SYSC 4907 – ENGINEERING PROJECT

Final Report

Ground Vibration Simulator for Investigating Vibration Effects on the Development of Turtle Eggs

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Abstract

The Davy Lab, in the Department of Biology at Carleton University, conducts conservation studies to better understand how environmental changes affect locally vulnerable bats, amphibians, and reptiles. They wish to conduct an experiment that looks at how ground vibrations from nearby industrial activity and highways impact turtle egg growth. In this project, the engineering team developed a tool that can replicate the ground vibrations caused by diverse industrial operations so that the lab may explore these effects in a controlled setting.

The team aimed to create a ground vibration simulating shake table for under $1000, as industrial shake tables begin at $5000 each.

With inspiration from the James Webb Space Telescope mirror positioning actuators, the team has created a ground vibration simulation table that costs less than $1000. Desired vibrations of [put values here] were achieved, and a User Interface and data collection system were designed to make the simulation table user-friendly.

The final design of the table cost under $800 for the initial table and data collection system, with the ability to add tables to the system for less than $200 per table. The simulation table is almost in a research-ready state and can be ready for the Davy lab by the beginning of the Summer 2023 term. The entire project is available as an open-source project on Github, so that the Davy lab and other labs can use the design to achieve their research goals.

Acknowledgements

We would like to express our heartfelt appreciation to the following individuals who have made valuable contributions to the completion of this project:

First, we would like to extend our gratitude to Nagui Mikhail for his help and advice early on regarding motors and achieving the desired results. We are deeply grateful for his unwavering support, which has been invaluable to us.

We would also like to thank Dr. Peter Gordon for his advice regarding measuring very small displacements and working at such a small scale (< 1 mm).

We would like to acknowledge Sam Gauthier for his contributions, including introducing us to Polyfractal's video as inspiration, helping with wood construction, and offering advice on 3D modelling and printing.

Our sincere thanks go to Matt Marshall—"that guy from fencing" as he asked to be called— and to Graham Bell for their help when last-minute 3D printed prototypes were needed.

We are deeply grateful to Davy Lab for giving us the opportunity to do something unique and trailblaze a new approach to the engineering capstone project. Also, for supporting us through the year financially, and teaching us so much about turtles and conservation.

Finally, we would like to extend our heartfelt gratitude to our supervisors for their encouragement throughout the year and for believing in us. Their guidance and support have been instrumental in helping us complete this project.

Thank you all for your support and guidance. We could not have completed this project without your help.

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1 Introduction ✓

As we enter an era of ever-increasing industrialization, the need for a sustainable and conscious approach towards the environment has become more crucial than ever. At the forefront of this movement are conservation research groups like the Davy Lab at Carleton University, dedicated to understanding the impact of local environmental changes on threatened species of bats, amphibians, and reptiles.

One of the lab's recent projects is investigating the effects of ground vibrations from adjacent industrial activities and roadways on the growth of turtle eggs. To tackle this issue, a team of engineering students – Meia Copeland, Shawaiz Khan, Talal Jaber, Marwan Zeyada, and Ranishka Fernando – developed a tool that can simulate these ground vibrations in a controlled environment.

For this engineering project, the team designed a shake table prototype that can simulate the vibrations produced by industrial activities, enabling the lab to investigate the impacts on turtle eggs more easily. This research will contribute knowledge to the field of reptile conservation, and impact how appropriate measures are taken to preserve these threatened species in the future.

1.1 Background ✓

As our cities continue to expand, the need for infrastructure like roads, housing, and power generation facilities has also grown. Unfortunately, these developments have a significant impact on the local ecosystems and ground-dwelling species in the area.

Industrial activities such as construction, pile driving, and heavy machinery cause ground vibrations that disturb the habitats and burrows of local species, potentially affecting their survival and breeding success. These vibrations have a frequency range of 20 – 45 Hz, and a displacement range of 0.27 – 1 mm [4]. These vibrations do not occur continuously, rather in intervals over a long period of time [5]. Despite the extensive research conducted on the impacts of roadways and power generation facilities on wildlife, the effects of ground vibrations produced by these sources are still not well understood.

Roadways and railways are significant sources of ground vibrations, with highways producing consistent vibrations for long periods every day. On the other hand, railways produce similar vibrations but not consistently. These ground vibrations have a displacement in the range of 0.16 – 0.8 mm, at frequencies between 10 – 20 Hz [1].

Power-generation facilities such as wind farms, hydroelectric plants, and nuclear facilities also generate ground vibrations, but most research has focused on the impacts of fully aquatic species. The vibrations associated with power plants using steam turbines have a displacement in the range of 0.8 – 2 μm, and a frequency of approximately 8 Hz [2]. Wind turbine farms create vibrations with a displacement of approximately 300 nm within a 150 m radius around the base of a turbine, with a frequency of 2 – 10 Hz depending on wind speeds [3].

1.2 Motivation ✓

The rapid growth of urban areas in Ontario and the consequent expansion of industrial and transportation infrastructure has resulted in significant changes to the local ecosystem. Although the effects of roadways, industrial activities, and power generation on wildlife have been studied, the impact of ground vibrations from these sources remains poorly understood.

The project team developed a tool that can simulate the ground vibrations produced transportation infrastructure so that the Davy Lab can investigate the impact of these vibrations on turtle egg development in a controlled laboratory environment. By measuring environmental parameters like temperature and humidity, the tool will enable the Davy Lab to study the effects of ground vibrations on turtle eggs and other ground-dwelling species. This research will provide valuable insights into the impact of human activities on the local ecosystem and help identify measures to mitigate their negative effects.

1.3 Project Objectives ✓

The objective of our project is to design and develop a tool that can accurately mimic ground vibrations from a range of industrial activities, such as construction and transportation, within a controlled environment. The device will generate vibrations with a frequency range of 2 to 20 Hz and a displacement range of 0.1 to 1 mm, like those produced by various sources of industrial vibration. The tool will have a surface area of 30 cm x 30 cm, sufficient for one egg incubation tub, with the displacement and frequency measured from this surface.

The device will be able to generate vibrations continuously or at intervals for a period of up to 95 days, which is the incubation period for snapping turtle eggs [11]. By meeting these objectives, we will enable the Davy Lab to investigate the impact of ground vibrations on turtle egg development under controlled and measurable conditions.

Existing shake tables used for industrial and engineering purposes could achieve the vibration needed. However, these machines are extremely expensive at over $6000 and inaccessible to the Davy lab. This project aims to create a device sufficient for this area of research, that costs under $1000 and can be easily put together by anyone interested in ground vibration research. The plans and documentation for the project will be made open-source and posted on GitHub for anyone to use in the future.

Additionally, in response to the lab's request, our objective is to design and develop an SQL database capable of keeping track of data collected from various sensors. The database will also store basic egg batch details to enable the lab staff to analyze the data for their research.

1.4 Accomplishments

[TODO]

Over 8 months, the team achieved most goals set out in this report, while keeping the project under a budget of $1000. The ground vibration simulator device is small enough to place on a table in the lab and have one turtle egg incubator placed on top. The table surface can vibrate up and down smoothly with a customizable displacement range between [range here]. The linear displacement mechanism to move the table up and down can be used in two configurations, each with a different displacement value. The mechanism can be easily redesigned for other displacements using 3D modelling software, and printed for no cost through the University.

To vibrate the table at a chosen frequency, a motor can be connected to the linear displacement mechanism. [Not yet implemented, update when implemented]. The motor is connected with a sensor to track rotations-per-minute (RPM) to create a feedback system where the user can select a frequency.

The ground vibration simulator device is controlled using an Arduino microcontroller which connects to a Raspberry Pi (RPi) computer. The RPi hosts a database and User Interface (UI) to track data and allow the user to control the frequency and duration of an experiment. The RPi can have multiple devices connected, allowing for a central control of all experiments.

1.5 Report Outline ✓

The final report for this project will start with an overview of the health and safety concerns, description of engineering professionalism, project management methods, and justification and suitability of the project for each team member. The report will then detail the research that informed the development of the ground vibration simulation device, including successful and unsuccessful approaches. The design of the simulator will be described in detail, including its components and how they work together. Additionally, the report will delve into the research conducted on the development of the user interface and database, providing insights into successful and unsuccessful approaches. The report will also outline the project plan, including milestones, activities, and budget breakdown. Finally, the report will discuss how the project objective was achieved through the collaboration of the engineering team.

2 The Engineering Project

2.1 Health and Safety ✓

The Health and Safety Manual provided by Carleton is used to keep in mind and address the standards and practices for a safe and healthy system for the project. The focus is Section 13 of the Health and Safety Guide (Tools and Machinery). Any defects in equipment would be reported as soon as noticed and would be taken care of. The user (Davy Lab) will be instructed and trained to operate the system properly, with thorough documentation provided to enable the lab to perform regular scheduled maintenance. Section 6.12 (Electrical Equipment and Apparatus) was also kept in mind. More specifically, extension cords (if used) for the system will not be used for permanent installations. If applicable, ground fault circuit interrupters will be used if there is a risk of an operator encountering water and electrical equipment simultaneously (depending on the placement of the system in the lab).

