ECE 445

Senior Design Laboratory Project Proposal

A Comprehensive Approach to Tumor Detection using RGB, NIR, and Immersive 3D Visualization

University of Illinois at Urbana-Champaign

Team Members:

- Zach Mizrachi (zdm3)
- TJ Shapiro (tylers5)
- Yue (Amy) He (yuehe4)

TA: Jason Zhang

February 8, 2024

Introduction

Problem

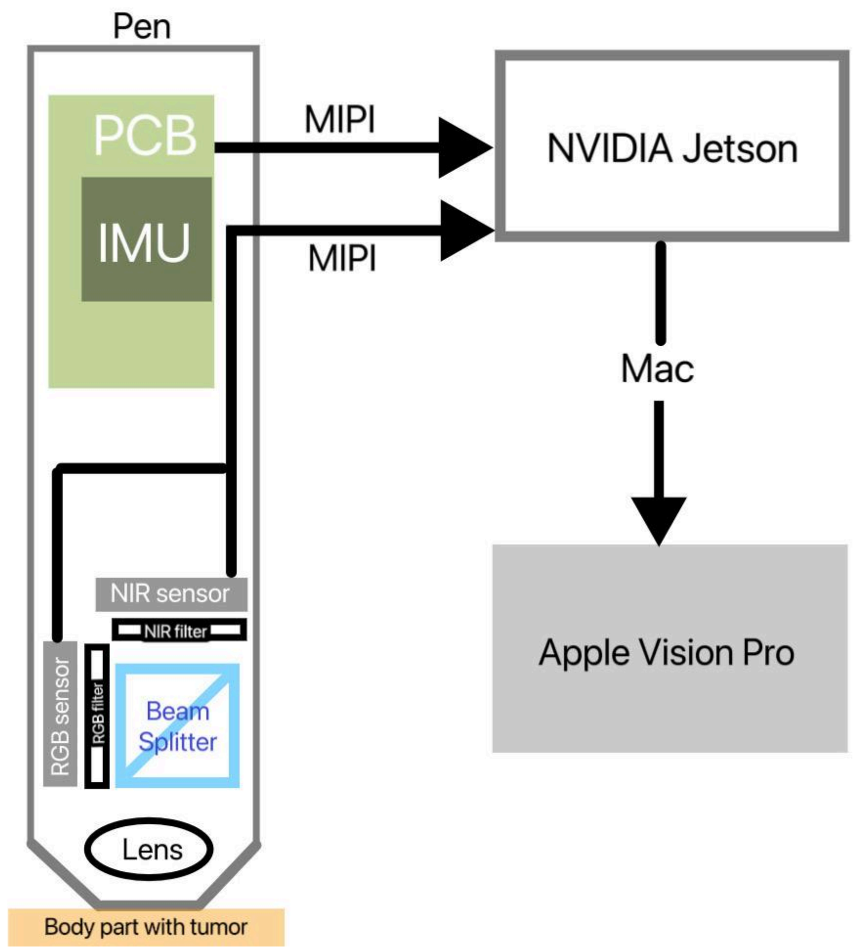
The prevailing method for tumor removal, traditional surgery, presents significant challenges due to its reliance on the surgeon's visual and tactile feedback, which are prone to human error. This approach often results in suboptimal outcomes due to limitations in tumor visibility and the potential for unintended damage to surrounding tissues. Additionally, traditional surgery may necessitate excessive tissue manipulation to enhance tumor visibility, thereby increasing patient morbidity. Consequently, there is a critical need for innovative solutions that mitigate these limitations and enhance the precision and efficacy of tumor removal procedures.

