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CIS II Written Plan
23 February 2016

Project 17: Robotic Ultrasound Needle Placement and Tracking: Robot-Robot Calibration
Mentors: Bernhard Feurst, Risto Kojcev, Oliver Zettinig, Salvatore Virga, Dr. Nassir Navab

I. Introduction and Background

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. As such, there is a genuine need for a safe, quick, and precise needle placement method. In recent months, the Computer Aided Medical Procedures (CAMP) laboratory has designed 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.

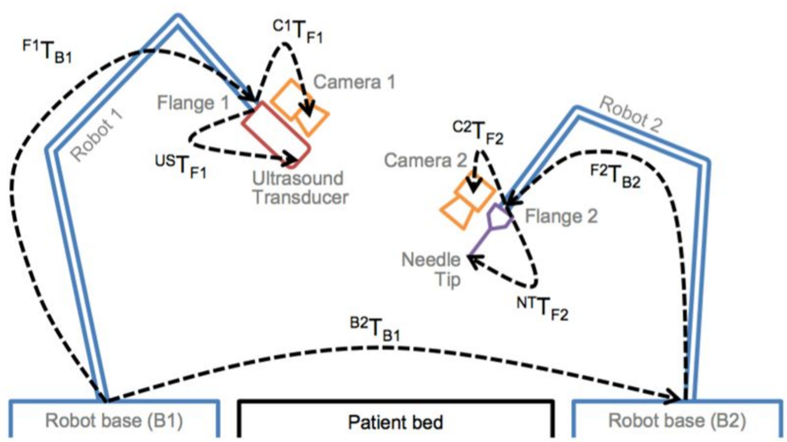


Diagram from *Dual-Robot Ultrasound-Guided Needle Placement* [8]

An important step in preparing this dual robotic system is identifying the robot base to robot base frame transformation. While a method to do this has already been implemented, CAMP lab has asked us to develop and test new methods that may provide greater accuracy and more flexibility in the operating room. Furthermore, this dual-robotic platform is used by the CAMP lab for a variety of research purposes, and a general purpose calibration program would be very useful. Our goal is the following: to develop a variety of robot-to-robot calibration algorithmic plugins for use with dual-robotic surgeries and experiments. These plugins will be validated for precision and then packaged with the software suite (ImFusion) already in use by the CAMP lab.

II. Technical Summary

Three separate algorithms will be developed and explored throughout the course of this project: checkerboard calibration, ARToolKit markers, and RGB-D feature and camera depth information. In addition, as a max deliverable, we plan to explore method of calibration that relies solely on the depth information provided from the RGB-D camera.

A. *Checkerboard*

This is the current calibration method implemented by the CAMP lab. By utilizing a precisely machined checkerboard (each square being 9 cm^2), we can derive the camera intrinsics. By using several snapshots of stereoscopic images from each RGB-D camera at specified orientations, the local three-dimensional environment can be reconstructed. A byproduct of this reconstruction is the 3D transformation from camera to checkerboard. We can utilize both of these transformations, along with the known camera-to-robot transformation to generate the unknown base-to-base transformation.

B. *ARToolKit Markers*

ARToolKit is a computer vision framework which provides a host of visually distinctive markers as well as recognition software that can determine their orientation. Using these markers and software, it is possible to construct a calibration problem similar to that constructed in the checkerboard case. We wish to explore the precision and efficacy of this solution under optimized cases. Optimization considerations include the number of markers needed and their orientations relative to one another as well as each camera.

C. *RGB-D Camera Feature and Depth Calibration*

The Intel RGB-D cameras used in this system provide traditional RGB images along with approximate per-pixel depth information using structured light deformation. We wish to explore the possibility of using this raw information to characterize the orientation of an arbitrary three-dimensional fiducial object. We plan to first characterize this object frame-to-frame using a feature extraction methodology (e.g. SURF, SIFT) and build a frame-to-frame correspondence. With this correspondence, we may generate a 3D point cloud from each frame and easily compute the base-to-base transformation.

D. *RGB-D Depth Only Calibration*

As a maximum deliverable for this project, a calibration method that relies solely on the depth information provided by the Intel RealSense camera will be explored. This methodology is helpful in situations where there is no contrast of colors or brightness to generate features from (e.g. when a tarp is placed over a patient in the operating room). This method would use a more robust form of ICP to align the grid-like (and very distinct) point clouds.

III. Deliverables

Minimum	Hand-eye Calibration Algorithm/Plugin for Camera Frame Transform
	Plugin for Robot-Robot Calibration Using Checkerboard
	Interface and Validation Experiments for Plugin
Expected	Plugin for ARToolKit Calibration
	Plugin for RGB-D Feature and Depth Calibration
	Interface and Validation Experiments for Plugins
Maximum	Plugin for RGB-D Depth Only Calibration
	Interface and Validation Experiments for Plugin
	Needle Tracking Experiments in Real Tissue