2.2 Engineering Professionalism

[TODO]

2.3 Project Management

One of the goals of this engineering project is to get real experience in working on a long-term team project. Therefore, the team uses industry level project management techniques to coordinate, manage, and execute project. Instead of sticking with one management technique, multiple techniques are utilized.

A Work Breakdown Structure (WBS) is applied as a tool to break down the project into chunks of manageable tasks for the team to understand and accomplish (e.g. Research, Implementation, Testing). Additionally, Gantt charts are also used as an organizational tool to emphasize visuality. It is used in the project to see task dependencies, duration, and various deadlines ranging from report deliverables to chunks broken down from WBS. Using the WBS allows for tasks to be accurately defined in the Gantt chart.

A Waterfall development method is used as the primary project management technique, due to the distinct phases that require few iterations throughout the project lifecycle. Activities and tasks flow linearly through five phases (Requirements, Design, Implementation, Verification, Maintenance).

2.4 Justification and Suitability for Degree Program

Table 1 - Roles, tasks, and relevant experience for each team member.

Team Member	**Tasks**	**Justification**
Meia Copeland *Computer Systems Engineering*	Linear Actuator Design	Designed 3D models for the linear actuator, and accessory parts such as frames, brackets, shafts, etc. ECOR 1010
	Simulation	Created simulations with 3D models to assess how the system would respond to physical interactions. SYSC ELEC 3105, 3600, SYSC 4505
	Signal processing	Wrote code to interact with sensors and process the outputs into useful data. SYSC 3310, SYSC 4805
	Hardware-Software interfacing	Created code libraries that interfaced between external sensors and the UI, for data collection and system control purposes.
	System integration	Utilized processes learned throughout degree program to integrate various system components and test them. SYSC 3020, SYSC 3303, SYSC 3310, SYSC 4805
	Project management	Created various project management processes to plan, track, and execute work as learned through degree program and co-op placements. SYSC 3020, SYSC 3310, SYSC 4805
Shawaiz Khan *Computer Systems Engineering*	Database	Experience in projects in SYSC 3010
	User Interface	Experience in projects in SYSC 3010 and an intro in SYSC 2004
	Hardware Integration	Experience in multiple hardware-software projects in SYSC 3010 and SYSC 4805
	Software Integration and testing	Experience in multiple hardware-software projects in SYSC 3010 and SYSC 4805
Talal Jaber *Electrical Engineering*	Electrical design	Designing required PCB for the system
	Hardware integration	Choosing the right motor and driver for the project in Elec 3907
	Simulation	Simulation using ANSYS in ELEC 3105
Marwan Zeyada	User Interface	Experience in projects in SYSC 3010 and SYSC 2004
	Hardware Integration	Experience in projects where hardware is the focus: SYSC 3010
	Database	Extensive experience in SYSC 3010 and other projects

Computer Systems Engineering	Software integration and testing	Great experience in software integration and testing due to working on multiple projects of that nature
Ranishka Fernando *Electrical Engineering*	Electrical design	Designing required PCB
	Hardware integration	Construct required circuitry and setting up the motor for testing – Experience from ELEC 3907 and past work experience as a Hardware Consultant
	Debugging	Extensive experience in development and operations through CO-OP and knowledge acquired from ELEC 2607 and ELEC 3500
	Simulation	Simulation using ANSYS in ELEC 3105
	Linear Actuator Design	CAD experience from ECOR 1010

Collectively, the team had all the necessary skills and knowledge to be successful on this project. Requirements for this project mostly involved electronics or computer systems techniques previously learned, with some very basic mechanical engineering and CAD that was learned in first year general engineering courses such as ECOR 1010 and ECOR 1101.

Further, this project involved working closely with a collaborator, the Davy lab. Project management and client-interaction skills were learned in courses such as CCDP 2100, ELEC 3907, SYSC 3010, SYSC 4805, and ECOR 4995. Most team members have some co-op experience, where working professionally with other engineers and clients was learned.

2.5 Individual Contributions ✓

2.5.1 Project Contributions ✓

Table 2 - Contributions of each team member to the project components.

Component		Contributor
Linear Actuator	3D modelling	Meia Copeland
	Simulation Testing	Meia Copeland and Ranishka Fernando
	3D printing	Meia Copeland
	Motor Control	Talal Jaber and Ranishka Fernando
	Actuator Testing	Meia Copeland
Shake Table	Table Support Design	Meia Copeland and Talal Jaber
	Assembly	Meia Copeland

Wiring	Assembly	Talal Jaber
Motors	DC Motor testing	Talal Jaber
	RPM Sensor	Talal Jaber
	Motor Feedback System	Talal Jaber
Environmental Sensors	Hardware connection	Meia Copeland
	Software Integration	Shawaiz Khan, Marwan Zeyada, and Meia Copeland
	Testing	Shawaiz Khan and Marwan Zeyada
Database	Schema design	Shawaiz Khan
	Implementation	Shawaiz Khan and Marwan Zeyada
	Testing	Shawaiz Khan
User Interface	UI Design	Marwan Zeyada
	Implementation	Marwan Zeyada and Shawaiz Khan
	Testing	Marwan Zeyada

2.5.2 Report Contributions ✓

Table 3 - Contributions from each team member to the Final Report document.

Final Report			**Contributor**
Introduction	Abstract		Ranishka Fernando, Meia Copeland
	Background		Meia Copeland
	Motivation		Meia Copeland
	Project Objectives		Meia Copeland, Shawaiz Khan
	Accomplishments		Meia Copeland
	Report Summary		Meia Copeland, Shawaiz Khan
The Engineering Project	Health and Safety		Shawaiz Khan
	Engineering Professionalism		TBD
	Project Management		Shawaiz Khan
	Justification and Suitability for Degree Program		All members
	Individual Contributions	Project Contributions	Meia Copeland
		Report Contributions	Meia Copeland

Research	Measuring Linear Displacement		Meia Copeland and Ranishka Fernando
	Methods of Vibration Simulation	Linear Actuator	Meia Copleand and Ranishka Fernando
		DC Brushless Motor	Talal Jaber
	Database Options		Shawaiz Khan
	User Interface Framework		Marwan Zeyada
Vibration Simulator Design	Measuring Linear Displacement		Meia Copeland
	Simulation of Linear Displacement	Flexure-guided Linear Actuator Design	Meia Copeland, Ranishka Fernando
		Table Design	Meia Copeland
		Motor Feedback System	Talal Jaber
	Database		Shawaiz Khan
	User Interface		Marwan Zeyada
Work Plan	Project Milestones		Meia Copeland and Shawaiz Khan
	Schedule of Activities/Gantt Chart		Meia Copeland and Shawaiz Khan
Budget Breakdown	Hardware		Meia Copeland
Reflections			Ranishka Fernando, Meia Copeland
Conclusion			Meia Copeland

3 Research on Simulator Design

3.1 Measuring Linear Displacement ✓

To ensure that the correct displacement is achieved, the displacement of the surface must be measured. Since the device will only be vibrating the surface up and down, a linear displacement sensor can be used. These sensors are available with many different technologies, such as linear potentiometers, linear variable differential transformers, capacitive displacement sensors, laser displacement sensors, and digital indicators. Due to budget constraints of the project that will be discussed later in this document, the sensor used would ideally be under $500 to implement.

Linear potentiometers are sensors that use variable resistance to measure position. Linear motion is converted to a changing resistance which can be directly converted to a voltage or current output. This output can be read by a computer to determine the displacement of the measured surface. Due to being an analog sensor, potentiometers have infinite resolution, however the smaller the measurement, the more it is affected by factors such as noise and the number of bits needed to convert to a digital value. The downside to using a potentiometer is the physical movement of the measuring device. Most potentiometers use a mechanical piece that moves to create resistance, which is subject to wear and tear. Since for one experiment, a slider would be expected to move up to 164 million times (20 Hz for 95 days), this greatly impacts the choice of sensor. Most sensors within a reasonable price range only have a lifespan of up to a 20 million cycle [4].

Linear variable differential transformers (LVDTs) convert the mechanical motion of an object, usually a tubular element that can move along a rod, into an electrical signal using induction. Preliminary searches show that LVDTs capable of measuring within the desired range of 0.1 – 1 mm and with sampling frequency of over 100 Hz are within budget [5]. However, these sensors also have a short life span relative to what is required, with one such LVDT we inquired about only capable of 10 million cycles.

Capacitive sensors are no-contact sensors, which use an electric field to detect the target's position thanks to interference with the electric field. This would eliminate the risk of wear and tear, as the device would not be in contact with a moving surface. However, upon inquiring about prices, sensors capable of detecting displacement within the desired range were over the budget of $500 for the sensor, and an additional $5000 for the required signal processing unit and cables.

