Final Year Project Report (2023-2024)

Powerless Vibration Sensor Probe using DHFLCs

Project ID: AS01a-23
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Main Objective

This project aims to develop a passive vibration sensing system using a threshold-less deformed helix ferroelectric liquid crystal (DHFLC) cell. Combining the DHFLC cell, piezoelectric film, and optical detector, the system can transform the slight vibration into a light intensity signal without a power supply. These vibration transducers can detect the perturbation in 3 dimensions and predict the accurate location of seismic events.

Objective Statements

1. Develop and build a passive vibration sensor system with DHFLC cell and piezoelectric film
2. Reach vibration sensor sensitivity of 0.3784 V/(m/s²)
3. The linearity in the electro-optical response <1% full detection range

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ABSTRACT

Passive vibration sensing systems are needed to capture and interpret vibrations without requiring an external power source, enabling efficient and continuous monitoring of structures, machinery, or environmental conditions. In this paper, we present a passive vibration sensing system mainly consisting of a deformed helix ferroelectric liquid crystal (DHFLC) cell, a piezoelectric film, and an optical detector. The combination of these components means the system can transform sligh vibrations into light intensity signals without a power supply. We evaluated our system's performance by comparing the vibration movement to the light intensity signals. Our experiments found that the system can reach the sensitivity of 0.4204 V/(m/s^2) and the linearity of 0.28% full range output.

SECTION 1—INTRODUCTION

1.1 Background and Engineering Problem

The escalating demand for large-scale, high-density sensing arrays necessitates advancements in sensor technology, demanding heightened sensitivity, an expanded response range, reduced cost, and a smaller footprint. The effective sensing of vibrations holds paramount significance across diverse industries, enabling the early detection of potential issues, optimizing critical component performance, and averting costly failures or accidents. For instance, in structural health monitoring, vibration sensors scrutinize structural conditions to identify damages [1]. Similarly, in seismology, these sensors monitor ground movements to detect earthquakes [2].

The widely adopted vibrational energy harvesting system, commonly used on bridges, converts mechanical vibration into electrical signals. While effective, this system demands high-frequency vibrations for optimal voltage generation, yet everyday vibrations typically fall within the 1-100 Hz range. Consequently, a powered amplifier is often required to produce a transferable voltage signal, resulting in increased energy consumption and maintenance costs.

However, a crucial challenge lies in the power supply of sensing probes. Maintaining batteries or energy harvesters for numerous sensors poses a considerable obstacle. The operation of a large number of vibration sensors necessitates a power source, introducing substantial challenges in battery or energy harvester maintenance, adding costs, and potentially disrupting mission-critical sensing systems. This challenge intensifies in remote locations such as underwater or underground deployments [3]. Deploying sensors in these environments amplifies the complexity of the issue. Hence, there is an urgent need for a cost-effective, passive vibration sensor to address this challenge.

A passive sensing technique emerges as an ideal solution, requiring no additional power during energy transduction. By eliminating power supply and signal processing components from the sensing probe, this approach ensures the foundation of a cost-effective, large-scale, high-density sensing network.

1.2 Objectives

This project aims to develop a passive vibration sensing system utilizing a threshold-less deformed helix ferroelectric liquid crystal (DHFLC) cell. Integrating the DHFLC cell, piezoelectric film [6], and optical detector, the system can convert slight vibrations into light-intensity signals without requiring a power supply. With mature techniques and no power source in the sensing probe, the proposed system boasts low cost, easy maintenance, and a long lifespan, making it suitable for application in remote, large-scale, high-density sensing networks. The core components of the system comprise a DHFLC cell, a piezoelectric film-based sensor [6], and an optical detector.

1.2.1 Objective Statements

1. Develop and build a passive vibration sensor system with DHFLC cell and piezoelectric film
2. Reach vibration sensor sensitivity of 0.3784 V/(m/s²)
3. The linearity in the electro-optical response <1% full detection range

1.3 Literature Review of Existing Solutions

Overview

In recent years, numerous methodologies for vibration sensing have emerged [9], focusing primarily on enhancing sensor sensitivity within high-frequency environments. However, these advancements have often neglected the critical imperative to address power consumption and maintenance costs. The prevailing issue lies in the elevated costs associated with each sensor, stemming from the necessity for power amplification systems at the sensor site and the intricate nature of system components [12]. This poses significant challenges in extending applications to large-scale, high-density sensing systems.

This project addresses this issue by prioritizing the elimination of power amplification in vibration sensors. The proposed solution involves replacing voltage signals with optical signals, leveraging the unique properties of ferroelectric liquid crystals (FLCs). Among FLCs, those exhibiting the deformed helix ferroelectric (DHF) effect during data transmission at the sensor site are particularly promising due to their fast electro-optical response.

Here are some summarizations of studies of different types of energy harvesting systems used with vibration sensors:

Piezoelectric vibrational energy harvesting system

Piezoelectric vibrational energy harvesting system is a self-powered technology that converts mechanical vibration into electrical signals and has been widely used in sensors for monitoring physical activity and physiological parameters [4]. When a piezoelectric material is vibrated by the outer source [8], a voltage is generated due to an imbalance of charge across its surface. This means the amount of voltage generated by the piezoelectric material is proportional to the frequency and amplitude of the vibration.

This system requires high-frequency vibrations to generate communicable levels of voltage, while everyday vibration cycles are measured in the range of 1-100 Hz [10]. In cases where piezoelectric vibrational energy harvesting systems are installed in environments with lower vibration cycles, a powered amplifier capable of supplying a constant voltage has to be installed to output a transferable voltage signal. As a result, the placement of the vibration sensors using this harvesting method has limitations in environment factors and volume constraints.

Electrostatic transducers

Electrostatic transducers can be used as vibration sensors and energy harvesters based on the principle of electrostatic induction caused by the mechanical movement of the conductor in an electric field [11]. This type of harvester converts mechanical vibration energy and signal into electrical voltage output.

The electrostatic sensor measures current flow in the signal wire, caused by the motion of the free electrodes in the electric field when a charge with an opposite polarity interferes.

The application of electrostatic sensors is limited to small amplitude vibrations due to its limited dynamic range. In a real world application of electrostatic transducers, a DC high-voltage source is required to maintain polarization in the electric field [11]. Furthermore, electrostatic transducers, typically comprise a thin layer of plate that is suspended between two electrodes, its plate separation is in millimeter scale for small amplitude vibration. Therefore electrostatic transducers may not be a reliable solution to building large-scale passive vibration sensors.

Electromagnetic vibrational energy harvesters (EVEH)

Electromagnetic vibrational energy harvesters (EVEH) boast a straightforward design, producing sound power at low frequencies [5]. Functioning based on Faraday's law of induction, these harvesters utilize a magnet passing through a coil to induce a current. In the inverse magnetostrictive approach, the magnetization state of magnetostrictive material is controlled by a biased magnetic field, followed by inducing strain to generate a change in magnetic flux. This flux change is then converted into electric power through a coil.

Advancements in low-power circuitry have enhanced the viability of electromagnetic harvesters. Notably, their ability to capture kinetic energy at low frequencies makes them stand out among vibrational harvesters. Despite the efficiency achieved in signal amplification power consumption and the capability to detect very low-frequency vibrations in low-frequency environments, it is essential to note that these energy harvesters still require a sustainable continuous power source nearby for the sensors to operate.

SECTION 2—METHODOLOGY

2.1 Overview

2.1.1 System Description

In this project, we created a passive vibration sensing probe that can detect vibrations without the use of a power supply. The core components of the system include a DHFLC cell, a piezoelectric film, and an optical detector.

The first main component of the system is the piezoelectric films, which is a thin layer of material that exhibits the piezoelectric effect, a property where mechanical stress applied to the material generates an electrical voltage [6]. This means that when vibration occurs, the piezoelectric film will convert the mechanical stress into electrical signals. The system will simulate vibration with a device and measure the displacement and speed of the vibration with a motion sensor.

The second main component is the DHFLC cell. DHFLC is a specific type of liquid crystal that exhibits ferroelectric properties. It can be used to modulate light transmission or reflection by altering its molecular orientation in response to an applied electric field. Furthermore, the threshold-less switching behavior means that it does not require a minimum voltage to initiate a change in its optical properties [7]. Therefore in this system, the electrical signal generated from the piezoelectric film will modulate the DHFLC's optical properties, where the change in the optical signal can be detected and analyzed to determine and measure the vibration.

Alongside the DHFLC cell, we use two polarizers in our system. The first zero degree polarizer is placed between the laser and DHFLC cell. This polarizes the light that passes through the DHFLC cell. Then, another 90 degree polarizer is placed between the DHFLC cell and the optical detector. The reason for doing this is when polarized light passes through the DHFLC cells, it acts as a wave plate and rotates the direction of the polarized light. So when the voltage generated by the piezoelectric film changes the angle of the helical structure, it will then change the polarization at different angles. As a result, only a partial amount of light can pass through at a specific 90-degree angle.

The third main component is the optical detector, which will be used to analyze the change in optical signal when the DHFLC's optical property is altered by the piezoelectric film. In the testing of the system, a laser is used to simulate an optical signal. The light intensity that the optical detector receives is measured and used for analysis.

The system block diagram below (Figure 1) demonstrates the process described above. The main measurements concerned will be the light intensity (in voltage) versus the displacement and speed data (in m/s) of the vibration simulator gathered from the motion sensor. These sensors will be connected to a computer so that the data can be observed and analyzed.

