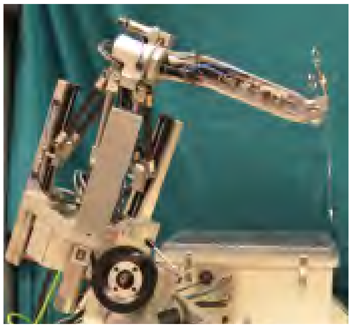
Surgical Instrument for Robotic Open Microsurgery

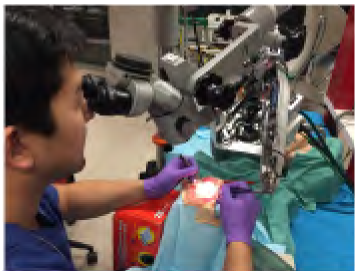
- Work closely with clinical collaborator to develop novel surgical instruments for robotic vein suturing.
- **What Students Will Do:**
  - Discuss requirements with clinical collaborator
  - Design solution
  - Fabricate solution
  - Test solution in simple model
  - Iterate design until satisfactory
  - Test in phantom
- **Deliverables:**
  - Completed instrument
  - Documentation
- **Size group:** 1-2
- **Skills:**
  - CAD/CAM
  - Machine shop experience
  - Design experience
- **Mentors:** Russ Taylor, Jeremy Richmon, MD,
  Kevin Olds, Allen Feng afeng@jhmi.edu,
- **Group leader:** Zaid Ashai

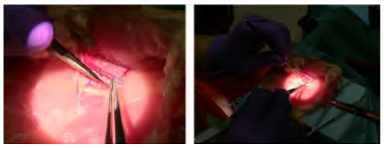


Surgical Instrument for Robotic Open Microsurgery

Robotic Suturing Study

- Use the Robotic ENT Microsurgery System (REMS) to conduct a study investigating robotic microsurgery
- **What Students Will Do:** run the REMS, recruit participants, run the study, analyze the data
- **Deliverables:** Completed study results and analysis
- **Size group:** 2-3
- **Skills:** at least one student needs C++ and robotics experience, others should have interest in robotics, BME, or medicine
- **Mentors:** Kevin Olds (kolds1@jhu.edu), Jeremy Richmon M.D., Russell Taylor

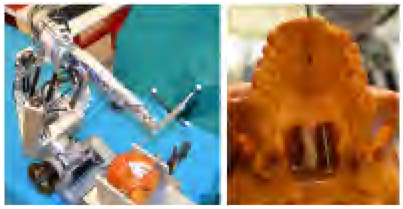


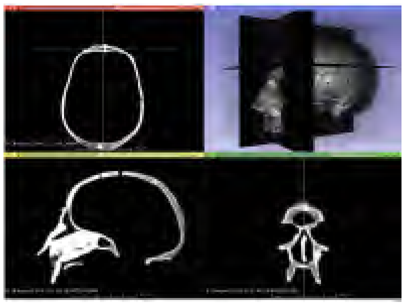


Note: May be combined with surgical tool project

Robotic Sinus Surgery Study

- Use the Robotic ENT Microsurgery System (REMS) to conduct a study investigating robotic sinus surgery
- **What Students Will Do:** run the REMS, recruit participants, run the study, analyze the data
- **Deliverables:** Completed study results and analysis
- **Size group:** 2-3
- **Skills:** at least one student needs C++ and robotics experience, others should have interest in robotics, BME, or medicine
- **Mentors:** Kevin Olds (kolds1@jhu.edu), Masaru Ishii M.D., Russell Taylor





Imaging in vivo neurotransmitter modulation of brain network activity in real-time

- **Joint PIs:** Dean F Wong[1,2], Arman Rahmim[1], Albert Gjedde[1,2]
- **Other collaborators**: Emad Boctor[1], Jakob Dreyer[2], Anthony Grace[4], Justin Hanes[3], Jin Kang[1], Xingde Li[1], Leslie M. Loew[5], Bill Mathews[1], Phillip Phan[1], Richard Price[3], Per Roland[2], Daniel Thorek[1]
- Affiliations:
  1. Johns Hopkins: Radiology, Neuroscience, Psychiatry, Ophthalmology, BME, EE, Carey Business School
  2. Neuroscience and Pharmacology (Y), University of Copenhagen
  3. BME, University of Virginia
  4. Neuroscience, University of Pittsburgh
  5. Cell Biology, University of Connecticut

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Problem Statement

- Quantification of neurotransmitter (**NT**) effects is one of the most fundamental components of the understanding of the underlying workings of the brain.
- It is the manner in which all neuronal systems communicate with one another by means of synapses.
- Neuroscientists measure these effects as membrane potential changes as well as changes of the number of action potentials with invasive methods (e.g., craniotomy).

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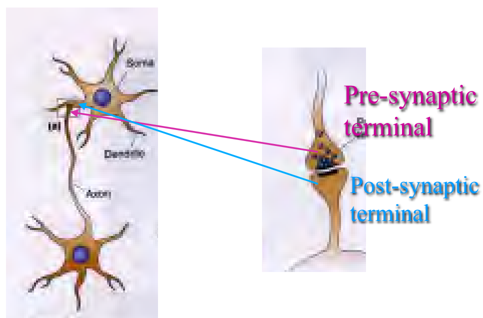
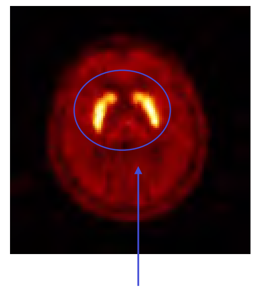
A neurotransmitter is released to propagate a signal from one neuron to another (chemical signal) .





Striata, brain regions rich in dopaminergic nerve terminals

The goal

- Methods such as PET also have temporal resolution of the order of several minutes.
- The goal is to develop a novel minimally invasive *in vivo* brain imaging approach that captures very rapid functional changes of activity induced by NT action with time constants in the millisecond range.

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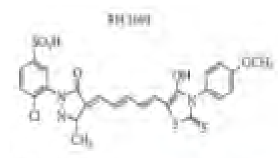
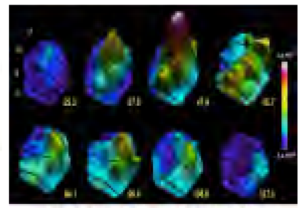
Voltage-sensitive dyes





- Voltage-sensitive dyes (VSDs) are dyes which change their spectral properties in response to voltage changes.
- They are able to provide linear measurements of firing activity of single neurons.
- Many physiological processes are accompanied by changes in cell membrane potential which can be detected with voltage sensitive dyes.
- Measurements may indicate the site of action potential origin, and measurements of action potential velocity and direction may be obtained.

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Imaging in vivo neurotransmitter modulation of brain network activity in real-time

- VRB tracking is a method for tracking tools by observing a projected light pattern.
- **What Students Will Do:**
  - Design and develop the hardware and software tools to enable VRB tracking in real applications
- **Deliverables:**
  - Hardware configuration for real-time VRB setup
  - MUSiiC Toolkit software module for real-time VRB tracking
  - Use VRB tracking as part of a calibration process (pivot calibration, US calibration)
- **Size group:** 1-2
- **Skills:** C++, Rigid Body Transformations, Computer Vision
- **Mentors:**
  - Alexis Cheng
    - (acheng22@jhu.edu)
  - Emad Boctor
    - (eboctor1@jhmi.edu)

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CIS II Project Spectroscopic Photoacoustic Flow Measurement

Medical UltraSound Imaging and Intervention Collaboration (MUSiiC) Lab

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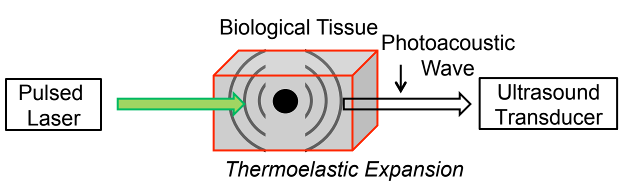
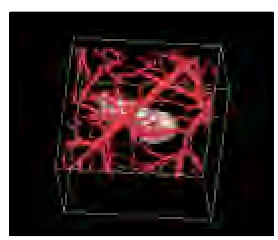
Spectroscopic Photoacoustic Flow Measurement Background

Photoacoustic imaging

- Real-time, Non-invasive, High penetration depth
- Functional Information such as blood oxygenation





Zhang, H. F. et al. (2006). "Functional photoacoustic microscopy for high-resolution and noninvasive *in vivo* imaging". *Nature Biotechnology* **24** (7): 848–851. doi: 10.1038/nbt1220.PMID 16823374

Non-invasive measurement of flow

- Vital information about the oxygen and other nutrients supply
- Diagnosis of a variety of disease including diabetes and cancer

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Spectroscopic Photoacoustic Flow Measurement

Photoacoustic Flow measurement

Existing techniques

- Doppler ultrasound ← large vessels such as arteries and veins
- Doppler optical coherence tomography ← detection depth < 1mm
- Electromagnetic methods ← expensive and bulky

Photoacoustic Flow measurement

- Blood flow measurement in capillaries (low blood flow rate and micrometer-scale diameter)

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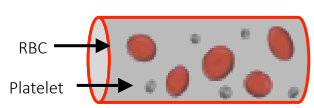
J. Yao, K. I. Maslov, Y. Shi, L. A. Taber, and L. V. Wang, "In vivo photoacoustic imaging of transverse blood flow by using Doppler broadening of bandwidth," Optics Letters, vol.35 (9), 1419-1421, 2010

Spectroscopic Photoacoustic Flow Measurement Statement of Purpose

Current flow measurement

- Generally we can only observe the velocity of red blood cell, which is the main contrast of moving objects.
- If it is possible to capture the different speed of substances in the blood vessels, this can be applied into drug delivery monitoring and dynamic status of substances in the blood vessels.