Laser displacement sensors, often known as point lasers, use triangle reflection to measure a single point. Laser profilers, on the other hand, measure the complete length of a line. The measurement precision of laser displacement sensors is great, but the efficiency is low due to point-by-point data collection [26]. Given the precision, using a laser to measure linear displacement would be ideal. However, it does not fit within the price point. Conducting laser measurements for micrometer range is within the price point, but measuring nanometers is beyond price point as it exceeds over a thousand dollars per sensor or instrument that is available to be purchased off the shelf.

Finally, digital indicators were investigated as a simple measurement tool [6]. These are the digital counterpart to dial indicators and have a rod that can be moved up and down to measure displacement. This rod has an attached optical reader, which reads microscopic marks along a thin glass scale. This allows the digital indicator to be extremely precise for a relatively low price, with a resolution of 0.001 mm available for under $100. However, a digital indicator cannot measure at as high a frequency as some of the other options. This has been discussed with the lab, and a solution will be provided in the project design section.

3.2 Methods of Vibration Simulation

Over the course of the turtle eggs' 65 to 95-day incubation cycle, vibration treatment would need to be applied continuously or in intervals. Methods to create the up and down linear displacement needed for the treatment will be presented here.

3.2.1 Linear Actuator ✓

A linear actuator is a device that converts some type of input into linear motion for the purpose of pushing, pulling, sliding, or otherwise moving things [7]. Traditionally this is done with a series of gears and a lead screw that converts the rotational motion of a motor into linear motion. Other linear actuators use flexures powered by motors or piezoelectric devices.

Linear actuators were investigated due to the desired motion being contained to one axis. Simple, traditional linear actuators are available off the shelf, however the precision needed (0.1 mm – 1mm) is a limiting factor with these actuators. Further, the actuator needs to change direction at 5 Hz – 20 Hz. Due to the backlash of the gears, screw, and lead nut used in traditional actuators, achieving this frequency would not be possible without severely affecting the performance and positioning of the actuator.

Flexure-guided linear actuators use a flexure system that can either amplify small movements or reduce larger movements while translating the movement into a linear motion. Piezoelectric actuators use a piezo device which deforms when voltage is applied [8]. This deformation is then converted into linear motion with a flexure. These devices are common in nano positioning devices, for very precise and fast movement. The desired linear displacement is easily achieved with these devices, however the frequency of the movements presents a challenge. Piezos are prone to hysteresis which could affect the performance as it must reverse the electric field at high speeds to change the direction of displacement at the desired frequency [9]. This has a similar effect to the backlash described for traditional linear actuators.

Flexures can also be used to translate rotational motion from a motor into linear motion. One example of this type of flexure is the fine stage actuator of the James Webb Telescope (JWST) mirror positioning system, designed by Ball Aerospace [10]. These types of flexures can be driven by DC or Stepper motors depending on the movement desired, which is coupled to the flexure with an offset camshaft. This type of flexure is capable of precise movements at high speeds, with the speed depending on the driving motor. Neither backlash or hysteresis are an issue with this type of flexure, as the offset camshaft only needs to rotate in one direction to drive the mechanical up and down motion of the flexure.

A replica of the JWST flexure design is available under a Creative Commons – Attribution – Non-Commercial license from user Polyfractal on Thingiverse.com [11]. This design can be almost fully 3D printed, apart from some shafts, screws, bearings, and the motor. It is capable of a 26 µm displacement as-is and can be altered to achieve the desired displacement of 0.1 – 1 mm by changing the dimensions of the flexure. This solution is extremely cost-effective, as the Carleton Library offers free commercial-grade 3D printing services to students and faculty. Other components are inexpensive and easy to find on online marketplaces such as Digikey and Amazon.

3.2.2 DC Brushless Motor

Initially, a DC brushless motor was investigated to produce vibrations by acting directly upon the table surface. This involved a simple vibrating motor attached under a tabletop with some insulating pads near the legs for eliminating noise. First looked at was a brushless 3-phase motor with a pulse-width modulation (PWM) controller to control the revolutions per minute (RPM) of the motor. PWM is a way to control the input power by pulsing the signal which reduces the average voltage. RPM is directly proportional with the frequency of vibrations. However, most small motors have a limit where the vibration frequency stops decreasing at around 30 Hz which is the minimum vibrations a normal vibrating motor can go due to the size and weight constraint of the motor and shaft (Figure 1).

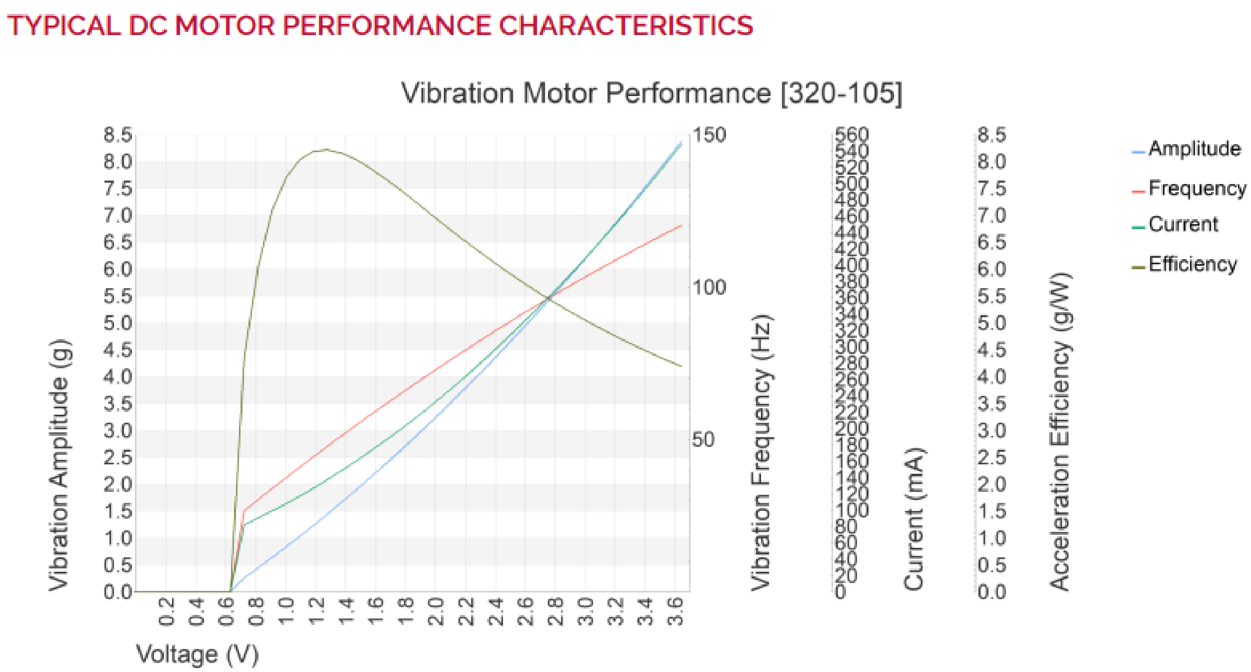

Figure 1 - DC motor frequencies [12]

Once the flexure-guided linear actuator was considered, a new solution was needed. The JWST design uses a stepper motor to achieve precision adjustments. However, this design requires continuous and smooth operation, which a DC motor can provide. The motor used in this project is a 5V DC motor, which is connected to gears to transmit mechanical power to the linear actuator. To control the motor, an L298N driver (Figure 2) is used, which is connected to an Arduino Uno microcontroller. This driver provides the necessary voltage and current to the motor to control its speed and direction. The driver can run 2 motors at the same time and control them using different PWM signal. The figure below shows the connections of the L298N driver. The driver needs a 12V dc power supply to run [13].

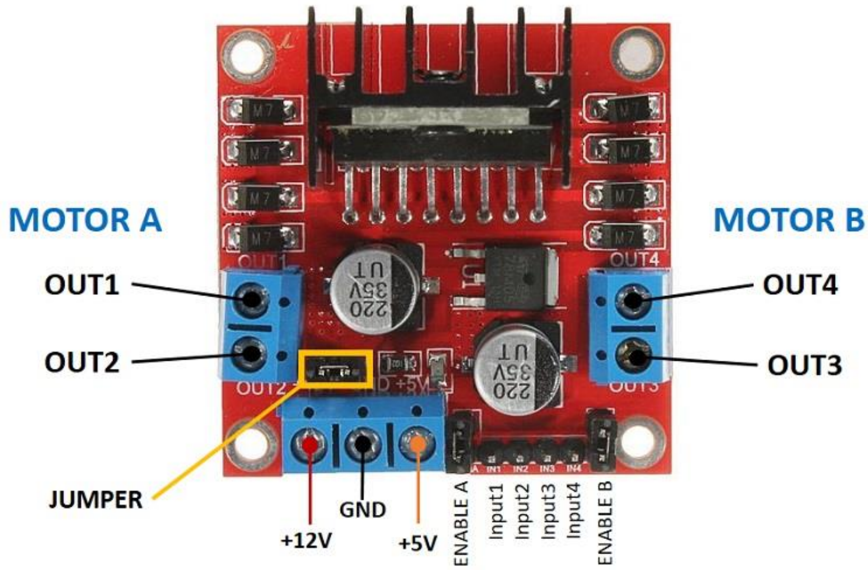

Figure 2 - 1298N Motor Driver

The motor's speed is measured using an IR sensor module (**Error! Reference source not found.**), which detects the rotation of the motor's shaft by sensing the interruptions caused by the revolutions of the motor. This sensor sends signals to the microcontroller, which then calculates the motor's RPM (revolutions per minute) using a mathematical formula.

