Interventional Photoacoustic Registration

600.446 Computer Integrated Surgery II, Spring 2011

Project Proposal

Team members: Saurabh Vyas, Robert Kim, Steven Su
Mentors: Dr. Emad Boctor, Dr. Russell Taylor

Summary and Goals:

Photoacoustic registration is a promising new technology that has the potential to replace existing registration methods such as EM an optical tracking. Photoacoustic registration involves shining a rapid pulses of laser on seeds which are placed in the surgical site. Seed will absorb and convert the light energy into sound waves which can then be detected by ultrasound. The main goal of this project is to perform 3 point registration using photoacoustic registration using 3D ultrasound data.

Background:

The photoacoustic effect was first discovered by Alexander Graham Bell in 1880. It is the principle by which electromagnetic (light) waves are converted to acoustic waves due to absorption and thermal excitation. The photoacoustic effect has been previously exploited to lead to the invention of photoacoustic spectroscopy and is currently used in biomedical applications such as structural imaging, functional imaging, and molecular imaging.

When matter is exposed to high frequency pulses of light, most of the light's energy will be absorbed by the molecules in the incident matter. As the energy from the light is converted to heat, the molecules become thermally excited. Heat waves will then radiate away from the matter causing sound waves due to pressure variations in the environment around the medium. These sound waves can then be detected by acoustic devices such as ultrasound.

Motivation:

Currently, most computer-integrated surgical systems use electromagnetic (EM) or optical tracking methods. Both of these methods have weaknesses that can be overcome with photoacoustic tracking methods. One principle weakness common to both EM and optical tracking is the necessity for EM markers or LEDs in or around the surgical site. Both types of markers are wired, meaning that the surgical area may be complicated by the wiring emanating from these markers. Photoacoustic registration and tracking does not require the placement of wired markers on or around the patient. Instead, metal seeds are used in place of traditional markers. Recent research and literature review indicates that the photoacoustic effect is best observed using a 532 nm source laser (green) on our particular type of seeds.

An additional weakness of optical tracking is that it is an all or nothing process. If the line of vision between the optical tracker and LEDs is blocked, tracking cannot occur. With photo acoustic registration, laser sources will be closer to the surgical site and ultrasound will be positioned closer to the patient. This avoids the possibility of interference and blockage of tracking.

Deliverables:

- **Minimum:** A pulse laser source will be used to project a single point onto a phantom from which several ultrasound slices will be obtained. For each corresponding slice, the point will be identifiable. There exists 6 DoF between the laser space, camera space, and ultra sound space. We will be responsible for performing sensitivity analysis and relative motion analysis. The most important aspect of this is integration of all individual components and their ability to function as one unit. Finally we will also be engineering our own phantoms.
- **Expected:** Using a moving 2D ultrasound probe, three points will be identified using 3D ultrasound data. In the case of the moving 2D ultrasound probe, a robotic stage will need to be to built, synchronized, and calibrated with the laser setup. We will develop modular software to integrate this robotic stage into the existing ultrasound setup. Finally we will engineer some mechanical structures to install the corresponding probes onto the stage.
- **Maximum:** We will attach and integrate a stereo camera to the laser fiber as well as a continuous wavelength laser (CWL) source. The CWL will then need to be calibrated to pulsed laser pattern. Finally the CWL will also need to be calibrated to the camera setup.

Technical Approach:

First, it is necessary to design and build a phantom that will be used for photoacoustic imaging. A single point will be projected onto the phantom using a pulse laser system (532 nm laser source). This point on the phantom will be detected using Sonix CEP ultrasound system and Sonix DAQ module. Horn's registration algorithm will be used to identify the coordinates of the point in the ultrasound coordinate system. After the ultrasound coordinates of the point are obtained, sensitive analysis and relative motion analysis will be done. For instance, the laser source will be moved to a certain known distance, and it will be validated if the ultrasound system is sensitive to reflect the same amount of motion.

