Design of the Diffuse Optical Tomography Device

A thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science degree in Physics from the College of William and Mary

by

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Abstract

The goal of this project is to design a low-cost apparatus to test diffuse optical tomography (DOT). DOT can be used to make an image similar to MRI but at a cheaper price and with a more portable, movable device. Near infrared light can pass through human tissue, but scatters and absorbs differently in the case of an anomaly. This data is used to construct an image of that anomaly. The device has now been completed with a design of six sources and twelve detectors. This device uses only one detector, which can be connected in sequence to each of the twelve detector fibers. The sources are custom-made dual wavelength Light Emitting Diodes (LEDs), driven by a microprocessor, and then connected to optical fibers that lead to the apparatus. The drive circuit has been modified to improve the current regulation. Preliminary measurements through synthetic fat show that the device is working; however signals show significant variation after the detector fibers are disconnected and then reconnected to the detector.

Introduction

The purpose of my senior research project is to construct a device to use in testing DOT. The idea is that the device can produce data, which NIRFAST can use to reconstruct any anomalies that lie within the biological material. This technology could make medical imaging cheaper and provide a more portable alternative to MRIs and PET scans.

Diffuse optical tomography

DOT measures the optical properties of a material by observing the IR light that traverses though it. In a strongly scattering material, a small, point-source of light will diffuse out to an increasing area as it propagates. However, after measuring the total light throughput at sufficient number angles, for a sufficient number of source positions, it is possible to reconstruct obstructions that lie within the material and change the light path (Boas, 2001). When the source is at one side of the material, and the detectors are on the other side, this method is called catch/throw. For catch/throw a near infrared light source is placed on one side of the detector and a photo detector that detects light is placed on the other side of the object. The photo detectors detect the intensity of the light that has taken a random walk through the object. If an object is present inside the material, the intensity will be less and there will be an increased phase shift, which defines the net path length of the light. An image can be reconstructed based on the measurements from the photo detector across various points. The device that I am constructing uses catch throw.

Typically, near infrared light between 700 nm and 900 nm is used because human tissue does not absorb these wavelengths strongly (Baker, 2010). Moreover, by using two different wavelengths (750 nm and 850 nm), one can see the difference between oxygenated blood and de-oxygenated blood. This reveals where the blood flow is highest.

This is because at higher wavelength frequencies, absorption by water increases making a spectral window to view hemoglobin with spectral differences between oxy-hemoglobin and deoxy-hemoglobin (Boas, 2001).

An alternate method uses reflected light to generate the image. This has advantages when the material is sufficiently thick that very little light could pass all the way through it. For this approach, the light source and the photo detectors are placed on the same side of the object being imaged. The detectors detect the light that is scattered off the object and back toward the source. These measurements can also be used to construct an image. It is important to note that different materials have different scattering properties of light passing through. The more detectors there are, the better an image can be made (Boas, 2001).

Goal of project

The overall goal of this project is to make a transverse illumination system that can image objects embedded within opaque biological material. The objects will be then imaged by using NIRFAST to reconstruct the image.. This type of research could be potentially useful to many medical fields as it is applicable to technologies that could be used as cheaper, and more easily transportable, alternatives to MRI. The goal of my senior project is to construct a device to test DOT across a material based on a model system developed to test NIRFAST reconstruction..

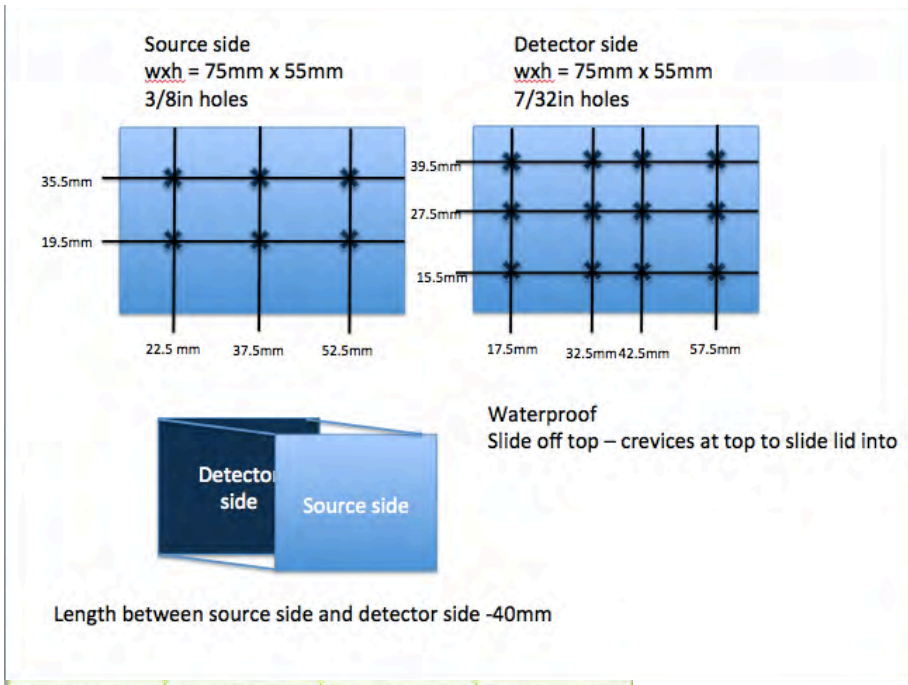
I have started with a system of sources and detectors with a sample material in between to determine the scattering of light and the effectiveness of detecting where different objects of different densities are located. The idea is to replicate the results of NIRfast or prove they the simulation is correct. The current NIRFAST simulation is using