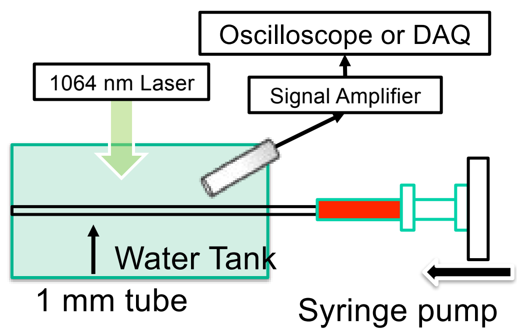
Flow velocity of platelet varies by aggregation

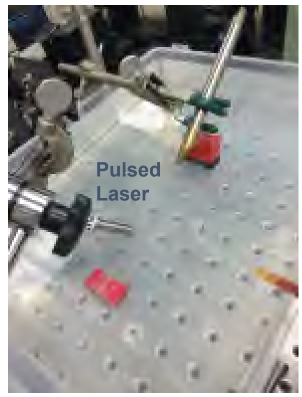
Spectroscopic photoacoustic Flow Measurement

- Spectroscopic property of different materials enable to differentiate each signals through PA.

Spectroscopic Photoacoustic Flow Measurement
Goal of the project

1. Development of PA flow measuring system

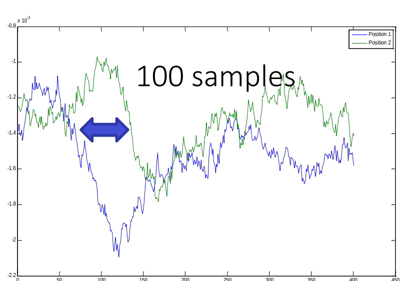




Spectroscopic Photoacoustic Flow Measurement
Goal of the project

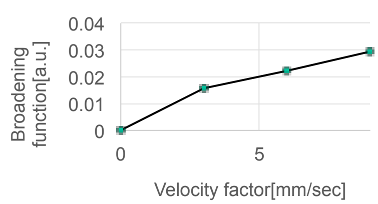
2. Development of PA Doppler algorithm

$$B_d = K\left(1 - \left|\sum\sum p_j p_{j+1}\right| / \sum\sum p_j p_j\right)^{1/2}$$



$$B_d = \frac{k}{T}\left(1 - \frac{\left|\sum_{j=1}^{n} p_j p^*_{j+1}\right|}{\sum_{j=1}^{n} p_j p^*_j}\right)^{1/2}$$

K: Calibration function



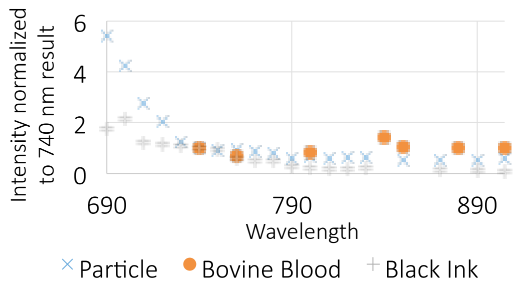
Cross-correlation based method

Spectral broadening based method

Spectroscopic Photoacoustic Flow Measurement
Goal of the project

3. Operating phantom experiments to proof the concept

- Different materials with their own spectral characteristics can be used to test our hypothesis.



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Spectroscopic Photoacoustic Flow Measurement
Project description

- Expected tasks:
  – Learn photoacoustic imaging and flow measurement
  – Work with laser system and ultrasound system
  – Writing signal processing algorithms including Doppler analysis
- Deliverable:
  – Establish photoacoustic flow measurement experiment setup
  – Testing algorithms through phantom experiment
- Size group: 1-2
- Skills:
  – Programming experience (MATLAB or C/C++)
- Mentors:
  – Emad Boctor
  – Haichong "Kai" Zhang

Mobile-Based Blood Flow Analysis of Chronic Wounds

TISSUE ANALYTICS
SIMPLIFYING WOUNDCARE

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Chronic Wounds

8.5 million patients

$30 billion spent each year

Insufficient access to care

Crude measurement technology

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Importance of Perfusion (Blood Flow) Measurement

- **Essential** for characterizing healing of wounds
- **Standard of Care**: Laser Doppler Imager (LDI), a $100,000 device.
- Wait time to get checked by Doppler is 3-4 weeks i.e. **too long**

Laser Doppler Imager

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Solution Criteria

Must-Haves

1. Input (e.g. video, series of photos) takes **<2 min** for user to obtain
2. Can be performed by a non-technical clinician (e.g. a nurse)
3. Solution leverages **existing** smartphone technology
4. Ability to classify perfusion in at least 3 bins (**good, medium, bad)**

Nice-to-Haves

1. No additional hardware added
2. Output takes <20 min to render after input is obtained
3. Meaningful visualization of surface blood flow produced

Possible Approach #1: Leverage Eulerian Video Magnification Software

- Eulerian Video Magnification (EVM) developed by MIT CSAIL Lab allows visualization of color flow
- Could develop a learning model that would be able to map EVM output to Laser Doppler Output (see Fig 1)

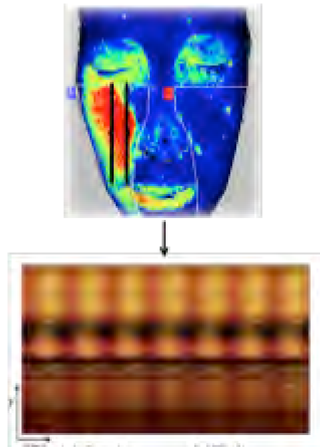

Figure 1: Mapping of LDI Output (above) to EVM output (below)

Possible Approach #2: Use of Minimalist Hardware Attachment

Single-Point Laser Doppler

- Use of small, LDI-based attachment may be able to provide a crude measurement

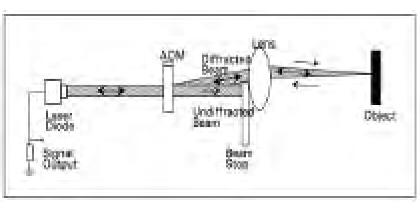

Figure 2: LDI Sensor Diagram

***Photoacoustic* Sensor**

- Placement of low-cost ultrasound probe adjacent t wound combined with laser based phone attachment

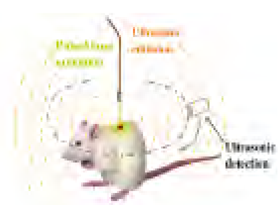

Figure 3: Photoacoustic Set-Up

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Project Overview

Deliverables

- Software-based proof of concept of solution
- If hardware-based, sensor identified and software-interface developed
- See slide 4 for more specific info

Size of Group

- 1-3 Students

Required Skills

- Matlab and Python. C/C++ are a bonus.

Mentors

- Dr. Emad Boctor
- Joshua Budman, M.S.E

Special Incentives!

•Potential for paid internship at Tissue Analytics for Summer of 2015

•Existing budget to cover material costs, if any

•Successful solution will be deployed to real customers **immediately**

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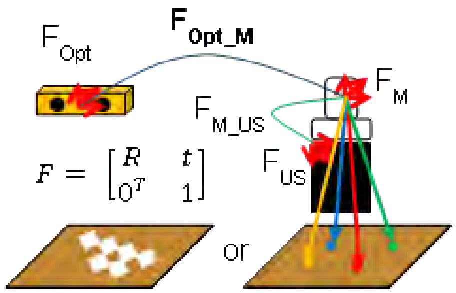
Real-time Virtual Rigid Body Tracking

- Motivation
  - Image guided interventions often require tools to be tracked by an external tracker
  - Many use optical trackers but..
    - The laparoscopic workspace is limited, so the size of the marker is also limited
    - The marker must be in the field of view, but may not necessarily be in the region of interest
- Solution
  - Virtual Rigid Body!!

Real-time Virtual Rigid Body Tracking



Cheng A. et al., "Virtual Rigid Body: A New Optical Tracking Paradigm in Image Guided Interventions". To Appear in SPIE Photonics 2015

- The camera can focus completely on the region of interest and continue to track the tool as the virtual rigid body is being projected onto the region of interest
- The size of the virtual rigid body can be as big as the field of view of the camera!
- Preliminary results show comparable positional accuracy to conventional optical tracking

Real-time Virtual Rigid Body Tracking

- **What Students Will Do:**
  - Task #1: Experimental testing for various dye including VSD, and PH sensitive dye
  - Task #2: In controlled experiments, measuring action potential using spectroscopic photoacoustic approach
  - Task #3: Develop and test these PA methods on a small animal model at the hospital.
- **Deliverables:**
  - Accomplishing tasks 1 - 3
  - Experimental design and hardware configuration
  - Data analysis and image reconstruction
  - As maximum deliverable and if time permits, students may test their approach in a more realistic setting using skull phantom
- **Size group:** 1-2
- **Skills:** C++ or MATLAB, ultrasound basics, and signal processing
- **Mentors:** Arman Rahmim, Emad Boctor, Behnoosh Tavakoli

Portable ultrasound 3D scanning

- Motivation
  - A need for affordable computer guided controller to replace high-cost robot arm
  - Limited range of reachability of robot arm
  - Portable scanning device
    - 3D Ultrasound scanning can be performed at any place, not in operation room with robot arms
- Solution
  - Portable moving robots!!