2.1.2 System Block Diagram

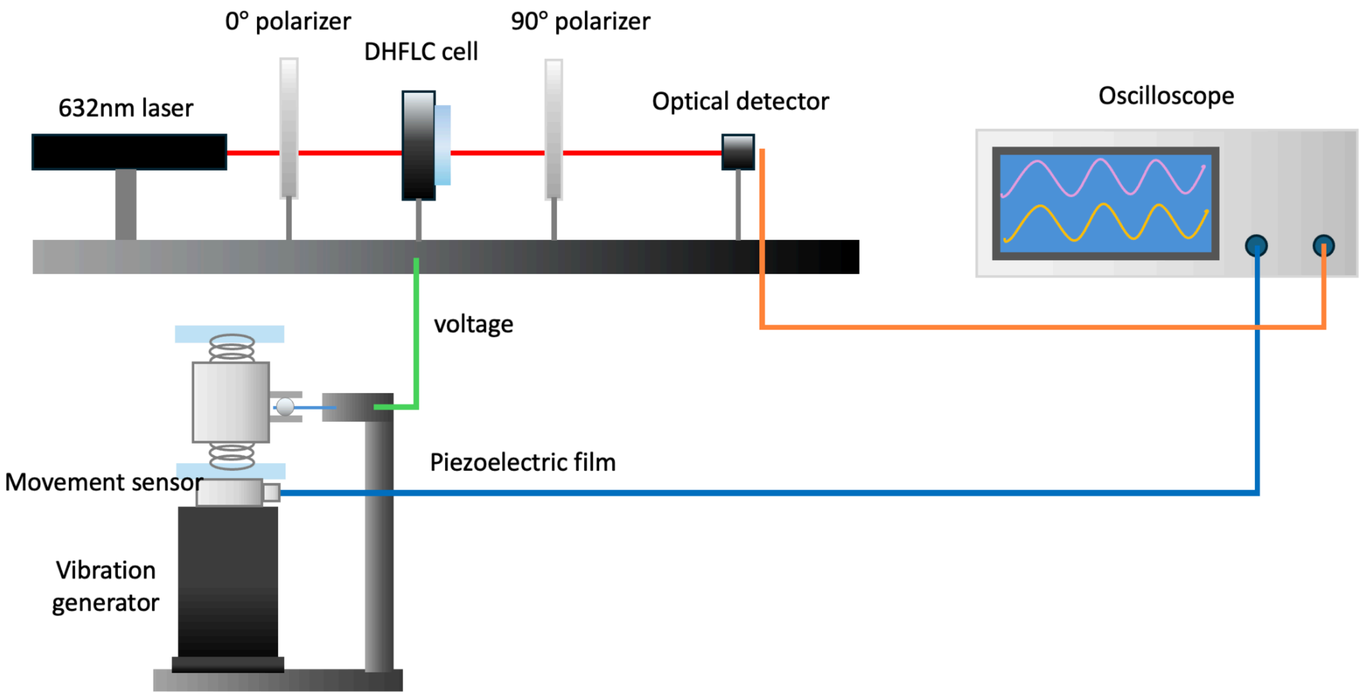


Figure 1: System Design

2.1.3 Components List

Table 1. List of Specifications

Item*	Parameters to be Measured
Optical Detector	Light intensity (V)
Movement Sensor	Displacement Speed (V/(m/s))

2.1.4 ECE Knowledge

ELEC3600 Electromagnetics: From Wireless to Photonic Applications

This course introduces applied electromagnetics from fundamentals to applications. The course content introduces subjects such as electrostatic fields, electromagnetic wave properties, and so on. Many of our project components use properties of electromagnetism. Most notably, our system will convert mechanical signal into an optical transmission. This light transmission part uses properties of electromagnetism and requires understanding which is covered in this course.

ELEC 4010L Display Technology

This course introduces students to flat panel display technologies, where the course concentrates on the optical and electrical aspects of displaying devices and the recent trend. Our project requires knowledge on liquid crystals, which is a key component of display technologies. The knowledge of the optical and electrical aspects of displaying devices using liquid crystals will be closely related to the knowledge needed for implementing the DHFLC cell.

ELEC 2100 Signals and Systems

This is an introductory course for signal and system analysis. In our project, the system will analyze various signals such as the received light transmission with the optical detector and also will measure the voltage generated by the piezoelectric film. The course provides knowledge on how to use various equipment such as oscilloscopes that may be used to measure such signals and also teaches students how to interpret the findings and measurements so that the measurements can be properly interpreted.

2.2. Objective Statement Execution

2.2.1 Develop and build a passive vibration sensor system with DHFLC cell and piezoelectric film

In this objective, the goal is to design the passive vibration sensor system and then build the system by combining all the key components mentioned in system description in 2.1. The outcome will be a physically built system that can detect vibration without a power supply. This objective requires many parts so to accomplish this, we split this objective into multiple subtasks listed below.

Task 1

Aim: Fabricate DHFLC Cell

Expected Outcome: Working DHFLC cell

Member(s) in charge: All

Work Description:

One of the key components in our system is the DHFLC cell. Figure 2 illustrates the molecular arrangement within a fabricated Deformed Helix Ferroelectric Liquid Crystal (DHFLC) cell. In this configuration, smectic layers align perpendicular to the substrate while the helical axis runs in tandem with the alignment layer's direction. The FLC molecules execute a conical rotation around this helical axis. The angle formed between the helical axis and a molecule is defined as the 'tilt angle.' When subjected to an electric field, the helical structure distorts, and the molecules align more closely with the field's orientation.

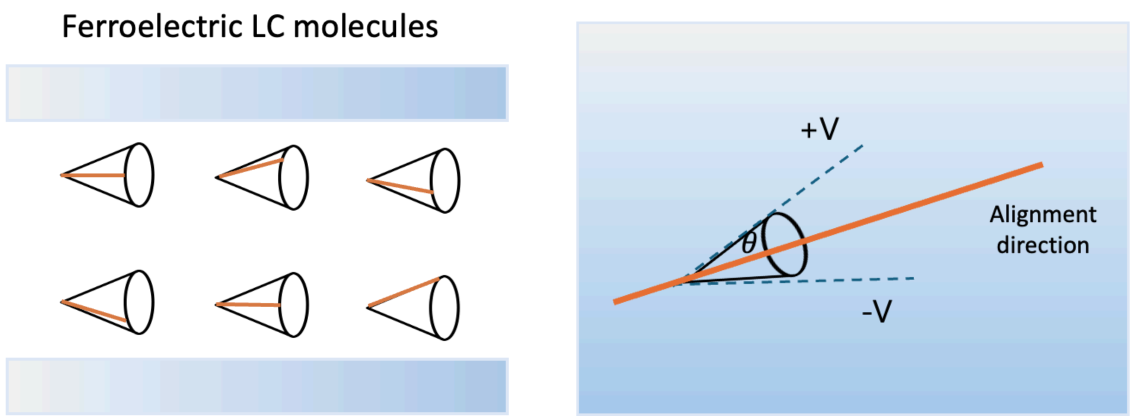


Figure 2:The schematic diagram(left) and alignment direction(right) of molecules orientation of DHFLC cell

Using this property of the DHFLC cell, our system employs the voltage generated by the piezoelectric film to induce changes in the helical structure. This modulation allows a laser to pass through the DHFLC cell, with the subsequent light signal captured by an optical detector [14]. The relationship between the piezoelectrically generated voltage and the helical structure's alteration is pivotal for the operation of our sensing mechanism.

To create the DHFLC cell, we worked in the lab with our designated teaching assistant (TA) Steven to fabricate the DHFLC cell. The process of fabricating the cell and the final outcome is shown below.

Fabrication of DHFLC Cell

Glass Preparation

Cut a glass into a 10 x 10 cm square using an open beam laser.
Subsequently, cut the square glass into smaller pieces measuring 15 x 20 mm.

Glass Cleaning

Figure 3: Glass Wash Machine (left) & UVO Cleaner (right)

1. Wash the glass pane with a cleaning agent at 50 degrees Celsius for 20 minutes.
2. Rinse the glass with flowing water at 50 degrees Celsius for an additional 20 minutes.
3. Allow the glass to dry thoroughly after rinsing.

Glass Baking

Bake the glass at 100 degrees Celsius for 1 hour.

Ozone Treatment

Apply ozone (O3) UV coating to the glass surface for 10 minutes.

Spin Coating

Figure 4: Spin Coating Machine (left) & Digital Hot Plate (right)

Apply N6 dissolved in 2,2,2-Trichloroethanol using spin coating at 800 rpm for 5s and 3,000 rpm for 2 minutes.

Soft Bake

Soft bake the glass at 100 degrees Celsius for 10 minutes.

Hard Bake

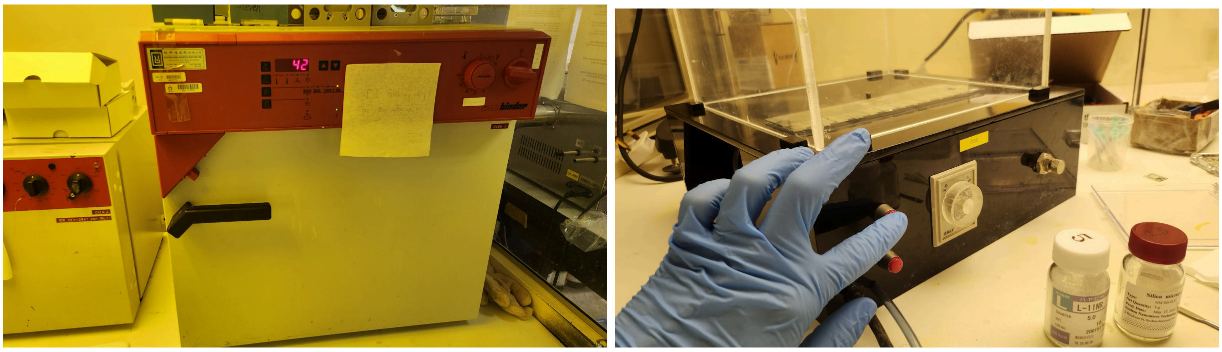


Figure 5: Oven for Baking the Cells (left) & Spacer Blower (right)

Perform a hard bake at 180 degrees Celsius for 1 hour.

Surface Rubbing

Rub the glass surface seven times in the vertical direction using a soft cloth to ensure surface alignment.

Spacer Application

Apply silica microparticles (1.5um diameter) as spacers on one of the glass panes after baking.

Glass Assembly

Figure 6: Use of Pincers for fixation (left) & Use of UV Glues (right)

Combine the glass pane with spacers and the one without spacers, placing them one upon another.

UV Gluing

Apply UV glue at the edges of the glass panes and expose them to UV light to secure them together, using pincers for fixation.