two meshes, one that has six sources, and another that has twelve detectors. This system was picked to increase distance variability. The source produces a light signal and passes through a medium. The detectors detect different amounts of light at various points. The data is used to form a graph like image that indicates if an anomaly was detected.

Project

Devices and equipment

The current device being built is modeled after the NIRFAST model discussed earlier. The system consists of 6 sources and 12 detectors. Figure 1 shows the setup of the device. The sources are connected to 750 nm and 850 nm LED's powered by a 5V source and a program that powers an LPC 1768, an Acorn reduced instruction set computing machine microcontroller development board which is an input/output electronic device, that controls the LED. The LED's connect to 6mm fiber optics, which are connected to the system box source side shown in the schematic in Figure 1. Figure 2 shows the actual device. The detector side has 12 3mm fiber optics, each of which can be connected to a photo detector. There are also plastic pieces that match the dimensions of the detector side of the system box to secure the detector fiber optics in place inside and outside of the box, as shown in Figure 3. Inside the box there is sample that is between the source fiber optics and the detector fiber optics. The current sample being used is layers of 5mm thick synthetic pieces of fat from SynDaver Labs which is designed to simulate actual human tissue. The fat is held in place with a plastic fitted piece, as shown in Figure 4. Figure 5 shows the circuit diagram of the electronics powering the diode. Figure 6 shows the schematics for the LT1016 CN8 ultra fast precision comparator, which when held high displays input data at the output keeping the output more consistent.



Position 4 (17.5, 39.5)	Position 3 (32.5, 39.5)	Position 2 (42.5, 39.5)	Position 1 (57.5, 39.5)
Position 8 (17.5, 27.5)	Position 7 (32.5, 27.5)	Position 6 (42.5, 27.5)	Position 5 (57.5, 27.5)
Position 12 (17.5, 15.5)	Position 11 (32.5, 15.5)	Position 10 (42.5, 15.5)	Position 9 (57.5, 15.5)

Figure 1: DOT Testing Apparatus Design. This diagram shows the design of the DOT apparatus and the placement of the 6 sources and 12 detectors. There is 40mm between the source and detector side.

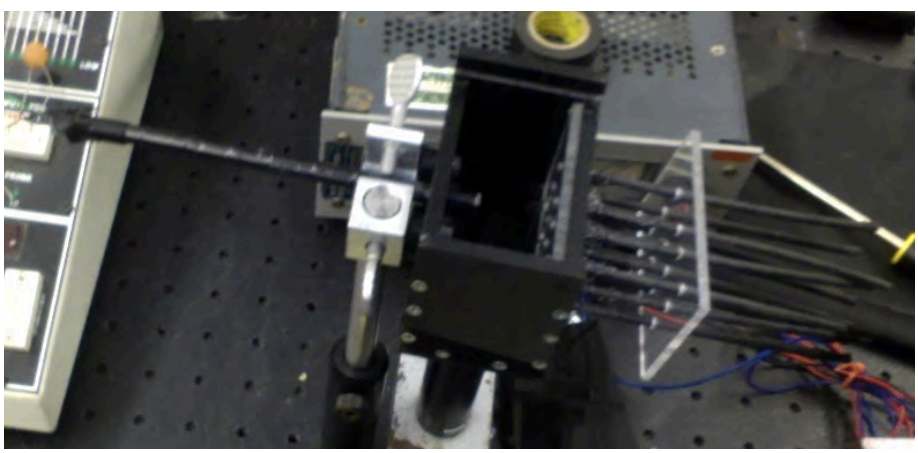


Figure 2: DOT Device. This is the actual product of the DOT testing apparatus design, with one source connected and 12 3mm fiber optics connected to the detector side so the photo detector can be moved to different positions by connecting to different fiber optics.