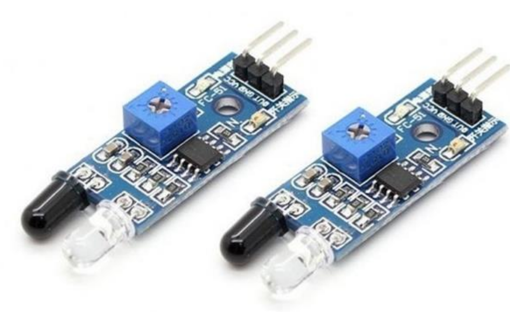

Figure 3 - IR Sensor Module

By controlling the motor's RPM, the speed and performance of the gears can be optimized to achieve the desired output. This setup enables the motor to run smoothly and efficiently while providing accurate feedback on its speed. Overall, this system provides a reliable and effective way to control the motor and ensure the proper functioning of the gears.

We need to achieve a speed of 1000 RPM to achieve our desired frequency. The motor will be connected to the linear actuator with a gear reduction system. Since DC motor have less noise when running at higher speeds.

3.3 Database Selection to Store Data Acquired

Keeping in mind the requirements of this project, we needed a database to store and retrieve data collected from various sensors of the design. A database comprises of three primary components: a database management system (DBMS), a query language, and a database schema. The actual storing and retrieval of data is handled by the DBMS, and users may interact with the data by sending queries to the DBMS using the query language. Furthermore, a database schema describes how data is arranged and stored inside a database's logical structure, acting as a guide for the database management system to ensure the consistency and correctness of the data. A database schema is included in Section 4.2 of the proposal to further explain and illustrate the design.

Given the duration of the incubation period (up to 95 days), our goal was to find a reliable database management system that could efficiently store and retrieve the large volumes of data gathered from the sensors. During our research, we found that there were different types of database management systems we could use. We compared "Relational Database Management Systems" (RDMS) with "Not only Structured Query Language" (NoSQL). We initially considered using a NoSQL database, specifically Firebase, due to its real-time updates to a remote server. However, after considering the cost implications of using Firebase, we decided to opt for a Relational Database Management Systems (RDMS) instead. RDMS was a reliable choice of our project due to its widespread use and our prior experience working with it. Moreover, according to industry statistics, RDMS is the most commonly used type of database management system [11], which made it a reliable choice for our project.

After determining that a relational database management system (RDMS) was the best choice for the project, we compared different options available under RDMS, including MySQL, PostgreSQL, and SQLite. Following our evaluation, we narrowed down the choices to SQLite and MySQL [14]. Initially we considered and did partially implement a database using MySQL as our RDMS for the project due to its ability to handle larger amounts of data and remote access capabilities, however, its implementation on the Raspberry Pi proved to be challenging due to the use of MariaDB, a MySQL fork. The lack of adequate documentation and resources online further reinforced our decision to select SQLite. Additionally, SQLite's lightweight nature, small memory footprint, and serverless architecture made it an efficient and cost-effective solution for storing and retrieving data collected.

Choosing SQLite meant using SQL as the query language. This meant taking advantage of a well-established and widely used language, allowing for efficient data management and manipulation

[15]. The language's syntax is straightforward, making it easier to write complex queries and retrieve specific data points from large datasets. Additionally, SQL's ability to join tables and perform complex operations enables the lab to perform a more in-depth analysis of the data collected.

3.4 User Interface Framework

The User Interface (UI) is one of the main components that determines the user experience and how effectively the device can be used. After researching the various options of frameworks available, mainly the python ones, our results got narrowed down to 2 options: Kivy and PyQT6.

Kivy and PyQT6 [16] are two of the most used Python Graphical User Interface (GUI) frameworks in the industry. Kivy, was made from the ground up for mobile GUI design, with the purpose of making clean modern looking GUIs that can be used on most system software like Linux, Windows, macOS, and Raspberry pi. It has great documentation but lacks on the online resources.

PyQT6 on the other hand, has almost all the same features as Kivy but has an extra important feature that will be of great use in our project. This feature is called QTDesigner [17], it's a program that allows you to seamlessly create GUIs by designing them on a 2D plane in a drag and drop fashion, and then adding functionality and style using python code. This allows for beautiful looking graphical interfaces that can be made with ease. Thus, we will be choosing the PyQT6 framework for our GUI.

4 Vibration Simulator Design

4.1 Measuring Linear Displacement ✓

To measure the small displacement created by the simulation table, a Mitutoyo Digital Indicator was selected. This solution cost <$300, and one sensor can be used for all experiments. The indicator is capable of measuring to a resolution of 0.01 mm.

The indicator is attached to a magnetic base with adjustable arm. [Attach photo]. A metal plate is attached to the frame of the simulation table so that the base can stay in place. The indicator is placed over the table, with the needle touching and slightly depressed.

In the current design, the values must be manually read and tracked by the user. To do so, a setting was designed for the user interface that executes a measuring protocol. The motor slows down to a very low frequency where the user is able to read the values on the indicator. The user then enters the values in the user interface, and it is tracked. The measuring only needs to occur for 1-2 minutes at intervals of once every 2-3 weeks. Since the experiment takes place over 65-95 days, these small periods for measuring should not affect experimental results.

The purpose of measuring the displacement is to ensure that the table has not run into any problems, as the displacement values should stay consistent throughout the experiment. If abnormal values are found, the linear displacement mechanism may have broken or is not operating properly, and the experiment is compromised.

This solution for measuring is inexpensive and simple, with minimal effects on the experiment.

4.2 Simulation of Linear Displacement

4.2.1 Flexure-guided Linear Actuator Design ✓

The 3D model replica (Figure 5) used as a starting point for the design is available under a Creative Commons Non-Commercial license, provided by user Polyfractal on Thingiverse.com [11]. The specific components that will be used from the print are the flexure (1), frame (2), and camshaft (3).

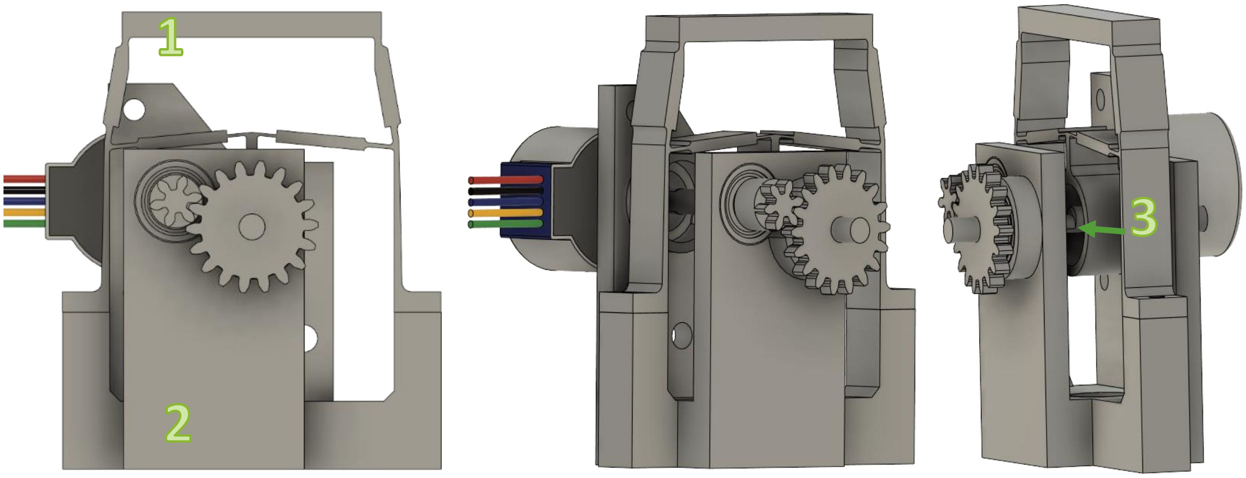

Figure 4 - Original design of the JWST fine positioning stage by Polyfractal, available on Thingiverse.com [11].

