OPTICAL IMAGING SYSTEM FOR THE MOUSE AIRWAY MUCOSA

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Abstract

- Airway diseases are an increasingly common issue in many humans.
- Accurate imaging of the airway lining (mucosa) can improve evaluations of new treatments.
- In humans, this has been done effectively using Optical Coherence Tomography (OCT) imaging, but has not been successfully scaled to use in small animals.
- The goal of this project is to create and validate a method of imaging the airway mucosa of a mouse test subject in vivo.
- This design uses a clear catheter shell containing an optical fiber for access and imaging of the airway mucosa.
- This design uses 2 servo motors to rotate and retract the optical fiber.
- Future work will be to properly scale the overall design to work effectively on a mouse.

Background and Impact

Background

- Our client is researching treatments for diseased airways.
- The effectiveness of new treatments is tested on the airways of small animals.
- Treatment effectiveness is evaluated by monitoring the thickness of the airway mucosa [1].
- Need a way to obtain data without injuring the mouse or damaging the airway.
- One way to achieve this is with an optical imaging device. A specialized type of OCT imaging, optical frequency domain imaging (OFDI), directs infrared light at tissues and generates cross sectional images by measuring the delays of back-reflected light.

Problem Statement

The goal of this project is to create and validate an optical frequency domain imaging (OFDI) probe for imaging in the airway of small animals.

Imaging Design Background

- Requires radial scanning of the mouse airway.
- The imaging device must be able to retract while rotating to produce a 3-dimensional scan of the mouse airway.
- The device must also send infrared light from an external light source into the airway, then reflect the light into the airway mucosa. The measurements of the back-reflected light must be compared to a reference source to calculate thicknesses.

Impact

- Design allows for respiratory treatments to be tested for effectiveness over time in vivo.

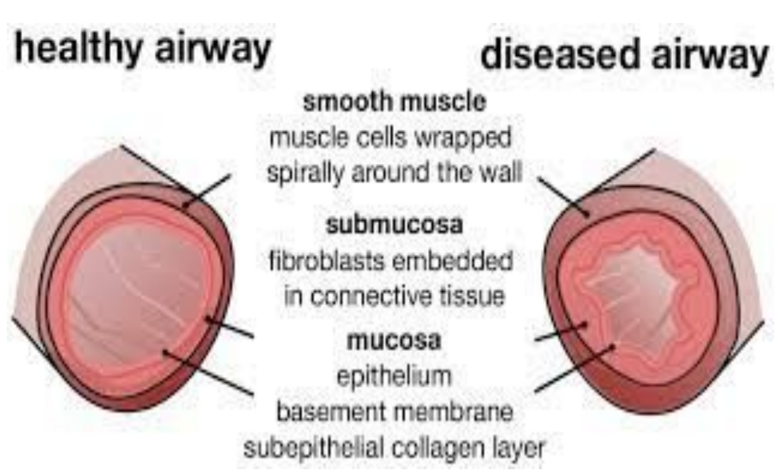


Figure 1: Demonstrates the difference between healthy and diseased tissue in the airway [2].

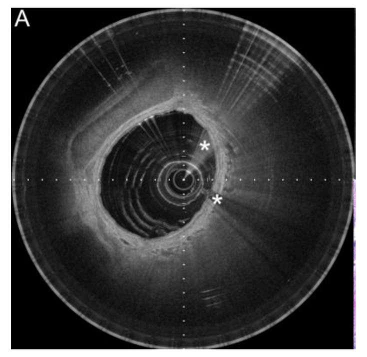


Figure 2: In vivo bronchoscopic catheter based OFDI imaging of lung airway. [3]

Design Criteria

- The device must be operable in vivo and cause no harm to subjects while following federal animal testing regulations
- The device must be reusable on different subjects and be autoclavable
- The imaging probe must withstand temperatures between 20°C (68 °F) and 135°C (275 °F) for storage and sterilization conditions
- The device must be approximately 1.5 mm in diameter to safely operate inside the mouse airway
- The device must measure the depth of the airway mucosa up to 1 mm with resolution between 5 and 20 micrometers[4] and a Signal to Noise Ratio of at least 80 [5]
- The prototype must allow for a 360 degree rotation of light
- The prototype must retract the optical fiber uniformly

Final Design and Prototype

OCT Framework

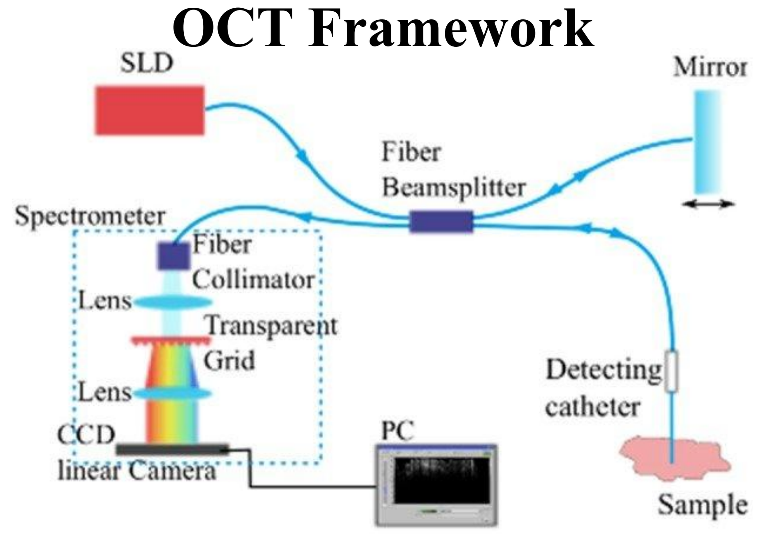


Figure 3: General set up needed for Optical Coherence Imaging [6]