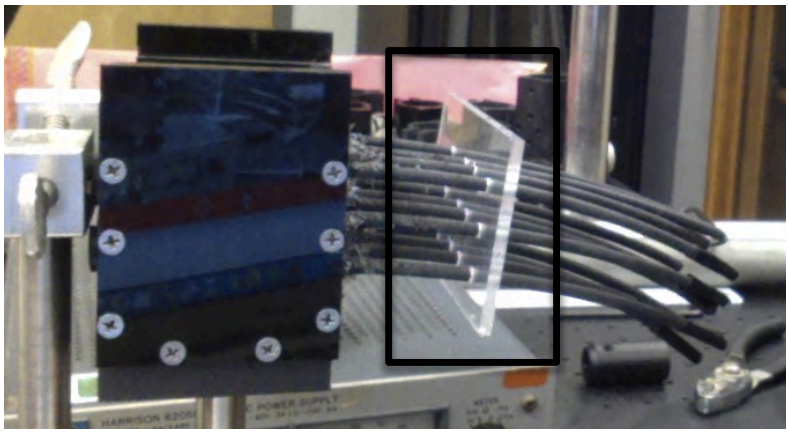


Figure 3: Fiber Optic Fitted Pieces. This is a plastic piece to add stability to the fiber optics.

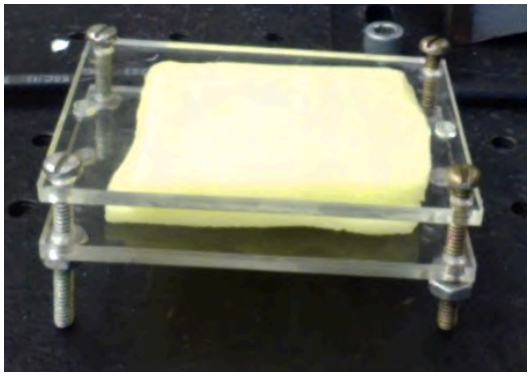


Figure 4: Synthetic Fat Setup. This holds the fat in place so that it may be placed between the source and detector.

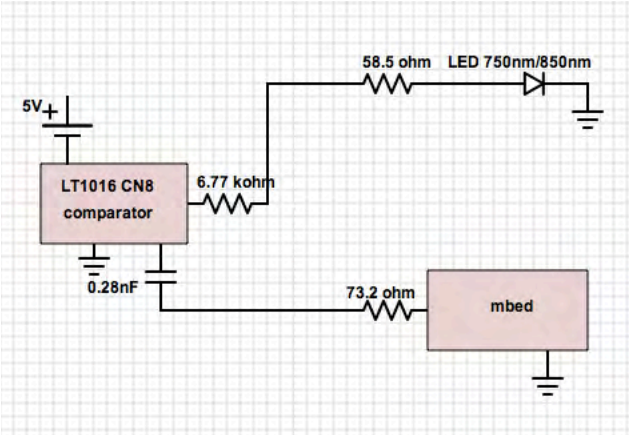


Figure 5: Source Power Electronic Setup. This is the electronic setup that powers the 750/850 nm LED. The mbed determines when the source is switched high. The comparator was added so that a larger current could be sent to the LED. The 6.77 kΩ resistor was added to reduce oscillations in the source signal when high.

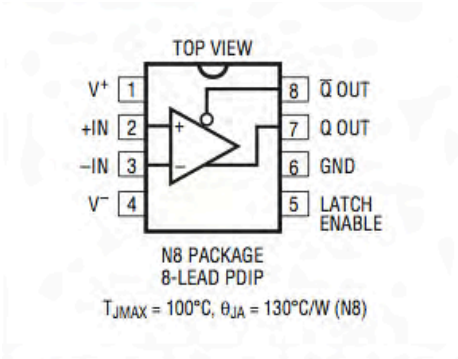


Figure 6: LT1016 CN8 Comparator. This is the logic gate for the comparator in the electronic setup. The comparator outputs the high signal.

Measurements

Figure 7 shows signal amplitude measurements of the system of a source and detector without a material between from the oscilloscope. This shows what type of signal is being sent out by the source and across the diode. There was a time delay as shown in the figure that seemed to be corrected by an addition of a capacitor-resistor system. Figure 8 shows there were also an unsteady signal with many oscillations when the signal was high. Figure 9 shows the results of adding a resistor, the 6.77 kΩ resistor in Figure 5. This reduced the oscillations when the signal was high, so using a larger resistor could regulate the time delay and oscillations.

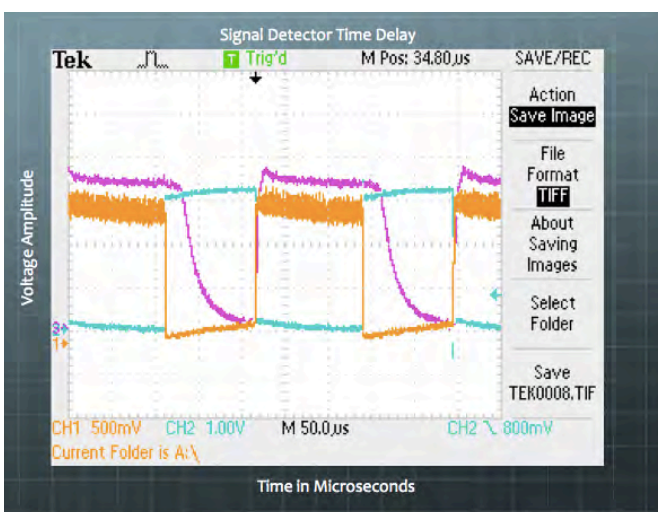


Figure 7: Time Delay Measurement. This shows the time delay by the detector, the purple line.

