Ultrasound-based Visual Servoing

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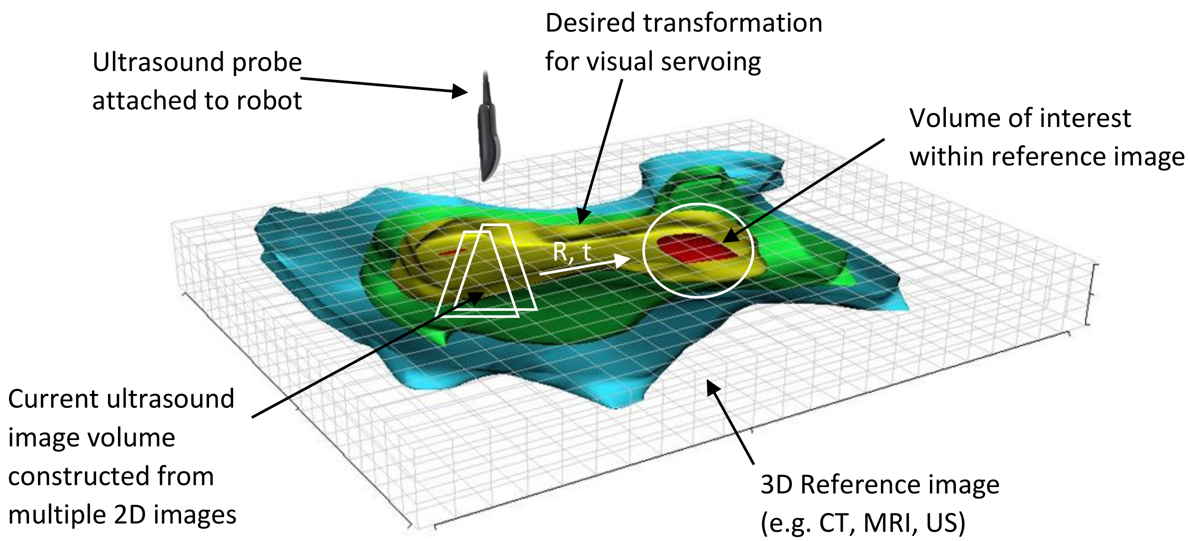
February 20, 2015

Summary

The goal of this project is to develop visual servoing for intraoperative robotic ultrasound. The robot would image the patient with an ultrasound probe at a predefined volume of interest. The predefined volume is selected from a reference image such as CT or MRI that was obtained before the procedure. This technique would allow the doctor to obtain accurate anatomy in real time, even when deformations and organ movement cause the reference image to differ from reality. An ImFusion plugin will be developed which obtains a 3D ultrasound volume from individual ultrasound probe images, then calculates the 3D transformation between the current ultrasound volume and the volume of interest to move a KUKA iiwa lightweight robot.



