SYSC 4907 – ENGINEERING PROJECT

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

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1 Introduction

Carleton University's Davy Lab is a conservation research group that works to better understand how environmental changes affect local threatened species of bats, amphibians, and reptiles. One such project involves investigating the effects of seismic vibrations from nearby wind turbine operations on the development of turtle eggs. Further, nearby highways can also generate ground vibrations that may have similar effects that must be studied.

Meia Copeland, Shawaiz Khan, Talal Jaber, Marwan Zeyada and Ranishka Fernando are engineering students working to create a device that can simulate the ground vibrations around wind turbines, so that the lab can study these effects in a laboratory setting.

1.1 Background

In the past decade, wind power has been the fastest growing source of new energy in Canada [1]. As the country moves towards its climate goal of increasing the share of zero-emitting energy sources to 90% by 2030, wind power will be instrumental to success. While an extremely useful tool in emission-free power generation, there are a variety of potentially negative effects on wildlife. The most thoroughly studied are the impacts on flying animals, such as bird and bats. Mortality from collision with the turbine rotors, as well as general avoidance of areas around turbines has been described [2]. However, wind energy's impacts on ground-dwelling animals are less known.

On-shore wind farms have been shown to produce low-frequency ground vibrations for many kilometers surrounding the turbines [3]. Some studies have investigated the impacts these vibrations have on the stress levels and behavior of ground-dwelling animals. While some terrestrial animals have shown increased levels of stress-hormones around wind turbines [4], the behavior of most terrestrial animals has not been shown to be significantly affected [5]. Most studies so far have focused on terrestrial mammals. The effects on egg development of reptiles and amphibians have not been examined.

The ground vibrations from wind turbines are predominantly caused by interactions between the wind and the entire turbine system, rather than just the spinning of the blades [6]. These frequencies typically range between 0.1 and 100 Hz [3]. To simulate these extremely low frequencies in a lab setting, a shake-table will be needed. The turtle eggs may be placed in an incubator, which in turn is attached to the top of the shake-table. Devices capable of such low frequencies exist, such as the Low Frequency Portable Shaker Table by the Modal Shop [7], which is capable of frequencies as low as 0.7 Hz. However, the device is not rated for continuous use throughout the incubation period of snapping turtle eggs, which is 65 to 95 days [8].

1.2 Motivation

As wind power becomes commonplace around Canada and the world, it is important to determine the effects wind turbines have on native species that may live or nest nearby. The Davy Lab would like to investigate these effects on the development of turtle eggs, particularly the ground vibrations caused by wind turbine use.

Our goal is to create a device that will allow the Davy Lab to simulate and control these ground vibrations in a laboratory environment, while also tracking environmental variables such as temperature and humidity.

1.3 Project Objectives

This device will simulate ground vibrations between 2 and 10 Hz, with displacements of 300 nm to 5.5 nm to simulate vibrations beside the turbine, and up to 2.5 km away [9]. The device will have a 30 cm X 30 cm surface, large enough to place once incubation tub. The displacement will be measured from this surface. The device will be able to create vibrations continuously for up to 95 days, which is the incubation period for snapping turtle eggs.

1.3.1 Specific Goals

VIBRATION – Motor rotation will be translated to vertical displacement using a linear actuator system. This system uses a camshaft and flexure that can reduce the linear displacement to a nanometer scale. A stepper or DC motor will be used, with the angular motion reduced through gears as necessary.

VIBRATION MEASUREMENT – The amplitude and frequency of the vibration can be measured using an accelerometer, or a linear displacement sensor.

CONTROL SIGNALS – System must be able to take a frequency and amplitude inputs and operate the motor accordingly. System must also be able to take measurement outputs and calculate frequency and amplitude.

USER INTERFACE – A small screen will be attached to the system and allow lab members to start and stop the experiment, set the vibration frequency and displacement, set the length of experiment, and export acquired data in a spreadsheet to a list of emails. Environmental and vibration variables will be displayed for monitoring while the experiment is active.

DATA ACQUISITION– Data for the frequency and amplitude of the vibrations will be captured once every 30 minutes. Environmental variables will also be captured once every 30 minutes. System must be able to convert the data into a spreadsheet for viewing after the experiment.