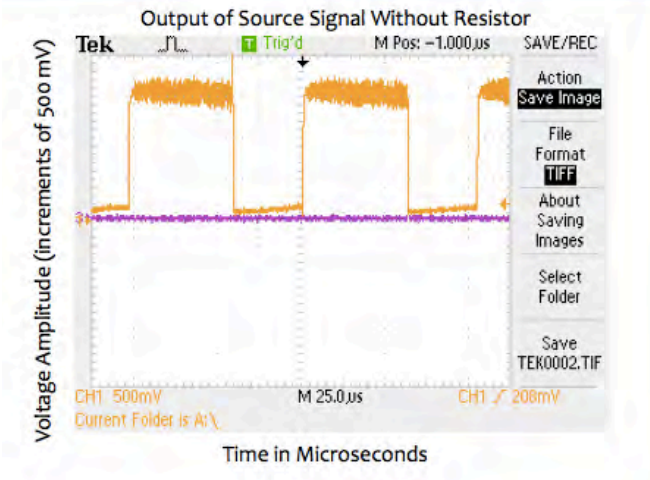


Figure 8: Output of Source Signal Without Resistor. This shows the source signal without the 6.77 kΩ resistor in the electronic setup, where there are oscillations of the signal when high.

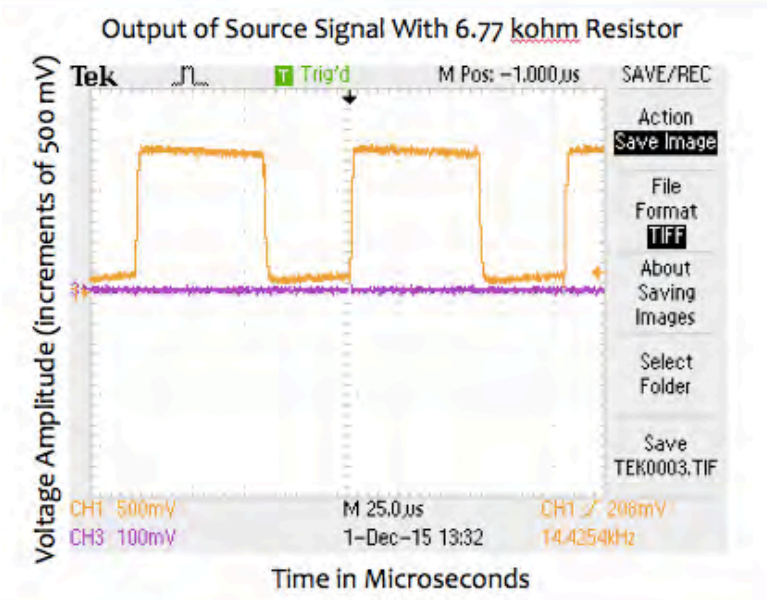


Figure 9: Output of Source Signal With 6.77 kΩ Resistor. When the 6.77 kΩ resistor was added to the electronic setup, oscillations of the signal were reduced when high.

An initial measurement of the source across the fat is shown in Figure 10. The yellow line is the power of the LED on one side of the synthetic fat and the purple line is what the fiber optic detected on the other side of the synthetic fat by the photo avalanche. The figure also showed the location of the specific source and detector position based on

the layout of the system box shown in Figure 1. It appeared that there was some saturation occurring to the photo detector. A filter will be put in place to prevent any more saturation.

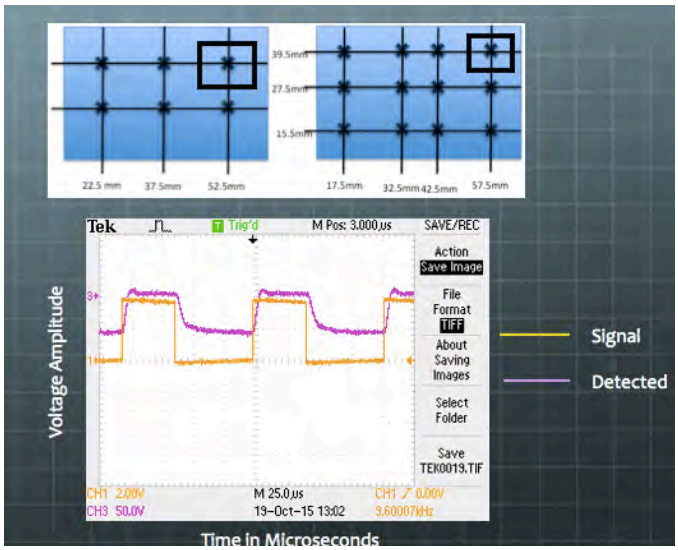


Figure 10: Position of Source and Detector of Data Collection. This data was taken at the source and detector position shown above. The detected signal still had a time delay from the source signal.

