Carthage Space Sciences: MPG-FOSS

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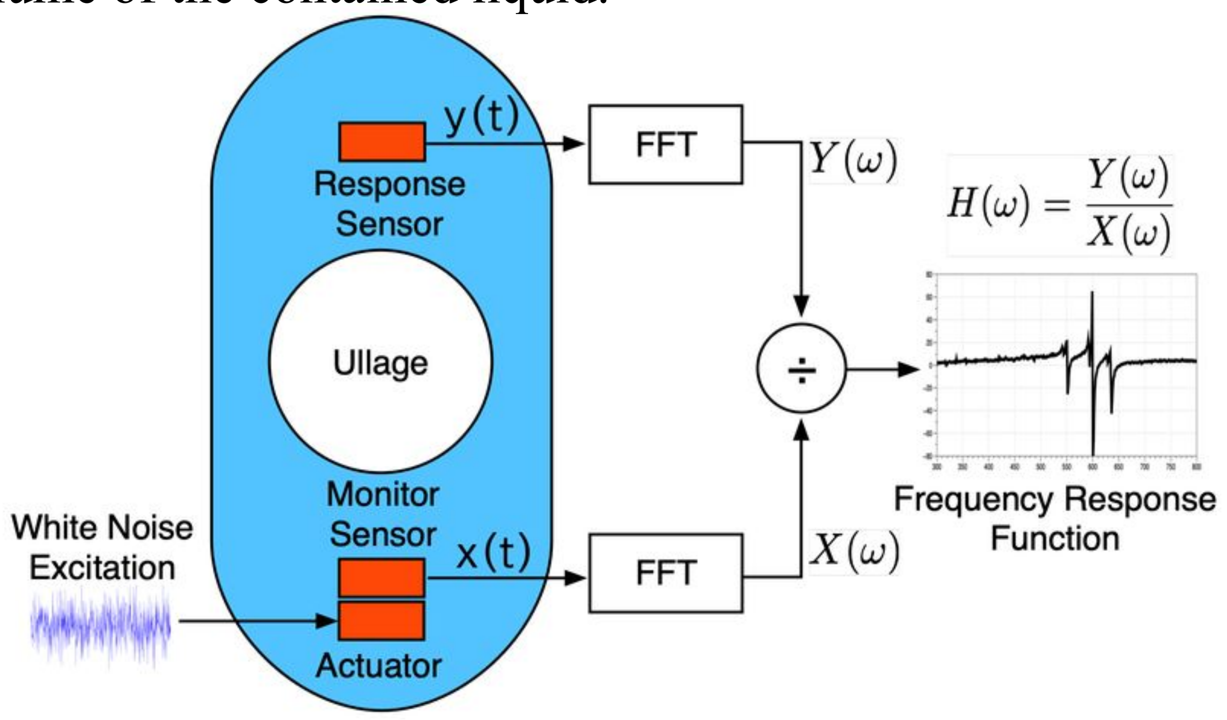
Project Overview

- Modal Propellant Gauging (MPG) is a Carthage and NASA Kennedy Space Center technology currently under consideration for adoption by several commercial and NASA programs.
- MPG provides zero-gravity propellant gauging using the vibrational response of a tank excited by a surface-applied actuator. It is non-invasive, real-time, and is one of only two low-gravity propellant mass gauging solutions at TRL 7 or above.
- MPG-*FOSS* is an extension of MPG in which the PZT sensors used in MPG are replaced with fiber optic strain gauges. FOSS is a NASA-patented technology that implements Fiber Bragg Gratings to measure strain in a test article with high sensitivity and no electromagnetic interference (EMI).
- The objective of this study is to assess the viability of replacing PZT-based sensors in an MPG experiment with FOSS-based strain sensors in an effort to reduce noise, improve sensitivity, and reduce the SWaP of MPG for spaceflight applications.