Quality Inspection

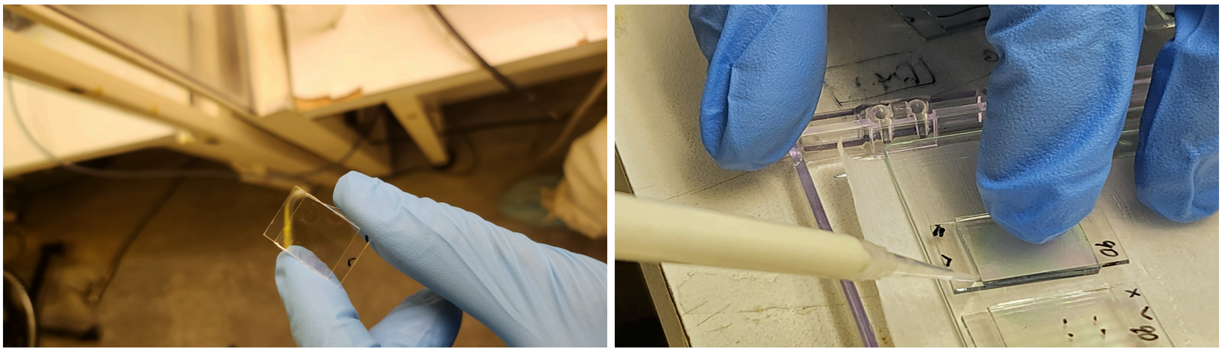


Figure 7: Checking cells for dust and selection (left) and Injection of nematic between glass panes (right)

Check and select cells that exhibit no dust or impurities, ensuring the selection of the best cells.

Liquid Crystal Injection

Inject Deformed Helix Ferroelectric Liquid Crystals (DHF LC) into the gap between the two glass panes in vacuum 130 Celsius.

Figure 8: Example of our group working in the lab to construct liquid crystal cell

Outcome

The outcome of this task is shown in Figure 9.

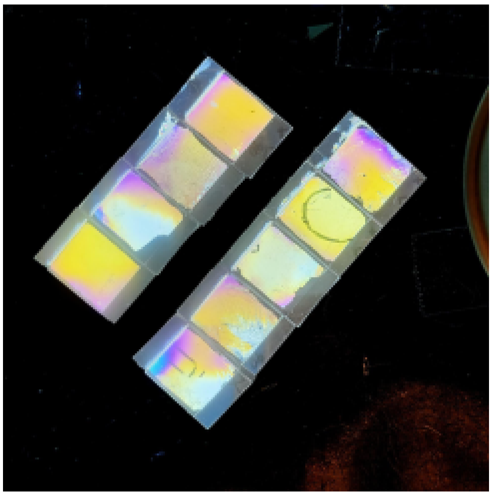


Figure 9: Fabricated cell

Task 2

Aim: Design the vibration sensor for the workshop to build

Expected Outcome: A workshop approved design of the vibration sensor

Member(s) in charge: All

Work Description:

The primary function of this vibration sensor is to convert mechanical vibrations into electrical voltage. This generated voltage is subsequently applied to drive liquid crystal (LC) cells. This conversion process is crucial for applications where vibration data needs to be accurately represented and manipulated through electrical signals.

This vibration sensor utilizes a piezoelectric element, where the bending of the sensor generates voltage. To effectively harness vibrations, the sensor is integrated with a mass-and-spring system. Vibrations cause the mass to oscillate, which in turn induces bending in the piezoelectric sensor. This bending generates a voltage output, which is then used to drive liquid crystal (LC) cells. The mass-and-spring configuration is critical as it enhances the sensor's sensitivity and response to vibration frequencies, thereby improving its efficacy in converting mechanical energy into electrical signals.

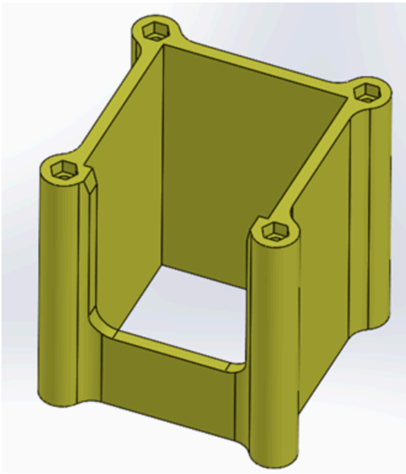
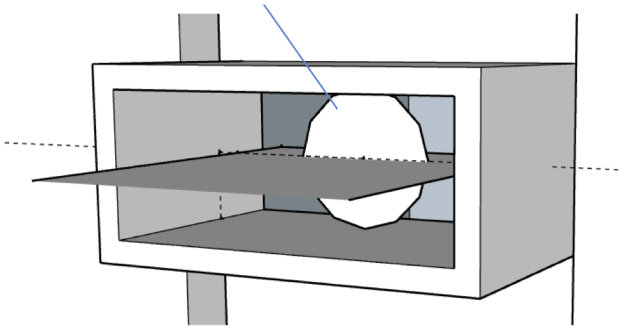


Figure 10: Casing of the mass and springs (3D printed Sleeve)

The original design of the vibration sensor included a casing to restrict the mass to vertical movements only. However, during testing, it was discovered that the casing caused friction that negatively impacted the sensor's performance. Upon further observation, it was clear that the mass naturally moved vertically without the need for such a restriction. So we removed the casing to reduce friction and improve the overall effectiveness of the sensor.



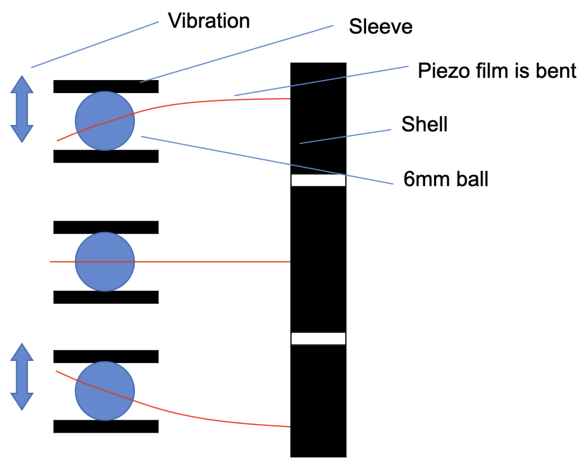


Figure 11: placement of piezoelectric film using metal ball(left)
and movement of the piezoelectric film(right)

In refining the design of the vibration sensor, we decided not to attach the piezoelectric film directly to the mass. Instead, we attached a 6mm metal ball to the piezoelectric film. This ball is then placed within a grid structure on the mass. This design ensures that when the piezoelectric film bends due to vibration, the initial angle of the film alters in correspondence with the movement of the mass. This change allows for a more dynamic and responsive interaction between the mass and the piezoelectric element, improving the sensor's sensitivity and the precision of voltage generation used to activate the LC cells.

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

$$k = \frac{G*d^4}{8*na*D^3}$$

G = E/2(1 + V)
d = D outer - d

G = Shear modulus of material
d = Spring wire diameter
D = Outer diameter of spring
na = number of active coils
E = Young's modulus of material
V = Poisson's ratio of material

$$m = \frac{500}{1000} \ \cdots \ converting\ mass\ unit\ to\ kg$$

$$G = 79.3\ \times\ 10^9 \ \cdots \ converting\ GPa\ to\ Pa$$

$$d_{wire} = \frac{0.9}{1000} \ \cdots \ converting\ diameter\ from\ mm\ to\ m$$

$$na = 4.5 \ \cdots \ number\ of\ active\ coils$$

$$D_{outer} = \frac{20}{1000} \ \cdots \ converting\ outer\ diameter\ from\ mm\ to\ m$$

$$k = \frac{(79.3 \times 10^9) \cdot (0.0009)^4}{8 \cdot 4.5 \cdot (0.02)^3} = 180.65\ N/m$$

$$k_{total} = 2\ \times\ k = 361.3\ N/m \ \cdots \ two\ springs\ in\ parallel$$

$$f = \frac{1}{2\pi}\sqrt{\frac{361.3}{0.5}} = 8.56\ Hz \ \cdots \ frequency$$

With two springs used in parallel, the total spring constant k total for the system is approximately 361.3 N/m, and the new natural frequency of the system is approximately 8.56 Hz.

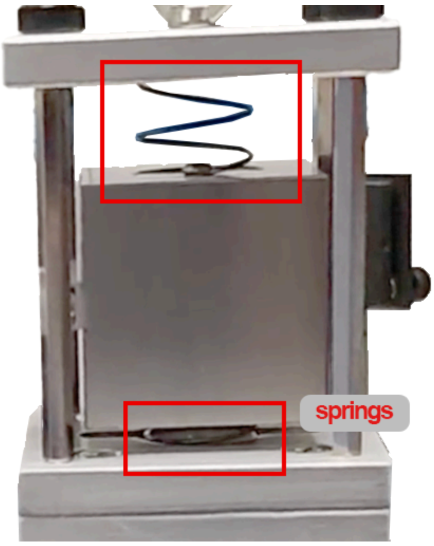


Figure 12: springs attached at the top and bottom of the mass cube

We selected dual springs, one attached at the top and the other at the bottom of the mass cube, with the following dimensions: a wire diameter of 0.9mm, an outer diameter of 20mm, a height of 15mm, and with 4.5 active coils. The springs were chosen to have just enough strength to support the mass without being excessively rigid, allowing for accurate translation of vibrations into mechanical motion that the piezoelectric film can convert to electrical signals. The calculations shown in the image guide the selection of these spring parameters, ensuring the system has the desired natural frequency and spring stiffness.

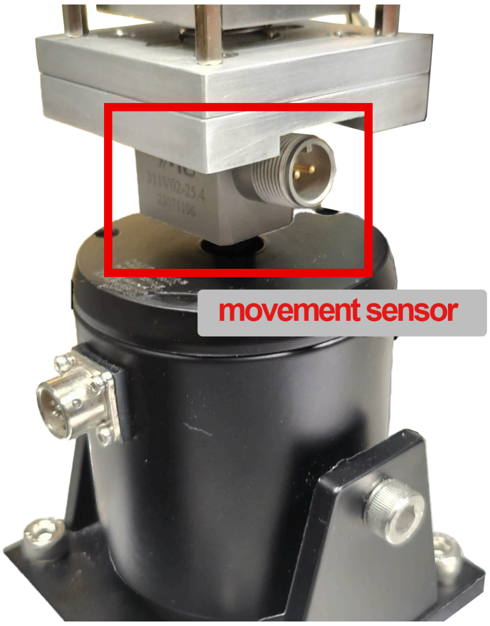


Figure 13: movement sensor installed between vibration generator and the mass-spring structure

In the final construction phase, a movement sensor, characterized by a sensitivity of 200mV/(mm/s), was placed in the mechanical chain between the vibration generator and the mass-spring ensemble. This placement ensures accurate data acquisition regarding the kinematics of the mass due to vibratory stimuli.

