Computer Aided Medical Procedures

Robotic Ultrasound Needle Placement and Tracking: Robot-to-Robot Calibration

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Background

Motivation

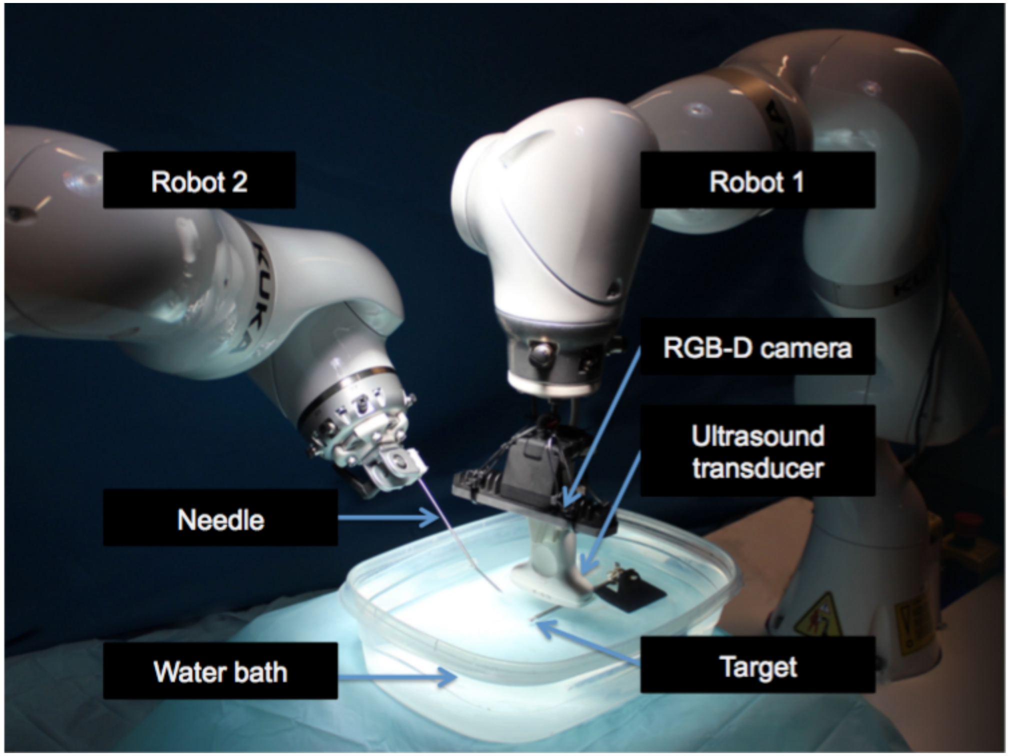
There are many medical procedures which depend on precise needle placement, including biopsy, targeted drug administration, brachytherapy, and ablation. Oftentimes, ultrasound imaging is used to guide a needle towards a target region identified through preoperative images. However, this methodology is often hampered by the need for skilled ultrasound technicians, the limited field of view, and the difficulty of tracking the needle trajectory and target.