Modal Propellant Gauging

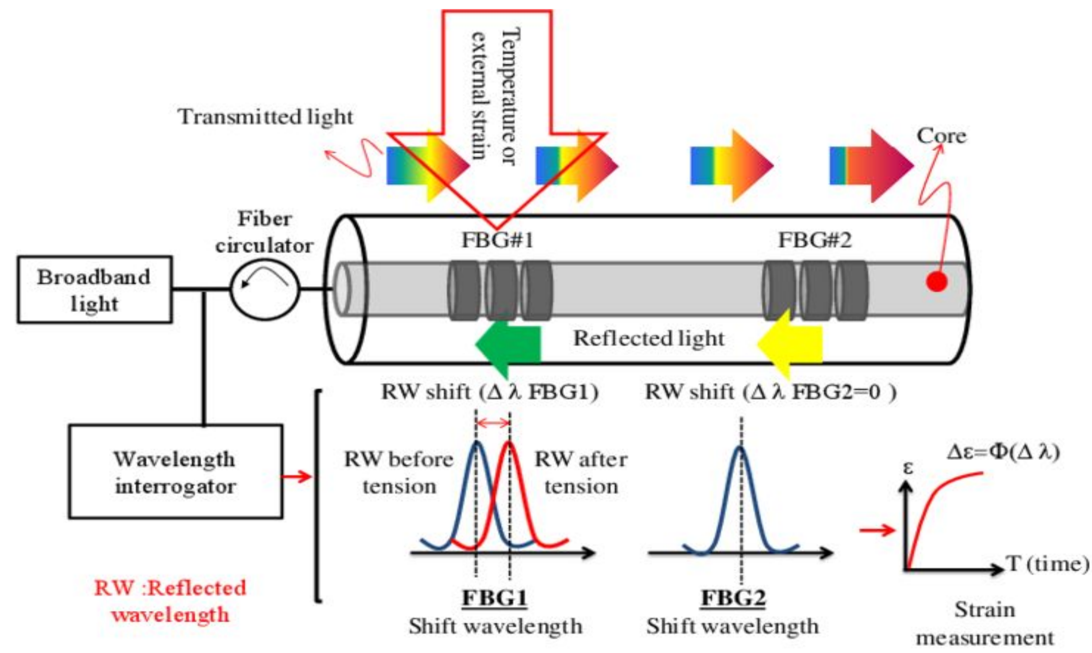
- MPG measures the resonant frequencies of a tank under broadband excitation from a white noise source.
- In microgravity, the contained liquid propellant adheres to the inside of the tank wall, *mass-loading* the wall and reducing its resonant frequencies. These mode frequencies are shifted in proportion to the volume of the contained liquid.



- The tank response is sampled at two different locations, one close to and the other far from the excitation. The frequency response function (FRF) is the ratio of the FFT obtained from the far (sensor) location and the close (monitor) location. By ratioing the two FFTs, the common white noise is canceled out, leaving only the resonant frequency spectrum.

Fiber Optic Sensing System

- FOSS is a technology developed at NASA's Armstrong Flight Research Center which measures the expansion and contraction of material substrates using Fiber Bragg Gratings (FBGs) which are inscribed into a length of optical fiber adhered to the substrate material.