Solution

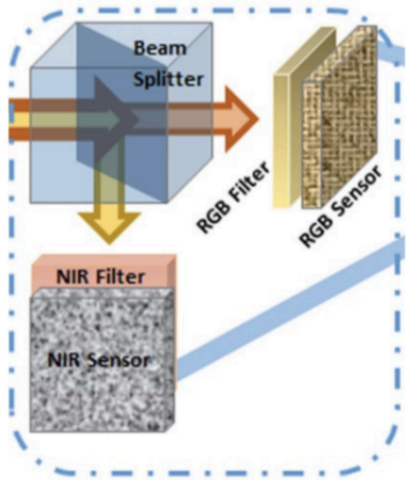
Our proposed solution addresses the limitations of traditional tumor removal procedures by introducing a compact and mobile camera system designed to augment the surgeon's capabilities. The system will focus on two primary tasks: tumor detection through segmentation from surrounding tissue and 3D reconstruction of the identified tumor. To achieve this, we will integrate a tumor-detecting pen system, validated in a pilot study, which utilizes fluorescent drugs to differentiate between tumor and healthy tissue.

In practice, the system will be deployed in conjunction with an Apple Vision Pro to provide real-time visualization of the surgical site. Utilizing augmented reality, the system will highlight the tumor based on near-infrared (NIR) reflection, guiding the surgeon's movements for precise tumor removal. Simultaneously, this augmented reality visualization will facilitate the capture of accurate images for subsequent reconstruction. Post-operatively, advanced image processing techniques will be employed to generate a detailed 3D model of the tumor, providing the surgeon with enhanced visualization and understanding of the surgical area. By improving the surgeon's visual capabilities and facilitating informed decision-making throughout the tumor removal process, our solution aims to enhance surgical outcomes and patient care.

Visual Aid



.



Noted above, the orange and yellow arrow is incoming visual light + NIR

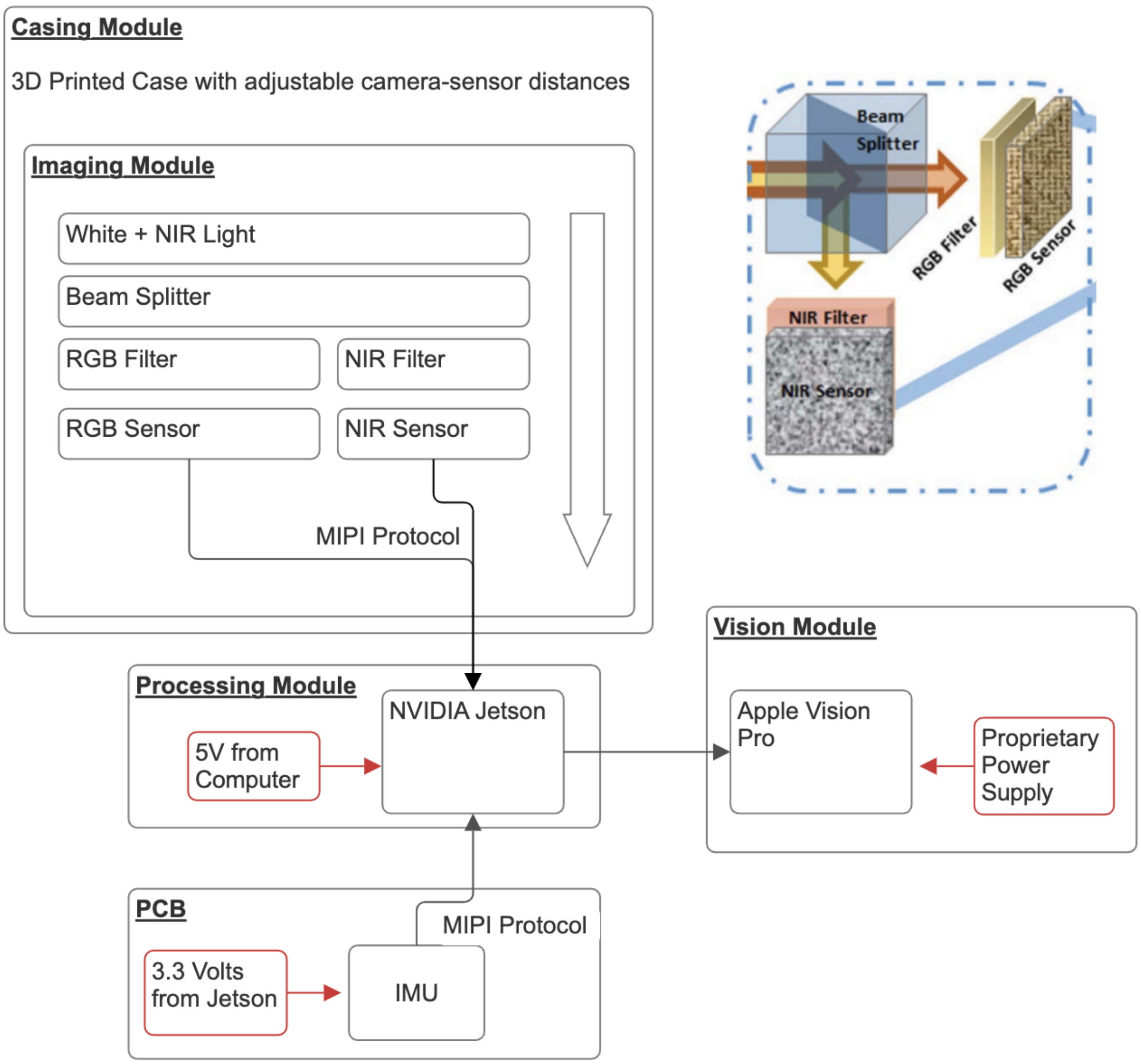
Source: Binocular Goggle Augmented Imaging and Navigation System Provides Real-time Image Guidance for Tumor Resection and Sentinel Lymph Node Mapping