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Solution? Ollie, Sphero

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Portable ultrasound 3D scanning

What Students Will Do:
Design and develop the mechanical structure, software tools to enable control ultrasound attached device

Deliverables:
Mechanical design to fix ultrasound probe on Ollie. Software configuration and function implementation with Ollie SDK. Ultrasound data collection with designed device. Evaluating feasibility and error.

Size group: 1-2

Skills: java(Android or iOS) , CAD

Mentors:
Emad Boctor
(eboctor1@jhmi.edu)
Younsu Kim
(ykim99@jhu.edu)

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RGB-D and X-ray Calibration for Camera Augmented Mobile C-arm (CamC)

CamC is the first medical augmented reality solution deployed within the surgery room and used for more than 40 interventions. It has shown its main positive impact in X-ray positioning , incision placement, target locating, foreign body removal, and K-wire drilling.

RGB-D and X-ray Calibration for Camera Augmented Mobile C-arm (CamC)

CamC allows the fusion of X-ray and the optical camera. The innovation behind CamC relies on its unique off-line calibration phase. Both the optical and the X-ray imaging systems are mounted rigidly on the mobile C-arm, therefore calibrated in the same coordinate system in an off-line process.

The direction of the current project is to integrate a RGB-D camera (e.g. Kinect) into the current framework, and having it calibrated with the current setup.

RGB-D and X-ray Calibration for Camera Augmented Mobile C-arm (CamC)

- **What Students Will Do:**
  - Getting familiar with the existing framework of the CamC
  - Integration of the Kinect into the CamC
  - Calibration of the Kinect with the X-ray source
  - Fusion of the 2D Kinect view with the CCD camera and the X-ray source
  - Validation on bone phantoms
  - Evaluation
- **Deliverables:**
  - Calibrated Kinect view into the application machine.
  - Overlaid views from Kinect, CCD camera, and the X-ray image.
- **Size group:** 1-3

RGB-D and X-ray Calibration for Camera Augmented Mobile C-arm (CamC)

- **Skills:**
  - Strong programming background with C/C++ is necessary
  - The following skills are a plus:
    - Kinect application
    - Point Cloud Library (PCL)
    - OpenCV
    - Basic knowledge in computer Vision
- **Mentors:**
  - Bernhard Fuerst
  - Nassir Navab
  - Contact: camp@jhu.edu

Path planning for robotic intra-operative SPECT

The involvement of the lymph nodes is the most important prognostic factor in women with early stage cervical cancer. However, radical lymphadenectomy is associated with significant morbidity. Therefore, the Sentinel Lymph Node Biopsy (SLNB), which is a safe and accepted procedure, is performed in these cases. Identifying deeply seated SLNs intraoperatively is difficult due to limited access and maneuverability → **SPECT imaging** comes into play

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Path planning for robotic intra-operative SPECT

Robotic SPECT can help reduce scan times and completely remove the human error factor.

The Problem: The path the robot has to take to perform a suitable reconstruction has to be planned and varies according to the patients physionomy, body part under study, etc.

Path planning for robotic intra-operative SPECT

What Students Will Do:

- Get familiar with state of the art path planning techniques
- Get familiar with the KUKA robot API
- (Possibly) get familiar with a Kinect API (OpenNI, NUI)
- Develop software for path planning:
  - Handle user input re: area under study;
  - Calculate a "good-enough" path for the robot to execute;
  - Have the robot execute the pre-calculated path.
- Validate & evaluate.

Deliverables:

- Software that can plan a "good enough" path for a reconstruction based on a user-given area of interest.

Size of group: 1-3

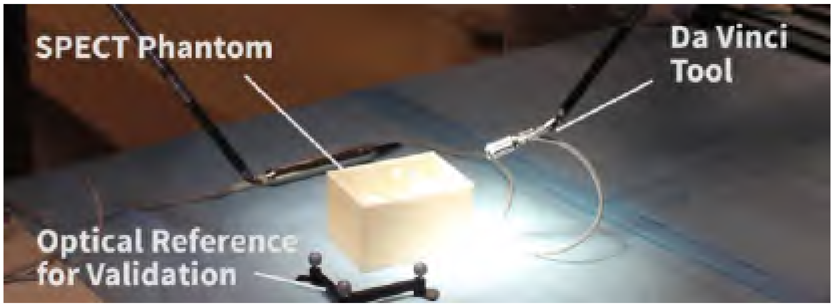
Path planning for robotic intra-operative SPECT

- **Skills:**
  - Strong programming background is necessary
  - The following skills are a plus:
    - C++ or C;
    - Basic knowledge in robotics;
    - Mathematics background.

- **Mentors:**
  - Bernhard Fuerst
  - Nassir Navab
  - Contact: camp@jhu.edu

Tracking of Gamma Probe for da Vinci

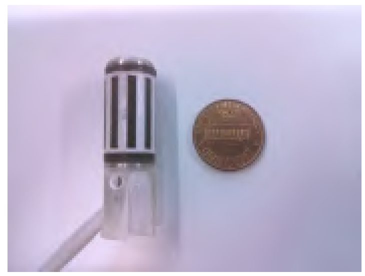
The involvement of the lymph nodes is the most important prognostic factor in women with early stage cervical cancer. However, radical lymphadenectomy is associated with significant morbidity. Therefore, the Sentinel Lymph Node Biopsy (SLNB), which is a safe and accepted procedure, is performed in these cases. Identifying deeply seated SLNs intraoperatively is difficult due to limited access and maneuverability.



Tracking of Gamma Probe for da Vinci

By collecting data laparoscopically using a prototype Gamma probe, we attempt to improve the reconstructed SPECT image's quality.

The Problem: A vital component of a good reconstruction is quality tracking of the probe. For this, we can combine video from the stereo 1080p endoscopic DaVinci camera and kinematics information from its API.



Tracking of Gamma Probe for da Vinci

- **What Students Will Do:**
- Get familiar with vision techniques
- Get familiar with the DaVinci research API
- Develop software for tracking the probe:
  - Acquire and process image frame, kinematics data;
  - Apply vision/other techniques to estimate pose;
  - Use AR techniques to overlay 3D model of probe on top of image data (optional);
  - Store the pose information in a way that makes it easy for this software to be integrated into existing ones.
- Validate & evaluate.

- **Deliverables:**
- Software that can track the probe on-the-fly from a video or live view and return its pose up to a pre-defined level of accuracy

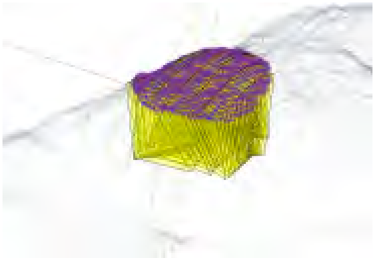
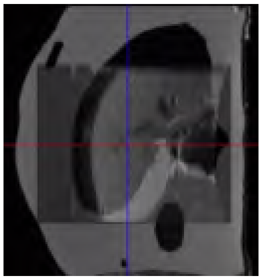
- **Size of group:** 1-3

Tracking of Gamma Probe for da Vinci

- **Skills:**
  - Strong programming background is necessary
  - The following skills are a plus:
    - C++ or C;
    - Basic knowledge in robotics;
    - Basic knowledge in Computer Vision;
    - OpenCV.
- **Mentors:**
  - Bernhard Fuerst
  - Nassir Navab
  - Contact: camp@jhu.edu

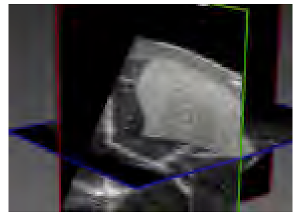
Ultrasound-based Visual Servoing

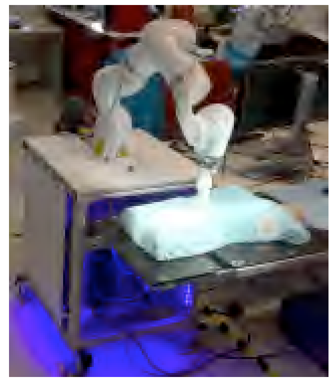
Robotic ultrasound is a thriving branch of computer assisted medical intervention research. Our goal is to find the ideal ultrasound scan of a predefined volume of interest inside the patient. Based on MRI (or CT) data, a surgeon can select a desired anatomy and our robot will automatically scan the patient accordingly. But due to deformations and organ movement, the reality differs from the dataset. For the perfect result we need to take the US image data into account.

Ultrasound-based Visual Servoing

ImFusion





ImFusion is a medical imaging software suite developed by CAMP fellows in Munich and provides a plugin interface for easy enhancement. For every ultrasound scan we need to find the distance between the desired anatomy and the actual scan. Based on this information, the robot can re-scan at the updated location.

The ultrasound probe is mounted on a KUKA iiwa lightweight robot, which can be programmed in Java through the proprietary Sunrise framework. It provides a communication interface in C++ which we can use inside ImFusion.