The primary intent of this configuration is to ensure precise detection and measurement of movement, which is then transduced into an electrical signal by the piezoelectric film.

Task 3

Aim: Test the workshop created vibration sensor

Expected Outcome: The vibration from the generator and the voltage from the piezoelectric film should be able to show results on an oscilloscope.

Member(s) in charge: All

Work Description:

Before adding the device into our overall vibration sensing system, we first had to test whether the device works on its own. This means testing the device without the laser, optical detector, and DHFLC components. To do so, we measured the vibration from the generator and the voltage from the piezoelectric film with an oscilloscope.

During our testing, we discovered that the voltage measured from the piezoelectric film had large noise. After further analysis, the noise was most likely caused by electromagnetic disturbance. Figure 14 shows an example of our test and the noise displayed on the oscilloscope.

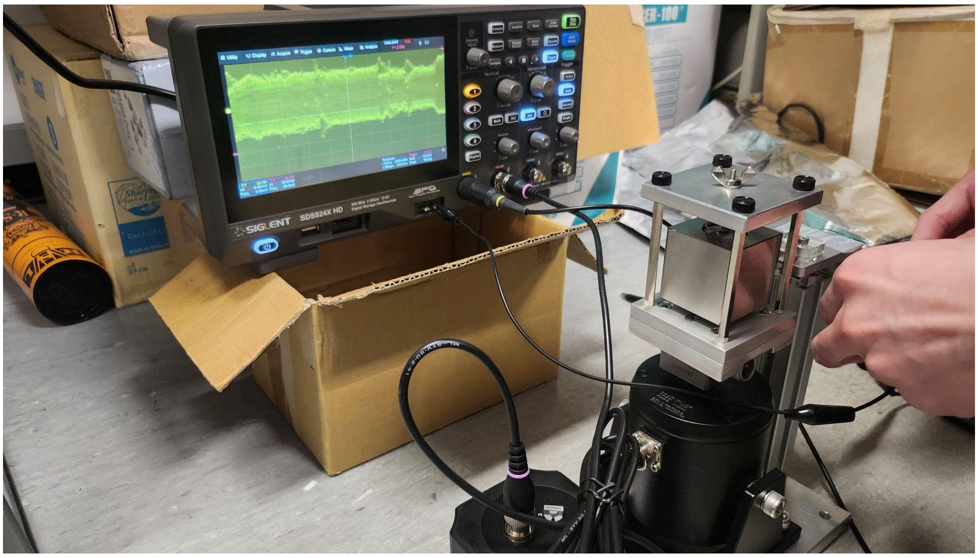


Figure 14: Experimental setup displaying noise disturbance

To reduce noise from electromagnetic disturbance, we decided to use a simple Faraday Cage by wrapping our device in aluminum foil. Figure 15 shows our solution of using aluminum foil as a Faraday Cage to reduce electromagnetic noise.

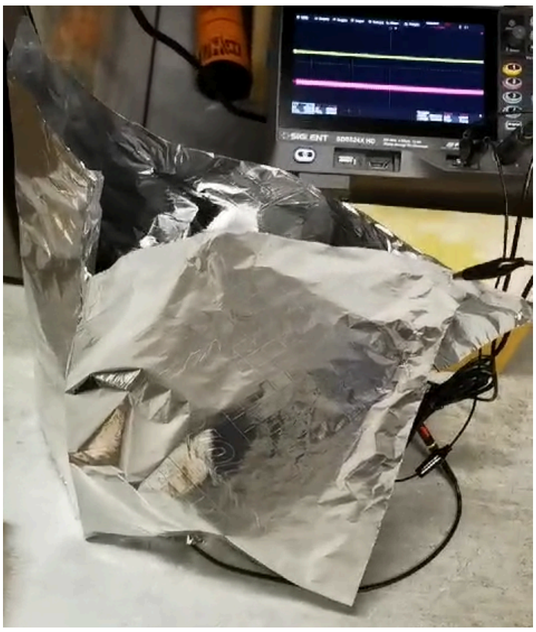


Figure 15: Experimental setup with Faraday Cage Shielding

Task 4

Aim: Integrate the vibration sensor device with the DHFLC cell to complete the full system

Expected Outcome: Combine the vibration sensor device with the DHFLC cell to build our full vibration sensing system as shown in our system diagram in Figure 1.

Member(s) in charge: All

Work Description:

The final part of building our system is combining our fabricated DHFLC cell with the vibration sensing device to complete our full passive vibration sensing system as shown in our system diagram in Figure 1. In our system diagram in Figure 1, the top half includes the DHFLC cell with two polarizers, a laser, and an optical detector. We used lab equipment provided for us to set up this part, where the setup is shown in Figure 16.

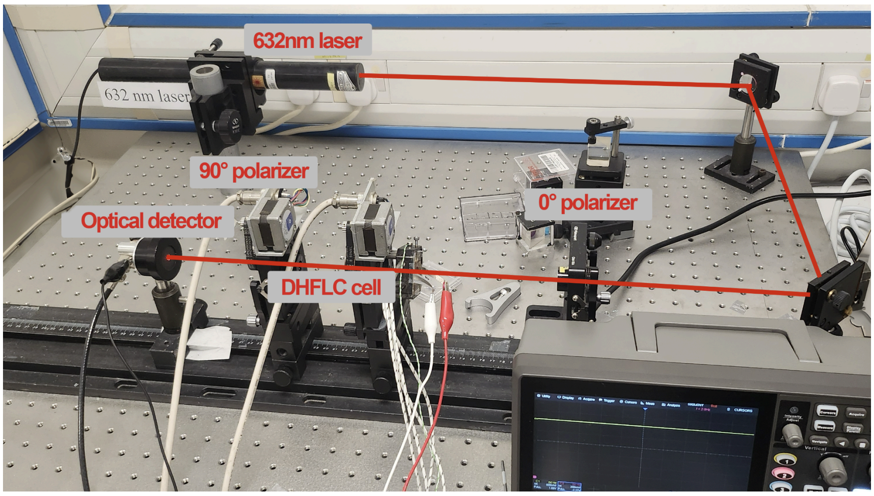


Figure 16: Equipment setup (optical signal)

Then, we connect the setup mentioned above to the vibration sensor device by connecting the piezoelectric film to the DHFLC cell, as shown in Figure 17. This completes our system and means our system is ready for experiments to try and reach the subsequent objectives in the sections below.

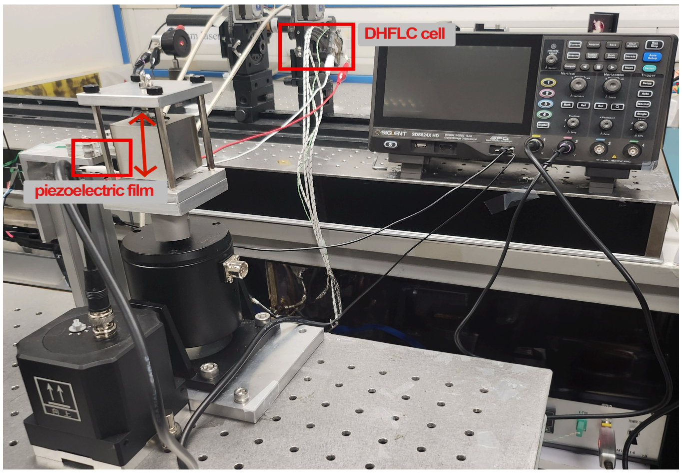


Figure 17: Equipment setup (mechanical signal)

2.2.1.1 Evaluation of Design and Build of Passive Vibration Sensor System

Expected Outcome:
The expected outcome of this objective is to design and build a passive vibration sensor system. It should include the main components of the DHFLC cell, piezoelectric film, and optical signal generator and receiver.

Actual Outcome:
The system that we built fulfilled the expected outcome listed above. The vibration sensor device is able to convert mechanical vibration into voltage and when passed through the DHFLC it alters the optical signal passing through it. The actual experimental data analysis are listed in the following sections below.

2.2.2 Reach vibration sensor sensitivity of 0.3784 V/(m/s²)

This objective is to reach vibration sensor sensitivity of 0.3784 V/(m/s²) in our final experimental results. This is done by obtaining and analyzing the data from the movement sensor and the optical detector.

Task 1

Aim: Carry out experiments of our system and gather data

Expected Outcome: Vibration speed and light intensity data from oscilloscope

Member(s) in charge: All

Work Description:

Our group worked in the lab with our designated TA Steven to run our experiments and collect data to analyze. Below are the experimental procedures:

Experiment Procedure

1. Initial Environment Setup
    - Wrap the experimental setup in aluminum foil to act as a Faraday Cage, reducing electromagnetic noise.
    - Place both the commercial sensor and the Passive Vibration Sensor System on the same level on the ground next to each other. Ensure they are firmly fixed using bolts to minimize external movements not related to the experiment.

2. Mechanical Signal Sensing
    - Set up the vibration generator to initiate vibrations. Begin with a low frequency setting and gradually increase to higher frequencies.
    - Use the commercial vibration sensor to capture the motion of the mass and spring during vibrations.

3. Optical Signal Sensing
    - Direct the laser beam output onto the piezoelectric film.
    - Ensure the optical signal passes through the DHFLC cell.
    - Record the voltage response from the piezoelectric film as it reacts to the vibrations.

4. Generating and Recording Vibrations

- Begin by shaking the table manually to create low-frequency vibrations and record the response from both sensors.
- Increase the complexity by dropping a mass from a predetermined height (use a ruler to ensure consistency in height across trials), creating a different vibration profile. Again, record the data from both sensors.

5. Data Acquisition and Analysis

- Connect both sensors to an oscilloscope to process and record the signal outputs.
- Compare the signals from both the commercial sensor and the Passive Vibration Sensor System.
- Analyze the data to calculate the sensitivity of the sensors, aiming to achieve or exceed a sensitivity of 0.3784 V/(m/s²).

Task 2

Aim: Analyze the data and calculate the vibration sensor sensitivity

Expected Outcome: The data should show a sensitivity of at least 0.3784 V/(m/s²)

Member(s) in charge: All

Work Description:

We repeated the experiment 30 times following the procedures listed in task 1. From the experiments, we took the recordings from the sensors which are gathered in CSV files and exported them for analysis using Python. Figure 18 shows the data from one of our experiments which we used to calculate sensitivity. Channel 1 represents the reading from the movement sensor, while channel 2 is the light intensity measured from the optical detector.

