

Ultrasound Imaging of Brain Shunts

600.446 Computer Integrated Surgery II, Spring 2013

Project Proposal

Team members: Rongguang Han, Yang Hong

Mentors: Dr. Emad Boctor, Dr. Russell Taylor, Dr. Jin Kang

Summary and Goals

The most common treatment for hydrocephalus is to place a cerebrospinal fluid (CSF) shunt to divert excess CSF to a re-absorption site and regulate the intracranial pressure. However, CSF shunts have an unacceptably high incidence of occlusions from in-grown tissues. Our project is to explore ultrasound imaging, together with photoelectric excitation to image the occlusions and brain shunts, so a system of minimally invasive clearing of the brain shunts could be further developed.

Clinical Background and Motivation

Hydrocephalus is caused by excessive cerebrospinal fluid (CSF) accumulates in the ventricular space, creating increased pressure on the brain. Pressure distends ventricles and can lead to death. The most common treatment for hydrocephalus is to place a cerebrospinal fluid (CSF) shunt to divert excess CSF to a re-absorption site and regulate the intracranial pressure. 40,000 shunt-related operations are performed annually in US.

However, CSF shunts have an unacceptably high incidence of occlusions from in-grown tissues like choroid plexus, connective tissue, neurogliosis and blood, which block CSF flow. Failure rates are estimated to be around 40% in the first year and 80% within 10 years. Currently, the only accepted clinical solution for resolving obstructions is either shunt replacement or revision. If removal of malfunctioning shunt presents hemorrhage risk, the shunt is left and new shunt placed.

Technical Background

Photoacoustic (PA) imaging, which is based on the photoacoustic effect, possessing many attractive characteristics such as the use of nonionizing electromagnetic waves, good resolution and contrast, portable instrumentation, and the ability to partially quantitate the signal, has been developed extensively over the last decade. It was first

discovered by Alexander Graham Bell in 1880. 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.

By launching high frequency pulses of light onto a medium, the energy of the light is absorbed and converted into heat, which makes the molecules become thermally excited. Then the pressure variations caused by radiation of the heat will propagate as ultrasound waves in the medium. So it can be detected by acoustic devices such as ultrasound.

Technical Approach

Three stages of the technique approach are designed this project.

Firstly, a brain phantom for ultrasound imaging will be designed and built based on the CT scan from real patient. Then, the shunt will be placed at a typical position in this phantom and the tissue-like material will be placed in the shunt.

At the same time, the laser system will be set up to project the laser on the tissue-like material without the brain phantom. A probe will be placed at a position that can be measured. Then, the data will be detected and collected by the ultrasound system. After processing the ultrasound data, a sensitive analysis will be conducted to demonstrate the validation of the algorithm and the system runs properly.

Specifically, the laser source will be placed at a position we measured accurately, and the computational data will be collected, processed and compared with the measured data. Both the data and the error will be analyzed in this sensitive analysis.

Now, both the phantom and the system are prepared. A same procedure will be done on the phantom without the skull. Also, a sensitive analysis will be done. This is to find whether the phantom will affect the accuracy and also to demonstrate the material we select satisfies the requirement for this project.

An image process will be done to achieve the visualization. In this part, the offline approach will be used.

Secondly, we will do the experiment on the phantom with brain skull. Certain technique will be used to solve the problem of defocused. Also, different levels of occlusion (tissue-like material) will be used to for the imaging. Up

to this point, we will use the offline approach, again.

Thirdly, data from different materials will be collected. Because of the certain characteristics of different materials, we can visualize the shape of the shunt, the obstacles and the clearing device.

Software will be implemented to pulse CW laser if needed.

Then, algorithms will be used for fast data processing. This is because if we can process the data between two images less than 0.1 second, we can generate a real time film other than separate images.

The monitor screen and the continuous wavelength (CW) laser source will be connected and used to achieve the visualization.

Deliverables

- **Minimum**

An ultrasound friendly brain phantom will be designed and built, with shunts inserted. Laser and US system will be tested preliminarily for PA signal detection with tissue-like material. After the phantom has been constructed, experiment data will be collected and processed without skull to form delayed images.

- **Expected**

Experiment data will be collected and processed with skull. Different levels of occlusion can be recognized from the image. Shunts, tissues and fluid will be able to distinguish.

- **Maximum**

Faster image processing method will be developed to achieve real-time imaging through the skull for occlusion and shunts. The procedure to clear the shunt can be monitored.

Milestone Validations

- Phantom will be constructed (Feb 28).
- Preliminary test of US probe and laser will be completed (Feb 28).
- Visualization of occlusion in shunts without skull will be achieved (March 18).
- Visualization of occlusion and clearing stem in shunts with skull will be achieved (April 15).
- Real-time imaging of occlusion and shunts with skull will be achieved (Hopefully, May 10).