2 Methodology Research

2.1 Vibrations to be Simulated

Several studies on the ground vibrations around wind turbines were conducted to determine the target frequencies and amplitudes for the simulation device. Much of this research has been conducted to examine the interference that wind turbine ground vibrations may have on sensitive seismic monitoring systems [3] [10]. Reports have shown that vibrations from wind turbines can interfere with these systems as far as 62 km away when wind speeds are high [3].

Several reports agreed that there are distinct structural bending modes detected around typical 80m tall turbines [3] [10]. These modes correspond to vibrations of 0.32 Hz, 2.56 Hz and 5.88 Hz.

The displacement of vibrations is also needed to create an accurate simulation of the vibrations around turbines. Botha found that, at approximately 5.8 Hz and 90 m from the base of the turbine, the velocity was 0.005 mm/s [9]. At 2 km from the base, the vibration reduced the amplitude to 10^{-6} mm/s, with the same frequency. These velocities at 5.8 Hz correspond to displacements of approximately 300 nm and 5.5 nm. These values will be used going forward.

Most of the literature monitored the vibrations using triaxial seismometers and accelerometers, therefore capturing the vibrations along the horizontal X- and Y-axes, and vertical Z-axis. However, many only presented the data along the Z-axis, as this vibration was far more significant than the horizontal movements [9] [3]. Other research only measured the Z-axis for this reason [11].

For this simulator, creating vibrations like those felt 50 to 90 m from the base of the turbine will be prioritized. A frequency of 5.8 Hz and vertical displacement of 300 nm will be targeted. If these variables are achieved, reducing the frequency and displacement will be attempted.

2.2 Methods of Vibration Simulation

Creating vibrations of both extremely low frequency and small displacement is the hardest and most critical piece of achieving success with this project. The vibration treatment would have to be applied continuously over the incubation period of the turtle eggs, 65 to 95 days [8]. Over the course of literature review and investigation on potential vibration methods, several methods were investigated, and will be discussed here.

2.2.1 Earthquake Shake Table

The first method investigated was to recreate a shake table, like those used in civil engineering research to examine the natural frequency of structures. These machines can produce extremely small frequencies, as earthquakes generate vibration frequencies between 0.2 Hz and 20 Hz [12]. However, the displacements of these machines is too large for our uses. Further, most shake tables act in a horizontal X- or Y-axis direction, whereas the most significant vibrations from wind turbines is accepted to be vertical, in the Z-axis. While this idea was overall scrapped, some elements were eventually reconsidered, such as the linear actuators used in many shake-table designs that allow for lower frequency and more precise displacement.

2.2.2 Sub-woofers and Haptic Transducers

A mechanical solution overall was not ideal, considering the expertise of the students involved in the project. Because of this, an electrical solution was investigated. First, sub-woofers and speakers capable of extremely low bass were looked at. Most sub-woofers can reach frequencies as low as 25 Hz, with some specialty designs going lower. Being able to turn up or down the volume would allow for more customization regarding the displacement as well. However, no realistic and cost-effective options were available in the 2 to 10 Hz range needed for this project.

Another option that was considered was a haptic transducer, such as those used in gaming and home theater setups. These transducers are capable of much lower frequencies, some purportedly as low as 5 Hz [13]. These devices are also able to be turned up and down, like sub-woofers and speakers. However, these devices are not built to use continuous sine waves, as would be needed for this application. The devices are meant to be active in short bursts, such as to accentuate rumbling in a video game or movie. Using a continuous sine wave at frequencies lower than 20 Hz, the transducer will run out of excursion potential and attempt to self-brake to prevent physical collision between internal components [14]. To solve the issue of using a continuous sine wave, it is recommended to pulse the sine wave [14]. However, transducers could also over-heat when used continuously. Finally, if the desired frequency could be achieved, damping the amplitude to the desired values would also be difficult. Testing with surfaces of different weights and materials would need to be conducted.