High-level requirements list

- The imaging module is required to capture RGB signals, NIR signals, and pose information, transmitting them to the NVIDIA Jetson for subsequent processing.
- The processing module will conduct image analysis and sensor fusion, while also storing real-time frames for later 3D reconstruction using the SFM algorithm.
- The modeling module is tasked with projecting the 3D reconstruction of tumor detection/biological information via a head-mounted display using augmented reality.

Design

Block Diagram



Subsystem Overview

Casing Module

The casing module houses and protects imaging-module components and the PCB component while allowing for adjustable positioning. Fabricated through 3D printing, it securely holds components such as filters, camera sensors, a beam splitter, a lens, and a PCB. Screws enable customization of component distances. The casing features an extending cable for seamless connection to the processing module, facilitating data transfer and signal processing. This ensures optimal functionality within the larger system architecture.

Imaging Module

The imaging module subsystem aims to capture and transmit RGB signals, NIR signals, and pose information to the Jetson via the MIPI protocol. Inside the casing, the imaging module consists of a lens, a beam splitter, an NIR filter, a RGB filter, a NIR camera sensor, and a RGB camera. These components are securely fixed at designated positions within the casing. Light enters the system through the lens located at the base of the pen, which focuses it onto two internal filters. Before reaching these filters, the light passes through a beam splitter, which divides it into RGB and NIR components. The RGB filter ensures that only RGB signals reach the RGB sensor, while the NIR filter ensures that only NIR signals reach the NIR sensor. This process enables accurate signal capture and transmission, and the signals from the camera sensors are sent to the processing module via a cable for further processing.

Processing Module

The processing module is tasked with analyzing image signals from the imaging module and IMU data from the PCB component, facilitating sensor fusion. This module comprises an NVIDIA Jetson device, which receives data from the imaging module via the MIPI protocol and from the

PCB component via the SPI protocol. The SPI connection extends to link the casing and the display. Real-time frames are stored in memory storage for subsequent processing, while the GPU handles the generation of a 3D representation based on the input data. This structured approach ensures efficient data handling and processing within the processing module. The processed data is then transmitted to the vision module.

PCB

The PCB consists of an Inertial Measurement Unit (IMU). The goal of the PCB component is to provide IMU data to the processing module, so that the processing module can utilize the Structure from Motion (SFM) algorithm to construct a 3D representation of the image signals. This SFM model is enhanced with IMU data from the PCB component. The incorporation of IMU data allows for optimal frame selection, ensuring that only high-quality image signals are utilized in the reconstruction process. By fusing IMU data from this PCB component, the processing module eliminates the need to estimate camera pose manually, thereby enhancing the accuracy and efficiency of the 3D reconstruction process.

