Photoacoustic Retinal Prosthesis: A New Paradigm Enabling Adaptive, High Resolution and Minimal-invasive Retinal Stimulation

Emad M. Boctor, Ph.D., Peter L. Gehlbach, M.D., Ph.D., Jeeun Kang, Ph.D.

Giving a piezo-optic (photoacoustic) sight to blind
Knowledge gap and developmental workflow

Microelectrode array (MEA)

Autonomous optimization of stimulation regime

- Light intensity
- Stimulation frequency
- Tone burst duration

Iterative optimizer for global optima

- Argmax (cellular response)
- Argmin (#iteration)

Optimal stimulation for cellular compartments

Photoacoustic Retinal Prosthesis:
A New Paradigm Enabling Adaptive, High Resolution and Minimal-invasive Retinal Stimulation

What Students Will Do: The objective of this project is to investigate and to develop a novel photoacoustic retinal stimulation approach. This technology can be deployed non-invasively to the retinal tissue and with high resolution (few microns) and adaptive stimulation. We will optimize stimulation parameters and validate this novel retinal stimulation platform using invitro studies.

Deliverables:
- Minimum Deliverables:
  - Develop and optimize retinal stimulation testing setup with both photoacoustic stimulation and real-time MEA recordings.
  - Develop optical scanning mechanism to scan 2 cm by 2 cm region.
- Expected Deliverables:
  - Optimize retinal stimulation mechanisms and performance characteristics.
- Maximum Deliverables:
  - Test and validate on retinal tissue.

Size group: 2 or 3
Skills: Experimental and mechanical design skills, and programming and data analysis skills.
Mentors: Jeeun Kang, Emad Boctor, Peter Gehlbach – eboctor@jhu.edu
Ultrasound-guided spine interventions often suffer from the insufficient visualization of key anatomical structures due to the complex shapes of the self-shadowing vertebrae. Therefore, we propose an ultrasound patch with redundant insonification to improve the key structure visibility. Further, there is a need for this wearable ultrasound technology to perform remote-controlled imaging in many clinical applications including fetal measurement. The project will focus on optimizing the current patch design and develop user interface to enable remote imaging with a novice user and remote expert.

**Ultrasound Patch**

- **What Students Will Do**
  - User interface: Design a tablet-friendly app or web interface to enable remote-controlled ultrasound acquisition.
  - Registration and Servoing: Develop a control algorithm for the ultrasound transducer to follow the needle. When the needle is inside the patient, the algorithm optimizes for optimal visualization of the needle tip; when the needle is outside, the physician uses the needle to control the transducer position. The transform between the needle and the ultrasound will be provided by camera-based marker tracking.

- **Deliverables**
  - Minimum: an app/web page with buttons to move the ultrasound probe, an algorithm to make the ultrasound probe track a needle, demo in simulation.
  - Expected: Demo on real hardware.
  - Maximum: A original, more user intuitive UI than what's described in the minimum deliverables. Demo in simulation or hardware. A conference presentation.

- **Size group**: 2

- **Skills**: programming, mobile app/web front end development, manipulator kinematics.

- **Mentors**: Keshuai Xu ([keshuai@jhu.edu](mailto:keshuai@jhu.edu)), Emad Boctor ([eboctor@jhu.edu](mailto:eboctor@jhu.edu)), Peter Kazanzides ([pkaz@jhu.edu](mailto:pkaz@jhu.edu))
3D ultrasound spine volume rendering with deep learning

- With a novel patch-ultrasound device, multi-angle spine volumes can be reconstructed. In this project, we are going to investigate the use of deep learning to model the rendering transfer function for spinal structure enhancement.

- **What Students Will Do:** The students will collect ultrasound data, develop deep learning algorithms for spinal structure rendering enhancement and analyze the results.

- **Deliverables:**
  - Minimum deliverables: An ultrasound dataset with mapped CT ground truth. A documentation for the dataset.
  - Expected deliverables: A deep learning algorithm developed and evaluated on the collected dataset, a readme file for code, a report for experiment results.
  - Maximum deliverables: Result analysis on potential animal experiment data. A paper manuscript for the project.

- **Size group:** 1 or 2

- **Skills:** Deep learning, computer graphics, ultrasound imaging

- **Mentors:** Baichuan Jiang (baichuan@jhu.edu), Emad Boctor (eboctor@jhu.edu)

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1. Scan the anatomy from multiple angles with a phased array probe.

2. Learning a volume opacity transfer function for rendering (enhancing the bone)

3. Render the spine anatomy in 3D

Collected tracked 2D US images

CT scan of the phantom for ground truth

3D ultrasound spine volume rendering with deep learning
Photoacoustic image based intra-operative surgical guidance system in a da Vinci surgical robot platform

• Clinical motivation
  • Nerve sparing radical prostatectomy
  • Post-operative complication
    • e.g., Erectile dysfunction, urinary incontinence

System diagram
Photoacoustic image based intra-operative surgical guidance system in a da Vinci surgical robot platform

• What Students Will Do
  • System integration & optimization
  • GUI programming

• Deliverables
  • (Minimum) Registration with manual data acquisition & tracking
  • (Expected) Semi-automated registration & tracking with GUI interface
  • (Maximum) Fully-automated registration & tracking

• Size group: 2
• Skills: programming skills including c++, python, and ROS
• Mentors: Hyunwoo Song, Hamid Moradi, Emad Boctor

Novel registration algorithm for surgical tool tracking using virtual markers

• Motivation
  • Surgical tool tracking using transrectal ultrasound (TRUS) transducer
  • Camera-Ultrasound image registration
  • Photoacoustic (PA) virtual marker
    • Not visible in camera image
      • $\lambda > 750$ nm
Novel registration algorithm for surgical tool tracking using virtual markers

• This project aims to implement a real-time photoacoustic (PA) image-guided surgical tool tracking system in a da Vinci surgical robot platform using virtual markers. A laser diode was attached to the surgical tool and pointing at the tool tip to generate photoacoustic point source which will be detected by the transrectal ultrasound (TRUS) transducer. We here develop a novel algorithm in which a laser line and the geometrical loci from photoacoustic reception are registered each other to enable TRUS to track the surgical tool tip.

• What Students Will Do
  • Data analysis, signal processing
  • System implementation
  • Some hardware works

• Deliverables
  • (Minimum) Simulation study of registration
  • (Expected) Validation in da Vinci robot
  • (Maximum) Automatic registration using GUI interface

• Size group: 2

• Skills: 
  • data analysis
  • programming skills including MATLAB, python, and ROS

• Mentors: Hyunwoo Song, Emad Boctor, Russ Taylor