This model replicates the James Webb Space Telescope (JWST) Mirror Actuator fine positioning stage, as described in a research paper by Ball Aerospace engineer Robert Warden [10]. The flexure and camshaft of this design can be altered to achieve the correct amount of displacement. Polyfractal's flexure is capable of 26 µm of displacement given a 1 mm offset on the camshaft. When attached to the table, this displacement is less and not measurable. By changing the camshaft offset or the width/height of the flexure can increase or reduce the displacement further.

The flexure model was simulated in Fusion 360 [18] to test displacement capability. This method allowed for faster iteration on the flexure and camshaft design, which can then be printed and integrated into the system for further testing. To increase the displacement, decreasing the height and/or widening the top of the flexure proved to be effective. Increasing the camshaft offset also increased the displacement.

A desirable displacement of 0.11 mm was achieved by widening the top of the flexure by ~2 mm and shortening the height by ~8 mm. The entire design was then scaled up by a factor of 1.375 mm. This flexure can be seen in Figure 6.

The camshaft was scaled up to have a diameter of 8 mm (previously 5 mm), with different offsets available. By changing the offset, the displacement also changes. [Provide some examples of the difference]

Figure 5 - Final design of flexure.

The gears from the original design were replaced by metal spur gears. These gears are available as a 64-tooth output gear, and options of 17-tooth, 21-tooth, 26-tooth, and 29-tooth input gears. The various configurations and possible output frequencies can be seen in Table 4. Gears are connected to the flexure using 3 mm and a 5 mm protrusion on the camshaft.

Table 4 - Different gear configurations and their output frequencies

Gear Ratio	Input Rotational Speed (RPM)	Output Frequency (Hz)
17/64	1500	6.6
	3500	15.5
21/64	1500	8.2
	3500	19.1
26/64	1500	10.2
	3500	23.7
29/64	1500	11.3
	3500	26.4

During testing of the actuator, it was noticed that the flexure had both up-and-down motions, as well as side-to-side. Initially, the up-and-down motion was isolated by designing a coupling plate that could be attached to the bottom of the table surface so the flexure could not move side-to-side. However when testing the actuator flipped on its side, to use the side-to-side motion instead, it was found that the displacement was different. These discoveries show that the actuator can be used both configurations to provide two different displacements. This makes the linear actuator more customizable, as any change results in two more options for experimentation.

4.2.2 Table Design ✓

As seen in Figure 6, the surface (1) on which the eggs are placed is fastened to a linear bearing pillow block (PIL) (2) on each side with custom 3D printed brackets (3). The PIL can slide along a 12 mm metal shaft with minimal friction, isolating any motion to one axis (up and down). The metal shafts are clamped to wood (4), which is fastened to a sturdy base that can be placed on a table. To reduce strain on the flexure, shock absorbing springs (5) are used to sandwich the PIL. This significantly reduces the force needed to push the table upward.

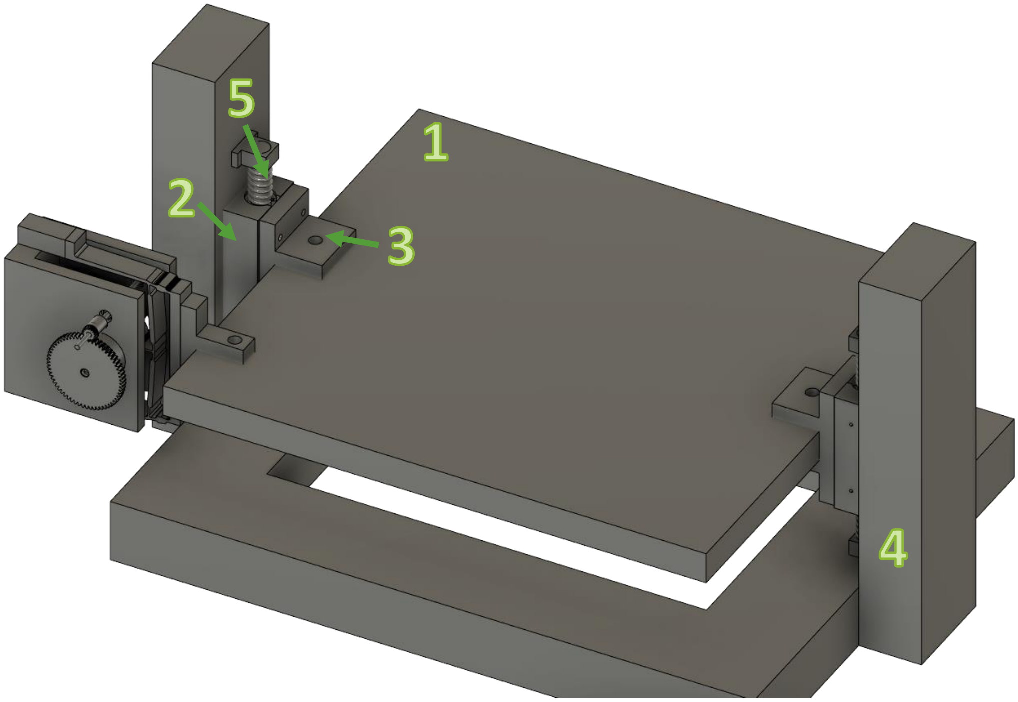

Figure 6 - 3D model of table design.

Figure 6 shows the linear actuator in a side-mounted configuration, where it is coupled to a custom 3D printed bracket. Further 3D modelling is needed to shape the frame of the actuator to attach securely to the table frame.

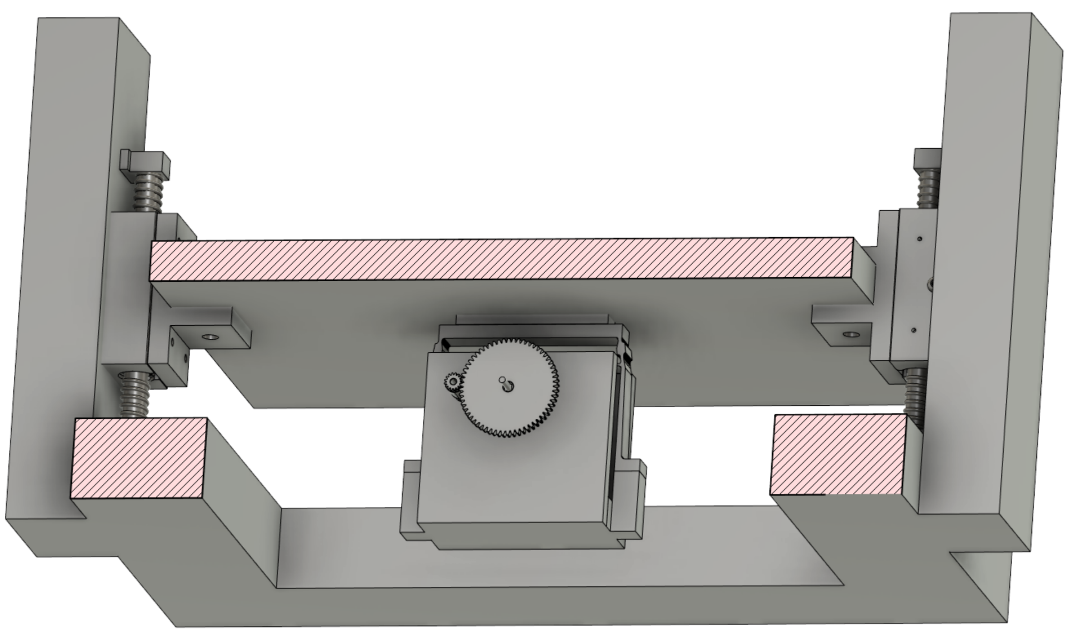

Figure 7 - 3D model of table design, actuator mounted underneath.

Figure 7 shows the option of mounting the linear actuator underneath the table, using a custom 3D printed coupling plate.

The wood base is constructed by hand using a 2x3x8 pine board, as can be seen in Figure 8. Leveling feet can be added as needed.

Figure 8 - Actual build of the table, with actuator in side-mount configuration.

The wooden design of the table is incredibly sturdy, however it requires a person somewhat knowledgeable in wood construction to accurately build. A consideration for the future is to design the frame so that it can be 3D printed and snapped together, making it accessible to anyone with access to a 3D printer.

4.2.3 Motor Feedback System

[TODO]

4.3 Database

Include statements about testing

After choosing our database management system, and the query language, our next important task was to create a database schema. To start, we would first identify the purpose and scope of the database and determine the tables and fields that needed to be included.