2.2.3 DC Brushless Motor

A mechanical solution was revisited, as most students in the group had some experience with systems involving motors. This solution first examines 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 PWM controller to control the RPM of the motor. However, most small motors have a limit where the vibration frequency stops decreasing at around 30 Hz due to weight and size constraints (Figure 1).

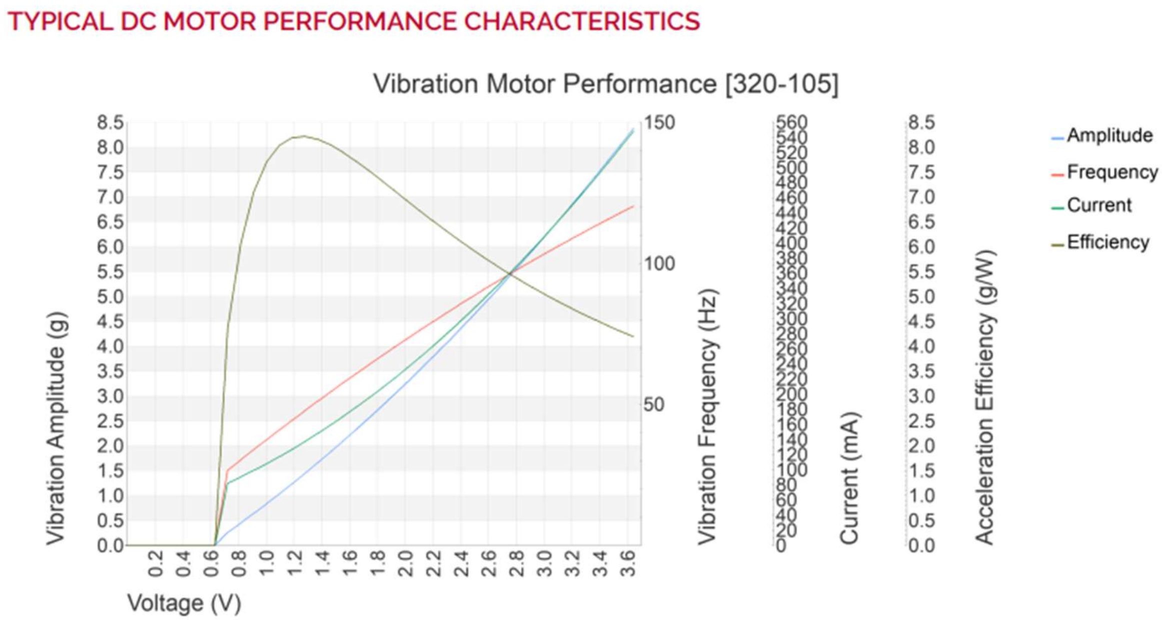

Figure 1 - DC motor frequencies [11]

2.2.4 Stepper Motor and Fine Control Linear Actuator

Finally, stepper motors were considered since they generally have a maximum frequency limit around 15 Hz. Once again, an issue arose in deciding how to attach the stepper motor to the bottom of a tabletop to produce the correct frequencies. Simply attaching the motor would produce equal vibrations in a vertical and horizontal direction.

Linear actuators in earthquake shake tables were revisited. These actuators could operate at low enough frequencies and provide vibrations in one direction. Depending on the actuator, the amount of displacement could also be controlled. Further, a linear actuator could be designed to be controlled by a simple and cheap stepper motor. In fact, such a design exists and is used on the James Webb Space Telescope (JWST), to position the mirrors [15]. Due to the precision required by the JWST, the linear actuators used are capable of displacements in the micron range. The fine positioning mechanism involves gears to reduce the [16]frequency of the stepper motor, which controls a camshaft with a small offset. This camshaft is coupled to a flexure, which in turn is capable of displacement on the micron-scale at the top of the flexure. Open-source 3D model replicas are available under a Creative Commons license, and the flexure and camshaft can be altered to reduce the amplitude further. This solution will be used going forward.

2.3 Database options to store data acquired

Keeping in mind the requirements of this project, a database was needed to store and retrieve data collected from various sensors of the design. A database schema is included in Section 3.4 of the proposal to further explain and illustrate the design.