Ultrasound-based Visual Servoing

- **What Students Will Do:**
  - Getting familiar with KUKA Sunrise and imFusion
  - Registration of ultrasound and MRI (or CT) images
  - Re-calculation of a planned path based on registration
  - Develop reliable communication between imFusion and robot based on Sunrise.Connectivity framework
  - Validation on ultrasound phantoms
  - Evaluation of different registration techniques

- **Deliverables:**
  - ImFusion plugin for automated US-MR registration and distance calculation
  - KUKA Sunrise application for registration-based repositioning of the ultrasound probe

- **Size group:** 1-3

Ultrasound-based Visual Servoing

- **Skills:**
  - Strong programming background in Java **OR** C++ is required
  - The following skills are a plus:
    - Robotics application development
    - OpenGL & GLSL
    - Basic understanding of Ultrasound & MRI
    - Basic knowledge in Computer Vision
- **Mentors:**
  - Bernhard Fuerst
  - Nassir Navab
  - Contact: camp@jhu.edu

Robotic Hip Bone Cutting With Real Time Motion Reflexes

Start with a beautiful, seriously cool, and brand new design of high performance robot arm featuring precise torque sensors in every joint. Then, add an optical tracker for real time visual feedback.

Students Will: Build the software tools to cut an implant shape from bone, then add the ability to sense and adjust for bone movement in real time.

Basic Demos: Simulated, Stationary, and Moving bone cutting using a phantom (dummy)

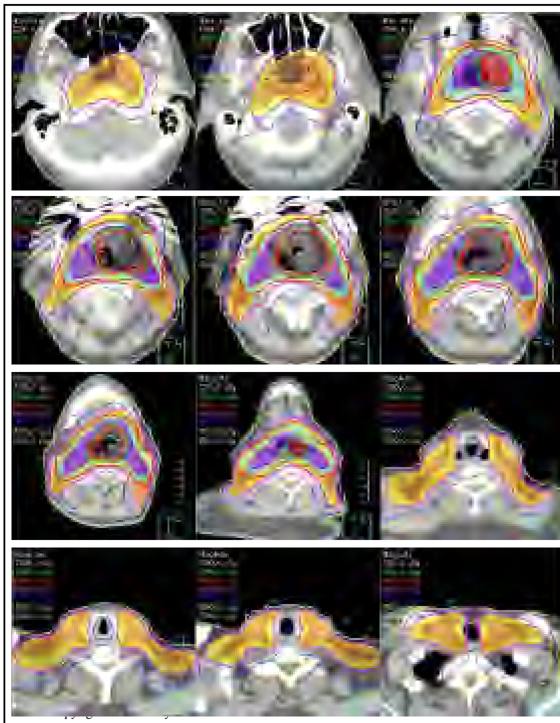
Stretch Demo: response to humans and obstacles contacting the arm

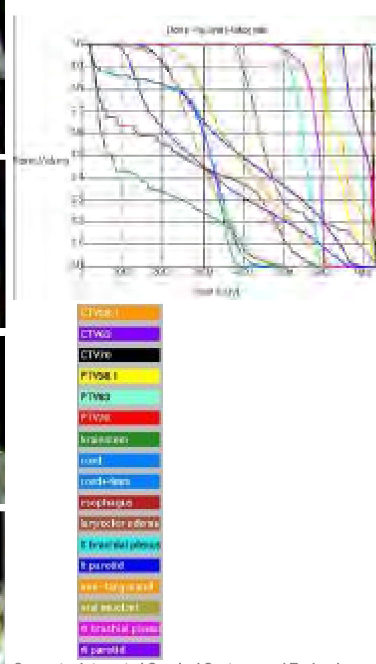
Group Size: 3
Skills: Work Hard, Play Hard, C++, Linear Algebra, Differential Equations, Robotic Manipulation, Trajectories, Planning, V-Rep Robot Simulator, Java

Student Participant: Andrew Hundt ahundt@jhu.edu
Faculty Mentor: Peter Kazanzides pkaz@jhu.edu

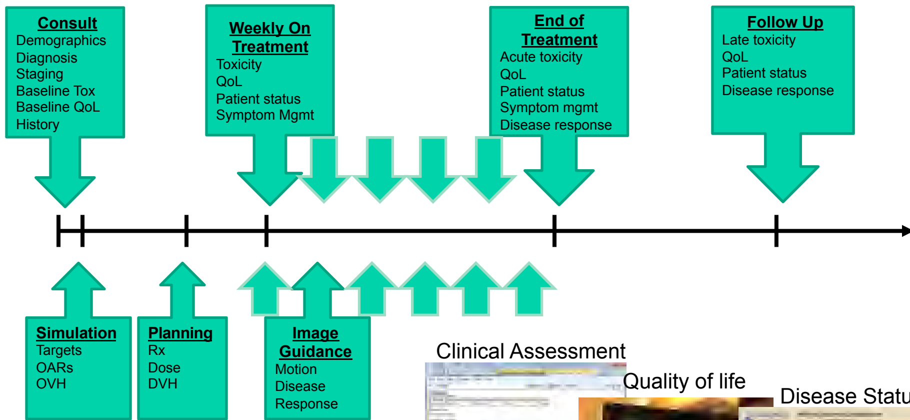
Error Correction for a Learning Health System in Radiotherapy

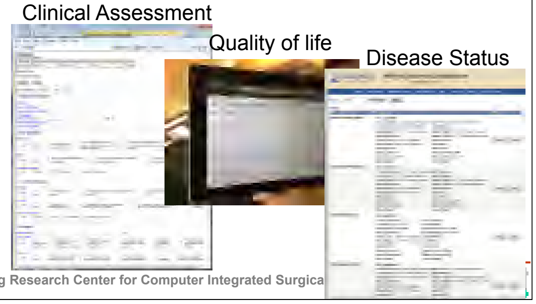
- The overall goal is to improve the integrity of the clinical data to be used in the learning health system with a system that can search through clinical data and identify potentially erroneous data. The system will report findings, possibly tag or correct them and have the potential to provide real time feedback during data collection in the clinic.
- **What Students Will Do:**
  - Develop framework to run on the database that respond to errant data
  - Allow for customized data integrity checks to be easily added as the system grows and the needs are identified.
  - Initial data checks will include excessive changes in clinical status such as weight
  - The system will be constructed to report findings in 3 ways
    - Listed report of all detected errors
    - Ability to tag data as suspect
    - Provide real time check on single data point entry when it is possible
- **Deliverables:** The overall framework and the documented API for developing new integrity checks
- **Size group:** 1-3
- **Skills:** SQL, C#, Object Oriented Design, Appreciation for how clinical data is collected and the types of errors that may occor
- **Mentors:**
  - Todd McNutt (tmcnutt1@jhmi.edu)
  - Sierra Cheng (zcheng4@jhmi.edu)
  - Scott Robertson (scott.p.robertson@jhmi.edu)