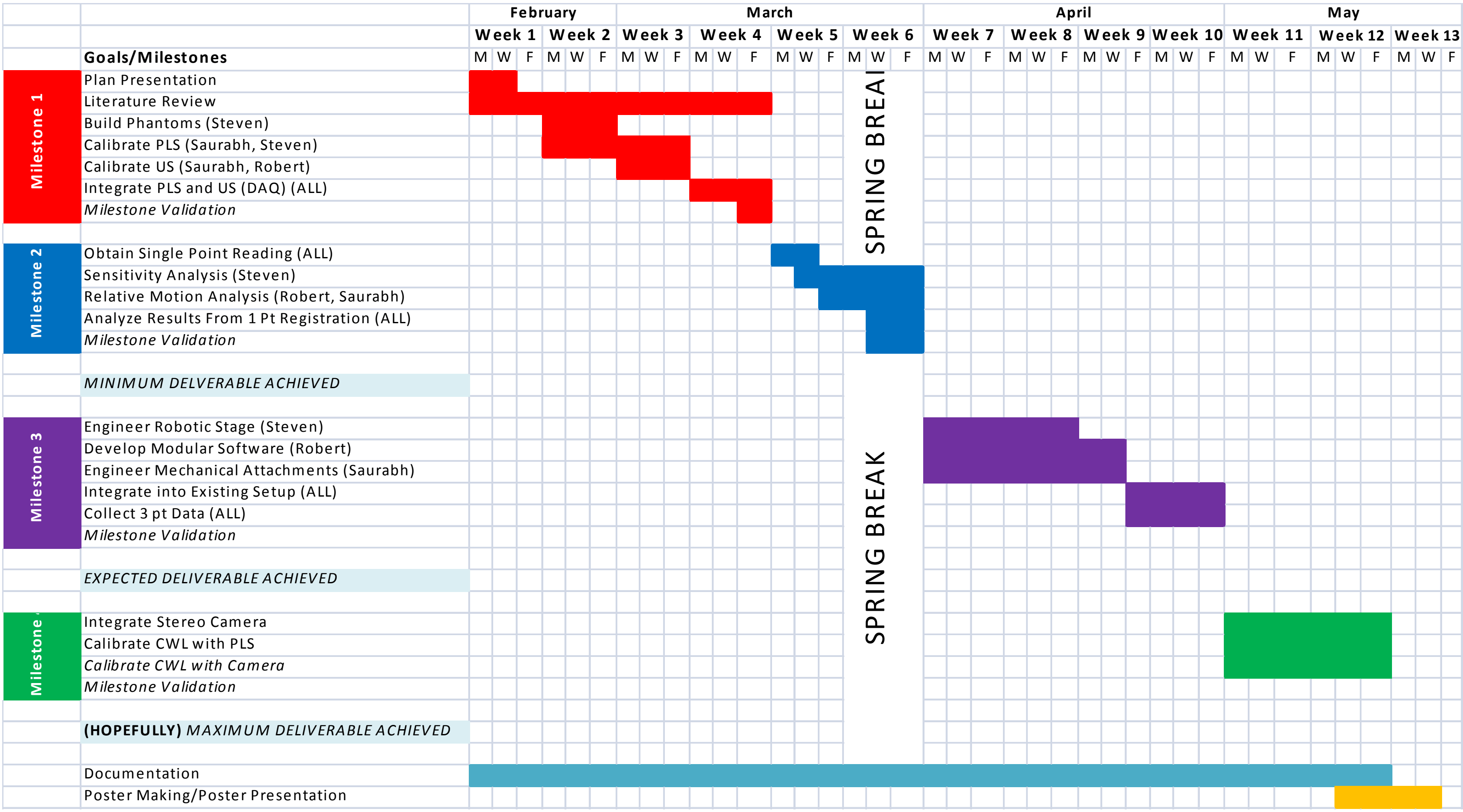
Once the system works properly, a laser pattern using three laser points will be projected onto the phantom. A robotic stage and an adapter to mount a 2D ultrasound probe to the robotic stage will be designed and constructed to acquire 3D ultrasound data. The 2D ultrasound probe on the robotic stage will be moved to detect all three points on the phantom. Modular software will be developed to synchronize and calibrate the robotic stage with the laser setup. The laser pattern could be changed and compared with the pattern detected and recorded by the ultrasound system to validate whether the entire system works correctly.

Lastly, a stereo camera and continuous wavelength (CW) laser source could be integrated to the pulse laser source. Software and algorithms will be implemented to calibrate the CW laser to the pulse laser and the CW laser to the stereo camera setup.

Milestone Validations:

1. Phantom will exist. DAQ data can be analyzed.
2. Obtain point using US slices. Use rigid transformations to evaluate accuracy of registration.
3. Robotic stage will exist. Changing the laser pattern and use the obtained rigid transformation to evaluate registration.
4. TBD. Need more physics background to create validation protocol.