Focusing on Relational database management systems due to them being the most widely used databases [17] and having previous experience related to it, our first choice was narrowed down between a ‘Structured query Language’ (SQL) and a ‘Not only Structured Query Language’ (NoSQL) types of databases, with pros and cons for both.

Other than being the most common database management approach, using SQL offered us faster query processing, and standardized and user-friendly language [17]. NoSQL on the other hand offers flexible scalability and flexible data types [18]. Taking the needs of the lab into consideration, flexibility would not be a big concern since our schema will stay consistent over time, NoSQL seemed excessive for this project which is why we eventually chose SQL, although using NoSQL will be set as a stretch goal.

Under SQL, we narrowed our choices to industry standards, MySQL and SQLite [19]. SQLite is a software library providing a relational database management system, not requiring servers to run, and is relatively easy to master when compared to MySQL [20]. MySQL on the other hand offers remote access and data security as well as the possibility of handling much larger amounts of data. Additionally, it allows access to multiple users to Read/Write to/from the database [20]. Keeping in mind the requirements of the project, MySQL is a better alternative when considering its popularity and the scalability aspect of our design. Further development may result in a change in approach and further consideration might be given to SQLite if it results in a more straightforward and simpler solution.

2..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 [21] are two of the most used python 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 [16], it’s a program that allows you to seamlessly create GUIs by designing it 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 graphical user interface.

3 Vibration Simulator Design

3.1 Actuator Test Plan

The 3D model replica (Figure 2) used as a starting point for the design is available under a Creative Commons license, provided by user Polyfractal on Thingiverse.com [22]. The specific components that will be used from the print are the frame, flexure, motor shaft, and camshaft.

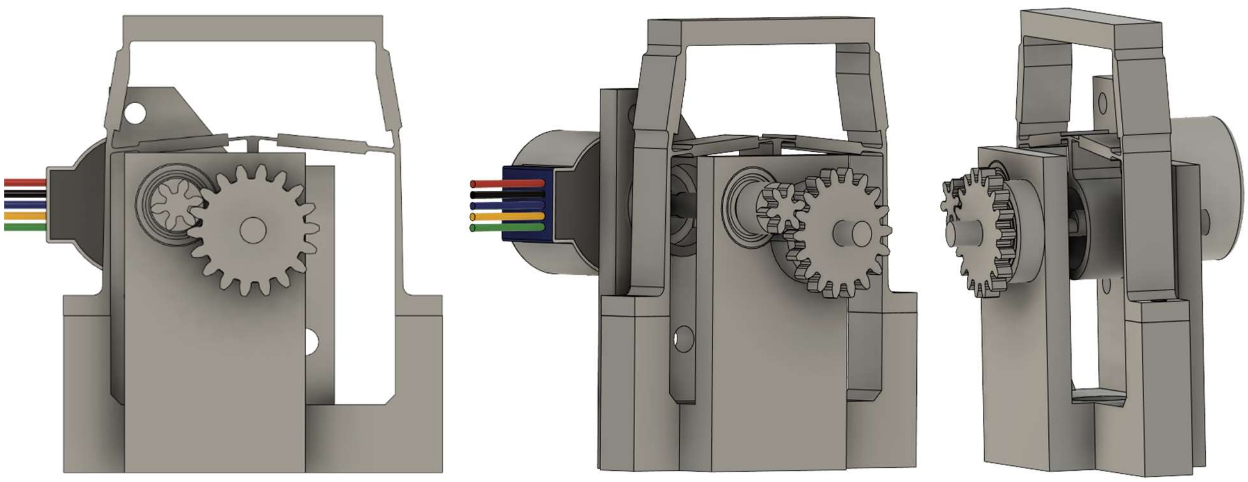

Figure 2 - Front and side views of the JWST Mirror fine positioning mechanism as designed by Polyfractal [22]

This model replicates the JWST Mirror Actuator fine positioning mechanism, as described in a research paper by Robert Warden. The flexure and camshaft of this design can be altered to achieve the correct amount of displacement. As is, the flexure has a displacement of approximately 40 µm. Changing the camshaft offset or the width/height of the flexure can reduce the displacement further.

The flexure model will be simulated in ANSYS [23] to test displacement capability. This method allows for faster iteration on the flexure and camshaft design, which can then be printed and integrated into the system for further testing.

