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

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under mentorship of Bernhard Fuerst, Risto Kojcev, Javad Fotouhi, and Nassir Navab

Introduction

- In dual robot surgery, coordination is key, especially if one robot is being used to acquire ultrasound images.
- The Computer Aided Medical Procedures research group at Johns Hopkins University has developed a multi-robot surgical platform with two KUKA iiwa robotic arms.

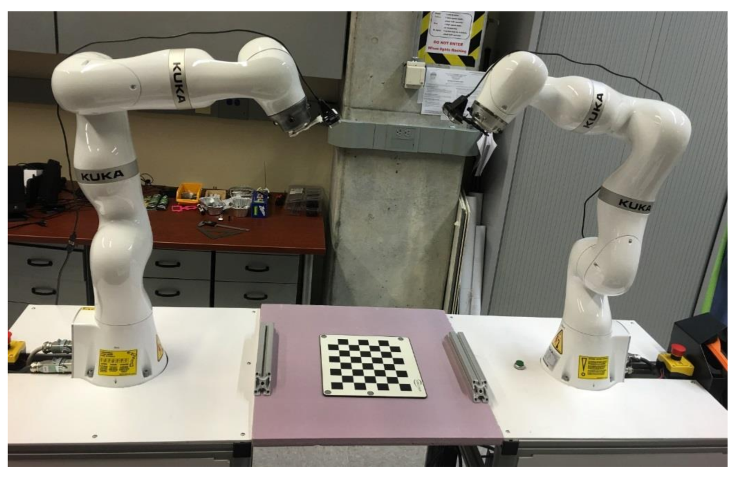

Fig 1: CAMP lab's dual-robotic platform.

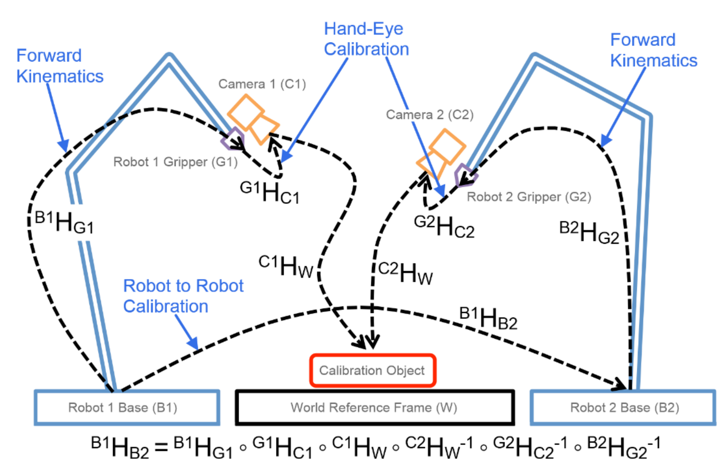

Fig 2: Reference frames and calibrations.

The Problem

- There is a need for an efficient method to precisely determine the transformation between two or more robots' base frames.
- The objective of this research is to explore a variety of robot-to-robot calibration methods and validate their efficacy for use in dual-robotic surgeries and experiments.

The Solution

- **Checkerboard Calibration:** Checkerboard poses can be computed with well known computer vision methods. We use a checkerboard to establish a world frame, and use this frame to connect the robot base frames.

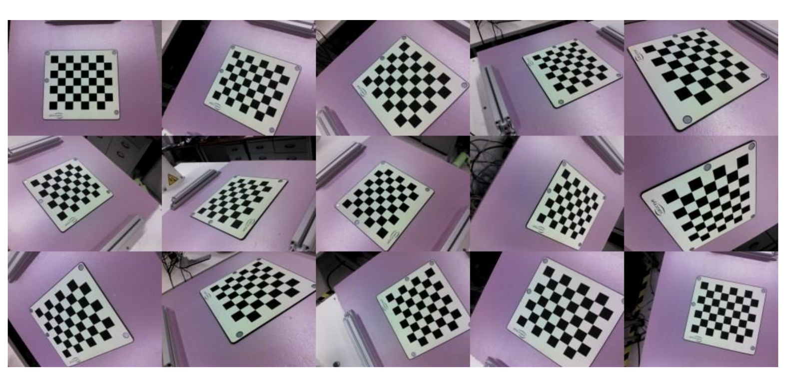

Fig 3: Checkerboard calibration images.

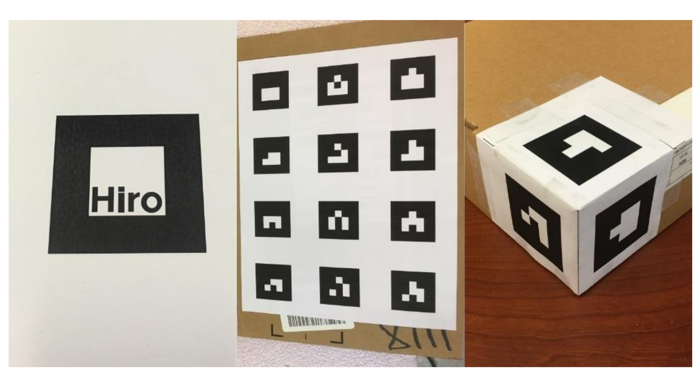

Fig 4: ARToolKit marker configurations.