Background Overview

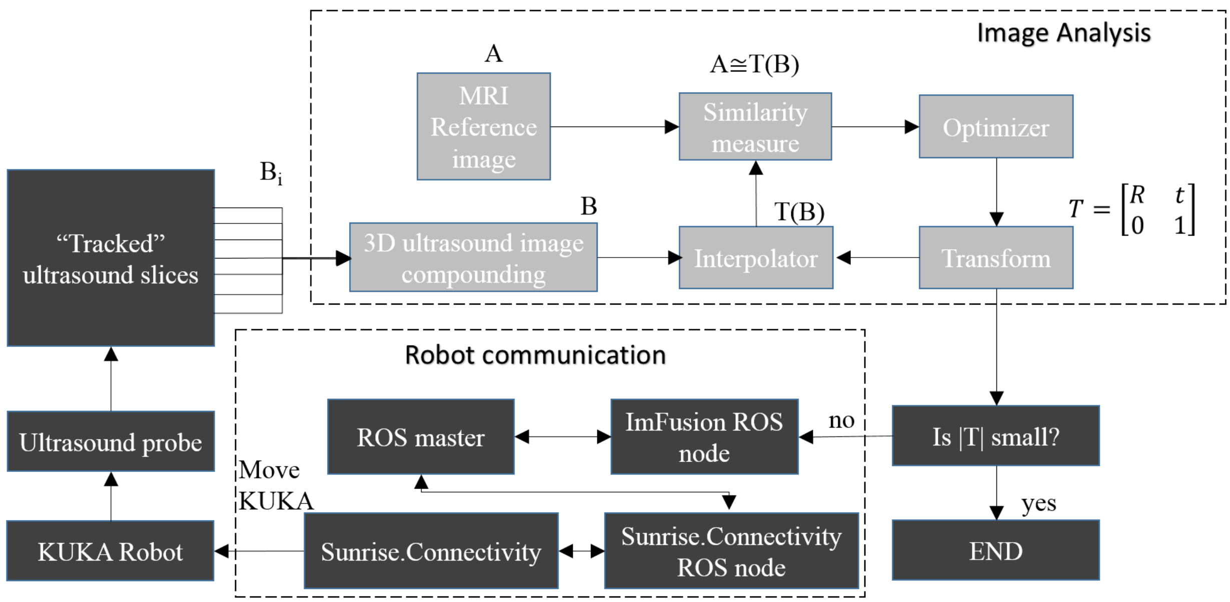
Among the different medical imaging modalities, ultrasound has several advantages: it is cheap, portable, provides images in real-time, and does not use ionizing radiation. In comparison, CT and MRI provide much higher contrast than ultrasound, which provides them considerable clinical utility for preoperative imaging. Unlike ultrasound, these provide static images that are difficult to update during surgery. As a result ultrasound is commonly used for intraoperative imaging to obtain real-time anatomical data. Doctors may also use preoperative ultrasound with intraoperative ultrasound for certain procedures. However performing a hand held 2D ultrasound scan is user-dependent because it requires unique skills and training to acquire high-quality images.

Robotic ultrasound is a thriving branch of computer-assisted medical interventional research. Due to the greater precision and dexterity of a robot for positioning of an ultrasound probe, robotic ultrasound can improve patient outcomes and shorten procedure times. By acquiring 2D slices of B-mode scans and tracking the probe location, it is possible to obtain a 3D ultrasound volume. Prior work has focused on the use of an ultrasound probe controlled by a human operator via a telemanipulation system, but this project focuses on the automatic guidance of the ultrasound probe by visual servoing. Visual servoing performs registration of the current input image and a volume of interest to obtain the transformation that will move the robot to the location of the volume of interest. The robot obtains a new image once it has moved and repeats the process until the current image corresponds to the volume of interest.

To combine the advantages of both intraoperative ultrasound and preoperative imaging, a hybrid solution is proposed which allows the doctor to select a particular volume in the reference image and have the robot acquire the ultrasound image at its corresponding location. The robot will perform visual servoing by using three-dimensional registration of ultrasound with a reference image to obtain the transformation between the current probe location and the desired probe location. This transformation will be used to update the position of the robot accordingly to acquire a new ultrasound image until the current probe location is sufficiently close to the desired probe location.

Technical Approach

System-level framework



The project will consist of two main software components: i.) an image analysis module which will calculate the transformation between the 3D ultrasound and reference image, and ii.) a robot communication module which will transfer information between ImFusion and KUKA regarding the current robot state.

Image Analysis

A workstation will be used to run ImFusion, which is a medical imaging software suite. It provides existing C++ modules for three-dimensional ultrasound-MRI and ultrasound-ultrasound registration, as well as functions that obtain the transformation between images. The software also provides a SDK that allows the addition of new plugins.

The ImFusion SDK will be used to create a new plugin that communicates with the KUKA robot controller. The plugin will take as input the 2D B-mode images from the ultrasound probe along with the current location of the probe. It will store a 3D reference image, the volume of interest, and a 3D ultrasound volume at the probe's current location obtained from aligning the 2D B-mode images based on position. Built-in modules will be used to obtain the three-dimensional rotation and translation between the ultrasound volume at the probe's current location and the reference image. The plugin will then communicate instructions to move the ultrasound probe according to the computed transformation.