Tests will use a 28BYJ-48 stepper motor and DC brushless motors. The gears from the print will be replaced by metal spur gears intended for RC cars. These gears are available as a 64-tooth output gear, and options of 17-tooth, 21-tooth, 26-tooth, and 29-tooth input gears. Other configurations are also available and will be tested as needed. The combination of these gears offers a significant reduction to the input frequency.

This design takes advantage of students' knowledge of electronics, CAD design, and control systems as was learned in courses such as ELEC 2507, ELEC 3105, ELEC 3509, ECOR 1010, SYSC 3600, and SYSC 4505. As well, this concept will exercise the team's ability to understand that where expertise is lacking, intuition and ingenuity can be used to take an existing solution and transform it to work for a new problem.

3.2 Motor Test Plan

As mentioned above, a motor is needed to drive the actuator. The debate is between using either a stepper motor or DC Brushless motor for the project. In order to ensure best fit for the purpose, both motors will be tested in a controlled environment with the same parameters and conditions. In order to ensure precision and accuracy in data, one condition will be the variable factor while the rest of the conditions stays the same. The conditions that need to be tested and measured are frequency, torque, and RPM. In order to collect data one factor will be changed in the same controlled environment while the rest of the conditions stays the same. To ensure accuracy, testing will be repeated three times for each factor and the average will be considered for the final data. During the experiment, additional noise from both motors will be considered by varying frequency. The team is considering the use of a DC Brushless mainly because it can achieve higher RPM. With the gear ratio being used, the required input RPM is around 1000 to give an output RPM of 350 which results in a frequency of 5.8Hz. Reaching the input frequency will be a bigger challenge when using a stepper motor.

In order to arrive at a conclusion, a vigorous analysis will be conducted after taking into account the frequency, torque, and RPM along with noise produced and the motor that aligns with the required frequency, torque and amplitude with least noise will be chosen for the project. External factors such as temperature will affect the experiment data thus a controlled environment at room temperature will be considered for the experiment.

3.3 Shake Table Test Plan

Once the linear actuator and motor have been designed and selected for the appropriate displacement and frequency, the table will be assembled. To reduce the amount of torque needed to vertically displace the table, stiff springs will be used as a suspension system. Further, vertical round rails will be used to keep the table from moving horizontally in the X- and Y- axes.

Different springs will need to be tested for optimal torque reduction, while not introducing amplification of noise from the surrounding environment, such as vibrations in the building. The choice of motor will also be examined again in case more torque is needed to displace the table.

3.4 Measurements

To ensure accurate vibration control and monitoring of the environmental parameters, several measurement devices will be included in the project. Sensor setup and data retrieval involves students' knowledge of data capture with microcontrollers and I2C as was learned in courses such as SYSC 3010, SYSC 4805 and ELEC 4601.

3.4.1 Vibration

Measuring the vertical displacement and frequency of the vibrations will be essential for matching the simulated vibrations to measured vibrations in the field. By using an accelerometer, the acceleration of the surface moving up and down can be measured. The displacement can be calculated, and vibration frequency can be estimated from the acceleration measured. Due to the small frequency and extremely small displacement, filtering is likely required to remove the noises outside of the target frequency. Appropriate accelerometers will be examined and tested to find the right fit.

Another option for sensing vibration is a linear position sensor. Because the displacement will only be in the vertical direction, a sensitive linear position sensor could be set up in contact with the table surface. Frequency can be estimated from this data.

3.4.2 Temperature, Humidity, and Pressure

Research involving the incubation of reptile eggs requires knowledge of the environmental variables. Temperature, humidity, and pressure sensors will be placed on or inside the incubation container to keep track of these variables.

3.5 Database

A Relational Database Management System (RDMS) using the MySQL tool will be used to keep track of all the required stats.

Figure 3 below illustrates the schema used to store the project data. Every experiment would have an individual ID number, a start time, an end time, an email associated with the experiment, and a species type.

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 (currently planned to be 30 minutes). 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.