Goal

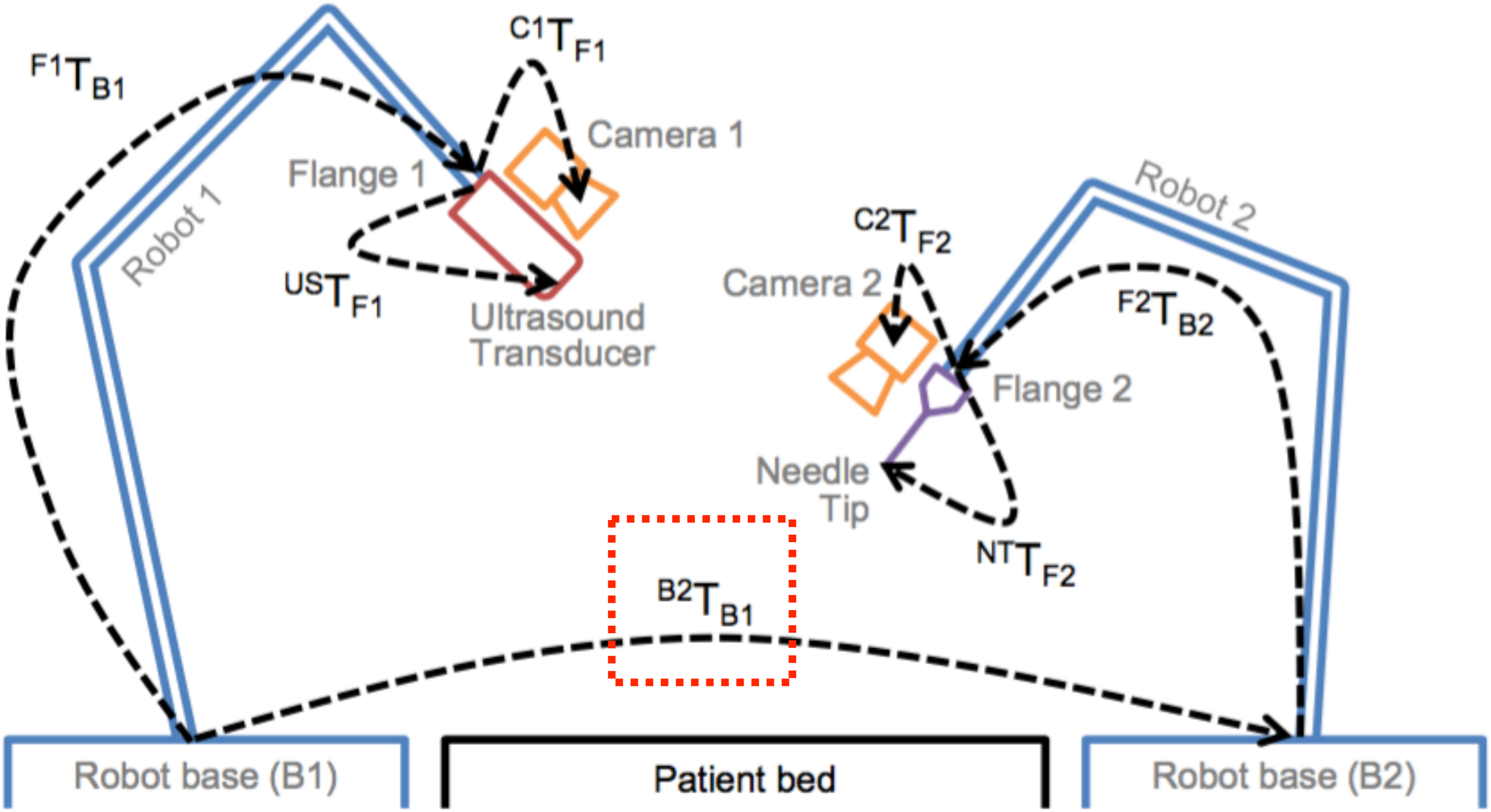
Develop a method for safe, quick, and precise needle placement for several medical procedures.

