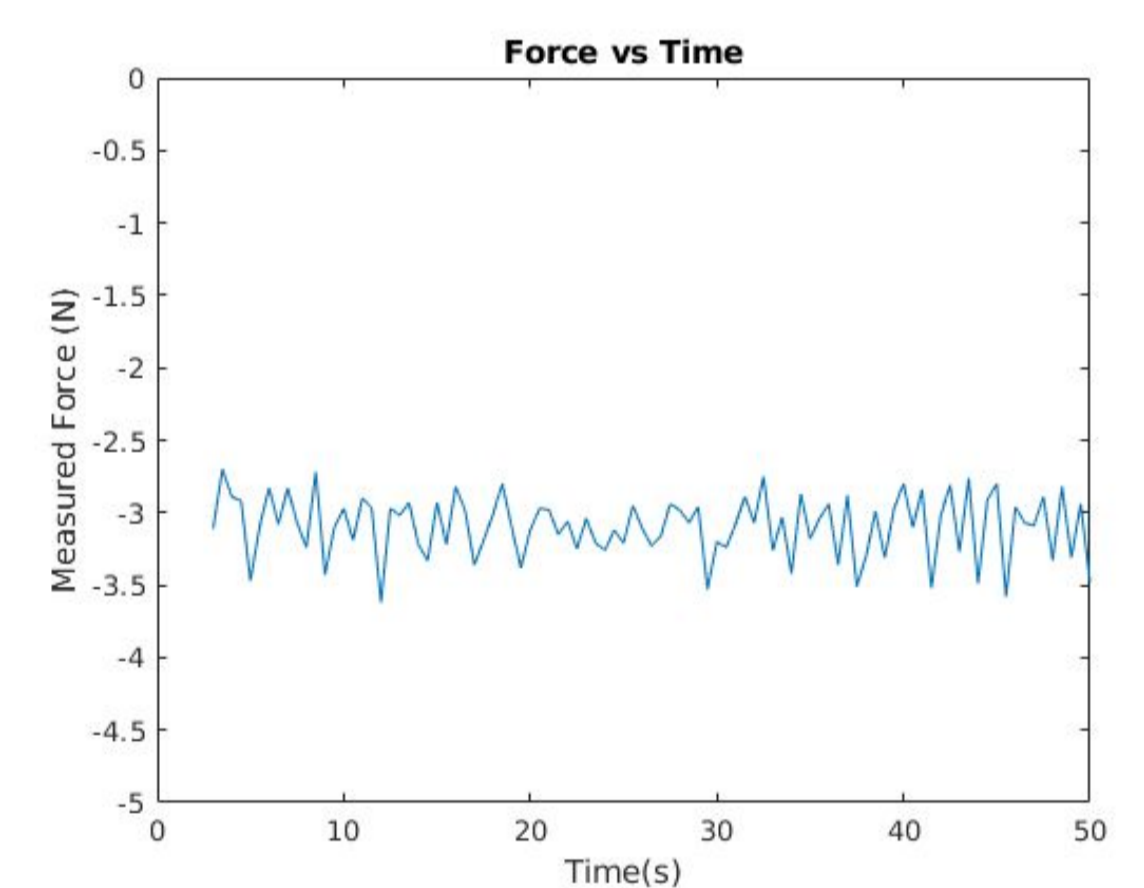
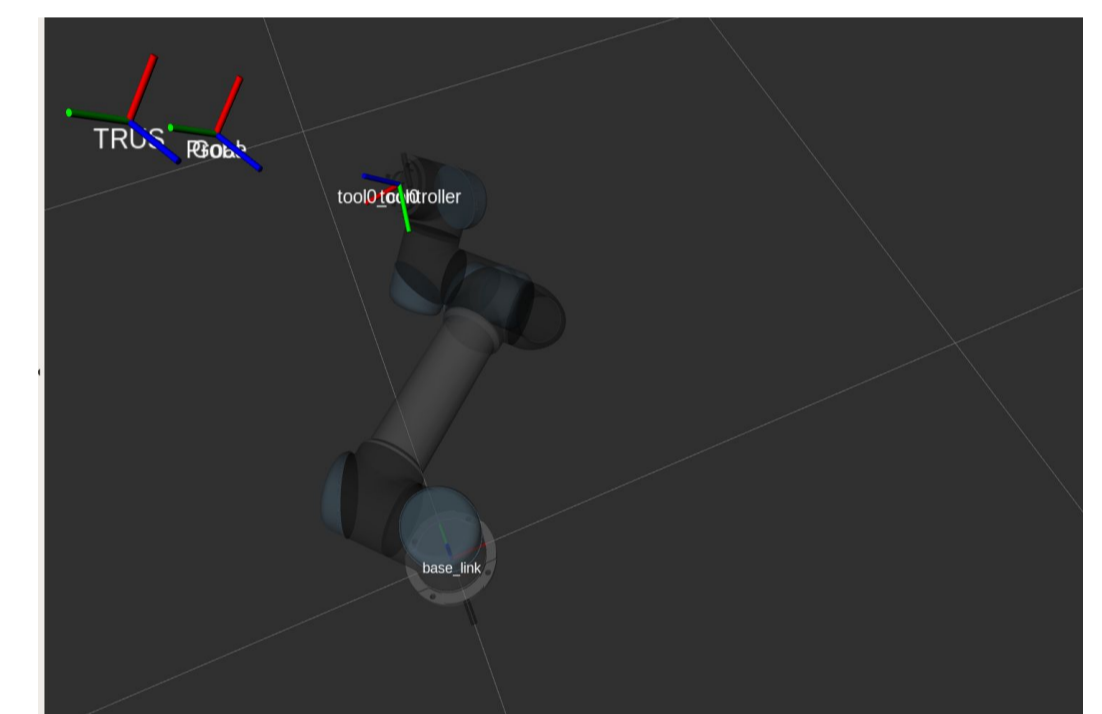


Fig. 3 Ultrasound Image for a cross fishing wire

- **Cross fishing wire is detected as a bright area in the US image. The coordinate of the brightest pixel will give the coordinate of the crossing location.**

Motion Planning and Virtue Fixture

- **Abdominal Probe**
 - Connect to the end-effector of the robot
 - Rotation with the TRUS probe
 - Implementation of the alignment between two probes
- **TRUS Probe**
 - Rotary stage
 - KDC101 Controller
 - MATLAB & LabVIEW ROS interface
- **Communication**
 - Two laptops
 - With ROS Master
 - Three nodes
- **Virtual Fixture**
 - Stay Around a Point
 - Maintain a Direction
 - Keep a constant reaction force



FURTHER WORKS

- Use another UR5 robot arm for Trus Probe to obtain translational motion and better calibration accuracy.
- Hand-Guide mode. (of the Abdominal Probe)
- Trus Probe Virtual Fixture