Two sets of data, including voltage amplitudes at given times, were later taken across all twelve detector spots using the top center source as indicated by Figure 11.

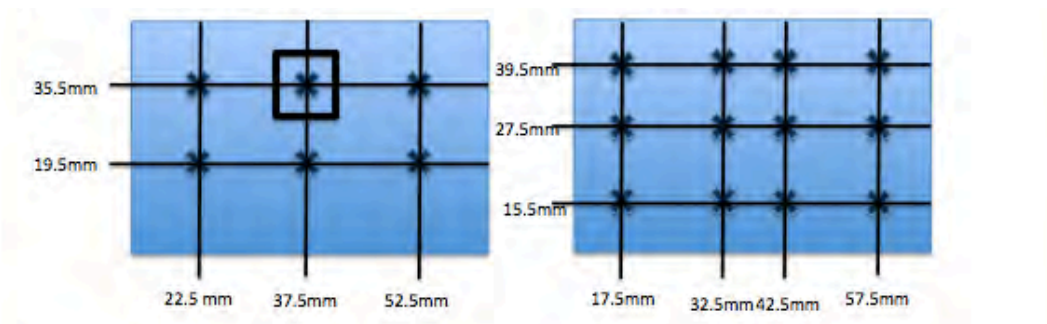


Figure 11: Position of Data Set Collection Across All Twelve Detectors. This is the source position when data was taken across all 12 detector positions.

Analysis

There have been multiple sets of data recently measured. This data consists of measurements across all twelve-detector positions with the top center source being used. Figure 12 shows where voltage detections through the fat were largest at position (32.5,

27.5) and Figure 13 shows a spot where voltage detections were relatively low at position (17.5, 15.5). These graphs show the diode signal plotted with the detected signal. The detected signal was multiplied by -15 to make them more easily compared. This also means at peak detection, approximately 1/15 of the source is travelling though the synthetic fat and being detected. The data appeared to correlate correctly to distances, meaning that detectors closer to the source were detecting a larger signal.

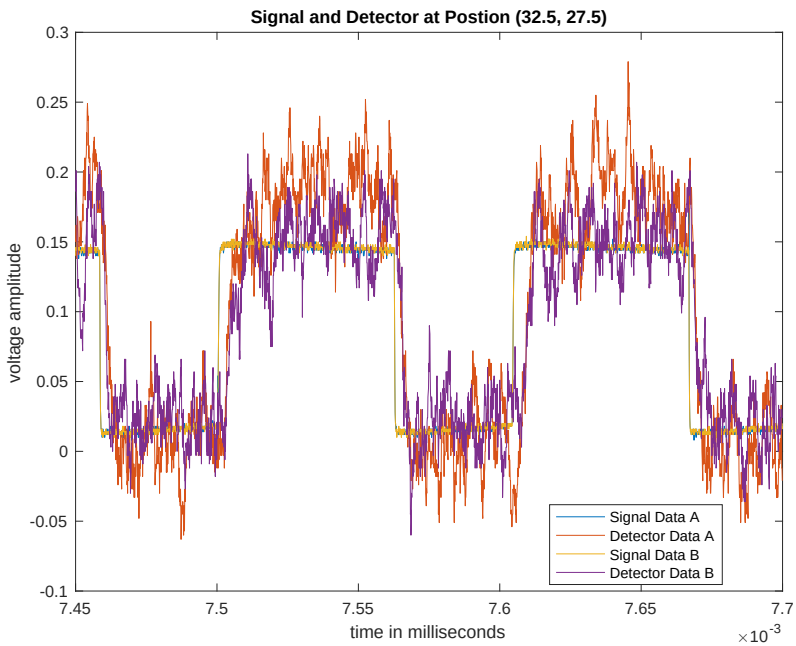


Figure 12: Signal and Detector at Detector Position (32.5, 27.5). This is a graph of source signal and detected signal from two data at detector position (32.5, 27.5). The detected signal was multiplied by -15 to make them more easily compared. Voltage detections were larger here than at most other detector positions.