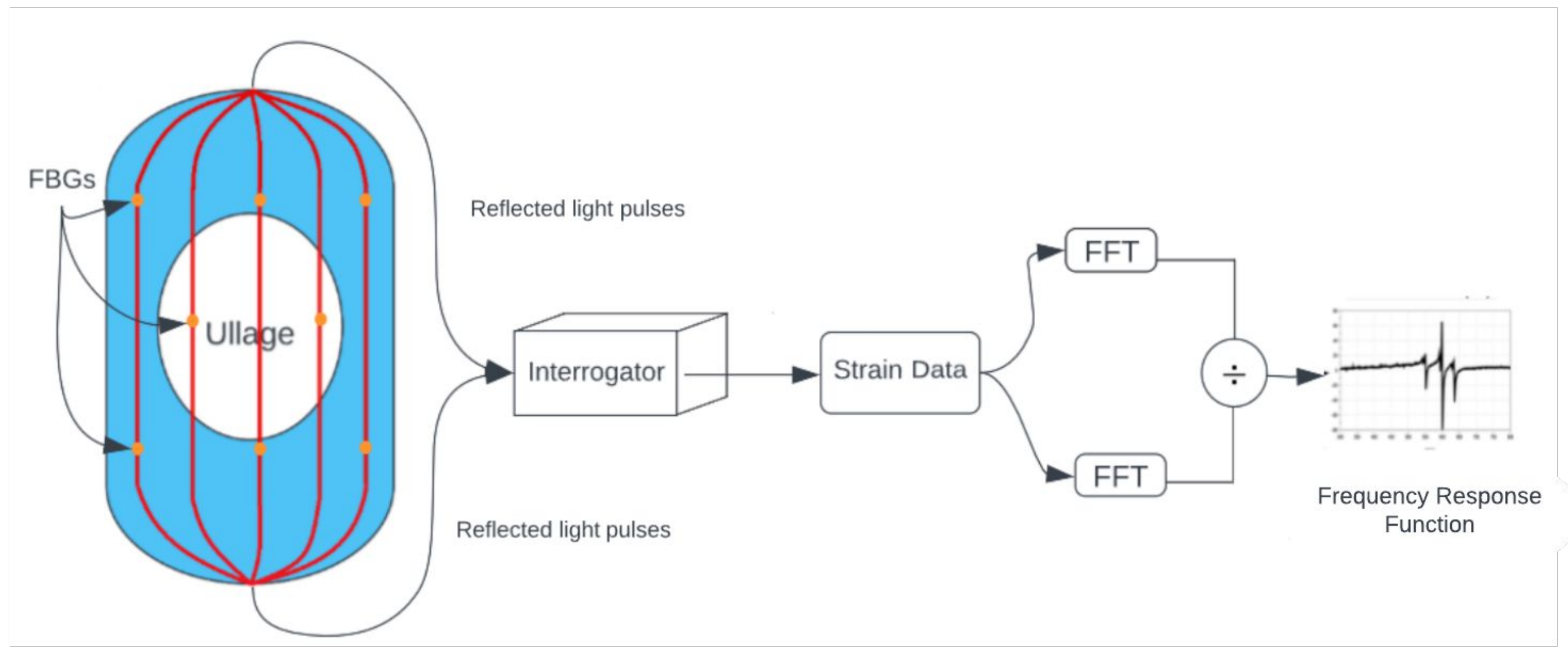


Malekzadeh, M., Gul, M., Kwon, I., Catbas, N. (2014), "An Integrated Approach for Structural Health Monitoring Using an in-house Built Fiber Optic System and Non-Parametric Data Analysis", Smart Structures and Systems

- FBGs, which are inscribed into a short segment along an optical fiber, are created by making periodic variations in the refractive index of the fiber core. The range of wavelengths that the FBGs are designed to reflect changes in relation to the conditions around the fiber. The changing conditions cause expansion and contraction along the fiber resulting in a shift in the reflected wavelength.

MPG-FOSS Architecture

- The primary device used in FOSS is called an interrogator. The interrogator is a lab hardware unit used to collect and packetize sensor information.
- The interrogator collects wavelength data by injecting white light into the core of a fiber and receiving the light reflected from the Fiber Bragg Gratings.



- The reflected wavelengths are then packetized - the packets are output from the interrogator via a USB connection which can be interpreted by data collection software.

Software Development

- Our software can interpret interrogator packets to perform data analysis and also has the ability to simulate fake packets of data, allowing for further development without a hardware dependency.
- The interrogator outputs a series of packets at a sampling rate of 19.23 kHz which contain information such as timestamps, a "yoho" message to identify the start of each packet, and the actual sensor data among other factors.
- Our Python program parses packet information according to its byte structure, and then evaluates and makes available the Center of Gravity (CoG) data provided from the FOSS.

- Our software outputs a csv file containing extracted packet information to MATLAB programs which then generates the Frequency Response Function. The data required for this process must undergo the conversion below.
- The CoG bit numbers generated are calibrated central wavelengths in the operating range of the interrogator. To make use of the available 18 bit register, the following conversion can be used to determine the central wavelength needed:

$$\lambda_{CW} = \frac{1514 + COG_{bit}}{2^{18} \cdot 72}$$

- In order to determine the strain ε or temperature change ΔT induced over a fiber, the default central wavelength value for the particular sensor is required. The relation between wavelength, strain, and temperature is then as follows:

$$\frac{\Delta\lambda}{\lambda_0} = (1 - \rho_e) \cdot \epsilon + (\alpha_\lambda - \alpha_n) \cdot \Delta T$$

Where is ρ the strain-optic coefficient and α is the thermal expansion coefficient

Future Objectives

- Carthage College intends to implement FOSS into MPG experiments to provide an easier installation, minimize the risks associated with exposed electronics, and lower EMI in the received data.

Acknowledgements

- We would like to thank our advisor, Dr. Kevin Crosby, NASA's T2U program, and the Wisconsin Space Grant Consortium (WSGC) for funding this project.