Timeline:


February
March
April
May
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Week 11
Week 12
Week 13
M W F
Goals/Milestones
Milestone 1
Plan Presentation
Literature Review
Build Phantoms (Steven)
Calibrate PLS (Saurabh, Steven)
Calibrate US (Saurabh, Robert)
Integrate PLS and US (DAQ) (ALL)
Milestone Validation
Milestone 2
Obtain Single Point Reading (ALL)
Sensitivity Analysis (Steven)
Relative Motion Analysis (Robert, Saurabh)
Analyze Results From 1 Pt Registration (ALL)
Milestone Validation
MINIMUM DELVERABLE ACHIEVED
Milestone 3
Engineer Robotic Stage (Steven)
Develop Modular Software (Robert)
Engineer Mechanical Attachments (Saurabh)
Integrate into Existing Setup (ALL)
Collect 3 pt Data (ALL)
Milestone Validation
EXPECTED DELIVERABLE ACHIEVED
Milestone
Integrate Stereo Camera
Calibrate CWL with PLS
Calibrate CWL with Camera
Milestone Validation
(HOPEFULLY) MAXIMUM DELIVERABLE ACHIEVED
Documentation
Poster Making/Poster Presentation
SPRING BREAK
SPRING BREAK

Dependencies and Resolutions:

- **Dependency:** Access to Dr. Jin Kang's lab and equipment
    - **Resolution Plan:** Dr. Boctor has collaborated with Kang previously and has gotten permission for us
    - **Resolve By:** N/A
    - **Resolved:** Yes
    - **Fallback Plan:** N/A
    - **Affects:** N/A
- **Dependency:** Help in learning how to build phantoms
    - **Resolution Plan:** Dr. Boctor has offered his lab members for assistance
    - **Resolve By:** 2/25/11
    - **Resolved:** No
    - **Fallback Plan:** Beg Dr. Taylor for money to buy them from elsewhere
    - **Affects:** Milestone 1 (and therefore all subsequent milestones)
- **Dependency:** Access to Dr. Boctor's lab (JHOPC)
    - **Resolution Plan:** Have Jcard access already
    - **Resolve By:** N/A
    - **Resolved:** Yes
    - **Fallback Plan:** N/A
    - **Affects:** N/A
- **Dependency:** Learn the physics of how to calibrate CWL with PLS
    - **Resolution Plan:** Dr. Emad Boctor has offered his PhD students to help us
    - **Resolve By:** 5/1/11
    - **Resolved:** No
    - **Fallback Plan:** Don't do maximum deliverables
    - **Affects:** Milestone 4 (Maximum Deliverables)
- **Dependency:** Funding for poster
    - **Resolution Plan:** Ask Dr. Taylor for the $40 required for poster printing at DMC
    - **Resolve By:** 5/5/11
    - **Resolved:** No
    - **Fallback Plan:** Dr. Boctor pays out of pocket
    - **Affects:** Final Grade in 600.446

Management Plan and Responsibilities :

- Weekly meetings with Dr. Emad Boctor at either Homewood Campus (Hackerman Hall, Postdoc Room) or JHMI JHOPC building on Mondays at 9:00 a.m.
- Team meetings every Monday, Wednesday, and Friday at Hackerman 224 from 7:00-9:00 p.m.
    - Monday: Updates and Planning for upcoming week. Delegation of individual tasks.
    - Wednesday: Integration of individual work.
    - Friday: Testing and verification of work.
        - Individual tasks will be completed over the weekend or in between meetings as schedules permit.

- Work and responsibilities will be split according to the following criterion:
    - Saurabh: Calibrate PLS, Calibrate US, Relative Motion Analysis, Engineer Mechanical Attachments
    - Robert: Calibrate US, Relative Motion Analysis, Develop Modular Software
    - Steven: Build Phantoms, Calibrate PLS, Sensitivity Analysis, Engineer Robotic Stage
    - ALL: Integrate PLS and US, Obtain Single Point Reading, Analyze Results From 1 Point Analysis, Integrate Robotic Stage into System, Collect 3 Point Data
- Schedule appointment to meet with Dr. Russell Taylor as appropriate (Contact: Allison Morrow, allison.morrow@jhu.edu)

Updates to the management plan will be made accordingly throughout the semester. The plan will be updated online when changes are made. Mentors will be notified accordingly.

References:

- Xu et al. Photoacoustic Imaging in Biomedicine. Review of Scientific Instruments [2006]
- Spike, BT. The Photoacoustic Effect. Physics 325 Lecture Notes [2006]
- P Oberhammer et al. Optimization and Quantification for Rigid Point Based Registration for Computer Aided Surgery. Advances in Medical Engineering. [2007]
- C. G. A. Hoelen et al. 3-Dimensional Photoacoustic Imaging of Blood Vessels in Tissue. Optic Letters. [1998]
- K Kostli et al. Two Dimensional Photo-acoustic Imaging by Use of Fourier Transform Image Reconstruction and a Detector with an Anisotropic Response. Applied Optics. [2003]