- **ARToolKit Calibration:** This approach uses a visual marker instead of a checkerboard. ARToolKit allows for different marker configurations which may give a more accurate calibration.

- **RGB-D Features and Depth:** SURF features are consistent from very different vantage points. By extrapolating the features into 3D space using the RealSense depth camera, we can compute the robot-to-robot transformation**.**

Fig 5: Two images of the same calibration scene taken by the two robots, with SURF features marked.

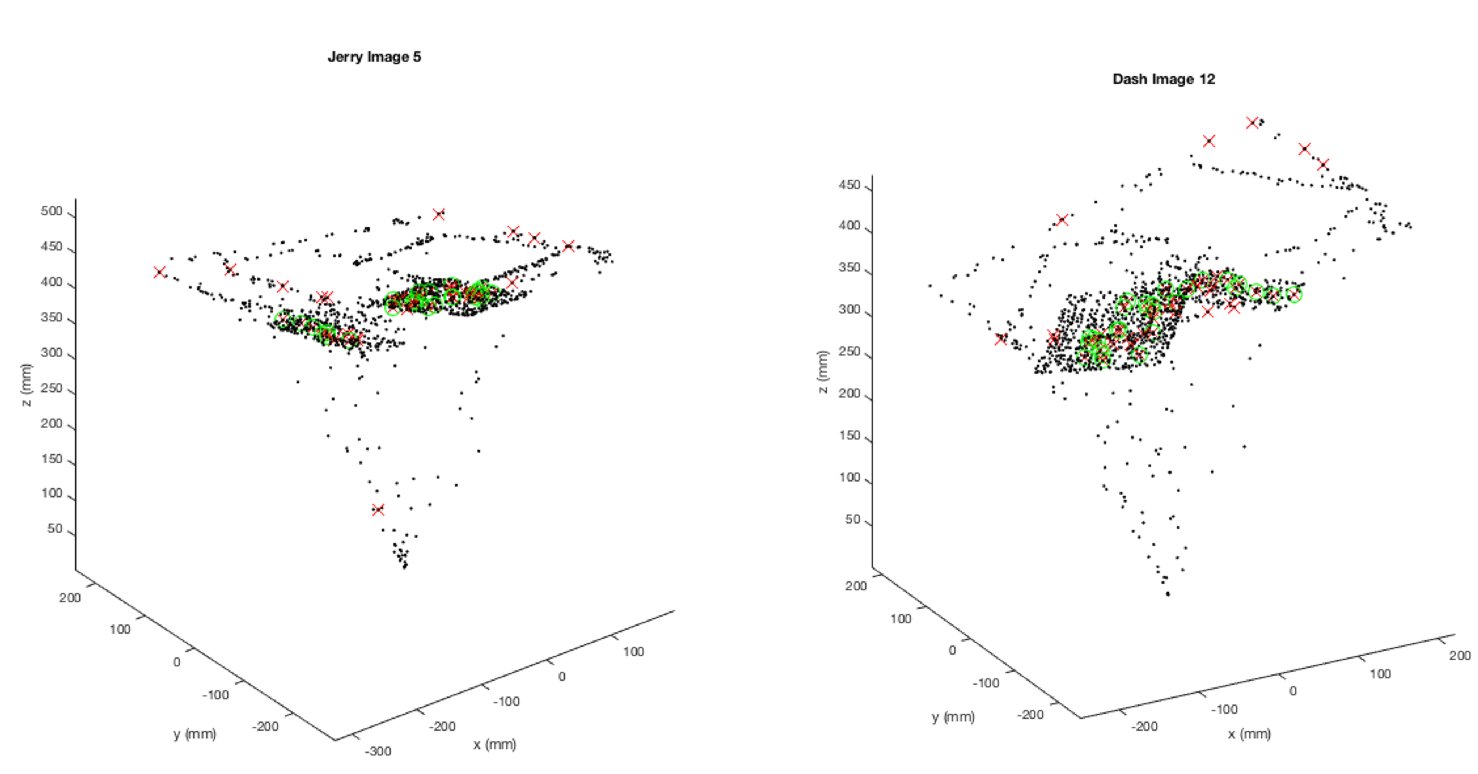

Fig 6: The extrapolated 3D feature point clouds of the calibration scene.