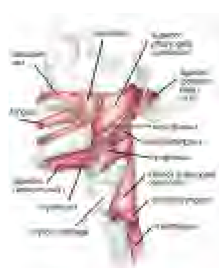


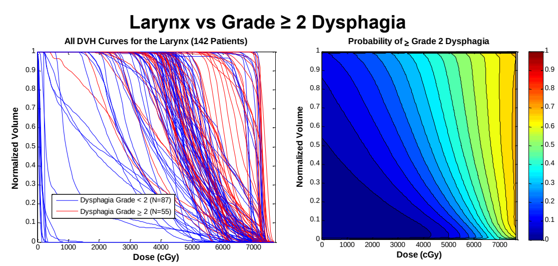
Treatment Timeline

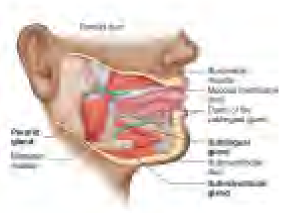


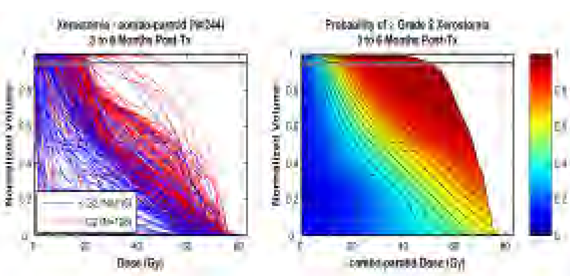


Dysphagia and Xerostomia









Learning Health System

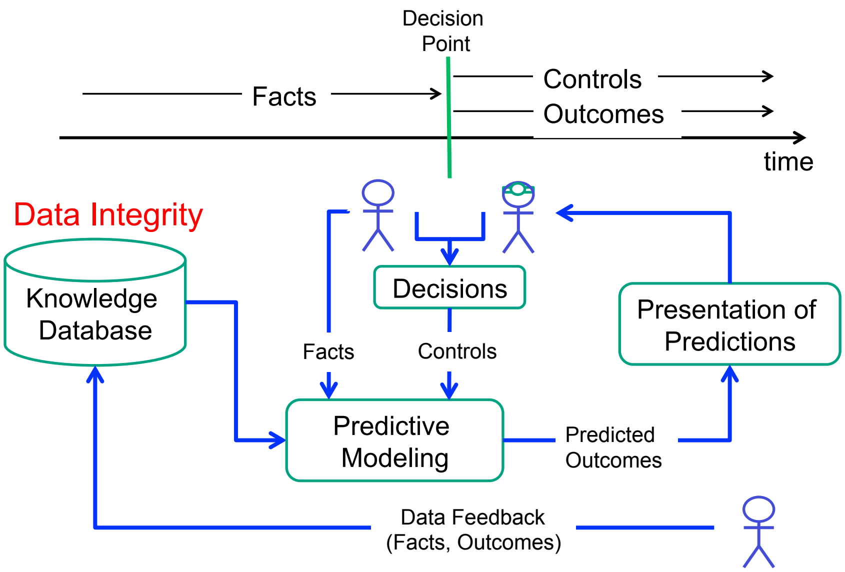


Image Processing for Video-CT Registration in Sinus Surgery

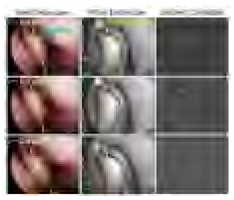
- In order to accurately navigate an endoscope during sinus surgery, we propose video-CT registration to accurately localize the scope. This involves computer vision techniques to reconstruct both the motion of the camera and the structure of the anatomy.
- **What Students Will Do:** develop an algorithm that can detect "occluding contours" in a video image for input into our video-CT registration algorithms. Upon successful completion, students will then develop a virtual overlay demo which shows anatomy from the CT in the endoscopic video frame, both visible and hidden.
- **Deliverables:**
  - Algorithm, code, and results for occluding contour detection (minimal deliverable)
  - Code and video demonstration of AR overlay of CT in video (maximal deliverable)
- **Size group:** 2-3 people
- **Skills:** basic computer vision, machine learning, graphics for rendering
- **Mentors:** Dr. Austin Reiter, Seth Billings

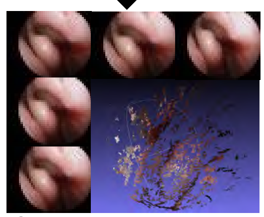
Registration Pipeline

Magnetic Tracker +
Monocular Endoscope

Data Capture System
(Publish/Subscribe
images/transforms)

Parallel Registration Algorithms (potential for inter-communications)





...

Arbitrary other registration algorithms may plug-and-play with our pipeline

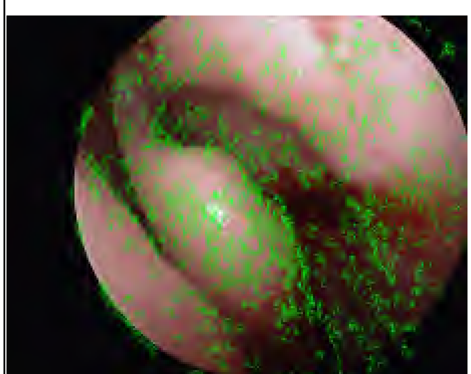
Gradient-based Virtual Template Matching

- Construct virtual templates from CT
- Match to video using correlation metric
- Optimize with GPU

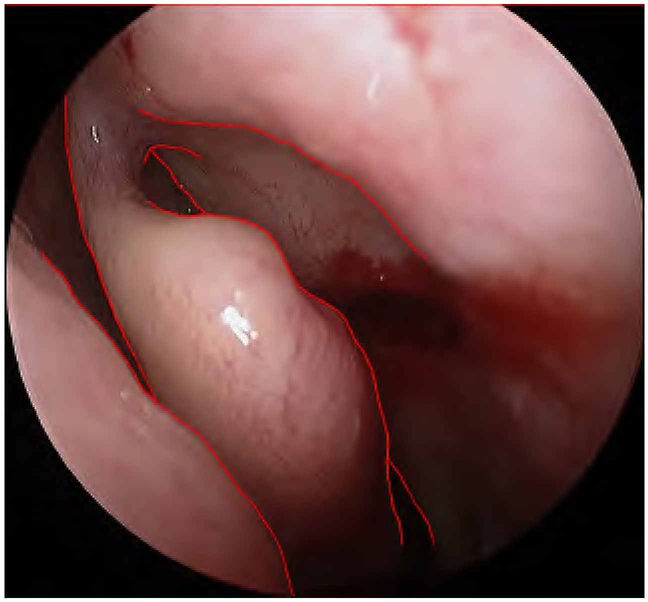
Sparse Bundle Adjustment

- Use magnetic tracker and/or template matching to disambiguate scale
- HMA for better feature matching
- Service-based system

Sparse Bundle Adjustment + Dense Reconstruction

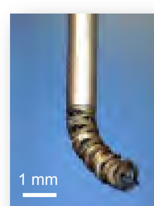


Example Occluding Contours



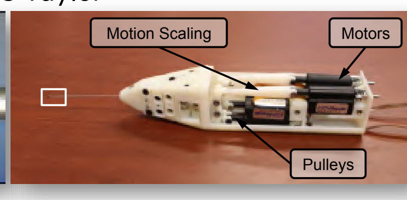
IRIS: Integrated Robotic Intraocular Snake

- Vitreoretinal surgery is one of the most challenging microsurgery disciplines. A tendon-driven snake micro-manipulator can provide dexterous intraocular tool motion.
- **What Students Will Do:**
  - Conduct experiments
    - To optimize the snake mechanism
    - To determine design specifications for the actuation unit
  - Develop a compact actuation unit with high precision motors
  - Integrate of tendon force sensing
  - Design control algorithm for IRIS



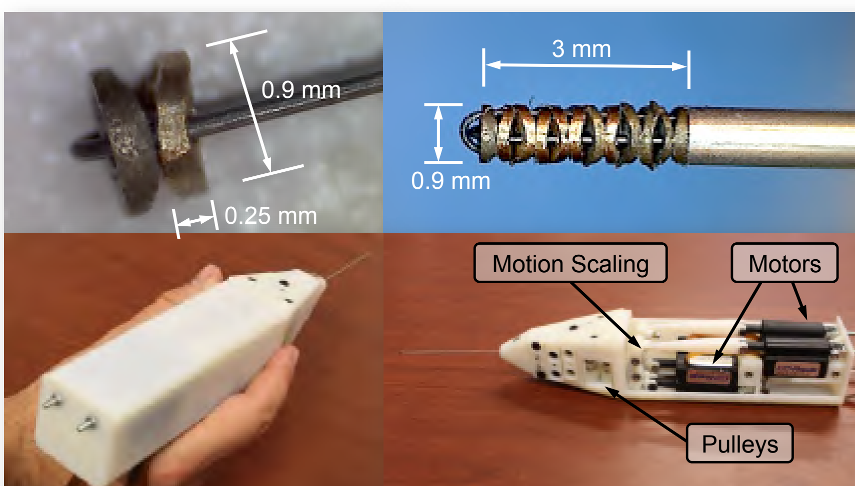
IRIS: Integrated Robotic Intraocular Snake

- **Deliverables:**
  - Prototype of the IRIS actuation unit
  - Control algorithms
  - Experimental results
- **Size group:** 2
- **Skills:**
  - Required: Good analytical skills, CAD, Programming (Matlab, C/C++)
  - Desired: Control Theory, Electronics, Prototyping, Embedded Systems
- **Mentors:** Xingchi He, Dr. Peter Gehlbach, Dr. Iulian Iordachita, and Dr. Russ Taylor



IRIS: Integrated Robotic Intraocular Snake

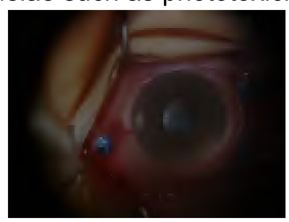
- Current status



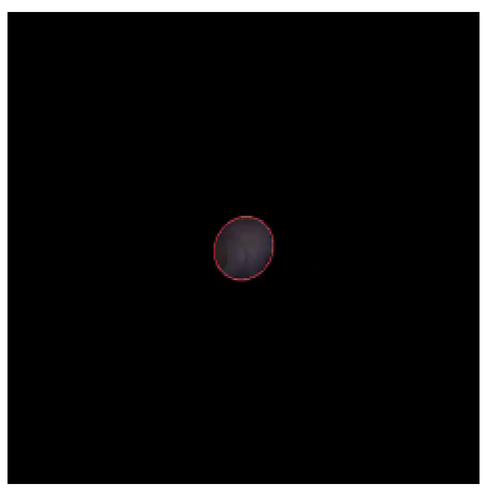
Reconstruction of Light Position from Shape of Illumination

Description: In Vitreoretinal surgery the surgeon uses a handheld instrument equipped with a fiber-optic light pipe to illuminate the retina from inside the eye. On microscopic images only the tip of the light pipe may be visible but not the shaft, thus the location of the light pipe cannot be reliably determined by just looking at the instrument itself. In this project we aim to determine the light pipe's position and orientation by looking at the shape of the illumination pattern on the surface of the retina.

Significance: This project is an important enabling step in an ongoing effort to create a “light exposure map” during retinal surgery and to correlate this map with clinical sequelae such as phototoxicity.