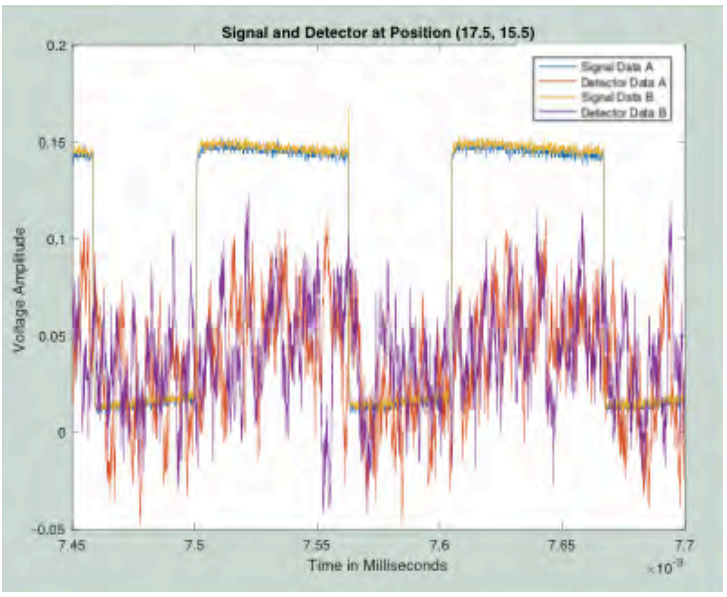


Figure 13: Signal and Detector at Detector Position (17.5, 15.5) This is a graph of source signal and detected signal from two data at detector position (17.5, 15.5). The detected signal was multiplied by -15 to make them more easily compared. Voltage detections were smaller here than at most other detector positions.

However, Figure 14 shows that there were some problems with variability. While at position (32.5, 39.5) both trials showed increase in detection compared to Figure 11, for example, one trial detected more than twice as much amplitude through the synthetic fat.

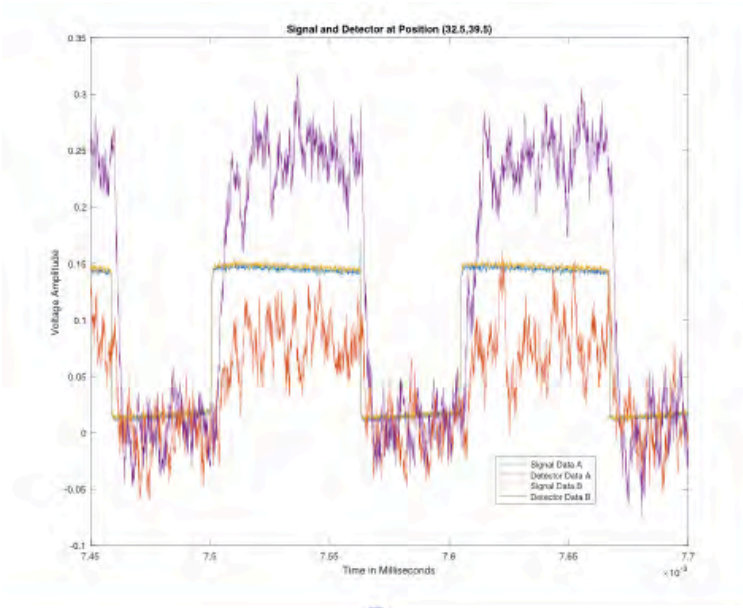


Figure 14: Signal and Detector at Detector Position (32.5, 39.5). This is a graph of source signal and detected signal from two data at detector position (32.5, 39.5). The detected signal was multiplied by -15 to make them more easily compared. This graph shows the variability between the different data collections.

Figures 15 and 16 show amplitude as a function of position, with Figure 15 being an initial estimate of the values of amplitude. The actual amplitudes were found by taking the average and multiplying by 2. The positions 1 through 12 correlate to the detector side where 1 is the top right corner, the detector position boxed in Figure 10, 5 is the center far right, and the numbers continue to move across right to left from top to bottom. The positions and the number they correlate to is made clear is Figure 1. The graphs show slight oscillation which makes sense because the detector positions as labeled so that the detectors are closer at the center, positions 2 and 3 for example, and farther away on the sides, like positions 1 and 4. There is also an overall down slope, which also makes sense because positions 9 through 12 along the bottom of the detector would be furthest away from the source.

Overall, there was a lot of variability meaning there is an error somewhere in the system. Since some points, like at position 7 whose amplitude as a function of time is also plotted in Figure 12, are very close, it is most likely not related to the signal itself or an electronic issue. This is backed by signal figures, such as Figures 12 and 13, where the input signal of both trials at different positions is clearly nearly identical. It is more likely that the variability comes from the movement of the fiber optics when they are being connected and disconnected. In particular it could be differences in the angle of light being received by the photo detector, which is one spot where there is coupling to a 3 mm fiber optic. The fiber optics are changed out and may not be placed back in the same way. This could also be moving the end of the fiber optic connected to the material slightly altering the position.