Figure 9 below illustrates the updated schema used to store the project data. Every experiment would have an individual ID number, a species type, a collection date, a start time, an email associated with the experiment, a timestamp for when the values where taken, and a field to check the error status of the hardware.

id	INTEGER
species	TEXT
collection_date	DATE
start_time	DATETIME
email	TEXT
frequency	FLOAT
displacement	FLOAT
temperature	FLOAT
humidity	FLOAT
pressure	FLOAT
timestamp	DATETIME
error_detected	TEXT

Figure 9 - Database Schemas

Moreover, linked to each experiment would be the values gathered from the temperature, humidity, and pressure sensors, as well as the vibration frequency and displacement detected by the appropriately chosen sensor (accelerometer/linear position sensor) at a specified time interval. Additionally, a field would be used to keep track of hardware failures (a bit output of 1 for example in case of a part malfunction), and another field would be used to keep track of the exact time the above data was collected at.

id	species	Collection Date	Start Time	Email	Frequency	Displacemen	Temperature	Humidity	Pressure	Error	Time
1	snapback	2023-06-23	2023-06-23 12:00	xyz@gmail.com	123.456	123.456	123.456	123.456	123.456	0	1:45
1	snapback	2023-06-23	2023-06-23 12:00	xyz@gmail.com	123.456	123.456	123.678	123.456	123.456	0	1:47

Figure 10 - Output as a CSV file.

The database will be stored as a ".db" file on the system. We will use Python code to convert it into a .CSV file (an example .CSV file is in Figure 10 above) and email it to the email account associated with the specific experiment whenever the user ends experiment on the user interface. A temporary email account associated with the lab to send out emails has been set up. However, an issue arose with emails regarding 2 Factor Authentication. Google's new security update restricts access to 3rd party applications without a phone number. [19] We initially tried to find a way around it for privacy, however eventually ended up using a phone number to

We initially used MySQL, but after encountering challenges with its implementation on the Raspberry Pi due to the use of MariaDB, we switched to SQLite (see Section 3.3). In addition to this change, the database schema continued to evolve over the development cycle, based on feedback from the Davy lab team. As a result, the final schema differs from the original proposal, progress report and the oral presentation. To provide a comprehensive reference, the previous schemas have been included in the appendix.

4.4 User Interface

The user interface (UI) provides a way that a user can interact with our device; therefore, it must be designed for efficiency and simplicity. Our design philosophy is to create a single interface for all devices (when there is more than one), which allows for easier access and control of all the devices present in the lab which will be done by having a tab for each device/experiment.

The framework and language to be used in the building of this UI is PyQT6 and Python respectively. A great feature of PyQt6 is its 2D design which allows for real-time designing of the UI on a 2D plane to then add functionality using code. This will streamline the UI process and allow for designs that are not as achievable as a pure code solution.

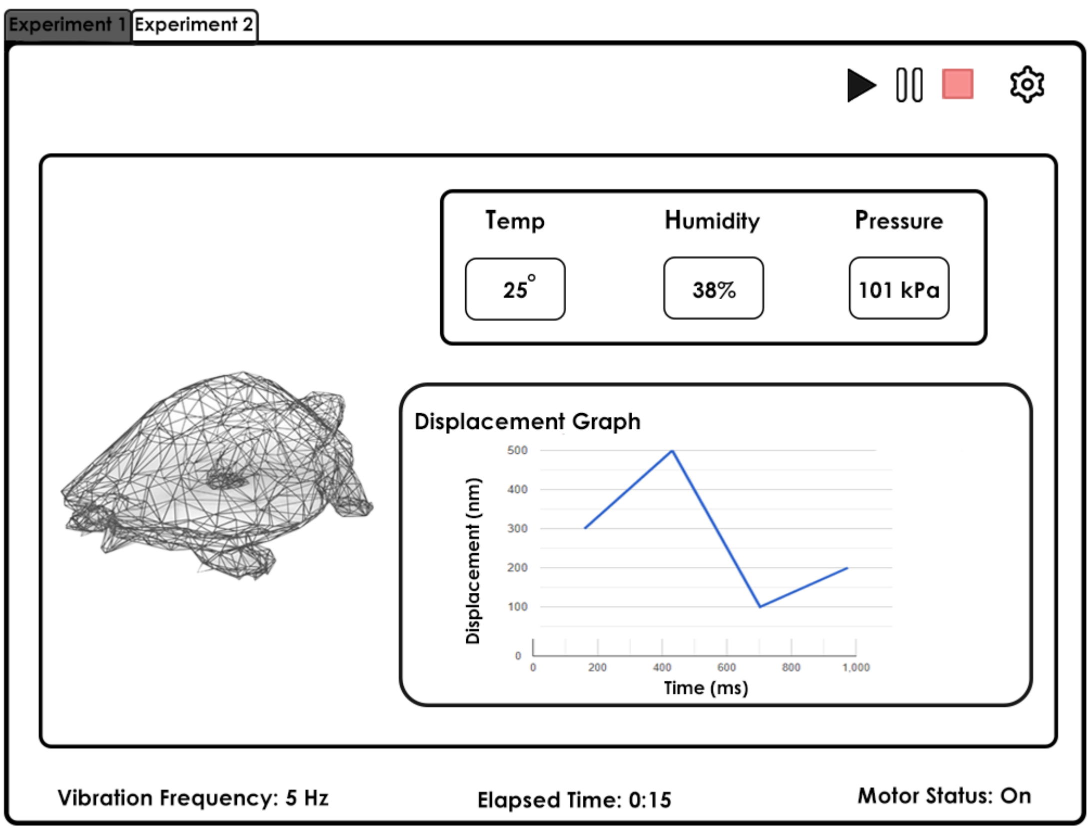

Figure 11 – Home screen UI Wireframe

Our UI consists of tabs, each tab is its own device/experiment. This allows for seamless switching and configuring of any device connected.

The main screen (Figure 11) provides plenty of useful information that can be seen in real-time such as data from the sensors, time elapsed in the experiment, and the status of the motor. From this screen you can stop, play, or pause the experiment. There is also a settings navigation icon which allows you to setup or change the experiment details on the fly.

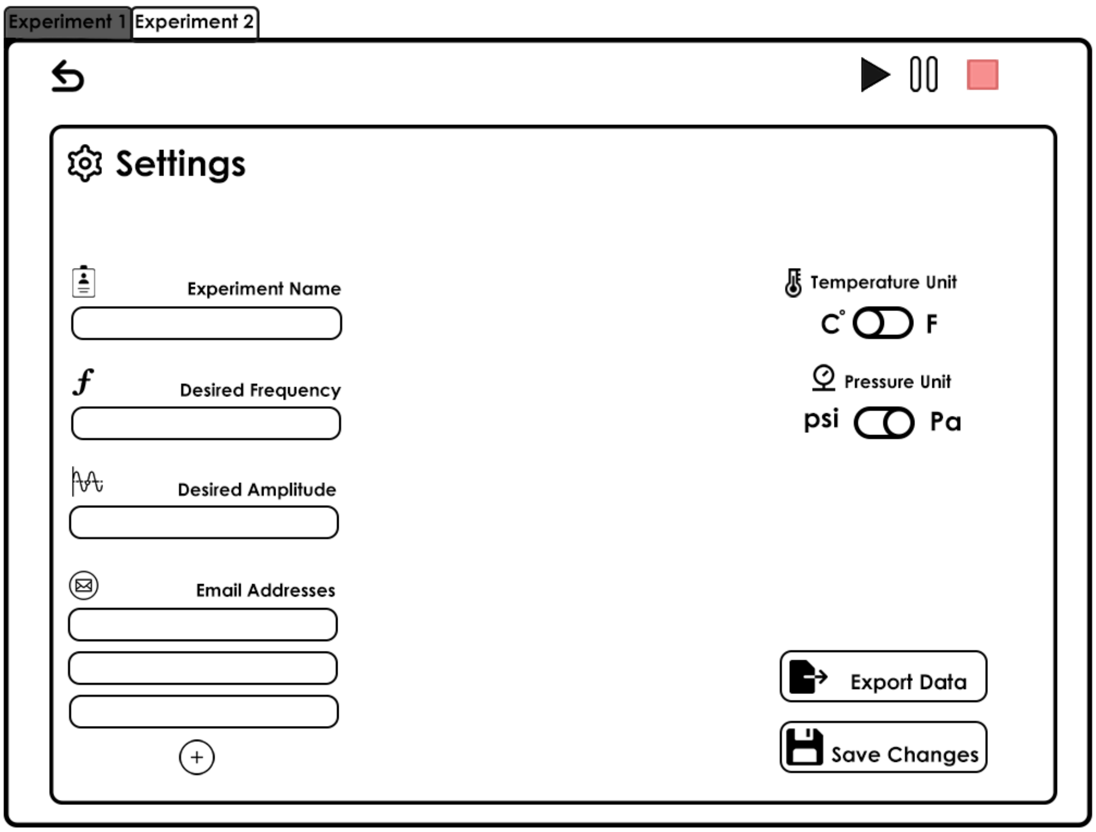

Figure 12 – Settings UI Wireframe

Once you navigate to the settings on any of the tabs/devices you are presented with options to change the parameters or units of your information (Figure 12). Lab members can input their email addresses so exported data can be sent as a spreadsheet file to them directly, or they can export data onto a USB flash drive.