Proposed Solution

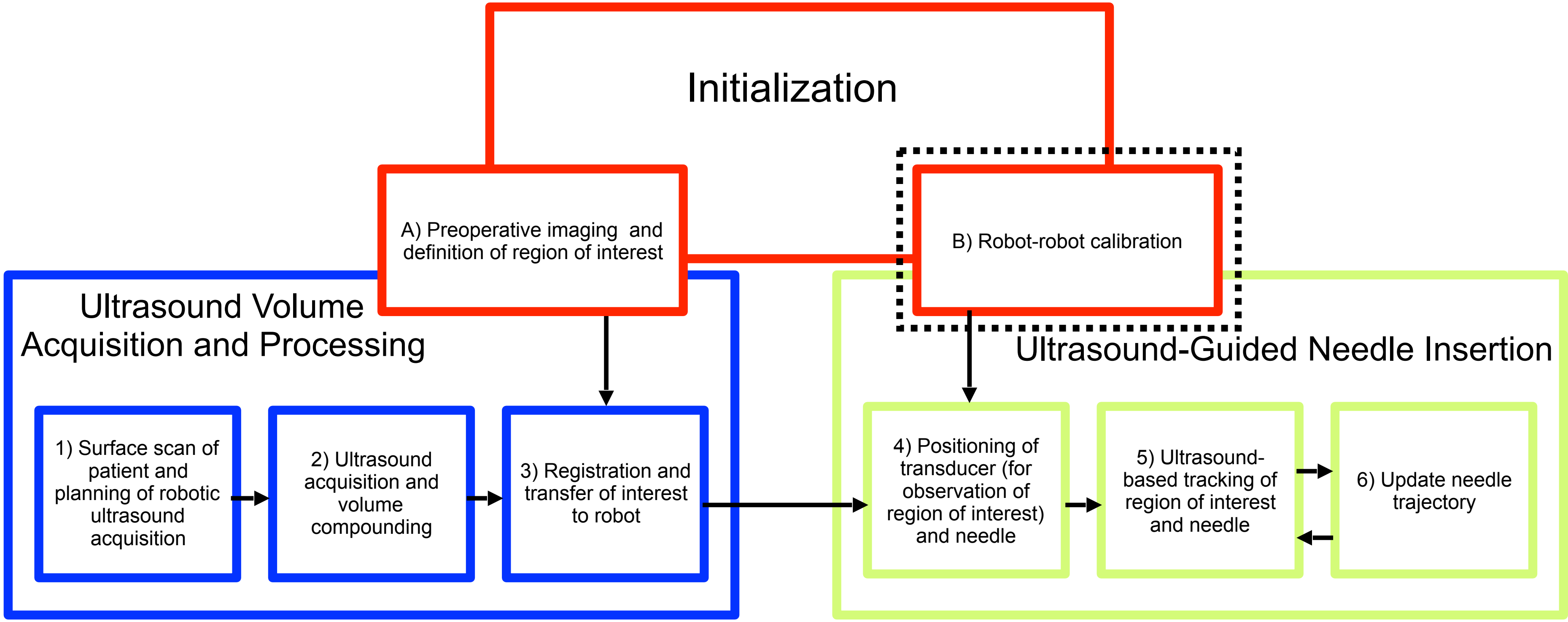
A novel dual-robot framework for robotic needle insertions which integrates impedance-controlled ultrasound image acquisition, preoperative and intraoperative image registration, visual servoing, target localization, and needle tracking.



Previous Work



Previous Work

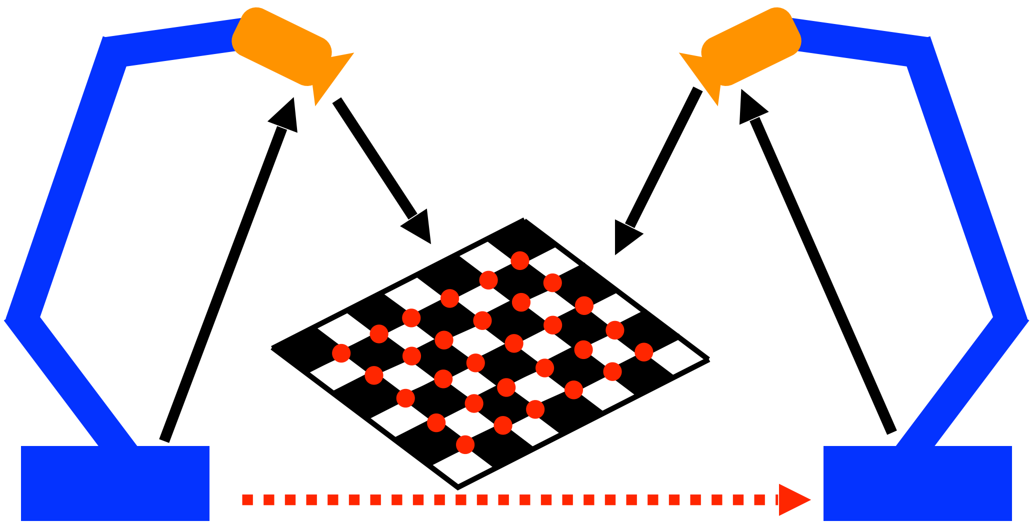


Mission Statement

Develop and validate a variety of robot-to-robot calibration algorithmic plugins for use with dual-robotic surgeries and experiments.