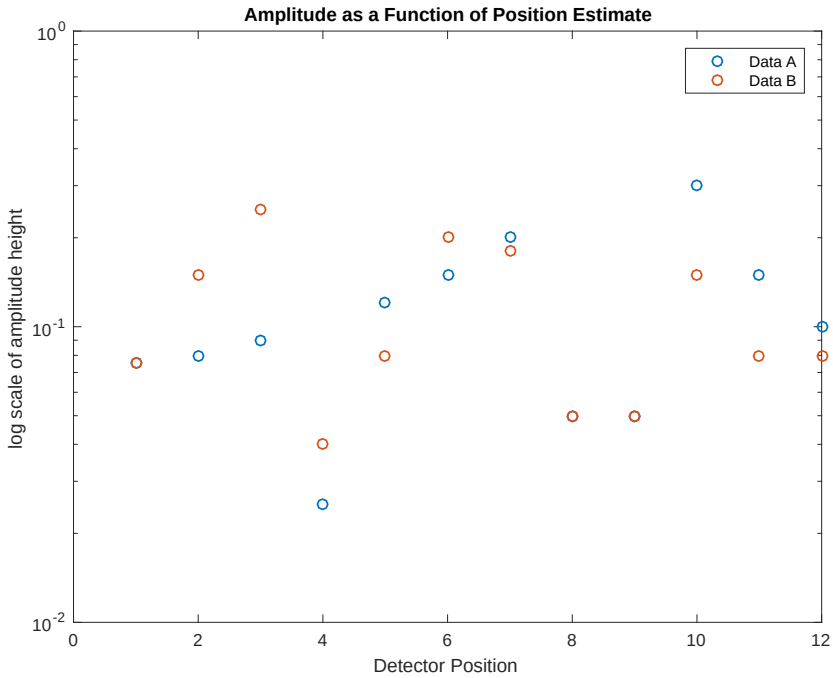


Figure 15: Amplitude as a Function of Position Estimate. This was an estimate of amplitude height to show if there was any correlation between amplitude height and detector position.

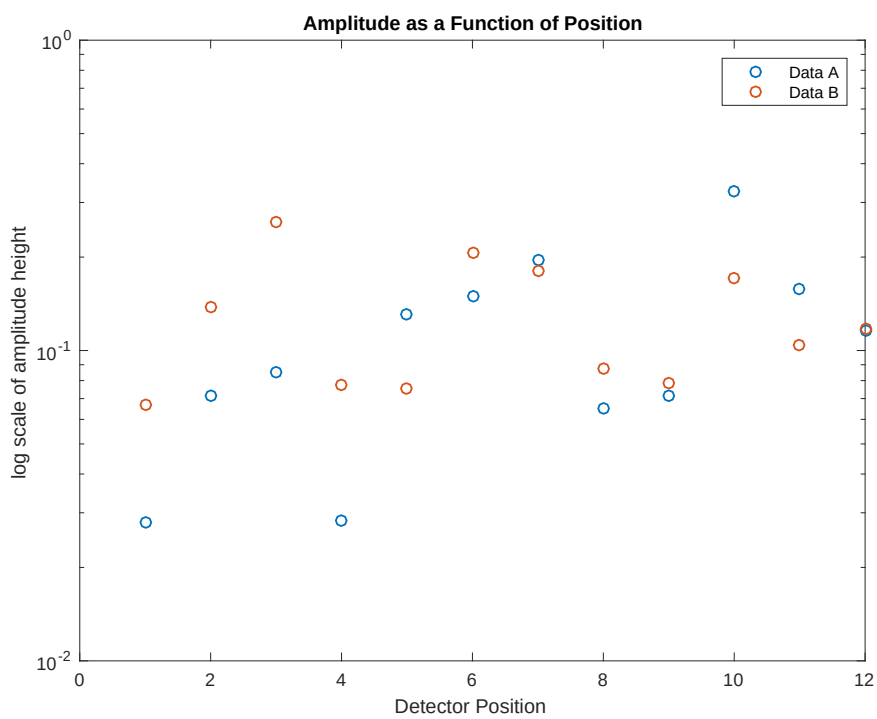


Figure 16: Amplitude as a Function of Position. This was calculated from the amplitude data to show if there was any correlation between amplitude height and detector position, labeled 1 through 12 on the x-axis and corresponding to detector positions from Figure 1. There was a lot of variability and not a lot of correlation.

Figures 17 and 18 show amplitude as a function of distance, with Figure 17 being an initial estimate of the values of amplitude. Similar to the position plots, the graphs show that as distance increases, it appears that amplitude decreases which would make sense because the light has further to travel and is more likely to scatter along the way. These graphs also show there was quite a bit of variability between collection of Data A and Data B. Again, this is most likely due to the fiber optic connections.