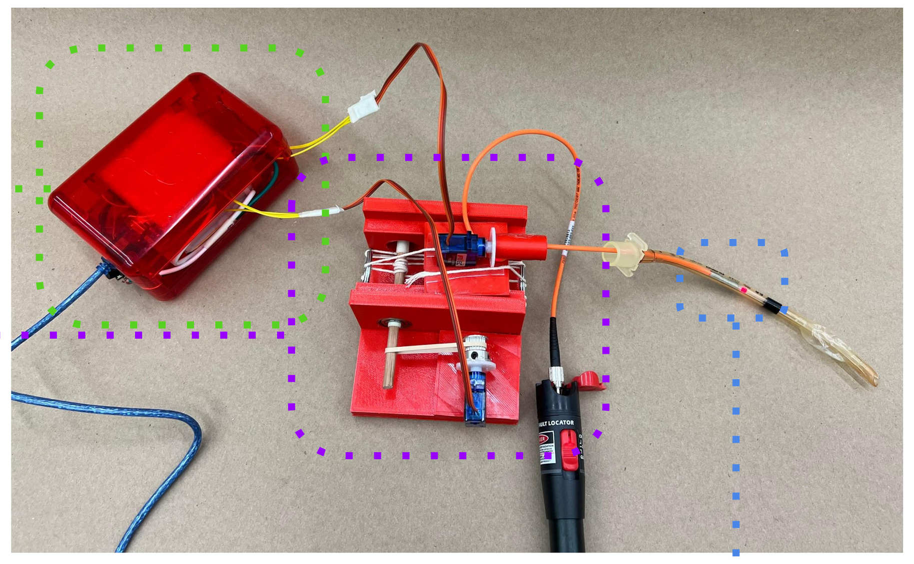


Figure 4: Overall Design including Optical Probe, Spinning Mechanism, and Electronics Box

Probe Design:

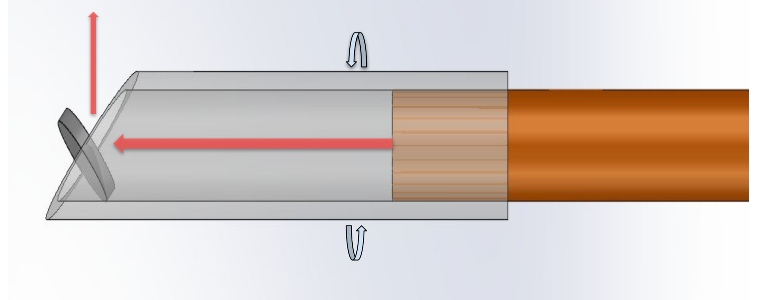


Figure 5: Rotating imaging probe with mirror to redirect light horizontally for mucosa depth measurement.

Spinning Mechanism Design:

- Designed in a way that further scale reduction is simple.
- Modular and customizable design to allow for easy implementation of changes need to scale to mouse airway.
- Speed and angle of rotation can be manipulated easily via the Arduino microcontroller and electronic circuit.
- Base system which allows for mechanical implementation outside of the mouse body.
- Optical laser is diverted horizontally for mucosa depth measurement using mirror connected to optical fiber.

