Group 07: Co-Robotic Ultrasound Imaging of Breast Assisting Mammography - Project Proposal

Team Members: Julian Brown, Yuxin(Ethan) Chen, Kevin Wang

Mentors: Dr. Emad Boctor, Dr. Web Stayman, Dr. Russell Taylor, Yixuan Wu

JOHNS HOPKINS
WHITING SCHOOL of ENGINEERING

LABORATORY FOR Computational Sensing + Robotics

MUSiiC Research Laboratory

Background and Significance

This project is focused on building a robotic system to augment current mammography screenings with autonomously acquired ultrasound images. Mammography is a screening for breast cancer using X-Ray imaging. While it does greatly reduce breast cancer mortality, it is not without its problems[1]. Over 40 million screenings are performed in the US every year and around 6 million patients (15%) are called back for further testing[2]. This results in time and money lost on the part of the patients and doctors, not to mention the stress involved with the possibility of cancer.

Mammography and Ultrasound Imaging in combination have been shown to increase the accuracy of breast cancer screenings. Mammography is a highly specific test, but lacks sensitivity, while Ultrasound is highly sensitive, but lacks specificity. When used together they result in a test that is both highly specific and highly sensitive. A 2006 NIH study showed an increase in diagnostic accuracy from 0.78 for a traditional mammogram to 0.91 for a mammogram plus ultrasound examination[3].

While adding imaging of a different type to 40 million examinations a year could sound logistically daunting, a robotic system for augmenting mammography with ultrasound imaging would minimize the change to the current screening procedure. No dedicated ultrasound technicians would be needed, and the testing would be easily repeatable and accurate. It would save an immense amount of time and money for millions of patients and doctors every year.

Deliverables

The deliverables for this project are split into three categories: minimum, expected, and maximum, and will be completed in that order. The deliverables required to meet each stage are outlined below.

Minimum:
- Calibration of the robotic arm.
- Setup of the imaging validation and tests.
- Hand-over hand control of the robot (already developed but needs to be integrated)
- Simple motion planning to land the ultrasound probe on a specific location on the compression plate. Offline (open loop) control, directing ultrasound probe to lesion from target.

Expected:
- A real-time interface to acquire stereo camera and ultrasound images.
- With the developed real-time interface, demonstrate automatic ultrasound acquisition of a region of interest (whole lesion) with a known location with respect to the tracking tag on the compression plate.
- Documentation

Maximum:
- Demonstrate dynamic and real-time adaptation as the tracking tags move.
- Force control of the robot arm to ensure safety.
- Integration and registration with a second modality (Mammography, CT, or preoperative 3D ultrasound).

Technical Approach

Current Status:

End-Effector has been completed. Two Point Grey Chameleon Cameras, a 6-DOF Robotiq Force Sensor and Ultrasound Probe have been installed on the UR5 robot. Hand-Over-Hand control is completed from another project.

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[1] Mammography. Ganga Breast Care Centre. (n.d.). Retrieved February 27, 2022, from https://gangabreastcare.com/mammography.php

[2] *Breast cancer - statistics*. Cancer.Net. (2022, February 24). Retrieved February 27, 2022, from https://www.cancer.net/cancer-types/breast-cancer/statistics#:~:text=More%20women%20are%20diagnosed%20with,(in%20situ)%20breast%20cancer

[3] Wendie, A., Berg, M. D., & Jeffrey, D. (2008). Combined Screening with Ultrasound and mammography compared to mammography alone in women at elevated risk of breast cancer: results of the first-year screen in ACRIN 6666. JAMA, 299(18), 2151-2163..

Calibration:

There are four main parts for calibration, which are UR5 calibration, camera calibration, hand eye calibration and ultrasound probe calibration. A flowchart of the approach is detailed in Figure 1.