Robot communication

The KUKA iiwa robot, which has 7 degrees of freedom, will manipulate an ultrasound probe that is mounted on its tool tip using motion plans from the workstation running ImFusion. Since movement and image data must be sent via LAN between the KUKA robot and workstation, there must be a network protocol for transferring information between them. Robot control will be provided using the KUKA Sunrise.Connectivity framework, and communication between Sunrise and ImFusion will use a use an intermediate interface which passes messages between the two processes. The current plan is to use ROS, which works by running processes on independent nodes and using a master server to pass messages between nodes. ROS provides packages for commonly-used robot functionality, and ROS nodes can be created for either Java or C++.

Since ImFusion only runs on Windows, a possible pitfall is that the core ROS system might have compatibility issues with Windows because it is only designed for Unix-based platforms according to the documentation. An alternative would be to run a ROS server within MATLAB and use OpenIGTLink to communicate between ImFusion and the ROS server, then use a ROS node for Sunrise. This would maintain the ability to use ROS to still be functions, and ImFusion already contains a module for OpenIGTLink. If this approach does not work, then a third alternative is to avoid using ROS completely and create an OpenIGTLink interface for Sunrise that will enable communication with the OpenIGTLink interface for ImFusion. This approach has the benefit of avoiding Windows compatibility issues, but a disadvantage is that ROS provides greater existing functionality than OpenIGTLink.

Deliverables

- Minimum
  - ImFusion plugin for automated ultrasound-MRI and ultrasound-ultrasound registration that returns transformation between the three-dimensional images
  - ImFusion plugin for communication between ImFusion and KUKA robot
- Expected
  - Given an initial ultrasound probe image and volume of interest, find the transformation between the two and move robot to location of reference image
  - Perform validation of path planning on different ultrasound phantoms
  - Evaluate performance of different registration techniques

    - Provide documentation of completed portions
- Maximum
    - Given only the volume of interest, obtain the corresponding ultrasound image and move robot to final location regardless of initial position

Timeline

Notes Highlighted items incidate milestones	Week	1	2	3	4	5	6	7	8	9	10	11	12	13
	Starting	Feb 13	Feb 20	Feb 27	Mar 6	Mar 13	Mar 20	Mar 27	Apr 3	Apr 10	Apr 17	Apr 24	May 1	May 8
Learn how ROS nodes work	Minimum													
Create ROS node for first time														
Set up PC and get ImFusion running														
Read KUKA Sunrise.Connectivity documentation														
Perform literature review														
First control of robot from ImFusion														
Understand how ImFusion plugins work														
ImFusion plugin that controls robot from ImFusion														
First image registration and outputs transformation														
ImFusion plugin that performs image registration and outputs transformation														
First ultrasound image acquisition using KUKA	Expected													
System-level integration of image analysis and motion planning modules														
Evaluate registration on gel block														
Obtain correct ultrasound given initial and reference image														
Perform system testing and validation with different ultrasound phantoms							Spring Break							
Evaluate performance of different registration techniques														
Integrate existing modules in ImFusion with Kinect sensor plugin	Maximum													
Obtain correct ultrasound volume given only reference image														
Final report														
Poster presentation														

Dependencies

Dependency	Reason	Resolution	Status
Ability to meet with mentors	To discuss current progress and get advice	Schedule weekly meetings with Bernhard Fuerst on Wednesdays at 9am	Resolved
Permission to use ImFusion	ImFusion is proprietary software which is not freely available to the general public	Research agreement with CAMP allows free usage of software for academic purposes and already have permission from Prof. Navab	Resolved
J-Card access to the Robotorium and Mock OR	To gain access to the KUKA robot and a workstation for ImFusion	Get Hackerman Hall J-Card access form signed by a faculty member then give to Alison Morrow	Resolved
Computer with GPU powerful enough to run ImFusion	ImFusion uses GPGPU computing for fast image processing and needs the ability to operate in real time	Work with mentors to obtain an account on workstation in Robotorium which has a Tesla GPU	Nearly resolved; still need account set up
Ultrasound probe and phantoms	To validate the path planning of the KUKA robot	Should already be located in Mock OR	Resolved
Kinect sensor	The maximum deliverable requires being able to start with the ultrasound probe away from the patient. This requires a sensor which can find the patient's location.	Should already be located in Mock OR	Resolved

Reading List

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