The user interface for the project is progressing at a steady rate. The Qt Designer and the PyQT6 library is proving to be very useful for creating a graphical user interface, they both allow for approaching the GUI in a way which allows you to freely design the look of the user interface without worrying about the functionality until the end. The basic layout is complete and most of the widgets are in place. The next step is to finish up the last few widgets and start applying the functionality to the various systems. We have been meeting with the Davy Lab to understand and address all their needs and solve any problems relating to the UI.

5 Work Plan

5.1 Collaboration

To communicate updates to one another, supervisors, and the Davy lab, the team has used a variety of communication platforms. Microsoft Teams is used for sharing documents and for discussion. A repository for code, documents, and designs is used on GitHub. All work completed will be made available in the repository as an open source so that other labs may use it for future research. Every Monday at 2:30 pm, the team members, managers, and Dr. Davy gather for progress meetings. Additionally, Jelena Nikolic-Popovic, a Senior Member of Technical Staff at Texas Instruments Canada, is working with the team (TI). She is donating some hardware and offering the team her knowledge of the TI equipment being used for the project.

5.2 Project Milestones

Table 5 - Milestone descriptions and completion dates.

Milestone	Completed	Description	Status and Remarks
Hardware Design	Oct. 21	Research will be used to come up with final designs for the vibration mechanism and measurement to be implemented.	Complete
Software Design	Oct. 21	Different components of the software system will be chosen and designed, such as GUI wireframes, framework for GUI development, operating system to be used, database schemas, and languages/libraries to use for software-hardware interfacing.	Complete
Finalize Part Orders	Oct. 21	Parts required for the final designs can be ordered to enable development as soon as possible.	Complete
Hardware Testing Phase	Dec. 10	Tests will be conducted as the linear actuator design and hardware setup is iterated upon. Different motors, gear configurations, and flexure and camshaft designs will be examined to determine the final design is able to hit all required frequencies and displacements.	In Progress
Software Development	Feb. 1	Various components will be implemented such as GUI, database, communication	In Progress

		protocols, custom libraries to retrieve data, and signals to control vibration mechanism.	
Hardware Development	Feb. 1	Once a final design is decided upon, the project's hardware components will be assembled. This phase includes having parts manufactured as needed.	In Progress
Software-Hardware Integration	Feb. 15	Final integrations between the hardware and software will be completed, such as retrieving data from all sensors and controlling the vibration mechanism.	N/A
Integration Testing	Feb. 15	Final integrations between the hardware and software will be thoroughly tested.	N/A
Acceptance Testing	Feb. 28	Tests will be conducted to ensure the project works as is required by the Davy lab.	N/A

5.3 Schedule of Activities/Gantt Chart

Table 6 - Schedule of activities for project completion, documentation, and presentations.

Task	Begin	Draft	Completed	Status
Kickoff meeting between engineering team and lab	-	-	Aug. 26	Complete
Research	Summer	Sept. 7	Sept. 30	Complete
Proposal	Sept. 7	Sept. 30	Oct. 21	Complete
Hardware & Software Designs	Sept. 7	Oct. 8	Oct. 21	Complete
Finalize Part Orders	-	-	Sept. 30	Complete
Hardware Test Phase	Oct. 1	-	Dec. 10	In Progress
Test Plan	Oct. 31	-	Jan. 15	N/A
Development – Software & Hardware	Sept. 30	Jan. 1	Feb. 1	In Progress
Software-Hardware Integration	Feb. 2	-	Feb. 15	In Progress
Progress Report	Nov. 1	Nov. 18	Dec. 9	Complete
Oral Presentations	Jan. 9	Form – Dec. 9	Jan. 23-27	Complete
Integration Testing	Feb. 15	-	Feb. 28	N/A
Acceptance Testing	Feb. 28	-	March 10	N/A

Poster Fair	March 1	-	March 17	Complete
Final Report and Video	Jan. 15	1st – Feb. 17 2nd – March 24	April 12	Complete

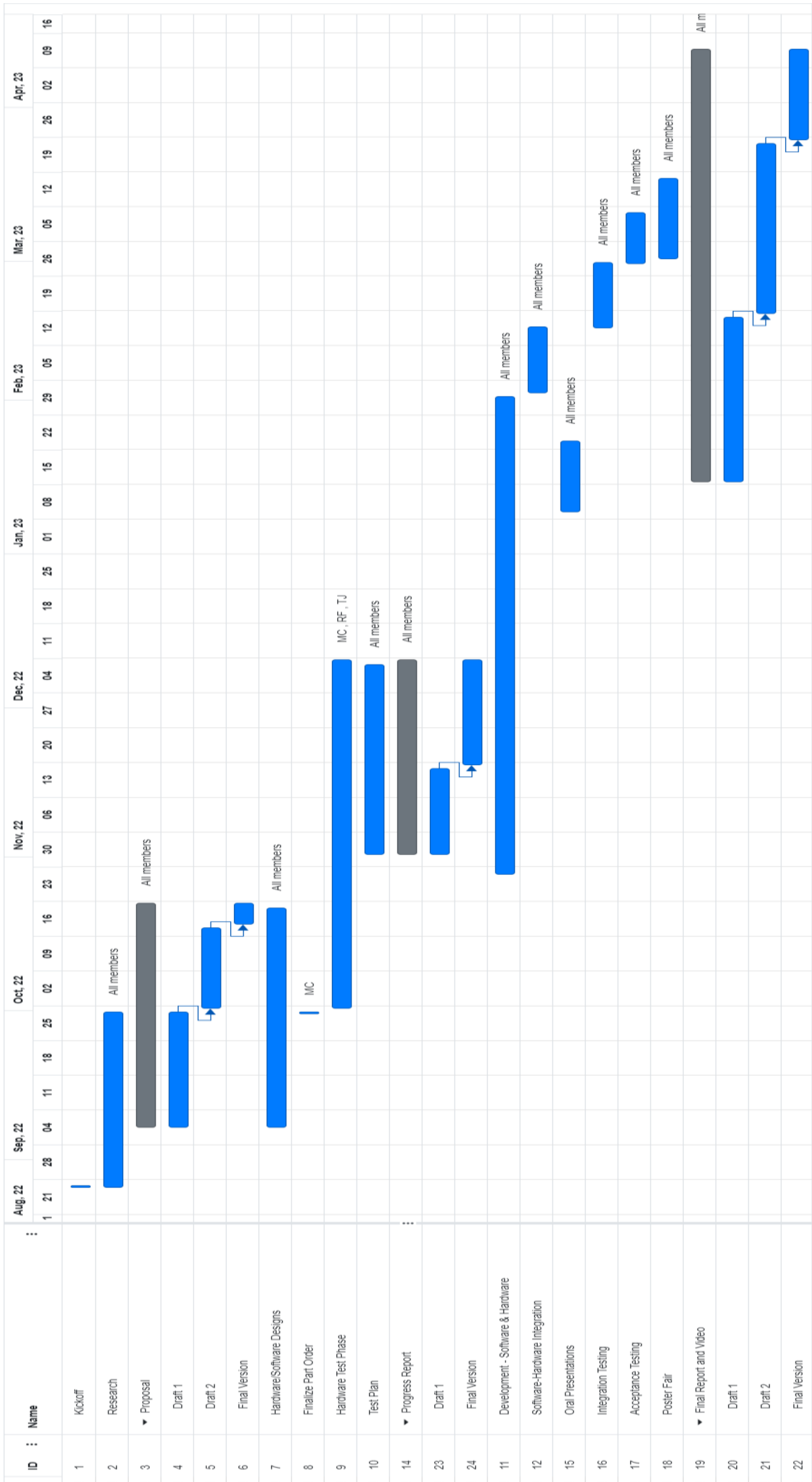

Figure 13 - Gantt chart

6 Budget Breakdown ✓

6.1 Hardware ✓

Note, hardware does not include 3D-printed components, as Carleton University's MacOdrum Library provides 3D printing services to students for free.

The project budget is currently $1000, provided by the Davy Lab. Additional funding is available as needed from the Faculty of Engineering and Design, and some hardware has been donated by Texas Instruments Canada. The breakdown in Table 7 reflects the items needed to build the final design of the shake table before taxes. Additional breakdowns of research and development costs and the cost per additional table are available in Appendix 3: Costs.

Table 7 - Hardware required to complete project, with sources and pricing.