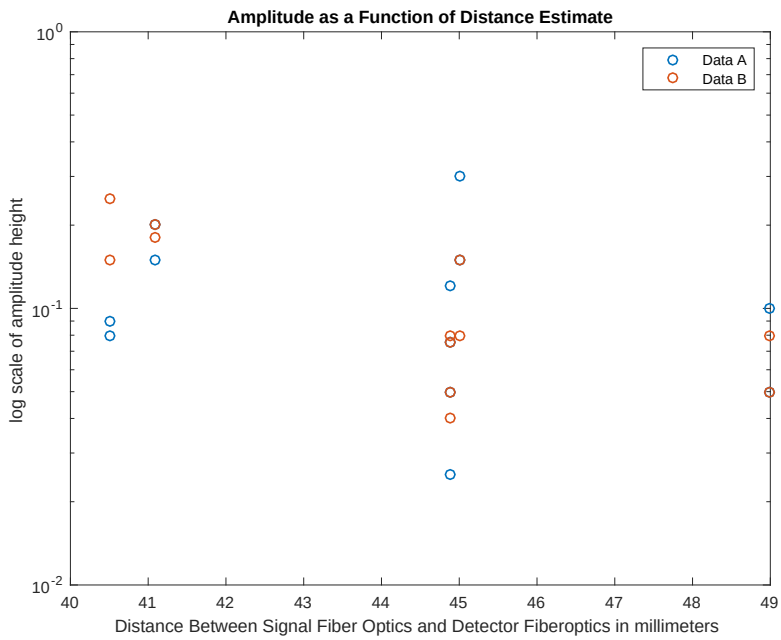


Figure 17: Amplitude as a Function of Distance Estimate. This was an estimate of amplitude height to show if there was any correlation between amplitude height and distance between source and detector.

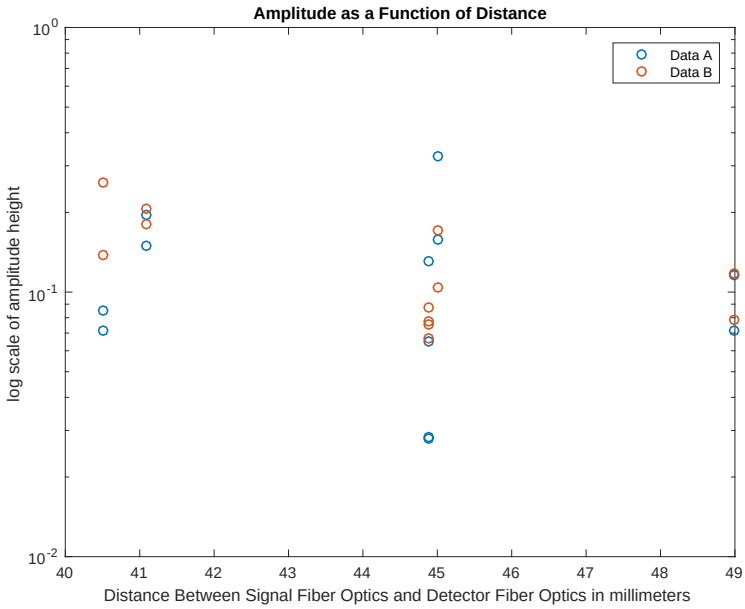


Figure 18: Amplitude as a Function of Distance. This was calculated from the amplitude data to show if there was any correlation between amplitude height and distance between source and detector, labeled on the x-axis in mm. There was a lot of variability and not a lot of correlation.

There also appears to be phase lag in signals. This is most likely due to the stability of the structure. It appears that the detector fiber optic to photo detector connection is still sensitive. This connection is shown is Figure 19. At certain spots on the window of the photo detector, the phase lag is less prevalent. However, this is not strongly documented or explained so should be a focus of the project later.

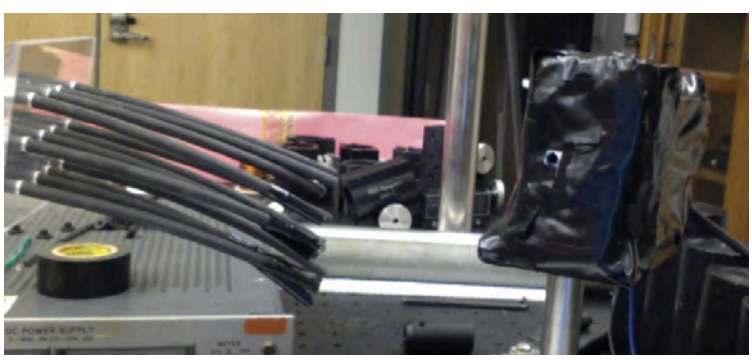


Figure 19: Fiber Optic Photo Detector Connection. This is photo detector and the 3mm fiber optics that connect.

Eventually this data will be used in better plots of detector data and intensity versus position. More data from different sources will be used and the time frame that the data is

taken across will be increased. It will also be important that the results have less variability which will most likely come from adjustments to the stability of the apparatus.

Conclusion

In conclusion, the DOT project is still in the data collecting stages. The current data collected has a lot of variability meaning the system can still be adjusted. It is important to ensure that the diodes and fiber optics remain stationary while different detector spots are being tested. Once the device is more stable, measurements from all source-detector combinations will be taken across synthetic fat. Multiple trials will be done to ensure that the measurements are repeatable. Other samples will also be tested.

References

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