Vision Module

The vision module is designed to project a 3D reconstruction of tumor detection and biological information via a head-mounted display using augmented reality. This functionality is achieved through the utilization of Apple's proprietary VisionPro platform, complemented by the SwiftUI and ARKit frameworks. This structured approach ensures seamless integration and efficient deployment of augmented reality technology for enhanced visualization and understanding of tumor detection and biological data.

Subsystem Requirements

Casing Module

- Protection: The casing module must provide adequate protection for the imaging-module components and the PCB component from physical damage, environmental factors, and electromagnetic interference.
- Adjustable Positioning: The casing should allow for adjustable positioning of the imaging-module components and the PCB component to the precision of 1mm. Screws or other mechanisms must enable customization of the distances.
- Connectivity: The casing must feature an extending cable for seamless connection to the processing module.

Imaging Module

- Component Integration: The imaging module must securely fix the lens, beam splitter, filters, and camera sensors at designated positions within the casing to ensure proper alignment and capturing of the signals.
- Signal Separation: The beam splitter, NIR filter, and RGB filter must effectively separate RGB and NIR components of the incoming light.
- Compatibility: The subsystem must be compatible with the MIPI protocol for signal transmission to the Jetson processing module.

Processing Module

- Sensor Fusion: The module should facilitate sensor fusion, integrating image signals and IMU data to enhance data accuracy and reliability.
- Protocol Compatibility: The module must support the MIPI protocol for receiving data from the imaging module and the SPI protocol for receiving data from the PCB component.

- Real-time Processing: Real-time frames from the imaging module and IMU data must be stored in memory storage for subsequent processing.
- The processing shall enable optimal frame selection based on IMU data to ensure that only high-quality image signals are utilized in the reconstruction process.
- 3D Representation Generation: The GPU within the module should generate a 3D representation based on the input data using SFM algorithm.

PCB

- The IMU data provided by the PCB module shall be compatible with the Structure from Motion (SFM) algorithm utilized by the processing module.
- The IMU should be capable of accurately measuring acceleration, angular velocity, and orientation.
- Protocol Compatibility: The module must support the SPI protocol for sending data to the processing component.

Vision Module

- The system shall ensure compatibility with Apple's VisionPro platform for augmented reality functionality.
- The system shall utilize the SwiftUI framework for user interface development.
- The system shall utilize the ARKit framework for augmented reality implementation.
- The system shall support real-time updating of augmented reality displays to reflect discrete frames of the captured tumor detection.

Tolerance Analysis

One of the most important aspects of this project is the management of our two different camera sensors and IMU, since the reliability of the incoming data from these sensors is crucial to the accuracy of the end result. Because we are operating over standard MIPI protocol and using power output from the Jetson, we rely on successfully following the protocol itself for the camera sensors to ensure safety and accuracy. Additionally, we will ensure proper ventilation of the mechanical device to prevent overheating of the sensors.

Down the line of the project, a major risk to the clarity of the 3D model produced by Structure From Motion is the focus and clarity of the images that we take. In order to address this, we will utilize information from the IMU to only take pictures in which we have low levels of acceleration and rotation. We must also rigidly attach the IMU to the pen device as to ensure no drifting between Structure from Motion frames.

Ethics and Safety

Our ethical and safety framework prioritizes patient welfare, equitable access to innovation, and safety throughout the pen's development and deployment.

Patient Autonomy: Ensuring informed consent, patients understand the purpose, risks, and benefits of the tumor-detecting pen.

Privacy: We securely manage patient data, adhering to regulations like HIPAA.

Transparency: We maintain a lab notebook documenting the design process and progress, fostering trust by openly communicating the pen's capabilities, limitations, and risks.

Clinical Validation: Rigorous testing ensures the pen's safety, accuracy, and effectiveness before clinical use.

Regulatory Compliance: Adherence to medical device regulations, obtaining FDA approval to ensure pen safety and efficacy.

User Training: Comprehensive training for surgeons and healthcare professionals minimizes errors during procedures.

Continuous Monitoring: Mechanisms for ongoing surveillance promptly address safety concerns during pen use in clinical practice.