Results

Calibration Method [#images/bot]	Handeye Calibration [#images/bot]	Sampled Point Mean Linear Error (mm)	Transformation Linear Error (mm)	Transformation Angular Error (deg)
Checkerboard A [30]	Checkerboard A [30]	2.7285	2.5994	2.5065
Checkerboard B [30]	Checkerboard B [30]	2.9312	5.3538	2.3211
ATK single marker [10]	Checkerboard B [30]	3.8115	6.2353	2.3956
ATK single marker [10]	ATK single marker [10]	4.9717	8.9781	1.8524
ATK 3x4 multi [10]	Checkerboard B [30]	4.4614	7.7350	2.5708
ATK 3x4 multi [10]	ATK 3x4 multi [10]	3.6976	3.5423	2.7076
ATK non-planar [10]	Checkerboard B [30]	8.1168	24.9807	1.7201
ATK non-planar [10]	ATK non-planar [10]	6.0413	8.0032	2.0756
RGB-D Features [16]	Checkerboard C [40]	34.7979	51.7487	8.4658

- The most accurate calibration was achieved using the checkerboard calibration.
- Generally, the mean linear error for points sampled in the workspace was less than the transformation linear error.
- The single ARToolKit marker was less accurate because it used only 4 feature points.
- The 4x3 multimarker was comparable to the checkerboard.
- The orthogonal multimarker gave the least angular error, but the restricted viewing angle led to large translational error.
- The RGB-D features and depth calibration method is not nearly accurate enough for medical purposes.
- Checkerboard and ARToolKit multimarker calibration best meet the need for quick and precise robot-to-robot calibration.
- External tracking hardware would be necessary to dynamically update the transformation during surgery.

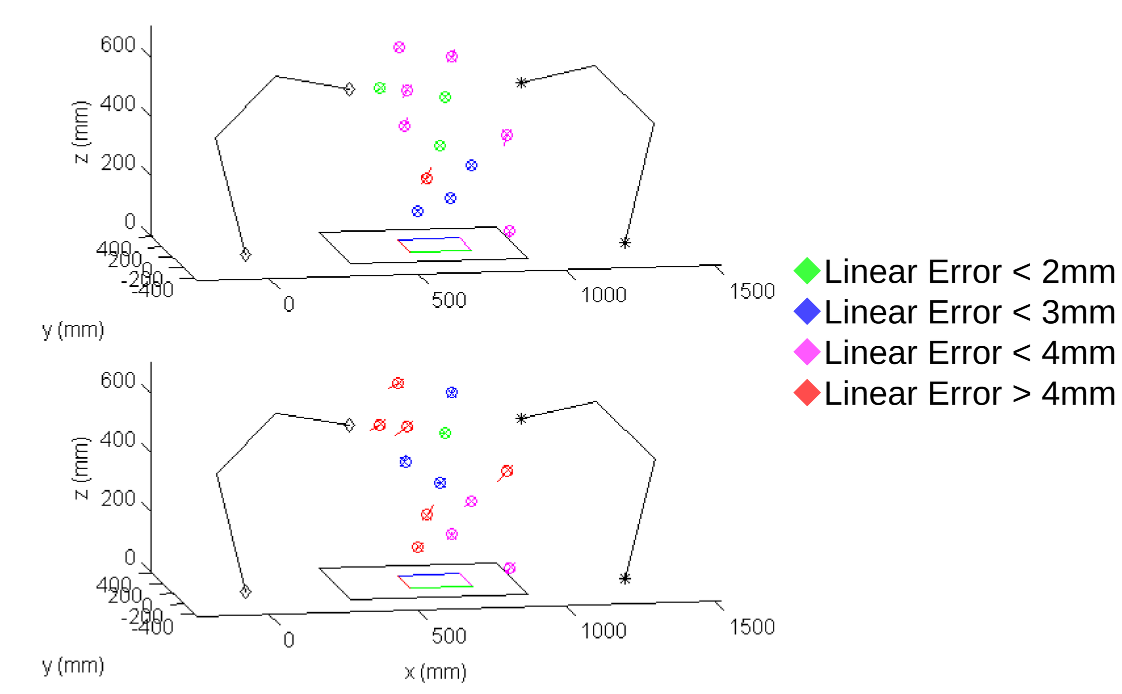

Fig 7: Error graphs for Checkerboard Calibration A (top) and ARToolKit 4x3 multimarker (bottom).

Future Work

- A depth only calibration method using the Intel RealSense cameras. Another project, Augmented Reality for Orthopedic and Trauma Surgeries, has done relevant work with aligning partially overlapping point clouds using Fast Point Feature Histograms.
- Explore ARToolKit multimarker configurations that combine the strengths of the markers tested. A non-planar multimarker with several markers on each side could give an excellent calibration.

Lessons Learned

- Gained experience with camera, hand-eye, and pivot calibrations.
- Learned new things about computer vision like SURF features, ARToolKit, camera models, and projective geometry.
- Always explicitly state the spatial relationship between frames.
- For real robotic research, troubleshooting hardware is inevitable.

Credits

- Camera and Handeye Calibration – Christopher and Matthew
- Checkerboard Calibration – Christopher and Matthew
- ARToolKit Calibration – Matthew
- RGB-D Features and Depth – Christopher
- Ground Truth and Error Analysis – Matthew

Acknowledgments

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