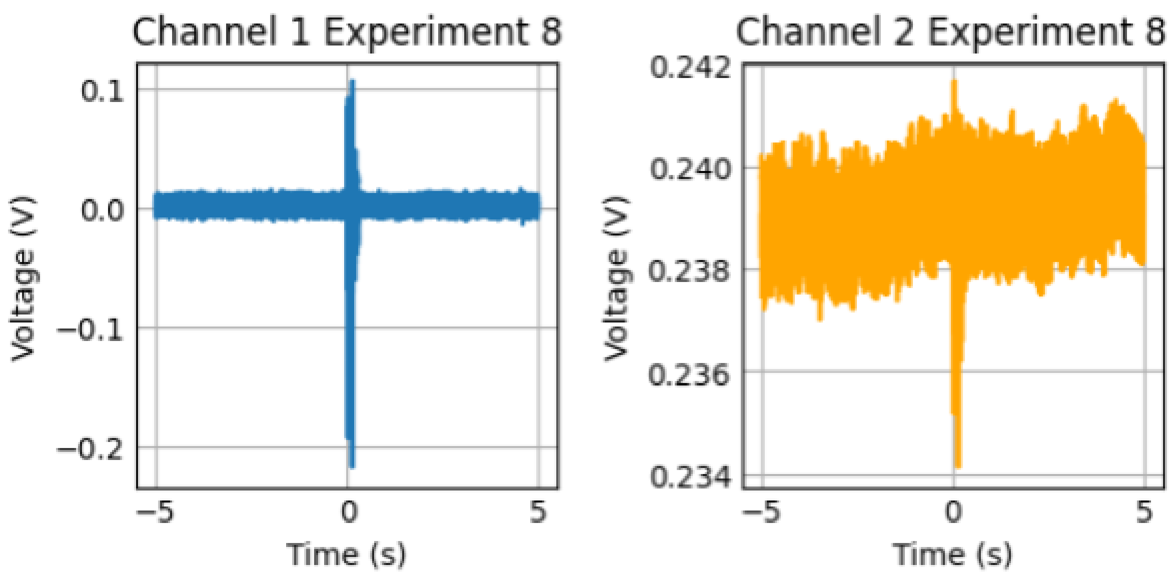


Figure 18: Voltage - Time graph of Mechanical and Optical signal

To calculate the sensitivity of our vibration sensor system using the data above, we use the following equation:

$$S' = \frac{b}{a} * S$$

$$S' = \text{Sensitivity of Vibration Sensor System}$$
$$S = \text{Sensitivity of piezoelectric film}$$
$$a = Max(Channel\ 1)$$
$$b = Max(Channel\ 2)$$

From the data in Figure 18, the value of a is 0.2175 V and the value of b is 0.2416667 V. The value of S is 0.3784 V/(m/s^2), which is taken from the piezoelectric sensor film used in our device. Using the equation above, we obtain a value of 0.4204 V/(m/s^2). This is our final result used for evaluating our system's sensitivity, which exceeds the objective goal of 0.3784 m/s^2.

2.2.2.1 Evaluation of the System's Vibration Sensitivity

Expected Outcome:
The expected outcome of this objective is for our system to have a vibration sensitivity of 0.3784 V/(m/s^2).

Actual Outcome:
Our experimental vibration sensitivity ended up being 0.4204 V/(m/s^2), which meets our target objective of 0.3784 V(m/s^2).

2.2.3 The linearity in the electro-optical response <1% full detection range

This objective is to achieve linearity in the electro-optical response <1% full detection range in our final experimental results. In the context of our experiment, the linearity is the linear fitting of error of displacement versus the light intensity output curve. The process of testing and reaching this objective is mostly similar to objective 2.2.2 as we will be using the same experimental results.

Task 1

Aim: Carry out experiments of our system and gather data

Expected Outcome: Vibration speed and light intensity data from oscilloscope

Member(s) in charge: All

Work Description:

Similar to 2.2.2 task 2, we perform experiments in the lab to gather data. The experiment procedure for obtaining the linearity is as follows:

Experiment Procedure

1. Initial Environment Setup
    - Wrap the experimental setup in aluminum foil to act as a Faraday Cage, reducing electromagnetic noise.
    - Place both the commercial sensor and the Passive Vibration Sensor System on the same level on the ground next to each other. Ensure they are firmly fixed using bolts to minimize external movements not related to the experiment.

2. Mechanical Signal Sensing
    - Attach the movement sensor to the system to accurately capture the motion generated by the mass and spring. This sensor will monitor the mechanical displacements caused by vibrations.

3. Optical Signal Sensing
    - Direct the output of the laser beam onto the piezoelectric film.
    - Ensure the optical signal is properly transmitted through the DHFLC cell.
    - Record the resulting voltage changes from the piezoelectric film, which are indicative of the mechanical displacements.

4. Generating and Recording Vibrations
    - Begin by shaking the table manually to create low-frequency vibrations and record the response from both sensors.
    - Increase the complexity by dropping a mass from a predetermined height (use a ruler to ensure consistency in height across trials), creating a different vibration profile. Again, record the data from both sensors.

5. Data Acquisition and Analysis
    - Connect both sensors to an oscilloscope to process and record the signal outputs.
    - Compare the signals from both the commercial sensor and the Passive Vibration Sensor System.
    - Analyze the data to calculate the sensitivity of the sensors, aiming to achieve or exceed a sensitivity of 0.3784 $V/(m/s^2)$.

Task 2

Aim: Analyze the data and calculate the linearity of the electro-optical response from the experimental results

Expected Outcome: Linearity of <1% in the electro-optical response

Member(s) in charge: All

Work Description:

Similar to 2.2.2 task 2, we perform experiments following the procedures from task 1 above and extract the data for analysis. Figure 19 shows the data collected from the oscilloscope. Channel 1 represents the data from the movement sensor whilst channel 2 represents the data from the optical detector.

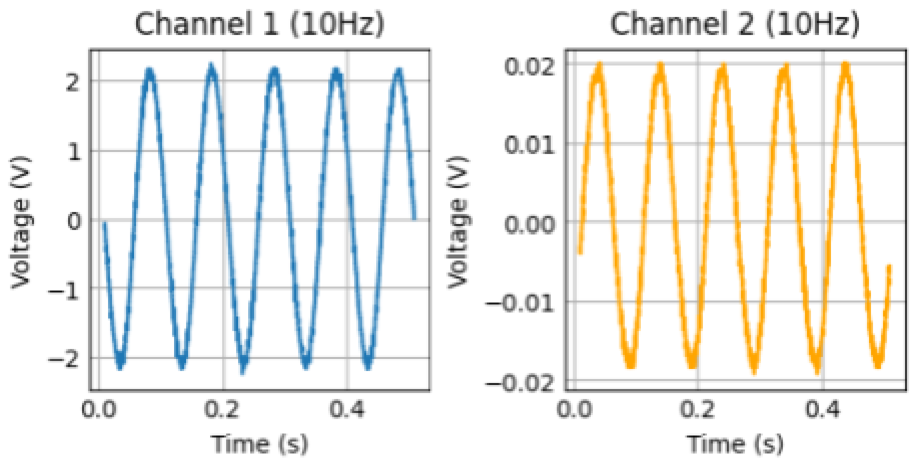


Figure 19: Voltage - Time graph of Mechanical and Optical signal

For finding the linearity between the movement sensor and optical detector, we take half a period from channel 1 and 2. Figure 20 shows the extracted data used for our linearity test.

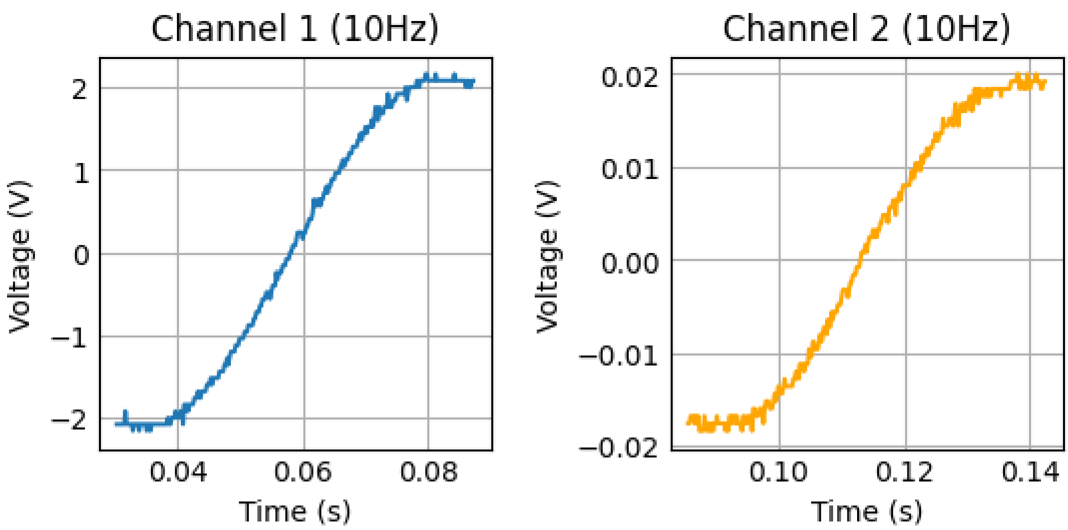


Figure 20: Voltage - Time graph of ½ period from CH1 and CH2

The movement sensor and optical detector data are plotted in Figure 21. We model the relationship of the movement sensor and light detected from the optical detector with a linear regression as shown in Figure 21, where we found a R-Squared value of 0.9972.