MPG - FOSS

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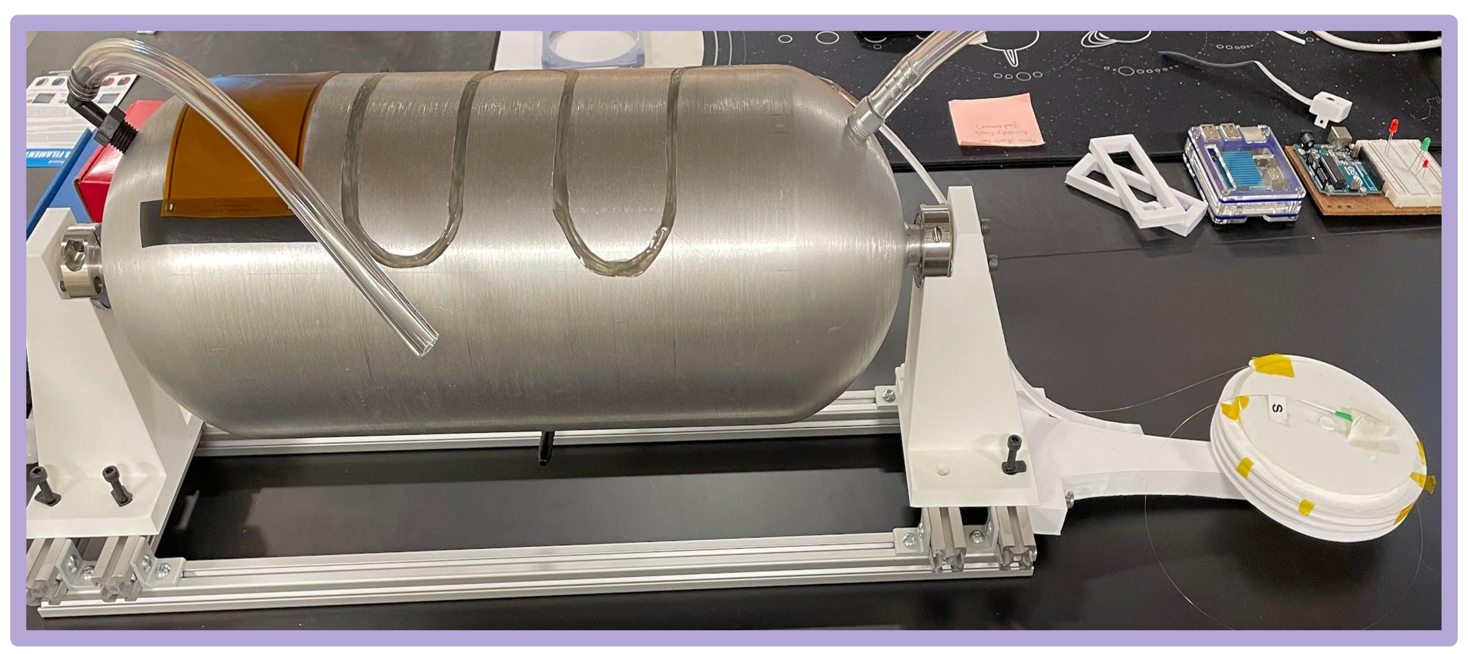
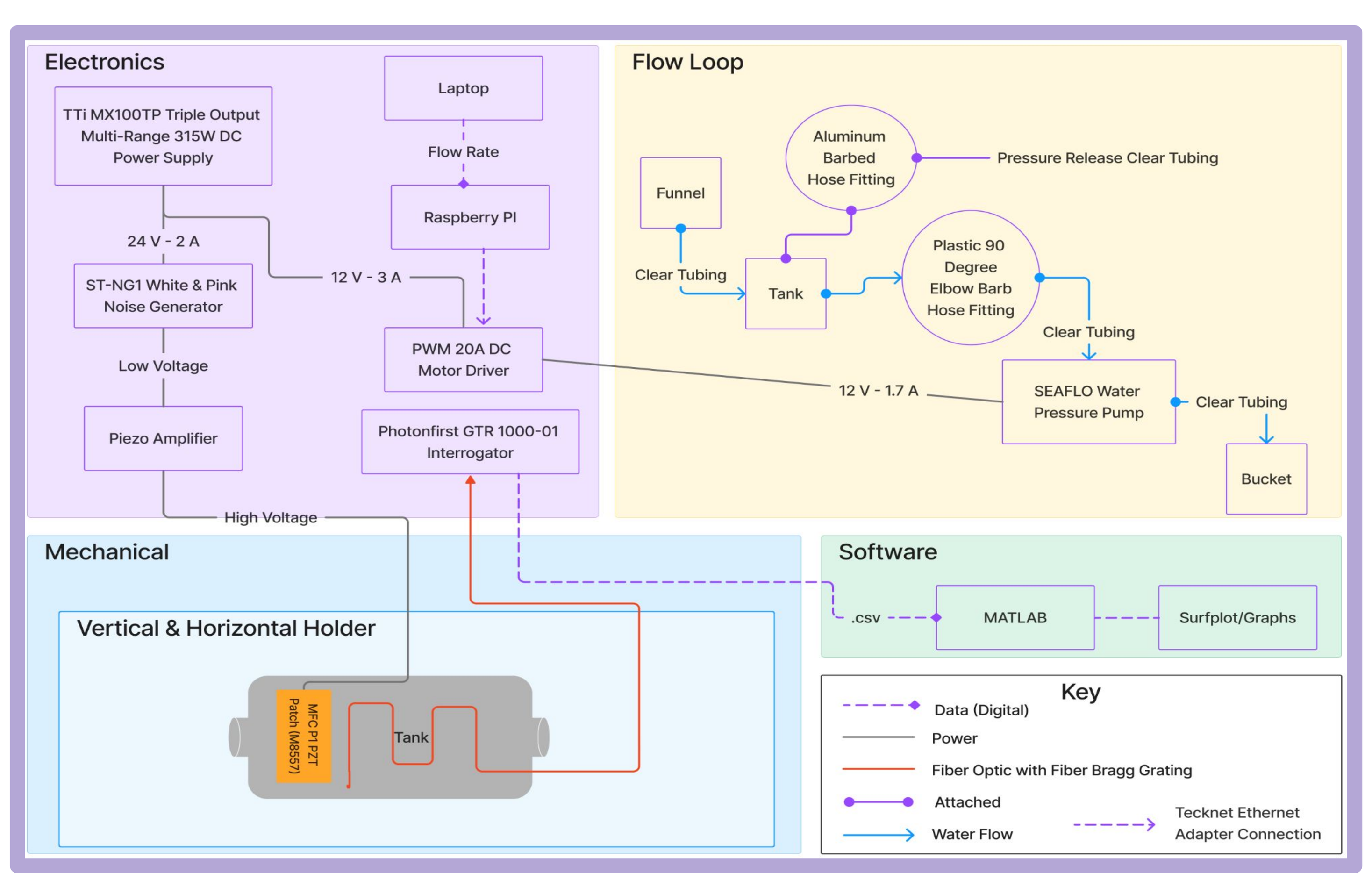
- The objective of this study is to assess the viability of replacing PZT-based sensors in an MPG experiment with FOSS-based strain sensors in an effort to reduce noise, improve sensitivity, and reduce the SWaP of MPG for spaceflight applications.
- Hardware consists of a tank, a flow loop for drain control, a tank scale, and a FOSS implementation.