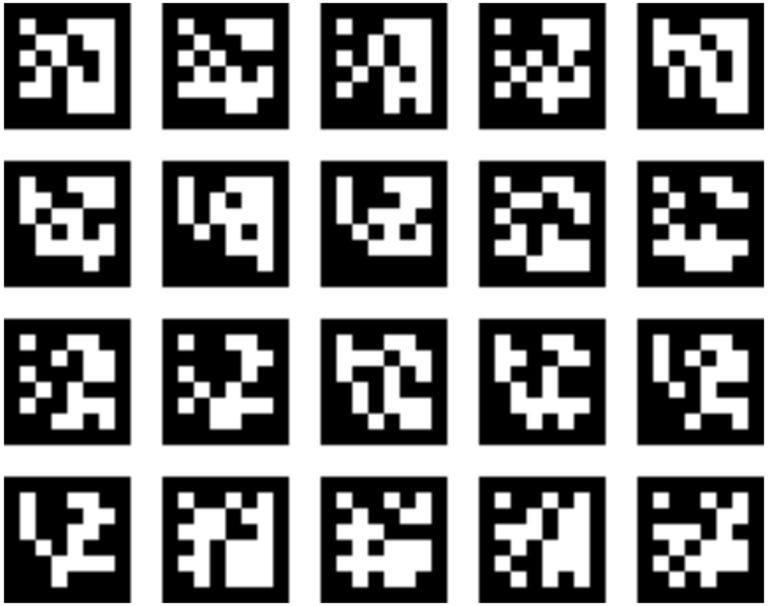
Algorithm #1: Checkerboard

- Using a precisely machined checkerboard whose dimensions are known, it is possible to determine camera intrinsics (focal length, axis skew, principal point offset) for the RGB-D cameras.
- Using the camera intrinsics, it is possible to create a local 3D scene reconstruction using a set of 2D image snapshots at arbitrary orientations.
- A byproduct of this reconstruction is the 3D transformation from camera to checkerboard.
- Using these transformations in conjunction with the known camera-to-base transformation, we can compute the base-to-base transformation.



Algorithm #2: ARToolKit Calibration

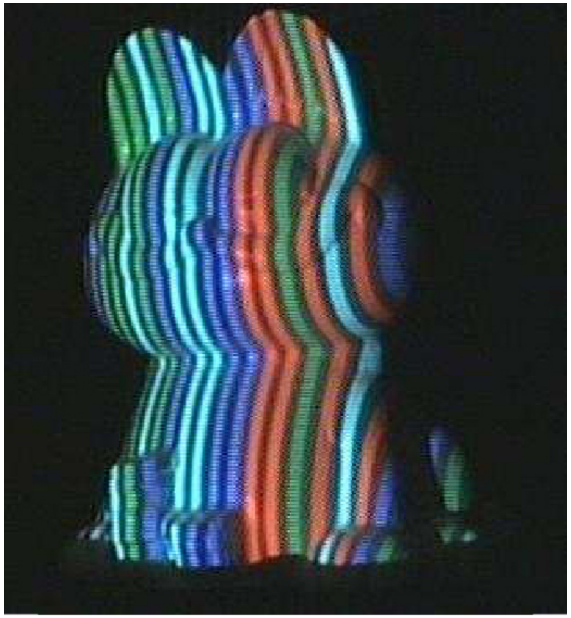
- ARToolKit is a computer vision framework that is often used for augmented reality applications.
- It provides a host of visually distinctive markers as well as recognition algorithms for use in identifying spatial relationships.
- We plan on testing if ARToolKit is a viable system for robot calibration.
- We wish to optimize the amount, position and variety of markers to minimize complication and error.

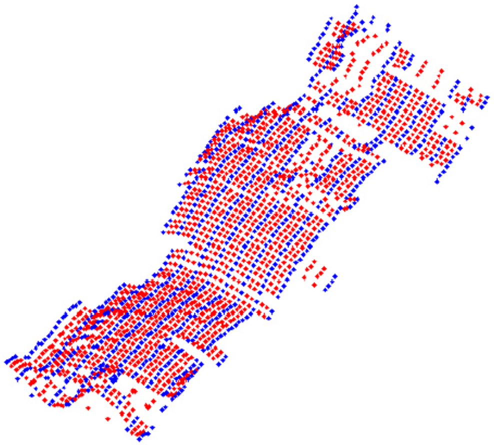


Algorithm #3: RGB-D Depth and Feature Information

- The Intel RGB-D cameras provide traditional RGB images along with approximated depth information using structured light deformation.
- Using Speeded Up Robust Features (SURF), we can generate two-dimensional point sets for each frame. From frame to frame, features are tracked between these sets using an exhaustive nearest neighbor search.
- After outlier rejection, 3D coordinates for the set of valid features can be estimated using two-dimensional coordinates in conjunction with the interpolated depth information.
- Once we have 3D coordinates for each feature and have created a correspondence of features from each camera's viewpoint, it is easy to compute the base-to-base transformation.