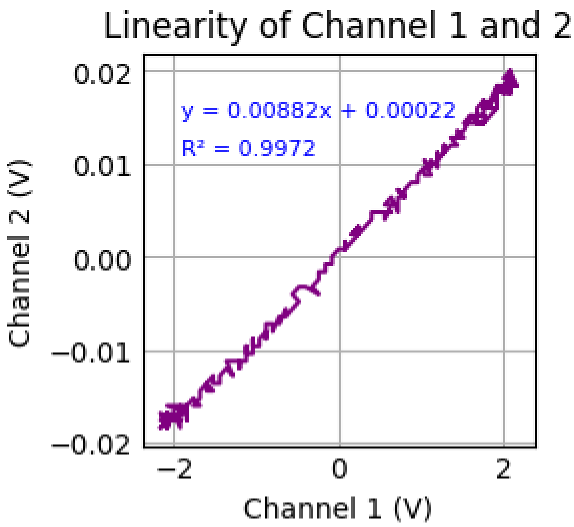


Figure 21: Linearity graph of CH1 - CH2

Using the R-Squared value, we can calculate the linearity of our system by using 1-R^2, where we obtain a linearity of 0.0028 or 0.28% full range output, which reaches the linearity in the electro-optical response of <1% full detection range.

2.2.3.1 Evaluation of the System's Linearity in the Electro-Optical Response

Expected Outcome:
The linearity in the electro-optical response should be under 1% full detection range.

Actual Outcome:
The linearity in the electro-optical response of our system is 0.28%, which is under 1%.

2.3 Main Objective Evaluation and Discussion

The main objective of our project was to build a passive vibration sensor system and incorporate a DHFLC cell into the system. This allows for a low-maintenance and long-lasting alternative to traditional sensor solutions that require power delivery.

The first main result evaluated was whether the system's design and build was functional. The design and build of the vibration sensor device should be able to convert mechanical vibration into voltage without a power supply through the piezoelectric film and should be able to connect with the fabricated DHFLC cell to alter the optical signal passing through it. Our testing shows that our system functions properly and successfully fulfills this objective.

The second and third main result evaluated was the system's sensitivity and electro-optical response. Whereas in above we evaluated the system's functionality, these two results benchmarks our system's abilities. We evaluated this through experiments, where our data showed that our system has a sensitivity of 0.4204 V/(m/s^2) and a linearity of 0.28% in the electro-optical response.

Overall, the outcomes of our project were successful as we reached all three of our main objectives. By reaching the first objective statement, we demonstrate that our system is able to passively detect vibrations. Then, our system obtained a sensitivity of 0.4204 V/(m/s^2) and a linearity of 0.28% in the electro-optical response which surpasses our second and third objectives, meaning that our system has relatively good accuracy and detection range. The second objective statement of reaching 0.3784 V/(m/s^2) is taken from the commercial piezoelectric vibration sensor we use in our device. This means that our system enhances the piezoelectric sensor sensitivity from 0.3784 V/(m/s^2) to 0.4204 V/(m/s^2). Therefore, by having a passive vibration sensing system with relatively high sensitivity and accuracy, our project can be useful and important in the field of passive vibration sensing.

Although our project is functional and is able to passively detect vibrations, there are many adjustments and optimizations that can be made to improve performance. In the design of our device, we can utilize enclosures or damping materials that isolate the piezoelectric film. This will help with minimizing environmental influences like temperature fluctuations or acoustic noise. Another improvement that can be made is developing methods to attach the piezoelectric film to the system while ensuring it remains isolated from unwanted ground interactions. Figure 22 below shows an example of this potential adjustment.

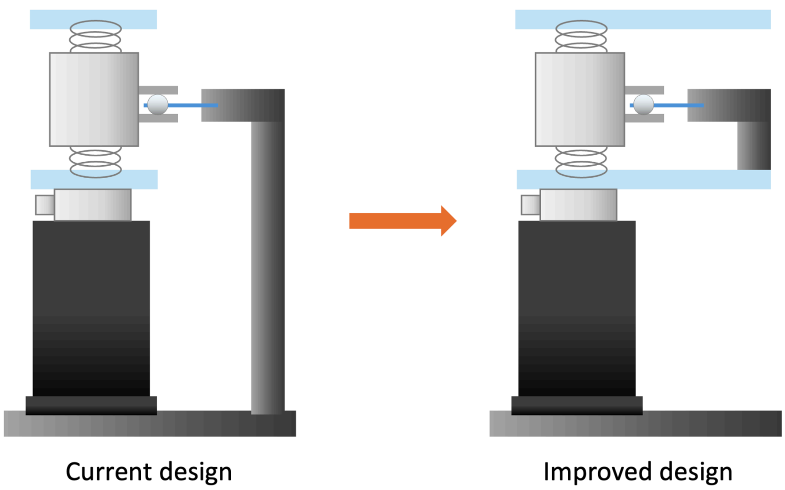


Figure 22: Improved design to isolate piezoelectric film from ground

The sensitivity can be improved by exploring alternative mass and spring configurations. Due to time constraints, we were only able to test with a single fixed mass and spring. With more time, we would perform experiments using different mass and spring configurations and .

A third adjustment that can improve our performance is by reducing noise. Although our experiment used aluminum foil to reduce electromagnetic noise, we can enhance the shielding around the sensor components further and optimize the grounding methods to reduce electromagnetic interference and environmental noise. We can also implement more sophisticated digital and analog filtering techniques to eliminate high-frequency noise and drift that can mask the true signal.

SECTION 3— Conclusion

In conclusion, the objective of our project is to design and build a passive vibration sensing system using a DHFLC cell, a piezoelectric film, and an optical generator and detector. The project aims to reach a sensitivity of 0.3784 V/(m/s^2) and achieve the linearity of less than 1% in the electro-optical response.

To achieve these objectives, we first fabricate a DHFLC cell. Then, we design and build a vibration sensor device capable of converting mechanical vibrations into voltage without a power supply. These two parts are then connected and integrated with the optical generator and detector to complete our system. We test our system by comparing the data from the vibration generator to the data collected by the optical generator.

From our experiments, we found that our passive vibration sensing system was able to successfully reach our target objectives. The system is able to successfully detect vibrations, where the system has a sensitivity of 0.4204 V/(m/s^2) and a linearity of 0.28% in the electro-optical response.

Our system has room for improvements where the sensitivity and system linearity can be enhanced through further optimization techniques. For example, future works to improve the sensitivity include exploring alternative mass and spring configurations. Due to time constraints, we were only able to test with a single fixed mass and spring, but ideally different mass and spring size and dimensions should be tested to find the best configuration possible.

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APPENDICES

Appendix A - Final Project Schedule

Table 2. Project Schedule

Objective Statements	**Task**	Group Member in charge	WK1 Date	WK2 Date	WK3 Date	WK4 Date	WK5 Date	WK6 Date	WK7 Date	WK8 Date	WK9 Date	WK10 Date	WK11 Date	WK12 Date	Wk 13 Date	Wk 14 Date	Wk 15 Date	WK16 Date	WK17 Date
Develop and build a passive vibration sensor system with DHFLC cell and piezoelectric film																			
	Fabricate DHFLC Cell	All members																	
	Design the vibration sensor for the workshop to build	All members																	
	Test the workshop created vibration sensor																		
	Integrate the vibration sensor device with the DHFLC cell to complete the full system	All members																	
Reach vibration sensor sensitivity of 0.3784 V/(m/s^2)																			

	Carry out experiments of our system and gather data	All members																	
	Analyze the data and calculate the vibration sensor sensitivity	All members																	
The linearity in the electro-optical response <1% full detection range																			
	Carry out experiments of our system and gather data	All members																	
	Analyze the data and calculate the linearity of the electro-optical response from the experimental results	All members																	

Appendix B - Budget

Table 3. Expected budget

Items*	Cost ($ HKD)
DHFLC Cell	$0, available from HKUST
Open Beam Laser	$0, available from HKUST
Piezoelectric Films	$2443
Workshop Device	$5864
Spring	$248
Other Lab Equipments	$0, available from HKUST
TOTAL BUDGET	**$8555**

Appendix C— Meeting Minutes

Meeting 1

Date: September 8, 2023

Time: 11:00 am

Location: Zoom Meeting

Attendees: Prof. Srivastava Abhishek, RO Min Kyu, Wong Yin Fun, YOUNG James Yang

Minutes taken by: YOUNG James Yang

- The professor has given us more background information into the FYP
- Professor has assigned us PG student Steven to help us with project materials, lab assistance, and provide other project information
- We will meet with Steven to take a look at the lab and to further explain the details of the project

Table 1. Action Items for Next Meeting

Action Item to be completed	By when	By whom	Status
Meet with Steven to visit the lab and discuss about the project	Sept.11	All	Ongoing
Finish FYP Proposal Report	Sept. 13	All	Ongoing

Meeting 2

Date: September 11, 2023

Time: 1:00 pm

Location: Lab (G107)

Attendees: RO Min Kyu, Wong Yin Fun, YOUNG James Yang, Steven YU (TA)

Minutes taken by: YOUNG James Yang

- We met with Steven (TA) to introduce us to the lab and give us more background into the project and what to prepare
- Amongst group members RO, Min Kyu, Henry, and James we discussed what to include in our proposal report and who should work on what. RO, Min Kyu and Henry will focus on research and James will focus on writing the report, although all members will do research and write the report as well.