Item	Source	Price
DC Brushless motor	BC-Robotics.com	$1.95
Motor driver	BC-Robotics.com	$9.99
Arduino	Amazon.ca	$23.99
Differential Gears 64T, 17T, 21T, 26T, 29T	Amazon.ca	$16.29
3mm Motor shaft	Amazon.ca	$7.59
2mm to 3mm Shaft coupler	BCRobotics	$3.95
Shaft collar 8mm	Amazon.ca	$9.99
Linear shaft 12mm x 150 mm (x2)	Amazon.ca	$14.99
Linear shaft 12 mm bearing PIL (x2)	Digikey.ca	$18.74
Linear shaft 12mm clamp	Amazon.ca	$17.49
Stiff springs (x4)	Amazon.ca	$43.66
Melamine surface	Homedepot.ca	$26.75
Knotty Pine Board 2x3x8	Homedepot.ca	$16.98
5/16-18 Nylon Insert Nut (x3) ($ 0.16 each)	Ottawa Fastener Supply	$0.48
5/16 X 2 Tap Bolts (x3) ($0.70 each)	Ottawa Fastener Supply	$2.10
A2 M5x16 Phillips Head Screw (x8) ($ 0.22 each)	Ottawa Fastener Supply	$1.76
#12 1 ¼" Sharp Point screw (Pack of 8)	Ottawa Fastener Supply	$3.79
Incubator	Provided by lab	$0
Raspberry Pi 4, 4GB	Digikey.ca	$80.95
Temperature & Humidity sensor	Amazon.ca	$16.00
Mitutoyo 543-789 Digimatic Indicator	Amazon.ca	$264.43
Mitutoyo SPC Connecting Cable	Amazon.ca	$72.58
IR Sensor Module	Amazon.ca	$10.89
Indicator Holder	Amazon.ca	$30.00
	TOTAL	**$695.34**

7 Reflections

The team has learned a tremendous amount about the engineering process through the research and design phase of the project conducted so far. It has been important for the team to acknowledge when an idea will not work out, and how to salvage work done to still produce a final product.

The initial goal of this project was to simulate vibrations detected in the presence of wind turbines. During the research and design phase, it was determined that the target displacement of these vibrations, ~300 nm, would be difficult to produce, and even harder to measure. Measurement devices capable of measuring within the nanometer range were extremely expensive and out of budget. Upon discussing these issues with the Davy Lab, it was decided to shift goals. Vibrations at the same frequency but a larger displacement would still be very useful to the lab, and the scope of the research was expanded to include a variety of industrial sources of vibration.

The team was able to find new vibration targets, and the research and designs to date could still be used with some tweaks. This has given the team a valuable experience in understanding limitations, and repurposing work for new goals.

8 Conclusion ✓

The main objective of this project was to provide a vibration simulator with which the Davy lab can investigate the effects of ground vibration from various industrial sources on the growth of turtle eggs. Shaking tables exist that can produce frequencies between 2 – 20 Hz, however none were found that could achieve the fine precision of 0.1 – 1 mm displacement that is required. Further, these tables were prohibitively expensive for the lab, the least expensive being $5000.

The team achieved the goals of creating vibrations of [values here]. This extreme precision in displacement can be attained by utilizing the James Webb Space Telescope mirror positioning system's elegant yet straightforward flexure-guided linear actuator design. From this starting point, the team customized the flexure to achieve higher displacements, and created a motor feedback system so that frequency of vibration could be selected and changed by the user. A user interface and data collection system were implemented for ease of use by the lab personnel. With this system, environmental variables such as temperature and humidity can be measured, as well as frequency and vibration of the table.

The most important aspect of the project was achieving the goals while staying under budget. The vibration simulator and data collection system can be built for $695.34, and additional tables can be added to the system for $176.16. This price point and open-source design makes researching ground vibration effects on species accessible to the Davy lab and other labs.

The Davy lab is excited to begin experiments with the system this summer. Not only will they be researching the effects on turtle eggs, but have found the system can accommodate other reptile species as well, such as snakes.

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Appendix 1: Relevant Courses

The team has collectively taken many different courses relevant to the project. For reference, the course codes and course titles mentioned throughout the document will be outlined here:

Table 8 - Cumulative relevant courses for required knowledge and experience.

Course Codes	Title
ECOR 1010	Introduction To Engineering
ECOR 1101	Mechanics I
SYSC 2004	Object Oriented Software Development
SYSC 3600	Systems and Simulation
SYSC 3010	Computer Systems Development Project
SYSC 3020	Introduction to Software Engineering
SYSC 4805	Computer Systems Design Lab
SYSC 4505	Automatic Control Systems I
ELEC 2501	Circuits and Signals
ELEC 2507	Electronics I
ELEC 3105	Basic EM and Power Engineering (previously), Electromagnetic Fields (current)
ELEC 3907	Engineering Project
ELEC 3509	Electronics II
CCDP 2100	Communication Skills for Engineering
ECOR 4995	Professional Practice

Appendix 2: Additional Diagrams

Database:

The figure below illustrates the database schema presented in the initial proposal.

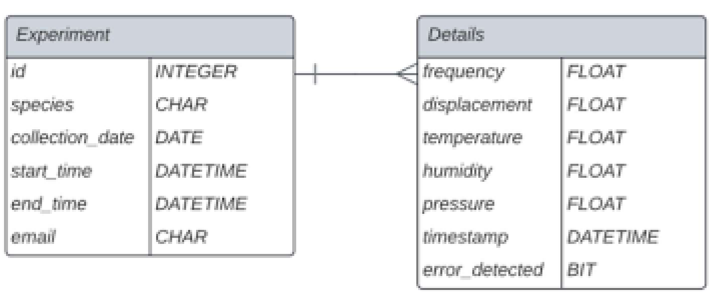

Figure 14 - Database schema from the proposal.

Appendix 3: Costs

These cost breakdowns contain before-tax prices.

Research and Development Costs

Item	Source	Price
DC Brushless Motor	BC-Robotics.com	$1.95
DC Brushless Motor	Amazon.ca	$23.53
Motor driver	TexasInstrument.com	$54.53
Motor Driver	BC-Robotics.com	$9.99
MC3479 Accelerometer	Digikey.ca	$21.47
MSP430 LaunchPad MCU	Digikey.ca	$22.94
Arduino Uno	Amazon.ca	$23.99
Differential Gears 64T, 17T, 21T, 26T, 29T	Amazon.ca	$16.29
5mm Motor shaft	Amazon.ca	$8.54
3mm Motor shaft	Amazon.ca	$7.59
3mm to 5mm Shaft coupler	Amazon.ca	$11.99
2mm to 3mm Shaft coupler	BCRobotics	$3.95
Shaft collar 8mm	Amazon.ca	$9.99
625-2rs Ball Bearings (x4)	Amazon.ca	$16.03
Linear shaft 12mm x 150 mm (x2)	Amazon.ca	$14.99
Linear shaft 12 mm bearing PIL (x2)	Digikey.ca	$18.74
Linear shaft 12mm clamp	Amazon.ca	$17.49
Stiff springs (x4)	Amazon.ca	$43.66
Melamine surface	Homedepot.ca	$26.75
Knotty Pine Board 2x3x8	Homedepot.ca	$16.98
5/16-18 Nylon Insert Nut (x3)	Ottawa Fastener Supply	$0.48
5/16 X 2 Tap Bolts (x3)	Ottawa Fastener Supply	$2.10
A2 M5x16 Phillips Head Screw (x8)	Ottawa Fastener Supply	$1.76
#12 1 ¼" Sharp Point screw (Pack of 8)	Ottawa Fastener Supply	$3.79
Incubator	Provided by lab	$0
Raspberry Pi 4, 4GB	Digikey.ca	$80.95
Temperature & Humidity sensor	Amazon.ca	$16
Mitutoyo 543-789 Digimatic Indicator	Amazon.ca	$264.43
Mitutoyo SPC Connecting Cable	Amazon.ca	$72.58
IR Sensor Module	Amazon.ca	$10.89
Indicator Holder	Amazon.ca	$30.00
	TOTAL	**$854.37**

Additional Table Costs

Item	Source	Price
DC Brushless motor	BC-Robotics.com	$1.95
Motor driver	BC-Robotics.com	$9.99
Arduino	Amazon.ca	$23.99
Differential Gears 64T, 17T, 21T, 26T, 29T	Amazon.ca	$16.29
2mm to 3mm Shaft coupler	BCRobotics	$3.95
Linear shaft 12mm x 150 mm (x2)	Amazon.ca	$14.99
Linear shaft 12 mm bearing PIL (x2)	Digikey.ca	$18.74
Linear shaft 12mm clamp	Amazon.ca	$17.49
Stiff springs (x4)	Amazon.ca	$43.66
Knotty Pine Board 2x3x8	Homedepot.ca	$16.98
5/16-18 Nylon Insert Nut (x3) ($ 0.16 each)	Ottawa Fastener Supply	$0.48
5/16 X 2 Tap Bolts (x3) ($0.70 each)	Ottawa Fastener Supply	$2.10
A2 M5x16 Phillips Head Screw (x8) ($ 0.22 each)	Ottawa Fastener Supply	$1.76
#12 1 ¼" Sharp Point screw (Pack of 8)	Ottawa Fastener Supply	$3.79
Incubator	Provided by lab	$0
	TOTAL	**$176.16**