Interventional Photoacoustic Registration and Visualization
600.446 Computer Integrated Surgery II, Spring 2012

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Stated Topic and Goal

Photoacoustic (PA) registration has been shown to be able to at least replicate the functionality of common surgical tracking systems such as electromagnetic or optical trackers. This technology involves shining points of laser onto a phantom or tissue that can be seen by a stereovision camera system. The laser energy is absorbed by the phantom or tissue and generates an acoustic wave that can be detected by an ultrasound probe.

The goal of this project is to develop a PA registration and visualization system that can perform a direct registration from 3D stereocamera (SC) space to 3D ultrasound space in an ex-vivo tissue environment and achieve sub-millimeter error results based on target registration error (TRE).

Background

The PA effect was first observed in 1880 by Alexander Graham Bell. The general principle of this phenomenon is that light waves will generate an acoustic wave when absorbed by matter due to thermal absorption and excitation. It was initially developed for use in the communication field, but has since been used in the medical field as well in the form of PA spectroscopy. This biomedical application is mainly used for functional and structural imaging thanks to the large contrast in absorption coefficients between blood and tissue [1].

When matter is exposed to pulses of light, the light energy becomes absorbed by the molecules within the matter. The absorbed energy thermally excites the molecules and generates heat. This causes the matter to expand and generate acoustic waves. These waves can be detected by an assortment of acoustic devices such as ultrasound probes.

Motivation/Relevance

Surgical tracking systems are widely used in computer integrated surgery. Some common ones include electromagnetic and optical tracking systems. These systems both require markers to be placed on the object of interest. In actuality, the markers are the objects that are being tracked. To determine the object of interest with respect to the markers, a calibration process must be performed. For example, the calibration of an optical tracking system can have an error of about 3.08mm and 3.26degree [2]. The PA registration that this project proposes does not require a calibration process and aims to achieve a sub-millimeter error.

Another factor of error for electromagnetic tracking systems is the presence of interference. This can come from large metal sources or electrical sources. The PA registration system will not have these limitations. However, it does have an issue that optical tracking systems share. This issue is that the visibility of site of interest is critical and necessary. One advantage that our system has in this issue is that the SC will be extremely close to the site of interest, which may not always be the case with standard optical tracking systems.

Technical Approach

There are four tasks within this project.

1. Fiber delivery system
    a. There are two main reasons to develop a fiber delivery system. First of all, we can use it to shine multiple laser points onto the phantom or tissue at the same time. This allows us to eventually move towards a real-time system. Secondly, a fiber delivery system will allow the PA registration system to move to a laparoscopic environment. This is necessary because the end goal of this system is to be used in laparoscopic procedures.
    b. Connect a fiber bundle to the laser source and split off the fibers at the other end. Lenses are then attached to each fiber to collimate the light.
2. 3D Ultrasound
    a. The main reason to use 3D Ultrasound as opposed to 2D Ultrasound is because we want to register 3D points between the SC space and the Ultrasound space. It also allows for easier placement of the 3D ultrasound probe because it was difficult to place the 2D ultrasound probe such that its image plane could see the PA signal.
    b. Collect 2D ultrasound radio-frequency data when the 3D probe is in a static location. Actuate the motor by a certain step size. Repeat this procedure until the desired volume is collected.
3. Automatic Segmentation
    a. The reason for this is to allow results to be reliably reproduced from a set of data. The manual method required the user to select an intensity threshold with trial and error.
    b. Determine intensity thresholds based on histogram of intensities. Make image or volume binary. Determine signal points based on the characteristics of each high intensity region.
4. Validation
    a. The reason for validation is to show that this PA registration system is successful in meeting the project goals.
    b. A visualization of ultrasound points in the camera space overlaid on the camera image. A representation of the ultrasound volume should also be visualized in the same space.
    c. A TRE will be calculated based on other fiducials placed within the phantom or tissue. The fiducials will be tested using the computed transformation from the PA signal points.

Deliverables

Minimum:
Phantom and ex-vivo tissue experimental results with 3D ultrasound
Fiber delivery system successfully projects multiple laser points concurrently
Visualization is only able to show the ultrasound points overlaid with the stereovision camera points
Automatic segmentation is working on individual 2D ultrasound images or individual slices of the 3D volume

Expected:
Minimum +
Visualization will also overlay a representation of the 3D ultrasound volume

Automatic segmentation works on an entire 3D ultrasound volume

Maximum:
Expected +
Ability to collect 3D RF data without manually actuating motor
Integrate complete system together

Milestones

Validation will be done after each milestone in the form of experiments. Results will be analyzed using TRE when appropriate.

Phantom construction
Date: February 27, 2012
Criteria: Create a phantom suitable for 3D PA imaging

Ex-vivo phantom construction
Date: February 27, 2012
Criteria: Create a phantom with ex-vivo tissue suitable for 3D PA imaging

3D Ultrasound
Date: February 27, 2012
Criteria: Able to segment PA signal from 3D Volume

Fiber Delivery System
Date: March 5, 2012
Criteria: Able to project multiple laser points

Visualization
Date: March 26
Criteria: Be able to display SC and US points in the SC space

Automatic Segmentation
Date: April 16
Criteria: Able to segment desired PA signal from a set of images

System Integration
Date: May 7
Criteria: Pieces fit together

Dependencies

Access to laboratories
 Dr. Boctor's lab - I already have access
 Dr. Kang's lab – I already have access

Access to equipment
 Laser – This are located in Dr. Kang's lab

Optics – We have permission from Dr. Boctor to purchase given reasonable price
Ultrasound Machine – This is located in Dr. Boctor's lab
3D ultrasound probe – This is located in Dr. Boctor's lab
Phantom materials – This is located in Dr. Boctor's lab

Management Plan

Time spent on project weekly: 15-20 hours

Meetings:
1. Mentors: Dr. Boctor and Dr. Taylor
   Location: Hackerman 127
   Time: Wednesday 1:30 pm
2. Mentors: Dr. Boctor, Dr. Taylor, and Dr. Kang
   Location: Hackerman 306
   Time: Monday 4:00 pm

Since I am working by myself, I will be responsible for every portion of this project.

The plan will be amended weekly. Any modifications will be uploaded to the project website. They will also be reviewed with my mentors.

Reading List

Hoelen C. et al. "Three-dimensional photoacoustic imaging of blood vessels in tissue". Optics Letters 1998. Vol. 23-8:648-650
Kuo N. et al. "Photoacoustic imaging of prostate brachytherapy seeds in ex vivo prostate". SPIE 2011
Oberhammer P. et al. "Optimization and Quantification for Rigid Point Based Registration for Computer Aided Surgery". Advances in Medical Engineering 2007. Vol. 114-3:230-235
Pham D. et al., "Current Methods in Medical Image Segmentation". Annual Review of Biomedical Engineering 2000. Vol. 2:315-337
Spike, B. "The Photoacoustic Effect". Physics 325 Lecture Notes 2006
Vyas S. et al., "Intraoperative Ultrasound to Stereocamera Registration using Interventional Photoacoustic Imaging". SPIE 2012
Xu M. et al. "Photoacoustic Imaging in Biomedicine. Review of Scientific Instruments". Review of Scientific Instruments 2006, 77

References

[1] Spike, B. "The Photoacoustic Effect". Physics 325 Lecture Notes 2006
[2] Boctor E. et al., "A Novel Closed Form Solution for Ultrasound". ISBI 2004