Algorithm #4: RGB-D Depth Only





- As a maximum deliverable, we are going to experiment with a non-feature based calibration that relies on solely the depth information of the RGB-D cameras.
- This is applicable in cases where there is no distinct contrast of colors or brightnesses to generate features from. An example of this would be in the OR when a tarp is placed over the patient.
- This method would use a form of ICP to align the uniform point clouds generated from the depth information. However, because the robots are viewing surfaces from very different angles, it requires a more robust ICP algorithm.

Deliverables

Minimum Deliverables

- Hand-eye calibration algorithm/plugin for camera frame transform
- Plugin for robot-robot calibration using checkerboard registration
- Interface and validation experiments for plugins

Expected Deliverables

- Plugin for ARToolKit calibration
- Plugin for RGB-D depth and feature calibration
- Interface and validation experiments for both plugins

Maximum Deliverables

- Plugin for RGB-D depth only calibration
- Interface and validation experiments for plugin
- Needle tracking experiments in real tissue

Dependencies

Hardware

- KUKA iiwa dual robotic system ✓
- 3D-printed Intel camera mounts ✓
- Access to Mock-OR and Robotorium ✓
- Calibration checkerboard ✓
- ARToolKit markers (printable)
- Other calibration objects (mentor/3D print in Wyman)

Software

- ROS, ImFusion, PCL, ARToolKit ✓
- KUKA ROS Module ✓
- Intel RGB-D Camera SDK ✓
- Bitbucket for version management ✓

Other (only under max deliverable)

- Risto's needle tracking algorithm ✓
- Tissue samples for ultrasound testing (mentor/available from butcher)