Reconstruction of Light Position from Shape of Illumination



Reconstruction of Light Position from Shape of Illumination

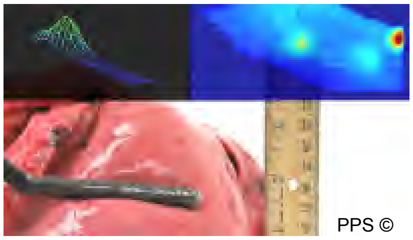
What Students Will Do:
- Build upon existing implementation
- Calibrate light pipe to determine illumination profile
- Determine light pipe pose from illumination
- Compute intensity profile
- Accumulate to make exposure map

Deliverables:
- Working implementation
- Demonstration & validation on phantom
- (Maximum) Demonstration on captured video images

Size group: 1-2
Required Skills: Image Processing, Programming (Matlab or C++)
Desired Skills/Course Background: Computer Vision
Mentors: Balazs Vagvolgyi (balazs@jhu.edu)

Optimized Tissue Structure Modeling and Abnormality Detection

- Goal:
  - construct a model of 3d geometry and/or surface stiffness of an organ/tissue using range and/or force sensor data
  - select next sample point optimally by optimizing stochastic model quality or by seeking extrema in predicted model


PPS ©

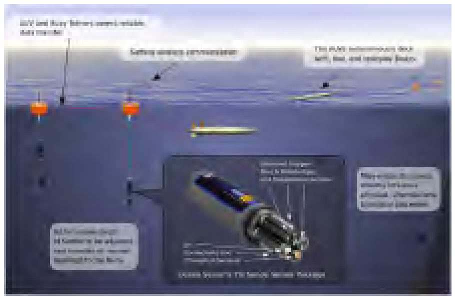
Tactile Mapping:
Where to press next to create the best possible stiffness model?

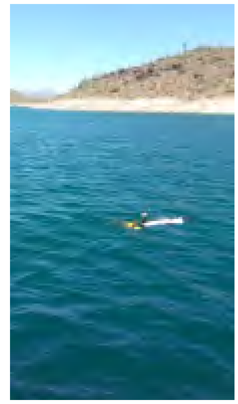

Fraunhoffer ©

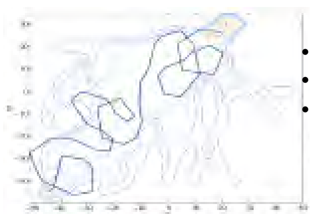
CT Mapping:
How to create the best 3D model with minimum images.

A conceptually related project:

Motion planning for adaptive sampling with underwater vehicles





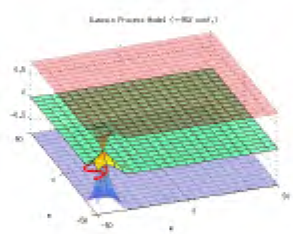


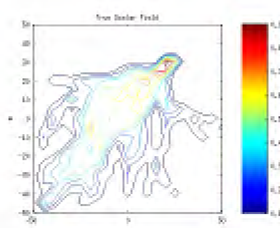
- Gaussian Process modeling
- Stochastic path optimization
- Seek Maximum

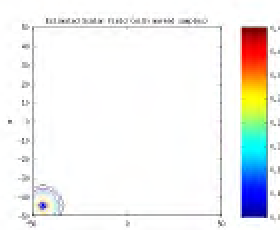
Iver 2 AUV

Adaptive sampling with underwater vehicles

Example (simulated models) : *maximum concentration tracking*







Existing Setup: Palpation Experiment

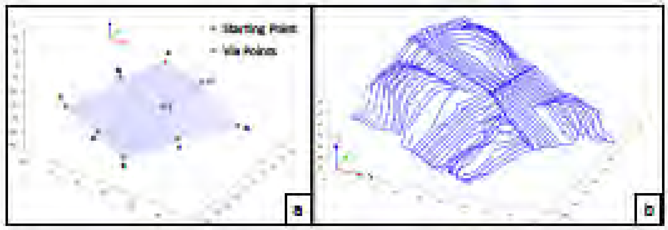


Fig. 10. Force-controlled Robot Exploration
a)is the planned scan pattern; b) is the actual scanned point cloud

Other existing infrastructure

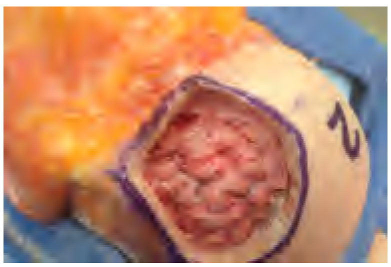
- C++ and MATLAB code for Gaussian process modeling and stochastic optimization
- Existing robot software and Hardware
  - DaVinci, LARS, Cartesian Stages
  - Force Sensing
  - Software runs all of the above
- Existing software for registration

Optimized Tissue Structure Modeling and Abnormality Detection

- **What Students Will Do:**
  - implement algorithms for creating 3D surface geometry and/or stiffness map over a given 3D surface using non-parametric modeling (e.g. Gaussian Processes);
  - implement path optimization for minimizing number of measurements vs model quality; and/or for localizing extrema
  - apply these tools to an existing TBD dataset
- **Deliverables:**
  - Matlab or C++ code to fuse measurements into a model
  - Matlab or C++ code to optimize tool/C-arm path
  - Demonstration using collected measurements from TBD
- **Size group:** two
- **Skills:** familiar with estimation concepts (or at least some statistics/probability theory); optimization is helpful
- **Mentors:**
  - Marin Kobilarov, marin@jhu.edu, Hackerman 117
  - Prof. Taylor, Preetham Chalasani

Image-guided Cranioplasty

- **Goal:**
  - Develop and demonstrate image-guided technology for improving immediate surgical repair of large cranial defects (>5cm^2) with customized cranial implants (CCI) following benign/malignant <u>skull</u> neoplasm (tumor) resection



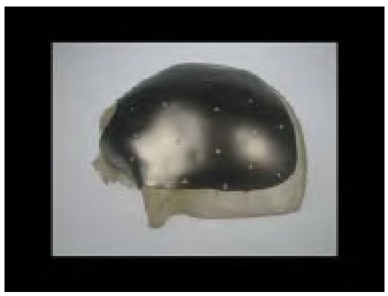


Image-guided Cranioplasty

- **Background:**
  - Many times it is challenging to reconstruct patients' skull with pre-fabricated implants since the actual size/shape is unknown until the tumor is removed.
  - The cranioplasty with perfectly sized CCI requires the patient brought back to the operating room at a second date (two-stage surgery).
  - A new approach (single-stage surgery) involves oversize design of the CCI in the preoperative phase. The implant will then be shaved to the actual required size/form in the operating room. The disadvantage is the considerable amount of time (average 40 minutes) for shaving the implant.

Image-guided Cranioplasty

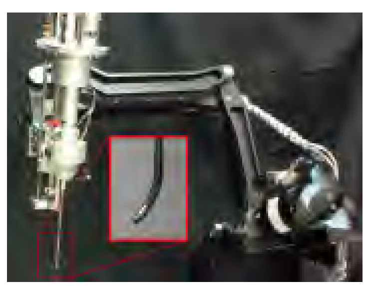
- **What Students Will Do:**
  - Develop a low-cost imaging procedure for intraoperative acquiring the contour of the skull fragment.
  - Segment the contour and register it to the preoperative CT image
  - Project the contour on the prefabricated oversized CCI to help the surgeon in shaving the exact size
- **Deliverables:**
  - Develop a low-cost system enabling the surgeon to resize the CCI in less than five minutes
  - Show the feasibility on plastic bones and cadavers.

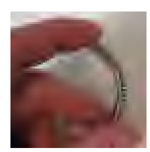
Image-guided Cranioplasty

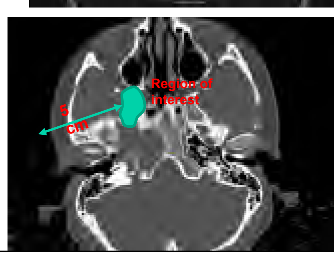
- **Group Size:**
  - One or two students
- **Skills:**
  - C++ and Matlab programing
  - APP development
  - Image processing (registration and bone segmentation)
- **Mentors:**
  - Chad Gordon (cgordon@jhmi.edu)
  - Mehran Armand (mehran.armand@jhuapl.edu)
  - Ryan Murphy (ryan.murphy@jhuapl.edu)

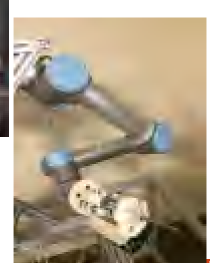
Skull Base Surgery with a Dexterous Manipulator

- ***Goal:*** *A* proof of concept study to show an existing JHU/APL dexterous manipulator can be used in lateral skull base surgery to reach the petrous apex without damaging the inner ear and can substantially improve the reach within the workspace when compared to the existing approaches





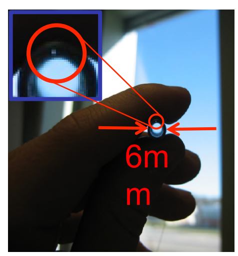




Skull Base Surgery with a Dexterous Manipulator

- *Background:*
  - Infralabyrinthine approach is one approach for reaching the tumor in petrous apex below the labyrinth of the inner ear (see the slides).
  - The surgical tools should pass an opening of 4 mm in diameter. The currently used rigid surgical tools have severe limitations for removing the tumor in the petrous aspect.
  - A cable driven Continuum dexterous manipulator (CDM) was initially designed for hip surgery can be scaled to use for this procedure. The CDM can be used to guide the tools to the region of interest.
  - CDM can be positioned in workspace manually or using a positioning robot (e.g. LARS or UR5 as shown)