- Steven also told us to actually enter into the lab, we would need to finish the lab safety training courses (MC04, MC03, MC07) for access to the lab.
- RO, Min Kyu will work out the budget with TA and professor for the project and aims to finish it a few days before deadline

Table 1. Action Items from Previous Meeting

Action Item to be completed	By when	By whom	Status
Meet with Steven to visit the lab and discuss about the project	Sept.11	All	Completed
Finish FYP Proposal Report	Sept. 13	All	80% completed, need to update and complete some parts after discussing with TA

Table 2. Action Items for Next Meeting

Action Item to be completed	By when	By whom	Status
FYP Budget	Sept. 30	RO Min Kyu	Ongoing
Completed lab safety training courses (MC04, MC03, MC07) for access to the lab G107.	Oct. 5	All	Ongoing
Work on fabricating LC cell	Oct. 31	All	Ongoing

<u>Meeting 3</u>

Date: October 19

Time: 9:00 am

Location: Lab (G107)

Attendees: RO Min Kyu, Wong Yin Fun, YOUNG James Yang, Steven YU (TA)

Minutes taken by: YOUNG James Yang

- We met in the lab to work on fabricating the cell

- The TA told us to start planning more specifics on the project, specifically about ideas for the mechanism of FLC and the best design of the mass-piezo film-spring-shell structure. All members will think about it and do some research

Table 1. Action Items from Previous Meeting

Action Item to be completed	By when	By whom	Status
Finish FYP Proposal Report	Sept. 13	All	Completed
FYP Budget	Sept. 30	RO, Min Kyu	Completed
Completed lab safety training courses (MC04, MC03, MC07) for access to the lab G107.	Oct. 5	All	Completed
Work on fabricating LC cell	Oct. 31	All	Ongoing

Table 2. Action Items for Next Meeting

Action Item to be completed	By when	By whom	Status
Work on fabricating LC cell	TBD	All	Ongoing
Consider the best design of the mass-piezo film-spring-shell structure	Oct. 31	All	Ongoing

<u>Meeting 4</u>

Date: November 10

Time: 11:00 am

Location: Lab (G107)

Attendees: RO Min Kyu, Wong Yin Fun, YOUNG James Yang, Steven YU (TA)

Minutes taken by: YOUNG James Yang

- We continued working on fabricating the cell
- We raised some ideas for the mass-piezo film-spring-shell structure with the TA, such as considering vertical vs horizontal mass spring system

Table 1. Action Items from Previous Meeting

Action Item to be completed	By when	By whom	Status
Work on fabricating LC cell	TBD	All	Ongoing
Consider the best design of the mass-piezo film-spring-shell structure	Oct. 31	All	Completed

Table 2. Action Items for Next Meeting

Action Item to be completed	By when	By whom	Status
Work on fabricating LC cell	TBD	All	Ongoing
Find manufacturers to purchase piezoelectric sensors	Dec. 31	All	Ongoing

<u>Meeting 5</u>

Date: December 12

Time: 10:00 am

Location: Zoom

Attendees: RO Min Kyu, Wong Yin Fun, YOUNG James Yang

Minutes taken by: YOUNG James Yang

- We discussed next steps and what to do over the Christmas break, where we needed to research and find parts to buy, first being the spring for the mass-spring system
- All members will also need to help with completing progress report, midterm poster, and meet with CT
- For the mid-term poster presentation, RO, Min Kyu will be our sole representative

Table 1. Action Items from Previous Meeting

Action Item to be completed	By when	By whom	Status
Work on fabricating LC cell	TBD	All	Completed
Find manufacturers to purchase piezoelectric sensors	Dec. 31	All	Completed

Table 2. Action Items for Next Meeting

Action Item to be completed	By when	By whom	Status
Work on FYP Mid-term poster	Jan. 10	All	Ongoing
Work on FYP Progress Report	Jan. 5	All	Ongoing
Meet with CT	Jan. 4	All	Ongoing
Mid-term Progress Day	Jan. 26	RO, Min Kyu	Ongoing

<u>Meeting 6</u>

Date: Jan 30

Time: 11:00 am

Location: Zoom

Attendees: RO Min Kyu, Wong Yin Fun, YOUNG James Yang

Minutes taken by: YOUNG James Yang

- After meeting with CT, we revised and completed the midterm poster and progress report and received a good response from CT. RO, Min Kyu also completed the midterm presentation day and won an award.

- For next phase, Henry will start purchasing system equipments such as spring and will try to buy them before Feb 22
- RO, Min Kyu will begin discussing and consulting our mass-spring system design with the workshop which he aims to start contact by Feb 28
- James will write the monthly report and aims to finish before deadline of Feb 23

Table 1. Action Items from Previous Meeting

Action Item to be completed	By when	By whom	Status
Meet with CT	Jan. 4	All	Completed
Work on FYP Mid-term poster	Jan. 10	All	Completed
Work on FYP Progress Report	Jan. 5	All	Completed
Mid-term Progress Day	Jan. 26	RO, Min Kyu	Completed

Table 2. Action Items for Next Meeting

Action Item to be completed	By when	By whom	Status
Purchase springs and other components	Feb. 22	Henry	Ongoing
Work on FYP Monthly Report	Feb. 23	James	Ongoing
Begin consulting with workshop for device design	Feb. 28	RO, Min Kyu	Ongoing

Meeting 7

Date: Feb 29

Time: 1:00 pm

Location: Zoom

Attendees: RO Min Kyu, Wong Yin Fun, YOUNG James Yang

Minutes taken by: YOUNG James Yang

- RO, Min Kyu has contacted the workshop and made good progress. He will make some revisions and will finalise the overall system design with the workshop and will ask the workshop to have the device ready for testing before April 8

Table 1. Action Items from Previous Meeting

Action Item to be completed	By when	By whom	Status
Purchase springs and other components	Feb. 22	Henry	Completed
Work on FYP Monthly Report	Feb. 23	James	Completed
Begin consulting with workshop for device design	Feb. 28	RO, Min Kyu	Completed

Table 2. Action Items for Next Meeting

Action Item to be completed	By when	By whom	Status
Finish device design	Mar. 15	All	Ongoing
Order and receive device from workshop	Apr. 8	RO, Min Kyu	Ongoing

<u>Meeting 8</u>

Date: April 9

Time: 11:00 am

Location: Zoom

Attendees: RO Min Kyu, Wong Yin Fun, YOUNG James Yang

Minutes taken by: YOUNG James Yang

- After consulting and finalising the device design with the workshop, we have ordered and received the system
- All members are working on testing the overall system. However, we ran into the issue where when using the data collector with the oscilloscope the oscilloscope shows no data. Also the piezo film has large noise for some reason. We will look to resolve these issues before April 10

Table 1. Action Items from Previous Meeting

Action Item to be completed	By when	By whom	Status
Finish device design and order from workshop	Mar. 15	All	Completed
Order and receive device from workshop	Apr. 8	RO, Min Kyu	Ongoing

Table 2. Action Items for Next Meeting

Action Item to be completed	By when	By whom	Status
Test vibration sensing system	Apr. 13	All	Ongoing
Achieve objective statement 2, 3 in experiments	Apr. 13	All	Ongoing

Meeting 9

Date: April 13

Time: 9:00 pm

Location: Zoom

Attendees: RO Min Kyu, Wong Yin Fun, YOUNG James Yang

Minutes taken by: YOUNG James Yang

- Our TA Steven was able to help us with resolving the noise issue with a Faraday cage using aluminum foil and also helped with the data collector problem.
- Our system was able to reach objective statements 2 and 3, meaning our system was successful
- All members now need to complete the FYP final report before April 17

Table 1. Action Items from Previous Meeting

Action Item to be completed	By when	By whom	Status
Test vibration sensing system	Apr. 13	All	Completed
Achieve objective statement 2, 3 in experiments	Apr. 13	All	Completed

Appendix D – Group Members' Contributions

RO Min Kyu (20314768)

Throughout this project, my responsibilities encompassed overseeing the overall project schedule, fostering effective communication among team members, and proficiently distributing tasks. My involvement extended across diverse facets, including project initiation, coordination, technical research, and hands-on laboratory work.

In the project's initial phase, I took charge of recruiting team members by reaching out to undergraduates through email communication. Following that, I actively participated in discussions to finalize the project scope and facilitated decision-making for the team.

Leveraging my extroverted nature, I utilized my leadership skills to allocate tasks based on team members' strengths, ensuring a smooth project progression. This entailed coordinating with the professor to secure project approval and maintaining open communication with the TA to obtain lab access and necessary equipment for cell fabrication.

October: along with my team, I participated in lab safety training courses (MC04, MC03, MC07), marking the commencement of our hands-on involvement in cell fabrication. Furthermore, I contributed to the selection of the project objective by researching DHFLC-related materials and proposing design concepts for the mass-piezo-film-spring-shell structure.

For the Reports, I conducted foundational research and personally drafted designs for the mass-piezo film-spring shell structure. My responsibilities included calculations for sensor components, numerical values, and material procurement, ensuring a seamless transition from conceptualization to equipment creation. I also managed budget applications for the required resources.

November: I actively participated in cell fabrication, overseeing the production of over five cell batches. Regular visits to the laboratory and continuous training from the TA honed my skills, resulting in proficient cell fabrication techniques.

December: My focus shifted to contributing to the mid-term poster. Utilizing my design skills, I collaborated with team members to structure and organize the poster content. Additionally, I played a pivotal role in drafting the content for the poster, ensuring clarity and conciseness. This month also involved managing the procurement of materials essential for the project, streamlining the process for the team.

Feb - April: I presented our project on the Mid-term poster presentation day and got 2nd runner-up for best poster award. I requested designs and communicated with the workshop to build a passive vibration sensor system, incorporating a DHFLC cell into the system. This phase involved detailed coordination to align design specifications with manufacturing capabilities.

April: After building the device, I conducted experiments to test the functionality and sensitivity of the newly developed sensor system. These experiments were used for validating our design concepts and collected data for further refinement.

In summary, my multifaceted contributions encompassed project management, team coordination, technical research, and hands-on laboratory work and building the device for the experiment.

YOUNG James Yang (20740589)

During this project, I worked on various tasks to help with the project. During the first month of the final year project, my main task was to help with writing and editing the proposal report. This was my main task in the beginning as English is my native language and therefore made it more suitable for me to write reports. My groupmates decided that although we all would do research for the project, it would be better if I focused more on writing and summarising their research findings in the progress reports.

This was helpful to our group as the reports would be more time-consuming to my group mates who are not native English speakers so having me write most of the report saves them a bit more time for them to focus on other parts of the project. I also shared various papers and articles I found that were helpful in writing our report and improving our understanding of the topic.

During October, each group member mainly focused on completing lab safety training courses (MC04, MC03, MC07). This was important as each of us had to do these courses to gain access to lab G107 so that we can work on fabricating the DHFLC cells and build other components of our system. The lab safety courses required me to read through the material and take an online quiz alongside also attending a on-site laser safety debriefing, which meant that we couldn't work in the laboratory as early as we predicted.

I also contributed to our research for designing parts of the system where my main contribution was finding a similar spring-shell structure that we aim to build with our own mass-piezo film-spring-shell structure. I provided a couple of resources that we looked over together to see parts that we could implement. For example, some of the resources I found made us consider the differences of using a vertical and horizontal spring mass system, and we had to discuss it with the TA to determine which would suit our project best.

After our group finished the progress report and did preliminary research on the topic, I worked in the lab with my groupmates guided by the professor provided TA. We went together almost every week during late October and November to fabricate liquid crystal cells where I helped with various parts of the lab such as coating the cells. Majority of the FYP work went here as fabricating the cell is a time-consuming process. Alongside laboratory work during October and November, I also worked on writing monthly reports for similar reasons as mentioned above for me focusing on writing the proposal report.

