Ultrasound Imaging of Brain Shunts

Team 1

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Mentors: Dr. E. Boctor, Dr. R. Taylor, Dr. J. Kang

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Overview

- Background
- Motivation
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**Background**

- **Hydrocephalus**: Excessive cerebrospinal fluid (CSF) accumulates in the ventricular space, creating increased pressure on the brain.

- **The most common treatment**: Placement of a CSF shunt to divert excess CSF to a re-absorption site and regulate intracranial pressure.
Neurosurgeons place shunts by

- Making scalp incision and drilling hole in the skull
- Passing a small catheter (1.5mm inner dia.) through the brain into a ventricle (often 3rd ventricle)
- Distal catheter placed under skin to peritoneum

40,000 shunt-related operations performed annually in US
Motivation

CSF shunts have an unacceptably high incidence of occlusions from in-grown tissues that block CSF flow

- Failure rates are estimated to be ~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
Motivation

**Challenge:** Can we develop a system for minimally invasive clearing of brain shunts to regain patency without shunt replacement?

- The company itself is in charge of developing an in-patient brain shunt clearing stem

**Goal:** Use external US probe, together with photoacoustic excitation to image occlusions and brain shunts inside the skull.
Photoacoustic imaging, which is based on the photoacoustic effect, has developed extensively over the last decade.

- Discovered by Alexander Graham Bell in 1880.
- 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.
High frequency pulses of light are absorbed by medium, causing its energy converted into heat, which leads to thermal expansion.

Pressure variations caused by radiation of the heat will propagate as ultrasound waves in the medium.

Ultrasound waves can be detected by acoustic devices such as an US probe.
Technical Approach 1

- Design and build, (borrow / buy) a brain phantom that will be used for the ultrasound imaging. The shunt will be placed at a typical surgery position in this phantom and the tissue-like material will be placed in the shunt.

Image from: http://sidschwab.blogspot.com/2012/01/theyre-all-insane-scary-insane.html
A pulse laser system will be used to project on the tissue-like material without the brain phantom. The data will be detected and collected by using the ultrasound system.

After the ultrasound coordinates were obtained, sensitive analysis will be conducted to demonstrate the validation of the algorithm and the system works properly.

Specifically, the laser source will be placed at a position we measured accurately, and the data will be collected, processed and compared with the measured data.
Technique Approach 1

- A same procedure will be done on the phantom without the skull. Also, a sensitive analysis will be done (to find whether the phantom will affect the accuracy).
- The image process will be done to achieve visualization.
- Offline approach.
Technique Approach 2.

- A phantom brain with skull will be used this time.
- Different levels of occlusion (tissue-like material) will be used to for the imaging.
- Certain technique (like time inverse image) will be used to solve the problem of defocused.
- Offline approach.
Technical Approach 3.

- Collect the data from different materials to visualize the shape of the shunt, the obstacles and the clearing device.
- Then algorithms will be used for fast data processing. Integrate monitor screen and the CW laser source to achieve the visualization in real time.
Deliverables

- **Minimum – without skull**
  - Design and build a ultrasound friendly brain phantom and insert the shunts.
  - Preliminary test of US probe for reflected PA signal detection
  - Collect and process the data of the occlusion with brain phantom into delayed image
Deliverables

- **Expected – with skull**
  - Collect and process the data of the occlusion into delayed image
  - Capability to distinguish shunts, tissues and fluids
  - Demonstrate PA imaging of shunts with different levels of occlusion
Deliverables

- Maximum
  - Demonstrate realtime PA imaging through the skull of shunts with different levels of occlusion
  - Monitor clearing of the shunt
Milestone Validations

- **Phantom construction**
  - Complete by February 28

- **Preliminary test with occlusion material**
  - Complete by February 28

- **Visualization of occlusion in shunts without skull**
  - Complete by March 18

- **Visualization of occlusion and clearing stem in shunts with skull**
  - Complete by April 15

- **Realtime imaging of occlusion and shunts with skull**
  - Complete by May 10
## Timeline

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<td>Implement certain technique (Yang)</td>
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Management Plan

- Weekly meetings with Dr. Emad Boctor 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.
Dependencies (1)

- **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
Dependencies (2)

- **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 realtime 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
Reading list


- Limng Nie, Xin Cai, Konstantin Maslov, Alejandro Garcia-Uribe, 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.


Thank you!

Questions?