Spinning Mechanism

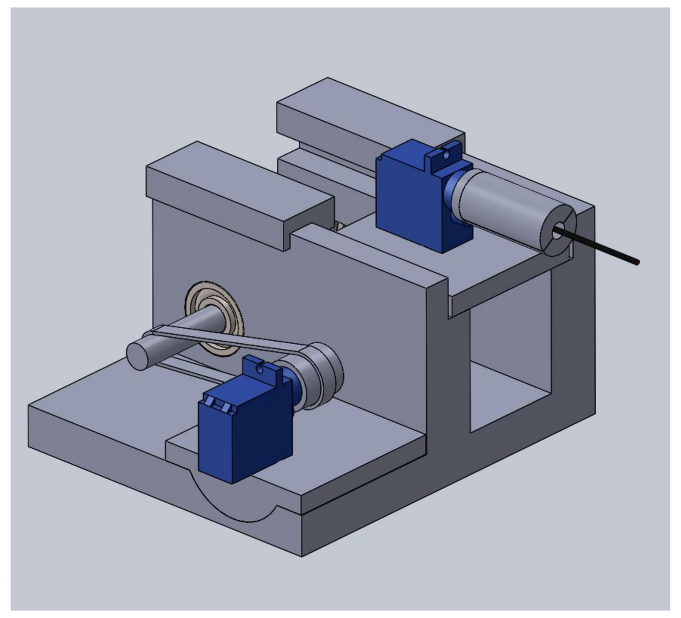
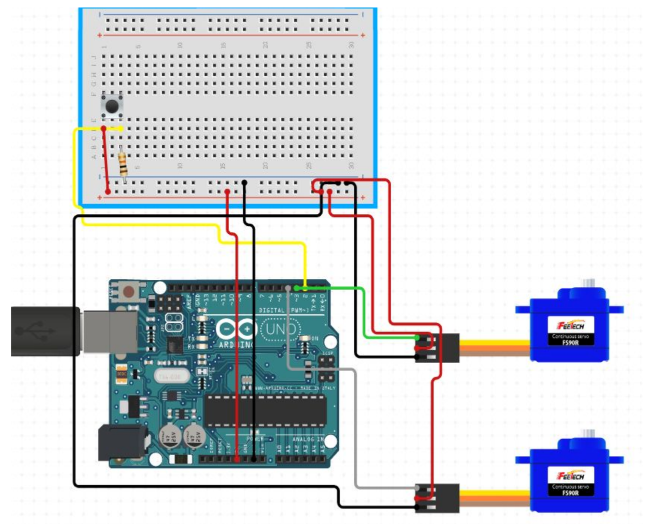


Figure 6 (left): Spinning mechanism including the retraction servo motor, axle, and moving platform containing the rotational servo motor.

Figure 7 (right): Circuitry used to enable retraction and rotational servo motor when button is clicked.

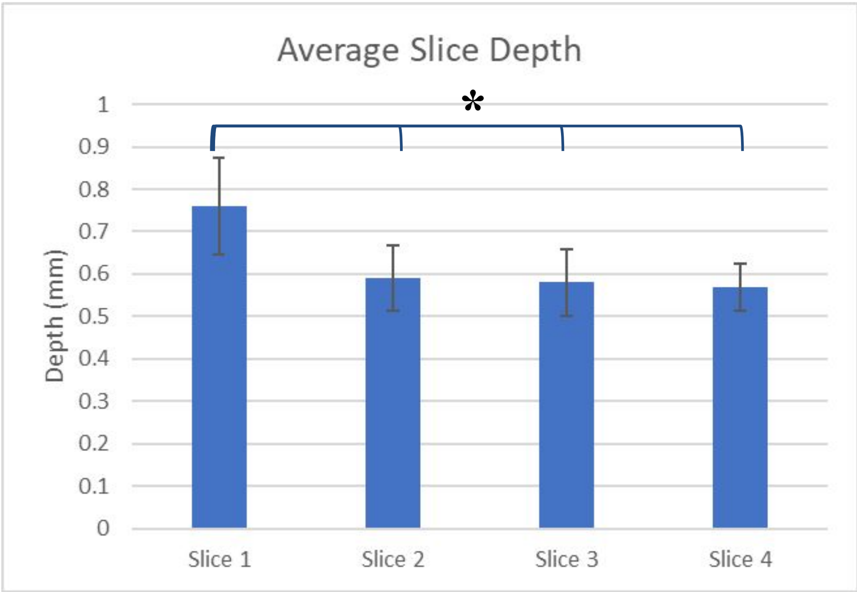
Electronics



Assembly/Fabrication:

- Created a SolidWorks model of our base for 3D printing.
- Base has holes for the bearings supporting our axle as well as fittings for our servo motors.
- Circuit with a microcontroller that takes inputs from a button and allows servo motors to retract and rotate the probe inside the catheter.
- A belt drive is used to transfer the rotation of the servo motor to the axle.
- Imaging probe is comprised of an optical fiber that runs through a clear intubation catheter.
- Light source on one end and a mirror on the other to reflect light out into the mucosa.

Testing and Results



Tested for:

- 360° rotation of diffracted light beam during testing 100% of time
- Horizontal diffraction of light for mucosa imaging during testing

Figure 8 (above): Consistency test of the effective retraction distance for each image slice captured. The Slice 1 depth was significantly larger than the Slice 2, 3, and 4 depth (n=40, p=0.032). Error bars represent ± Standard Error. α=.05

Figure 9 (right): Pictures taken during testing at various increments: (1) starting position, (2) 90° rotated, (3) 180° rotated, (4) 270° rotated, (5) retracted for next slice.

Discussion and Future Work

Strengths of Design

- Allows for rotation, protraction, and retraction of catheter inside the airway
- Allows light to pass through catheter via an optical fiber

Weaknesses of Design

- Too large to implement on mice
- No imaging system attached to design
- Current leaks through system without button being pressed

Future Work:

- Scale down our prototype
- Connect an imaging system to the end of our optical fiber
- Test using lab mice in vivo
- Add safety features
- Create prototype using durable materials
- Prevent current from leaking through the circuitry

Acknowledgements

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