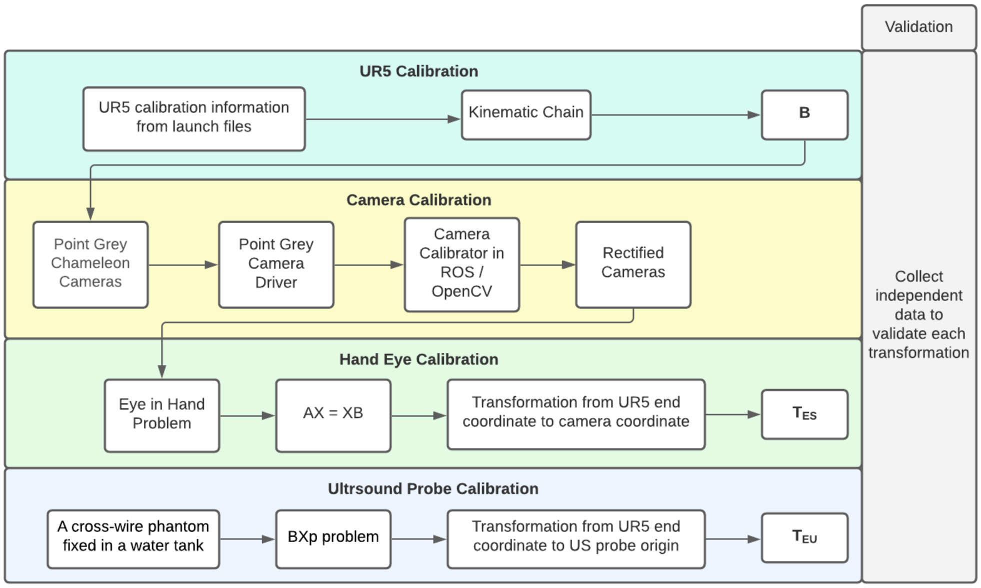

Figure 1: Flowchart Detailing Technical Approach Towards Calibration

For UR5 calibration, since each UR5 has been calibrated at the factory, the UR5 calibration information has been extracted from the UR5 manipulator. The kinematic chain is generated and used to calculate the forward kinematics and inverse kinematics.

For camera calibration, two point grey chameleon cameras have been calibrated to get rid of the distortion on the image edges. Point grey camera driver is installed and used to connect point grey camera to ROS. Then camera calibrator in ROS is applied to calibrate the cameras by using an 8*6 checkerboard with 25mm squares. Then the rectification matrix and camera matrix are exported and applied through the image_proc ROS package to generate the rectified camera images.

For hand eye calibration, it will be a hand-in-eye problem. AprilTag will be used as the marker. AprilTag ROS package will be used to get the transformation from camera coordinate to the marker coordinate. The UR5 robot will be moved to different positions and look at AprilTag. The transformation from UR5 base coordinate to UR5 end coordinate and the transformation from camera coordinate to AprilTag marker coordinates will be recorded at each position. Then the transformation from UR5 end coordinate to camera coordinate will be solved by establishing an AX=XB problem.

For ultrasound probe calibration, a cross-wire phantom fixed in a water tank will be used. The transformation from UR5 end coordinate to US probe coordinate to ultrasound probe coordinate will be calculated by solving a BXp problem.

After calibration, those transformations will be validated by collecting independent data and plug those transformations back to check their accuracy.

Robot Motion:

Regarding robot motion, there are three movements that the robot must perform. First, the robot is moved from any position, to its initial position via hand over hand control. Next, the robot must navigate to a specific lesion site. Finally, the robot must perform a “wobble” motion at the lesion site to acquire volumetric US data. The approach that will be taken to achieve these movements is outlined in Figure 2.

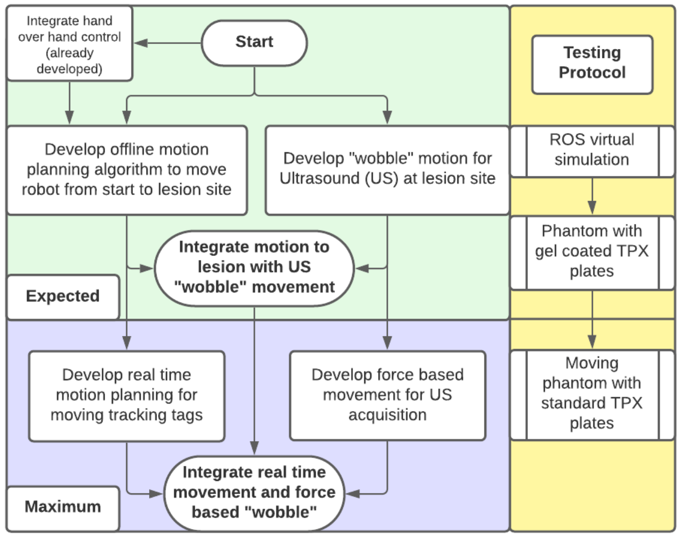

Figure 2: Flowchart Detailing Technical Approach Towards Robot Motion Planning

In the green box, is the plan to achieve the expected deliverables of motion. First, hand over and control will be integrated into the robot workflow. Next, an offline robot motion planning algorithm for motion to the lesion site and the "wobble" motion will be developed simultaneously as they have no dependency upon each other. When these two prongs are complete, they will be integrated into the expected motion deliverable. In the maximum deliverable outlined in the blue box, these motions will be extended to account for more realistic scenarios; motion planning will incorporate real time adjustments to account for patient movement, and the "wobble" motion will incorporate force sensing to account for realistic US acquisition. The yellow boxes detail the testing protocol that will be used. Expected deliverables will be validated using a ROS virtual simulation then using a physical simulation consisting of a phantom in between acoustic gel coated plates. The maximum deliverable will follow an identical testing protocol, with the addition of a moving phantom and standard TPX plates without the acoustic gel coating.