Optical Fiber epoxied to a test tank

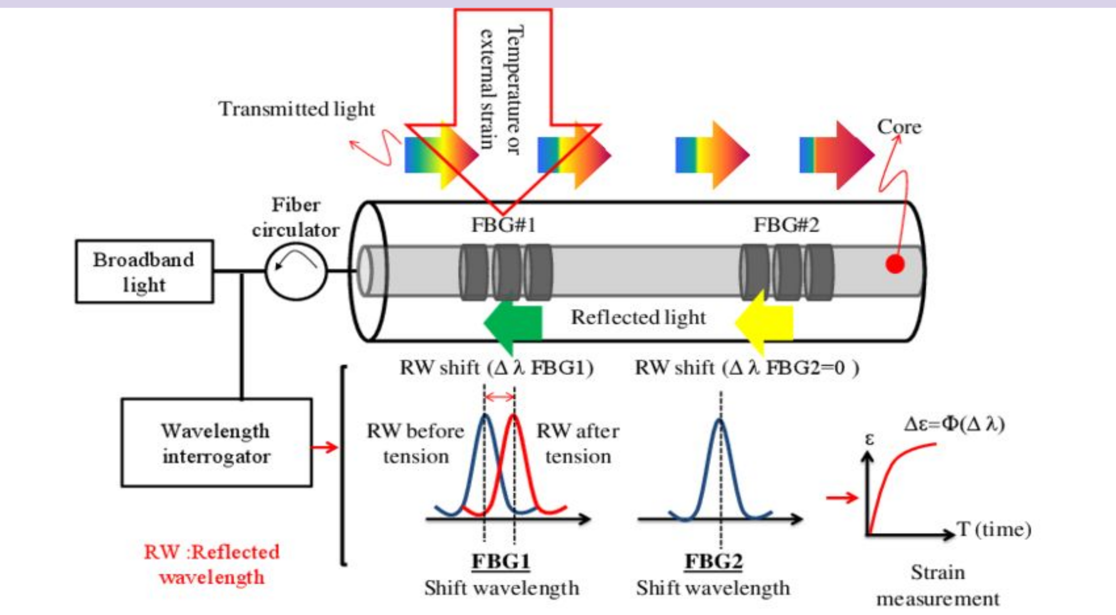


Functional block diagram for the MPG-FOSS Experiment

Measuring Fill Level of a Tank with the Fiber Optic Sensing System (FOSS)

Fiber Optic Sensing System

- FOSS is a NASA-patented technology, developed at Armstrong Flight Research Center. FOSS implements Fiber Bragg Gratings (FBG) to measure strain in a test article with high sensitivity and no electromagnetic interference (EMI).
- The **interrogator** provides 1516-1583 nm light excitation to an attached optical fiber.
- Fiber Bragg Gratings (FBGs) along the length of the fiber respond to strain by modulating the frequencies of reflected signal.



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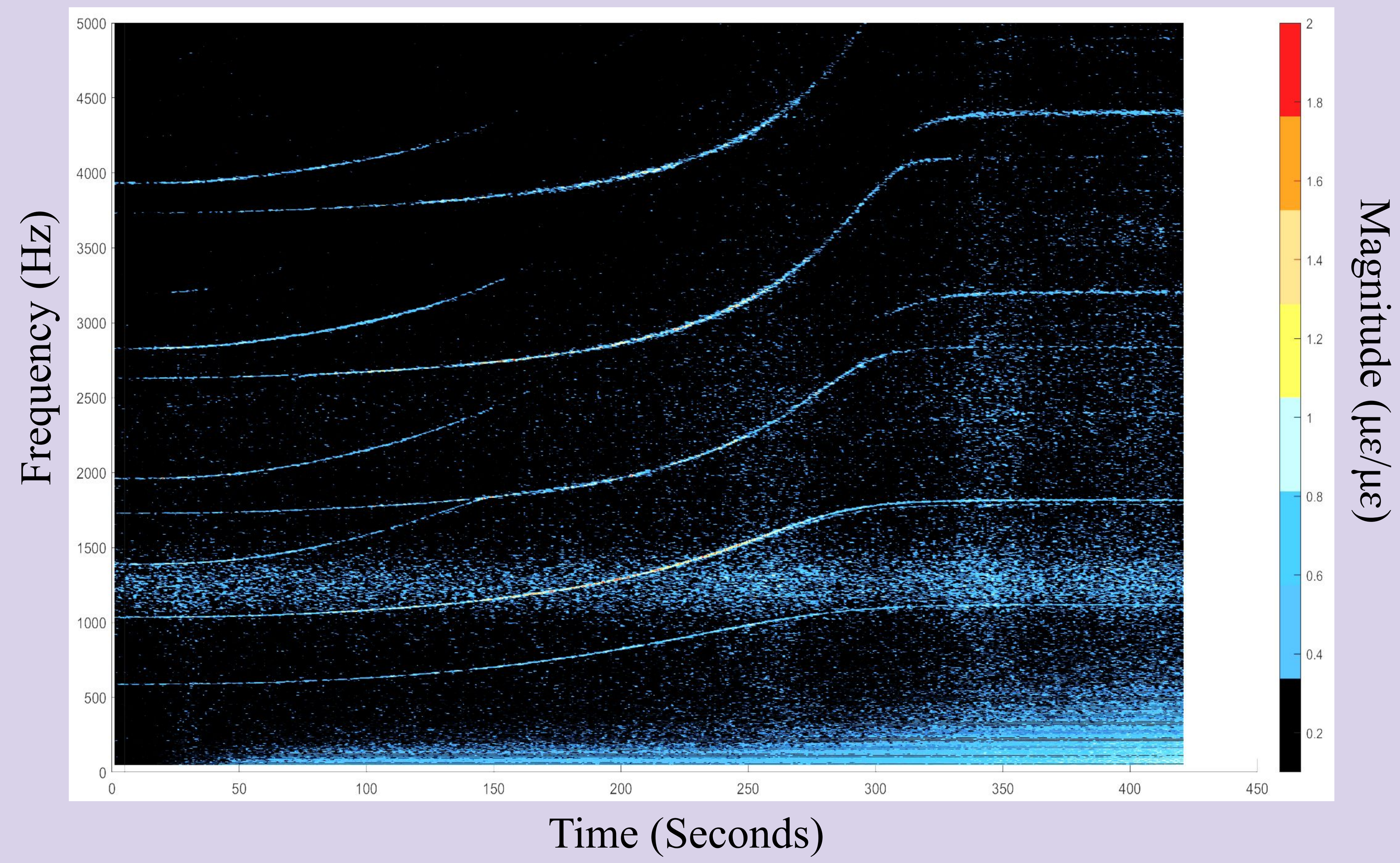
Software