Skull Base Surgery with a Dexterous Manipulator



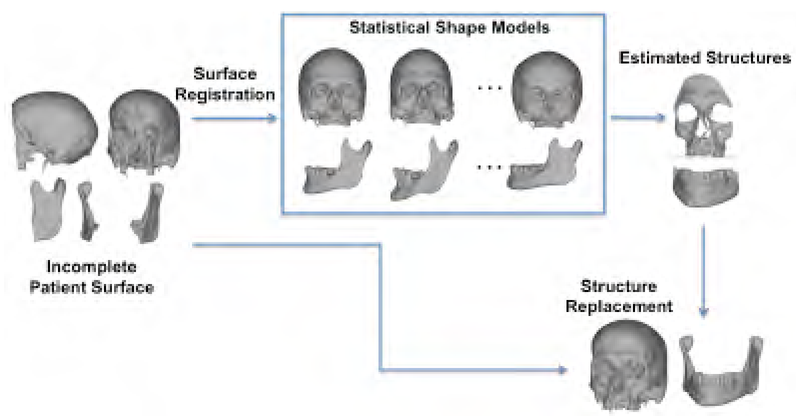
- **What Students Will Do:**
  - segment the surgical path in the CT scan
  - Simulate the motion of the CDM to ensure reaching the apex without disturbing the major nerve and substrates in the path
  - Simulate and demonstrate the reachability of the CDM within the apex.
  - Integrate an small endoscope passing through the hole (shown in the inset of the top figure)of within the wall of the CDM
  - Show the feasibility of the approach using the plastic phantom of the temporal bone and inner ear (bottom figure)
- **Deliverables:**
  - Show the feasibility by designing experiments to show that CDM can reach and safely operate within apex
  - Comparison of the reach of the CDM with conventional use of rigid tools

Skull Base Surgery with a Dexterous Manipulator

- *Size of Group:*
  - 2-3 Students
- *Skills:*
  - Experiments, Programming (C++ and/or Matlab)
- *Mentors:*
  - Dr. John Carey (jcarey@jhmi.edu)
  - Dr. Mehran Armand (mehran.armand@jhuapl.edu)
  - Dr. Hoa Liu(liuhao.hit@gmail.com)

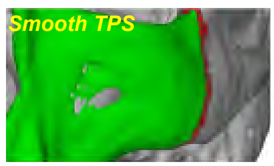
Smooth Extrapolation of Unknown Anatomy

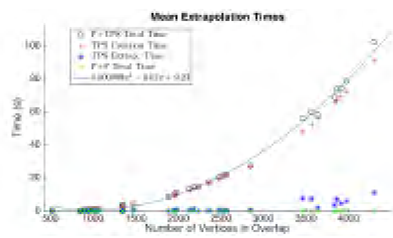
- Estimate a full model of a patient from partial anatomy for surgical planning and/or intraoperative navigation



Smooth Extrapolation of Unknown Anatomy

- We have an algorithm to perform extrapolation of anatomical structure via Statistical Shape Models and Thin Plate Splines (TPS)
- TPS construction is computationally expensive
- It would be nice to achieve a speed-up without sacrificing significant accuracy

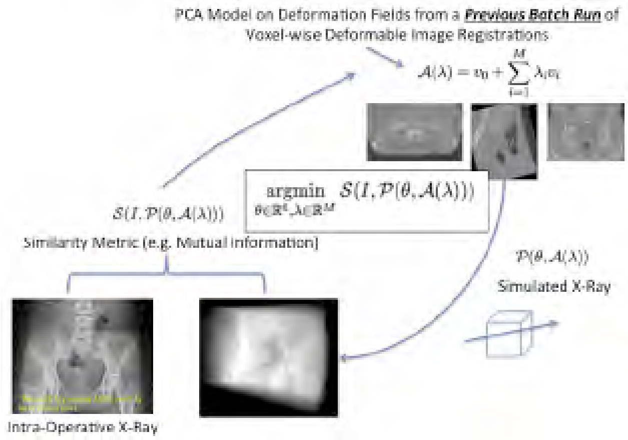


Smooth Extrapolation of Unknown Anatomy

- **What Students Will Do:** Implementation of various TPS approximations (at least 3) and/or alternatives
- **Deliverables:**
  - C++ Source Code
  - Source Code Documentation
  - Report comparing the speed of execution and accuracy of TPS approximations/alternatives v.s. the baseline TPS
- **Size group:** 1
- **Skills:**
  - C++, Image Processing, CIS 1 PA5
- **Mentors:**
  - Robert Grupp (grupp@jhu.edu), Prof. Taylor

2D/3D Patient-to-Atlas Registration

- Estimate a patient's 3D volume (CT) from a series of 2D radiographs
- Enable 3D surgical planning or navigation without a large dose of radiation (CT)



2D/3D Patient-to-Atlas Registration

- **What Students Will Do:**
  - Generation of reasonably accurate atlas/SDM that will fit on GPU memory
  - Implementation of Displacement Field DRR computation
  - Incorporation of SDM and DRR into optimization framework
    - Start with 1 X-Ray, but move to *n*
  - Implementation of atlas/SDM leave-out evaluation
- **Deliverables:**
  - Python, C++, CUDA source code
  - Source Code Documentation
  - Analysis of execution runtimes
- **Size group:** 2 for entire atlas/SDM pipeline, 1 for just DRR
- **Skills:**
  - Python, C++, CUDA/Open CL, Image Processing, Image Registration, Unconstrained Optimization, CIS 1 PA5
- **Mentors:**
  - Robert Grupp (grupp@jhu.edu), Prof. Taylor

Force-Sensing Microneedle for Retinal Vein Cannulation

- This project aims to modify a tremor-cancelling robot (Micron) for assisting retinal vein cannulation.

- **What Students Will Do:**
- Force sensor calibration/characterization
- New control mode(s) to aid cannulation (LabVIEW)
- Artificial retinal vein phantom, single subject experiments and statistical analyses (MATLAB)

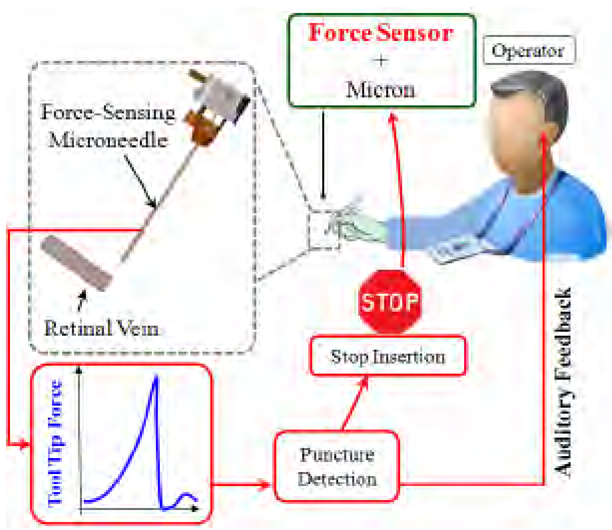
- **Deliverables:**
- Software: LabVIEW code
- Retina vein phantom
- Experimental results that demonstrate feasibility

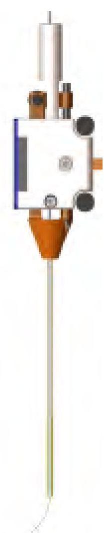
- **Size group:** **2** people
- **Skills:** LabVIEW, MATLAB

- **Mentors:** Berk Gonenc (bgonenc1@jhu.edu), Iulian Iordachita

Force-Sensing Microneedle for Retinal Vein Cannulation

- This project aims to modify an existing tremor-cancelling robot (Micron) for assisting retinal vein cannulation.





MRI-compatible needle driver:
1. Automatic needle shape extraction
2. Needle modeling & path planning: simulation

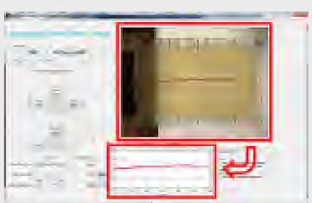
Two **main tasks** are incorporated in this project:
1.Real-time automatically extract needle shape and curve fit
2. Needle deflection modeling and trajectory prediction

What Students Will Do:
1. Image processing, Character extraction, Registration, 2D→3D Reconstruction
2. Math model, Simulation, Experiments

Deliverables: a math model, software, experimental results

Size group: 2 people
Skills: matlab (other image process software), basic control theory
Mentors: Meng Li, PhD student (limeng.jeeding@jhu.edu)
Iulian Iordachita, professor

Automatic needle shape extraction



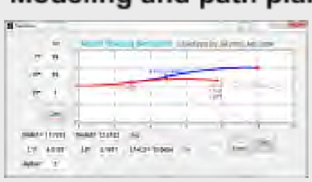
Description

Automatically extract needle shape and curve fitting

Image processing, Character extraction, Registration, 2D→3D Reconstruction

Requirement: Matlab
Difficulty: ★★☆☆☆

Modeling and path planning: simulation



Needle deflection modeling and trajectory prediction

Math model, Simulation, Experiments

Requirements: Matlab, control theory
Difficulty: ★★★★☆

Bonus

You will learn how to cook soft tissue phantoms. It's fun.

You're likely to be a co-author of corresponding papers.

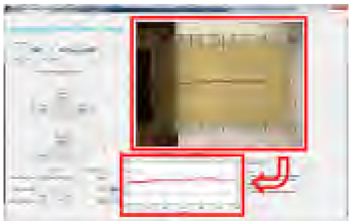
Notice

You may be asked to help on mechanical or electronical refinement work of the robot system, based on your ability and interest.

Mentor

Meng Li, PhD student
Iulian Iordachita, Professor

Task 1: Automatic needle shape extraction



This part of work is relatively simple but important, its results serve as the ground truth for the second part.

A lot of similar program can be found on internet and literature, which may help you develop fast.