Integration and registration with a second modality (Mammography, CT, or preoperative 3D ultrasound):

To integrate and register with a second modality, the first step would be to find some reference features that can be detected in both ultrasound and second modality. Then step two would be to use some segmentation software to extract the feature points and build model from both ultrasound and second modality. Step three would be to use the iterative closest point (ICP) method to find the transformation from the ultrasound image to the image from the second modality.

Milestones

Table 1: Project Milestones and Dates

Milestone Name	Planned Date	Status
General Milestones		
Project Proposal Presentation	February 10	Complete
Project Proposal Document	March 1	Complete
Background Reading Presentation	March 10	In Progress
Checkpoint Presentation	April 12	Not Started

Demonstration Video	April 30	Not Started
Calibration		
Camera Calibration	Feb 27	Completed
UR5 Calibration	Feb 27	Completed
Hand Eye Calibration	March 4	In Progress
Ultrasound Probe Calibration	April 20	Not Started
Robot Motion Planning		
Hand over Hand Control Integration	March 11	In Progress
Offline Motion Planning to Lesion Site	April 15	Not Started
"Wobble Motion" at Lesion Site	April 15	Not Started
Maximum Deliverables		
Adaptive Motion Planning	April 29	Not Started
Force Sensitive "Wobble"	April 29	Not Started
US - CT Registration	April 29	Not Started

Dependencies
The dependencies of this project as well as their status and backup plan should they be unable to be acquired are outlined in Table 2.

Table 2: Co-Robotic Ultrasound Dependencies

Dependency	**Domain**	**Status**	**Backup**
Linux System	Motion Planning	Acquired	Wyman computer lab
ROS	Motion Planning & Computer Vision	Acquired	Wyman computer lab
OpenCV	Computer Vision	Acquired	ROS package
Hand over hand code integration	Software environment	Acquired	Rewrite the code
Mentor Availability	All	Acquired but subject to change	Communication and planning
UR5 Robot	Motion Planning	Acquired	ROS Simulation
Two Point Grey Chameleon Cameras	Motion Planning	Acquired	ROS Simulation
6 DoF Force Sensor	Force Sensing	Acquired	ROS Simulation
Ultrasound Probe	Ultrasound Imaging	Acquired	Path planning without US acquisition
TPX plates	Ultrasound Imaging	Acquired	Purchase and construct
Acoustic Gel	Ultrasound Imaging	Acquired	Purchase

Cross Wire Phantom	Ultrasound probe calibration	Required	Build by ourselves
Moving Cross Wire Phantom	Ultrasound Imaging - Maximum	Required	Build by ourselves
Segmentation Software	Integration with second modality - Maximum	Required	Build the software by ourselves with deep learning

Management Plan

The management plan for this project will follow the following points:

- Setting up weekly project meeting with mentors: Yixuan, Dr. Boctor, Dr. Taylor, Dr. Stayman
- Weekly team meeting for progress updates
- Code Management by Github
- Other documentation uploaded to google drive

Work between team members will be split as outlined by Table 3.

Table 3: Work Distribution

<table>
<tr><th>Yuxin(Ethan)</th><th>Julian</th><th>Kevin</th></tr>
<tr><td>Camera set-up & Camera Calibration</td><td colspan="2">UR5 Calibration</td></tr>
<tr><td colspan="2">Hand Eye Calibration</td><td>Imaging (US integration, potential other modalities)</td></tr>
<tr><td>Ultrasound Probe Calibration</td><td colspan="2">Hand-Over-Hand Integration</td></tr>
<tr><td colspan="3">Robot Motion Planning</td></tr>
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Reading List

- Wendie, A., Berg, M. D., & Jeffrey, D. (2008). Combined Screening with Ultrasound and mammography compared to mammography alone in women at elevated risk of breast cancer: results of the first-year screen in ACRIN 6666. JAMA, 299(18), 2151-2163.
- Buist, D. S., Porter, P. L., Lehman, C., Taplin, S. H., & White, E. (2004). Factors contributing to mammography failure in women aged 40–49 years. Journal of the National Cancer Institute, 96(19), 1432-1440.
- LaValle, S. M. (2006). Planning algorithms. Cambridge university press.
- Gilboy, K. M., Wu, Y., Wood, B. J., Boctor, E. M., & Taylor, R. H. (2020). Dual-Robotic Ultrasound System for In Vivo Prostate Tomography. In Medical Ultrasound, and Preterm, Perinatal and Paediatric Image Analysis (pp. 161-170). Springer, Cham.
- Aalamifar, F. (2016). Co-robotic ultrasound tomography: a new paradigm for quantitative ultrasound imaging (Doctoral dissertation, Johns Hopkins University).
- Zhang, H. K., Cheng, A., Kim, Y., Ma, Q., Chirikjian, G. S., & Boctor, E. M. (2018). Phantom with multiple active points for ultrasound calibration. Journal of Medical Imaging, 5(4), 045001.