IV. Dependencies

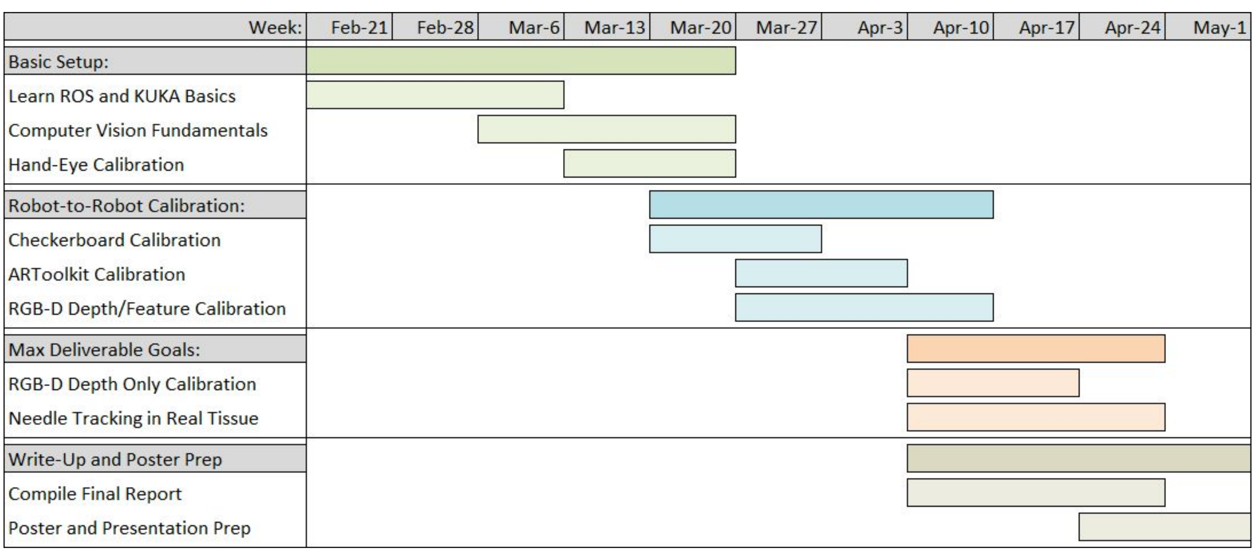
Category	Dependency	Status	Alternative
Hardware	KUKA iiwa Dual Robotic System	✓	---
	3D-Printed Intel Camera Mounts	✓	---
	Access to Mock OR and Robotorium	✓	---
	Calibration Checkerboard	✓	---
	AR Markers	Printable (Paper)	---
	Other Calibration Objects	Mentor Supplied	3D Print in Wyman
Software	ROS, PCL, ARToolKit	✓	---
	KUKA ROS Module	✓	---
	Intel RGB-D Camera SDK	✓	---
	Risto’s Needle Tracking Algorithm	✓	---
	Bitbucket for Version Management	✓	---
Other	Tissue Sample for Ultrasound Testing	Mentor Supplied	Buy from Butcher

V. Management

Meeting Schedule	
Weekly CAMP Group Meetings	Wednesday 9 AM
Weekly Meetings with Risto Kojcev	Tuesday 9 AM
Meetings with Oliver Zettinig and Salvatore Virga	Schedule As Needed
Meetings with Bernhard Feurst and Javad Fotouhi	Schedule As Needed
Individual Group Meeting	Wednesday 3 PM
	Saturday 3 PM

Group Member Responsibilities	
Christopher Hunt	Matthew Walmer
RGB-D Feature and Depth Calibration Plugin	ARToolKit Calibration Plugin
RGB-D Depth Only Calibration Plugin	Needle Tracking Experiments in Real Tissue
ROS Familiarization	
Hand-Eye Calibration Algorithm	
Checkerboard Calibration Plugin	

VI. Time Table



Important Dates:

Date	Milestone Description
March 12th	Understand the fundamentals behind the KUKA ROS module. This will be tested by implementing a small script which will move a KUKA in the Mock OR to a set of discrete positions.
March 22nd	Understand the fundamentals of computer vision as they apply to camera calibration (e.g. intrinsic and extrinsic parameter optimization). By this time, an interface for the hand-eye calibration code should be completed and ready for implementation.
March 26th	Implement the hand-eye calibration algorithm in C++. A mathematical analysis of the error propagation will be completed by this date and a calibration experiment will be done to validate the accuracy of the algorithm.
March 29th	An interface for the three expected calibration plugins shall be completed. Additionally, a global validation experiment will be designed such that accuracy across the calibration plugins can be standardized.
April 2nd	Implement the checkerboard calibration in C++. A mathematical analysis of the error propagation will be completed by this date and the calibration experiment will be done to validate the accuracy of the algorithm.
April 6th	A decision will be made on the feasibility of completing the maximum deliverables based on the current progress of the expected deliverables.
April 9th	Implement the ARToolKit calibration in C++. A mathematical analysis of the error propagation will be completed by this date and the calibration experiment will be done to validate the accuracy of the algorithm.
April 12th	Begin preliminary research into the maximum deliverables. This includes writing interfaces and designing experimental protocols.
April 16th	Implement the RGB-D features and depth calibration in C++. A mathematical analysis of the error propagation will be completed by this date and the calibration experiment will be done to validate the accuracy of the algorithm.
April 23rd	Implement the RGB-D depth calibration in C++. A mathematical analysis of the error propagation will be completed by this date and the calibration experiment will be done to validate the accuracy of the algorithm.
April 30th	Perform needle tracking experiment in real tissue and have documented the accuracy of the experiment using the completed plugins.

VII. Supplemental Readings

1. 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.

2. 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.

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

4. H. Bay, T. Tuytelaars, and L. Van Gool. **"SURF: Speeded Up Robust Features."** *Computer Vision – ECCV 2006 Lecture Notes in Computer Science* (2006): 404-17. Web.

5. 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.

6. 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.

7. 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.

8. R. Tsai, and R. Lenz. **"A New Technique for Fully Autonomous and Efficient 3D Robotics Hand/eye Calibration."** *IEEE Trans. Robot. Automat. IEEE Transactions on Robotics and Automation* 5.3 (1989): 345-58. Web.

9. K. Strobl, and G. Hirzinger. **"Optimal Hand-Eye Calibration."** *2006 IEEE/RSJ International Conference on Intelligent Robots and Systems* (2006). Web.