MATLAB scripts process reflected wavelength data. Script outputs include:

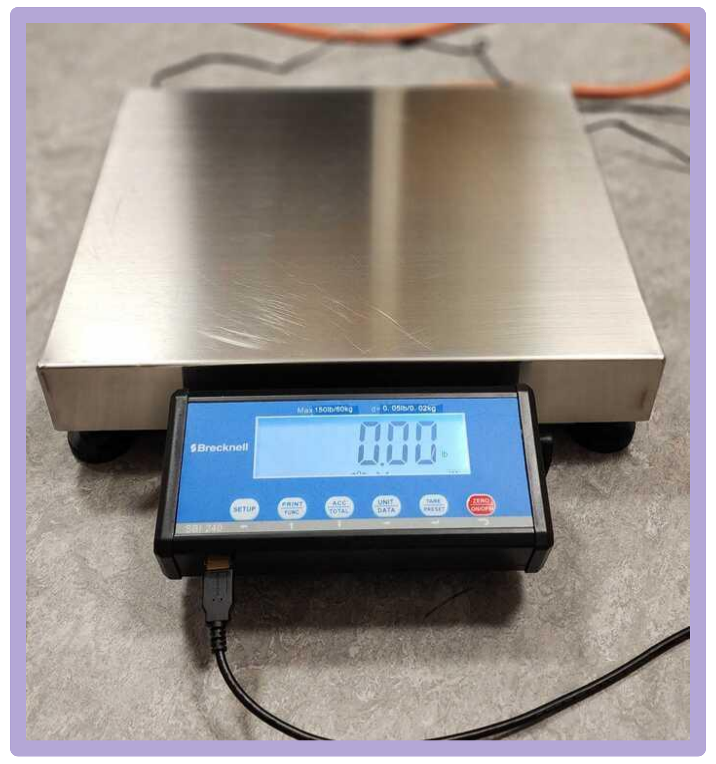
- Four sensor (FBG) input grid of graphs
- Eight sensor input grid of graphs
- Transmissibility Functions for each sensor pair