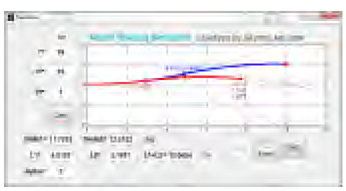
My project is about automatic needle placement into soft tissue. The needle driver is a 2 DOF robot, which can perform needle insertion and rotation movement.

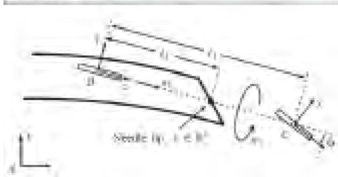
To evaluate the effect of insertion, 1 or 2 cameras are engaged to capture the shape of the needle (as shown in figure). Accurate 2D or 3D needle shape and position are crucial to model correction.

Right now, I use cursor to manually retrieve the points on the needle, and based on which, apply polynomial fitting to the curve. This is time consuming and lack of precision. I expect an real-time automatic needle shape extraction software integrated in my matlab GUI to help complete the task.

The needle is inside the phantom and has good contrast to the background. Binaryzition and thresholding methods have considerable result according to my previous attempts. After that, character extraction algorithm will be used to detect points belong to the needle. Polynomial fitting, reconstruction of 3D needle shape and register it to the robot frame are the last procedures.

Task 2: Needle modeling & path planning: simulation





Nonholonomic Modeling of Needle Steering. R J Webster, et al. 2006

Basic:
1. Test different models;
2. Predict needle path;

Upper level:
3. Real-time path updating with respect to target position

Advanced:
4. Real-time path updating with tissue stiffness

The needle is called a “bevel tip” needle. During insertion, the needle will bend to one side as shown in the figures. To achieve accurate target position, needle “steering” approach is used to rotate the needle during the procedure and make it bend toward a different direction.

On one hand, modeling the behavior of needle is essential. Based on the model, one also has to determine when and how to steer the needle. The first figure shows the trajectory prediction based on one of the models in previous literature.

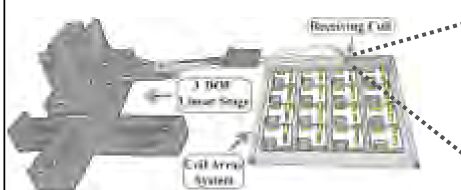
There are several models people have built. I will use an advanced tool and an innovative approach in experiments to examine theses models. I will also try to build my own model.

You will help build models relating to different tissue stiffness and target position. When a model is at hand, help simulate the procedure in Matlab, generate the predicted trajectory. As a step forward, the path can be updated in real-time. We will conduct experiments in soft tissue phantoms to evaluate the models.

Sensor Fusion of 6-DOF Tracking using EM and IMU with Metal Compensation

- **Goal**: Implementing a hybrid tracking sensor fusion algorithm, using EMT and inertial sensing, to create a tracking system that has high accuracy and minimal susceptibility to metal objects
- **What Students Do**
  - Calibrate the existing IMU and EM Tracker with AX=XB
  - Implement a real-time Extended Kalman Filter(EKF) sensor fusion algorithm which is already tested on synthetic data
  - Perform tracking experiments with a robot as ground truth
  - Help in publishing a paper based on the results
- **Deliverables:** sensor fusion, EKF, demos, signal processing
- **Size group:** 1-2
- **Skills:** C++, Basic Matrix Operations
- **Mentors:** Prof. Kazanzides, Tutkun Sen

Sensor Fusion of 6-DOF Tracking using EM and IMU with Metal Compensation



Custom EMT with IMU (Fraunhofer IPA)

Tracking Systems :

Enable the doctor to visualize anatomical information, derived from preoperative or intraoperative images, registered with respect to the actual patient anatomy.

- ✓ At each board, there are 3 transmitter coils placed perpendicular
- ✓ Each transmitter coil is excited sequentially and the induced voltage at the receiving coil is measured
- ✓ Based on the measured voltage, the position of the receiving coil is estimated

Electromagnetic Tracking

- ✓ Tracking accuracy 0.5 mm ~ 1.0 mm
- ✗ Requires wired sensor
- ✗ Susceptible to ferromagnetic materials

Electromagnetic + Inertial (Hybrid) Tracking

- ✓ As accurate as optical tracking (?)
- ✓ No line of sight constraints
- ✓ Minimal susceptibility to ferromagnetic materials (?)
- ✓ 3 axis Accelerometer, Gyroscope, Magnetometer IMU
- ✓ Custom wireless EMT+IMU system (Fraunhofer IPA)

2D/3D Patient-to-Atlas Registration

- **What Students Will Do:**
  - Generation of reasonably accurate atlas/SDM that will fit on GPU memory
  - Implementation of <u>Displacement Field</u> DRR computation
  - Incorporation of SDM and DRR into optimization framework
    - Start with 1 X-Ray, but move to *n*
  - Implementation of atlas/SDM leave-out evaluation
- **Deliverables:**
  - Python, C++, CUDA source code
  - Source Code Documentation
  - Analysis of execution runtimes
- **Size group:** 2 for entire atlas/SDM pipeline, 1 for just DRR
- **Skills:**
  - Python, C++, CUDA/Open CL, Image Processing, Image Registration, Unconstrained Optimization, CIS 1 PA5
- **Mentors:**
  - Robert Grupp (grupp@jhu.edu), Prof. Taylor

Real-time NLP on Clinical Documents

- The goal of this project is to implement and enhance methodologies to gather meaning out of clinical documents (radiology, lab, pathology) to calculate value-based outcomes using algorithms.
- **What Students Will Do:** students will be responsible of partnering with the JHM Technology Innovation Center engineers to implement NLP processes in a real-time setting working with Electronic Medical Record systems. They'll be partnering with an existing project with JHU APL engineers to extend ad-hoc systems to work real-time based on clinical systems.
- **Deliverables:** project scope documentation, clinical verification, annotations (if needed), system development, clinical integration
- **Size group:** 1-2
- **Skills:** NLP and healthcare experience are big pluses
- **Mentors:** Gorkem Sevinc (gs@jhmi.edu), Dean Kleissas (Dean.Kleissas@jhuapl.edu)

PACSPulse Proactive IT Monitoring Tool

- The goal of this project is to implement a novel NOC monitor to monitor health of large clinical systems with significant data. The Picture Archiving and Communications System (PACS) alone generates 100GB+ of logs each day with rich, unorganized data. This system will consume data from multiple clinical systems to provide a "health" dashboard for operations.
- **What Students Will Do:** Students will develop the methodologies to consume and analyze a large amount of data using open source and proprietary tools. They'll build predictive analytical dashboards based on the data to provide real-time, post-incident and forecasting views of operations to business owners.
- **Deliverables:** project scope documentation, system/ methodologies to consume large amounts of data, analytical dashboards to slice/dice data, business verification.
- **Size group:** 1-2
- **Skills:** big data, SQL/NoSQL, data analysis, dashboarding / visualization
- **Mentors:** Gorkem Sevinc (gs@jhmi.edu)

Johns Hopkins Health-E App

- The goal of this project is to leverage technology to increase medication adherence. Through a mobile application, patients will get reminders and manage their prescriptions in an integrated fashion – new medication prescribed by a doctor will automatically be present in patient's app, and the care providers will be able to monitor the patient's adherence of prescriptions.
- **What Students Will Do:** Students will be responsible of building the back-end and front-end infrastructure, along with the mobile application. They'll be responsible of integration with clinical systems and development of a design with realistic usability.
- **Deliverables:**
  - Project Scope Documentation
  - Functioning, integrated back-end
  - Functional mobile application
- **Size group:** 2-3
- **Skills:** web / mobile development, user interface / experience development
- **Mentors:** Gorkem Sevinc (gs@jhmi.edu), Francoise Marvel (fmarvel1@jhmi.edu)

Real-time use of PICU Acuity tracking for Dynamic Clinical Allocation and Training

- The goal of this project is to objectively measure patient acuity for assessing the needs of a pediatric ICU for the day. Two existing scoring systems in place are used for acuity and risk of mortality – Pediatric Early Warning Score (PEWS) and Pediatric Risk of Mortality Score (PRisM). A system for centralized unit management leveraging early warning systems and acuity will be built to better manage clinical staff allocation and training.
- **What Students Will Do:** Students will be responsible of understanding the PICU workflows, clinical allocation, building the back-end and front-end infrastructure and clinical interoperability with IT systems.
- **Deliverables:**
  - Develop a bed tracking system using physiological data from PEWS/PRisM
  - Develop active discharge prediction for patients in the PICU
  - Catalog of clinical skill strengths / weaknesses to identify gaps
- **Size group:** 2-3
- **Skills:** web and systems development
- **Mentors:** Gorkem Sevinc (gs@jhmi.edu), Jim Fackler (jim@jhmi.edu)

Mosquito Dissection

- **Goal:** Develop prototype technology and workflow for extracting the salivary glands from mosquitoes
- **Significance:** Part of a collaboration with a small company making a malaria vaccine
- **What Students Will Do:**
  - Learn current manual process
  - Work with existing project team on concept development
  - Develop and evaluate prototype
- **Deliverables:**
  - Prototype hardware and proposed workflow
  - Evaluation on uninfected mosquitoes
- **Size group: 1-2**
- **Skills:**
  - Simple CAD, rapid prototyping and fabrication skills
  - Computer vision, programming experience desirable
- **Mentors:** Prof. Taylor, Amanda Canezin