In mid-December I worked on writing and organising the mid-term FYP poster whilst RO, Min Kyu worked on finding images and designing the poster. With feedback from our LANG4031 professor, I made modifications to make our poster cleaner and more engaging to the audience by shortening the descriptions and RO, Min Kyu helped with making our poster look more visually appealing by adding nicer backgrounds and images.

During the spring semester, I mainly helped in writing reports and analyzing the data from the experiments. I helped with writing monthly reports and checking our group's project progression. Since I couldn't attend all the experiments, I decided to help by using my Python skills to analyze the data. For example, I helped with plotting the diagrams and calculating relevant data such as sensitivity and linearity.

Wong Yin Fun (20695681)

In the initial phase of the project, my primary task was to familiarize myself with the materials provided by the professor and my groupmates. I spent time reading through these resources and also took the initiative to search for additional articles related to our project to gain a deeper understanding.

During the preparation of the Proposal Report, James, who has a strong command of English writing, took the lead in composing many of the passages. My role in this phase was to contribute ideas, review the content, and identify any missing elements that needed to be included.

At the beginning of the project, we had a meeting with the TA to gain more clarity on our objectives and requirements. Since our project involved conducting experiments in the laboratory, it was necessary for all of us to complete safety training. Additionally, we relied on the model designed by RO, Min Kyu to search for relevant formulas and calculate the specific specifications required for our experimental materials.

In October, I unfortunately contracted Covid and, out of concern for the well-being of others, I made the decision to miss the first two experiments. However, I made sure to stay updated by reading the messages exchanged between RO, Min Kyu and James regarding the progress of the experiments so that I wouldn't fall behind.

In November, I returned to actively participate in the experiments and familiarized myself with the process of cell fabrication. Unfortunately, the batches of cells that we produced did not meet the desired quality standards for injecting liquid crystal. This prompted our group, along with the TA's guidance, to brainstorm and devise strategies to improve the quality. Additionally, we finalized the specifications for the piezoelectric sensors that needed to be purchased.

In December, I encountered a slight deviation in the requirements and deadline for the poster presentation in my LANG4031 section compared to RO, Min Kyu and James' section. As a result, I worked on my own to create the poster according to the specific requirements of my class. I communicated the requirements to RO, Min Kyu and James to determine if any adjustments were needed.

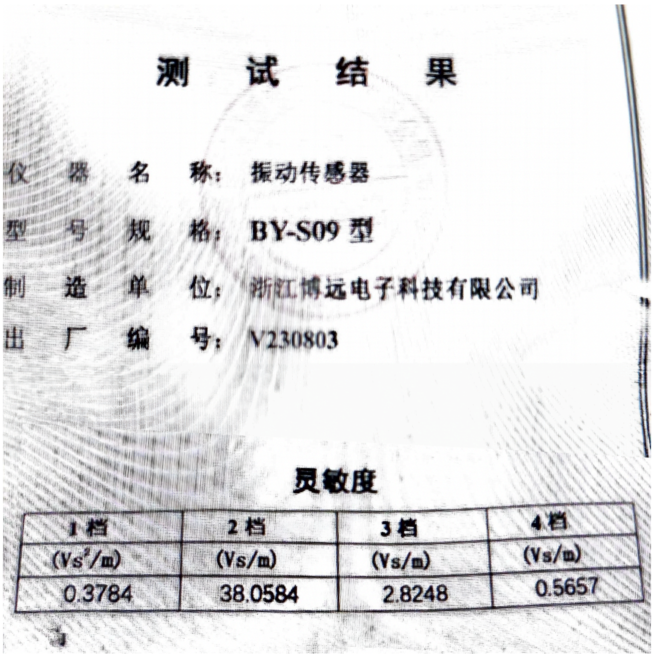
During this month, we also engaged in discussions regarding the most suitable place to order the piezoelectric sensors.

In early January, we received the sensors, and I promptly handed them over to the TA. We updated our project plan and scheduled another day for further experimentation and progress.

During the Spring semester, I ordered different springs which used to be attached with the mass cube. And I repeated the experiment about fabrication of DHFLC cells and also tested the piezoelectric film. Then, we wait until the workshop finishes the mass cube. I conducted experiments about testing the sensitivity and functionality of the sensor system and collecting data from it.

Appendix E – Deviations from Proposal and Progress Reports

In our proposal, our second objective statement stated that our vibration sensor sensitivity needed to reach at least 165 V/(m/s). Due to the current setup of our experiment, we cannot get the speed sensitivity (V/(m/s)). However, the piezoelectric film is designed to sense the acceleration (sensitivity of 0.3784 m/s^2) and our system's mass and spring is designed to enlarge its sensitivity. Therefore, after consultation with our TA Steven, we revise the objective statement to compare the measured acceleration sensitivity with a commercial one instead, namely the piezoelectric vibration sensor inside our vibration sensor device. The image below shows the datasheet of the piezoelectric vibration sensor where we got the sensitivity of 0.3784 m/s^2.



测 试 结 果

仪 器 名 称：振动传感器

型 号 规 格：BY-S09 型

制 造 单 位：浙江博远电子科技有限公司

出 厂 编 号：V230803

灵敏度

1档	2档	3档	4档
(Vs^2/m)	(Vs/m)	(Vs/m)	(Vs/m)
0.3784	38.0584	2.8248	0.5657

Datasheet from Piezoelectric Vibration Sensor

Monthly Report for ECE FYP/FYT

<table>
<tr><td>Project Code:</td><td>AS01a-23</td><td>Supervisor(s):</td><td>Srivastava Abhishek</td></tr>
<tr><td>Project Title:</td><td colspan="3">Powerless Vibration Sensor Probe using DHFLCs</td></tr>
<tr><td>Group Member(s):</td><td colspan="3">1) RO Min Kyu (20314768) 2) Wong Yin Fun (20695681) 3) YOUNG James Yang (20740589)</td></tr>
<tr><td>Reporting Period:</td><td colspan="3">Report #1 ■ Oct (Fall)
Report #2 ☐ Nov (Fall)
Report #3 ☐ Feb (Spring)
(please attach Reports #1-2 to the Progress Report to be submitted in Jan)
(please attach Reports #3 to the Final Report to be submitted in Apr)</td></tr>
<tr><td>Progress Report:

• List the work completed in this reporting period.
• Identify the major difficulties encountered.
• Comment on the overall progress.</td><td colspan="3">Work Completed in this Reported Period

All members completed lab safety training courses (MC04, MC03, MC07) for access to the lab.

Did more research, including studying the basic principles of threshold-less deformed helix ferroelectric liquid crystal (DHFLC) cells. Learned the process of fabricating a threshold-less deformed helix ferroelectric liquid crystal (DHFLC) cell and practiced cell fabrication in the laboratory.

Went into the lab and worked on cell fabrication. Cell fabrication progress: O3 UV coating → Soft Bake → Hard Bake → Rubbing →Blow Spacer → (N6) → Rubbing → Cell → Liquid Crystal Injection →Electrode → Experiment

To upgrade the passive vibration sensing module with higher accuracy, we roughly designed the module with a longer, multi-stranded bending piezoelectric film and a larger mass attached to it.

Difficulties encountered
We encountered some challenges in the cell fabrication process. This is the first time any of us have worked with cell fabrication inside a lab so many of the fabrication process, equipment used, and other parts were new and foreign to us. Fortunately, we had TA Steven to help explain to us the technical details and design choices so that we could understand the process.

Comments on Overall Progress
Overall, our project is progressing well. We have started work in the lab and have made good progress with our design.</td></tr>
<tr><td>Future Plan:

• Write down the working plan for the next reporting period.</td><td colspan="3">1. Finish designing and selecting components for passive vibration sensing module
2. Complete Cell fabrication</td></tr>
<tr><td>Group Representative's Signature:</td><td colspan="3">YOUNG James Yang</td></tr>
</table>

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Monthly Report for ECE FYP/FYT

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During late October and November, we went to the lab every week for cell fabrication with the guidance of TA. The cell fabrication involves the process described: O3 UV coating → Soft Bake → Hard Bake → Rubbing →Blow Spacer → (N6) → Rubbing → Cell → Liquid Crystal Injection →Electrode → Experiment
The first few batches of FLC cells had some issues so we had to redo them.

We started designing the mass-spring shell sensing module component and calculating the specification of each component to be sent to the workshop. We also looked into some potential manufacturers to start sourcing the piezoelectric film and other components of our project.

Lastly we modified our introduction and literature review from our proposal with more updated information and also improved the writing and language used to better suit academic research style.

Difficulties encountered
We are still working on the mass-spring calculations and the design of the parts.
Sourcing the spec which meets our experiment is a challenge, length of piezoelectric film should be longer than the commercial film, in the process of sourcing the manufacturer to get samples.

Comments on Overall Progress
Overall, our project is progressing well. We will meet with CT during winter break to discuss our progress.</td></tr>
<tr><td>Future Plan:
• Write down the working plan for the next reporting period.</td><td colspan="3">1. Continue working on design and calculations for mass-spring system
2. Work on methodology (cell fabrication, sensor)
3. Progress report + Meet with CT</td></tr>
<tr><td>Group Representative's Signature:</td><td colspan="3">
YOUNG James Yang</td></tr>
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Monthly Report for ECE FYP/FYT

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Project Title:	Powerless Vibration Sensor Probe using DHFLCs		
Group Member(s):	1) RO Min Kyu (20314768) 2) Wong Yin Fun (20695681) 3) YOUNG James Yang (20740589)		
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Progress Report: • List the work completed in this reporting period. • Identify the major difficulties encountered. • Comment on the overall progress.	**Work Completed in this Reported Period** We completed the progress report and met with the CT to discuss our current progress, mid-term poster, and report. Our meeting with the CT went well and we made some adjustments and completed our progress report. We also completed the mid-term poster and RO, Min Kyu presented our project on the presentation day and got 2nd runner-up for best poster award. Began contact with a workshop to discuss design of the system. We also ordered the piezoelectric sensors. **Difficulties encountered** The first piezoelectric sensor we bought had some issues and therefore we ended up buying another type that the TA recommended instead. **Comments on Overall Progress** Overall the project is progressing fine.		
Future Plan: • Write down the working plan for the next reporting period.	1. Order rest of components (springs, etc) 2. Begin testing		
Group Representative's Signature:	YOUNG James Yang		

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