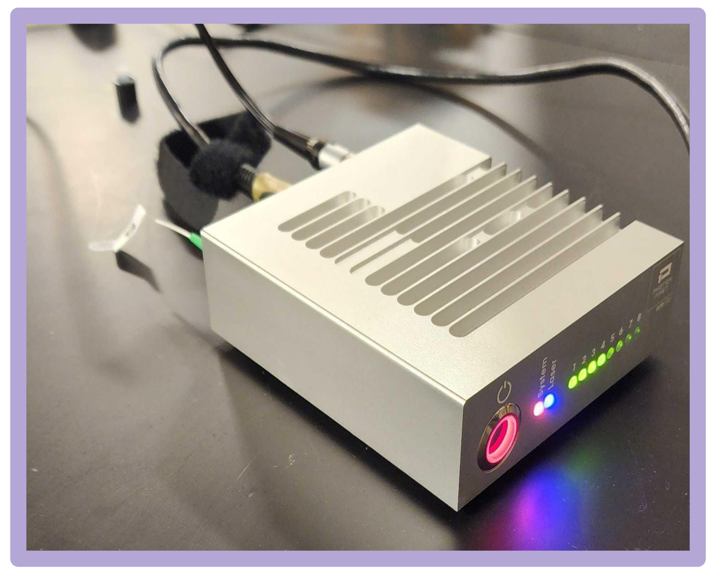


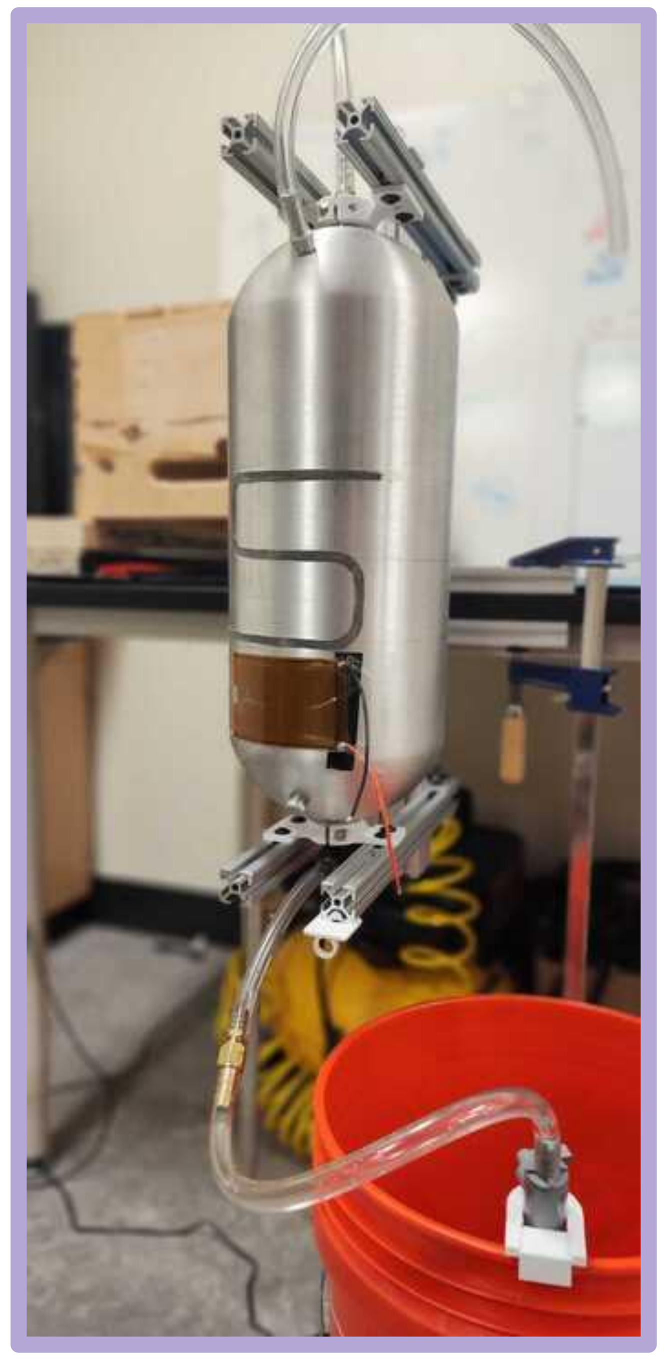
A python script records tank mass via a USB connection to a mass scale. Transmissibility data is correlated with mass scale data in a reference library. Mass estimates for new data are made via correlations between reference data and new test data.

Accomplishments

- Measured vibrations with FOSS and extrapolated frequencies of our tank from processed data.
- Gathered data from the interrogator is able to be processed by our MATLAB scripts.
- Collected data from water drains which can be converted into easy to view plots.
- Integrated a scale into the data collection process allowing for weight measurements of our tank.







Future Objectives

- Implement FOSS into MPG experiments to minimize the risks associated with exposed electronics and remove the possibility of EMI in our data.
- Train a neural network to collect and interpret data.
- Create a library of a variety of modal frequencies for our tank depending on the fill level.

Acknowledgements

- We would like to thank our advisor, Dr. Kevin Crosby, NASA's T2U program, and the Carthage College Aspire Program for funding this project.