Management

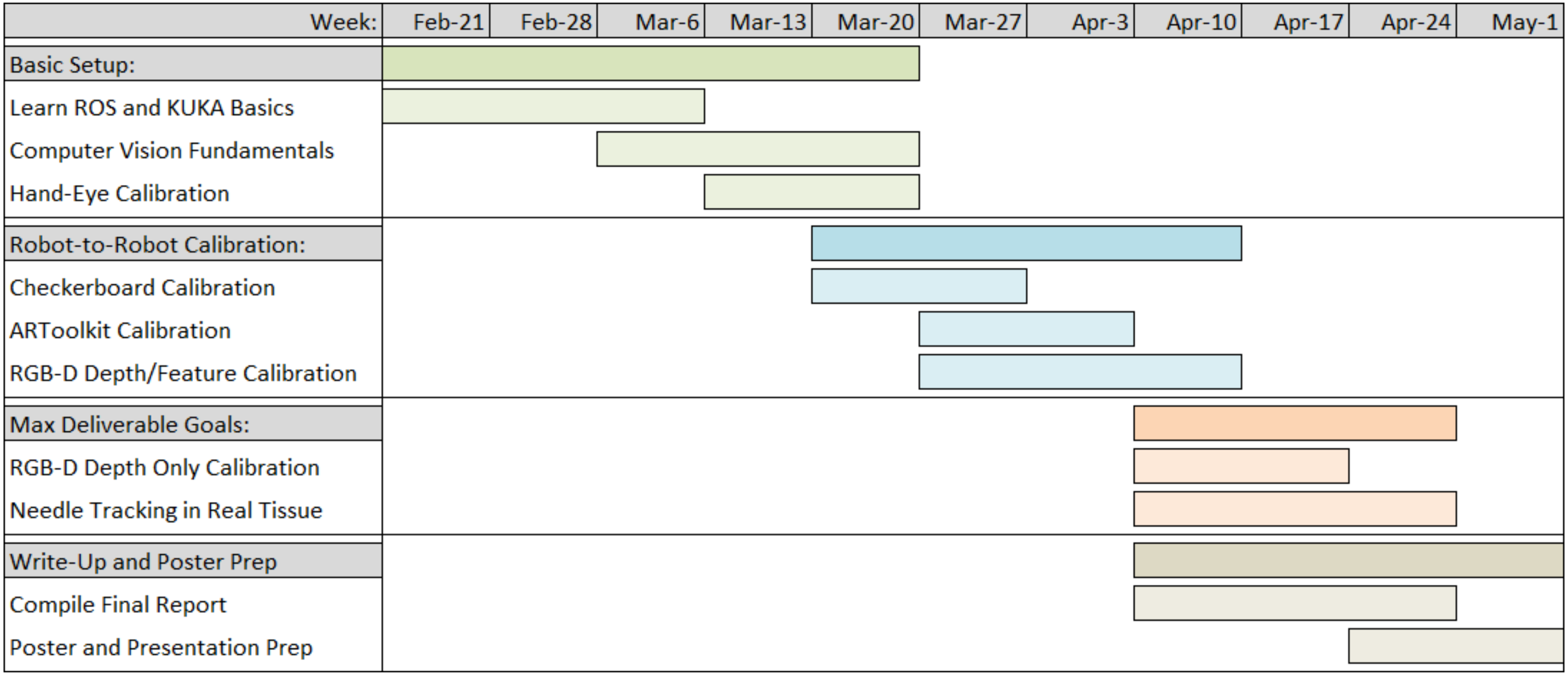
Meetings

- Weekly online meetings with mentors:
  - Risto: Tuesdays @ 9AM
  - Oliver and Salvatore: Schedule as needed
  - Ben and Javad: Schedule as needed
- CAMP lab meetings – Wednesdays @ 9AM
- Group meetings – Wednesdays and Saturdays @ 3PM

Team Members

- Christopher Hunt
  - Background: BME Instrumentation focus, Robotics minor
  - Responsibilities: RGB-D feature calibration, Depth-only calibration
- Matthew Walmer
  - Background: BME Comp Bio focus, CS and Mathematics minors
  - Responsibilities: ARToolKit, Needle tracking in real tissue
- Shared Responsibilities:
  - ROS, Hand-eye Calibration, Checkerboard Calibration

Time Table



Checkpoints

- March 26th: Have a strong background in ROS and the computer vision skills necessary to implement these algorithms. This will be verified by a functioning implementation of a hand-eye calibration algorithm.
- April 16h: Have developed and tested plugins (with completed interfaces) for the 3 robot-robot calibration methods
- April 30th: Have explored depth only RGB-D calibration method and if time allows tested needle tracking in real tissue samples.

Readings

1. R. Kojcev, B. Fuerst, O. Zettinig, J.Fotouhi, C. Lee, R.Taylor, E. Sinibaldi, N. Navab, **"Dual-Robot Ultrasound-Guided Needle Placement: Closing the Planning-Imaging-Action Loop,"** Unpublished Manuscript.

2. O. Zettinig, B. Fuerst, R. Kojcev, M. Esposito, M. Salehi, W. Wein, J. Rackerseder, B. Frisch, N. Navab, **"Toward Real-time 3D Ultrasound Registration-based Visual Servoing for Interventional Navigation,"** IEEE International Conference on Robotics and Automation (ICRA), Stockholm, May 2015.

3. B. Fuerst, J. Fotouhi, and N. Navab. **"Vision-Based Intraoperative Cone-Beam CT Stitching for Non-overlapping Volumes."** *Lecture Notes in Computer Science Medical Image Computing and Computer-Assisted Intervention -- MICCAI 2015* (2015): 387-95. Web.

4. K. Daniilidis. **"Hand-Eye Calibration Using Dual Quaternions."** *The International Journal of Robotics Research* 18.3 (1999): 286-98. Web.

5. D. Tan, F. Tombari, S. Ilic, N. Navab, **"A Versatile Learning-based 3D Temporal Tracker: Scalable, Robust, Online,"** The IEEE International Conference on Computer Vision (ICCV), 2015, pp. 693-701.

6. G. Caron, E. Mouaddib, E. Marchand. **"Single Viewpoint Stereoscopic Sensor Calibration."** *2010 5th International Symposium On I/V Communications and Mobile Network* (2010). Web.

7. R. Hartley, and A. Zisserman. **"Projective Geometry and Transformations of 2D."** *Multiple View Geometry in Computer Vision*. 2nd ed. Cambridge, UK: Cambridge UP, 2003. 25-62. Print.