Timeline

		February			March				April				May	
		Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
Milestone 1	Goals/ Milestones													
	Plan Presentation (Both)													
	Literature Review (Both)													
	Prepare Phantoms (Han)													
	System setup (Han)													
	Collect data (Han)													
	Process Data (Yang)													
	Sensitive Analysis (Yang, Han)													
	Experiment on phantom w/o skull (Both)													
	image process (Yang)													
	Milestone Validation (Both)													
Milestone 2	Experiment on the phantom with brain skull (Han)													
	Different levels of occlusion set on the phantom (Han)													
	Collect Data (Han)													
	Process data (Yang)													
	implentent certain technique (Yang)													
	Milestone Validation (Both)													
Milestone 3	Collect data from different materials (Han)													
	Process data (Yang)													
	image process (Yang)													
	Implement software to pulse CW laser (Han)													
	New algorithm for fast data processing (Yang)													
	Integrate CW laser and monitor screen (Han)													
	Milestone Validation (Both)													
Documentation (Both)	Documentation (Both)													
	Poster Making and Presentation (Both)													

Dependencies

- Dependency: Access to Dr. Boctor's lab and equipment
 - Resolution Plan: Dr. Boctor has informed his postdoc to provide the equipment
 - Resolve By: 2/22/2013
 - Resolved: No.
 - Fallback Plan: N/A
 - Affects: All subsequent milestones

- Dependency: Get the brain phantoms
 - Resolution Plan: Do research on material suitable for ultrasound and learn how to build the brain phantoms/ Also search on the internet for the cheap brain models
 - Resolve By: 2/22/2013
 - Resolved: No
 - Fallback Plan: Beg Dr. Taylor for money to buy a professional model from elsewhere
 - Affects: Milestone 1

- Dependency: Learning how to collect the data using external probe
 - Resolution Plan: Dr. Boctor has informed his PHD to help us
 - Resolve By: 2/22/2013
 - Resolved: No.
 - Fallback Plan: N/A
 - Affects: Milestone 1

- Dependency: Learn how to connect new software to the device
 - Resolution Plan: Dr. Boctor has offered his PhD students to help us
 - Resolve By: 5/1/2013
 - Resolved: No
 - Fallback Plan: give up the maximum deliverables
 - Affects: Maximum Deliverables

- Dependency: Monitor the real-time clearing of brain shunts
 - Resolution Plan: the clearing stem is built by the company
 - Resolve By: 5/1/2013
 - Resolved: No
 - Fallback Plan: give up the second maximum deliverable
 - Affects: Maximum Deliverables
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Management Plan

- Weekly meetings with Dr. Emad Bector at either Homewood Campus or JHMI
- Team meetings every Monday, Friday at 7p.m for sharing updates and discussing further plans
- Work and responsibilities will be split according to the following criterion:
 - Rongguang Han: Phantom construction, data collection
 - Yang Hong: data collection, signal processing
- Keep Dr. Russell updated weekly by email, or schedule appointments as appropriate
- The plan will be updated online when changes are made. Throughout the semester. Mentors will be notified accordingly.

Reading List

- Szabo, Thomas L. , “Diagnostic ultrasound imaging: inside out”, Amsterdam: Elsevier Academic Press, 2004.
- Limng Nie, Xin Cai, Konstantin Maslov, Alejandro Garcia-Urbe, Mark A. Anastasio, Lihong V. Wang, “Photoacoustic tomography through a whole adult human skull with a photon recycler”, Washington University, Department of Biomedical Engineering, St. Louis, Missouri 63130.
- Thomas R. Nelson, “Three-dimensional Ultrasound Imaging”, University of California, San Diego, La Jolla, California.
- Xueding Wang, Yongjiang Pang, Geng Ku, George Stoica and Lihong V. Wang, “Three-dimensional laser-induced photoacoustic tomography of mouse brain with the skin and skull intact”, 10/1/ 2003, Vol.28, No.19, Optics Letters.
- Medical Imaging Signals and Systems, J. L. Prince and J. M. Links, (Pearson Prentice Hall, Upper Saddle River, NJ), 2006.
- The Essential Physics of Medical Imaging, J.T. Bushberg, J. A. Seibert, E. M. Leidholdt and J. M. Boone, (Lippincott Williams & Wikins, Philadelphia, PA), 2001.
- Physical Principals of Medical Ultrasonics, C.R. Hill, J.C. Bamber and G.R. ter Haar, (John Wiley & Sons Ltd) 2004.