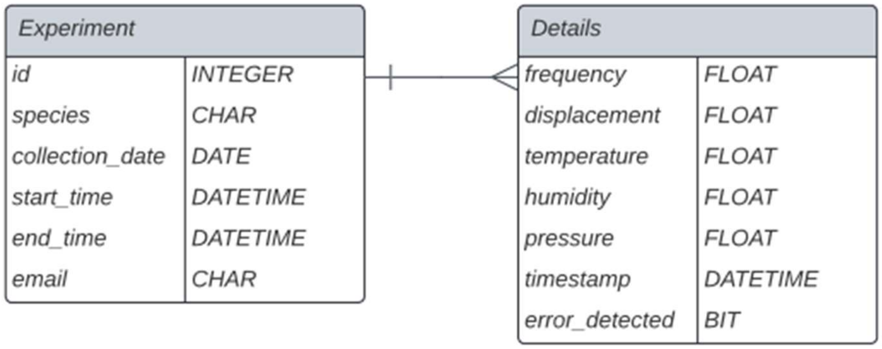

Figure 3 - Database Schemas

3.6 User Interface

The user interface (UI) is the only way 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 it’s 2D designer 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.

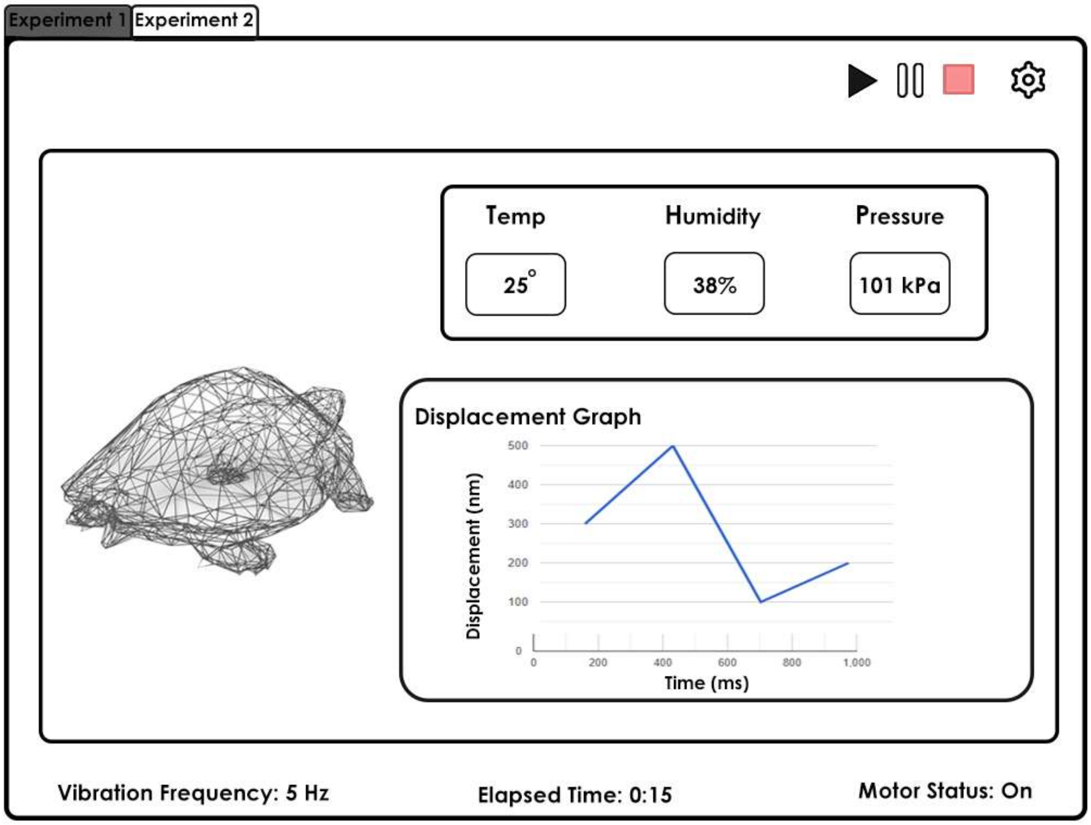

Figure 4: Home screen UI Wireframe

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 4) is home to 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.

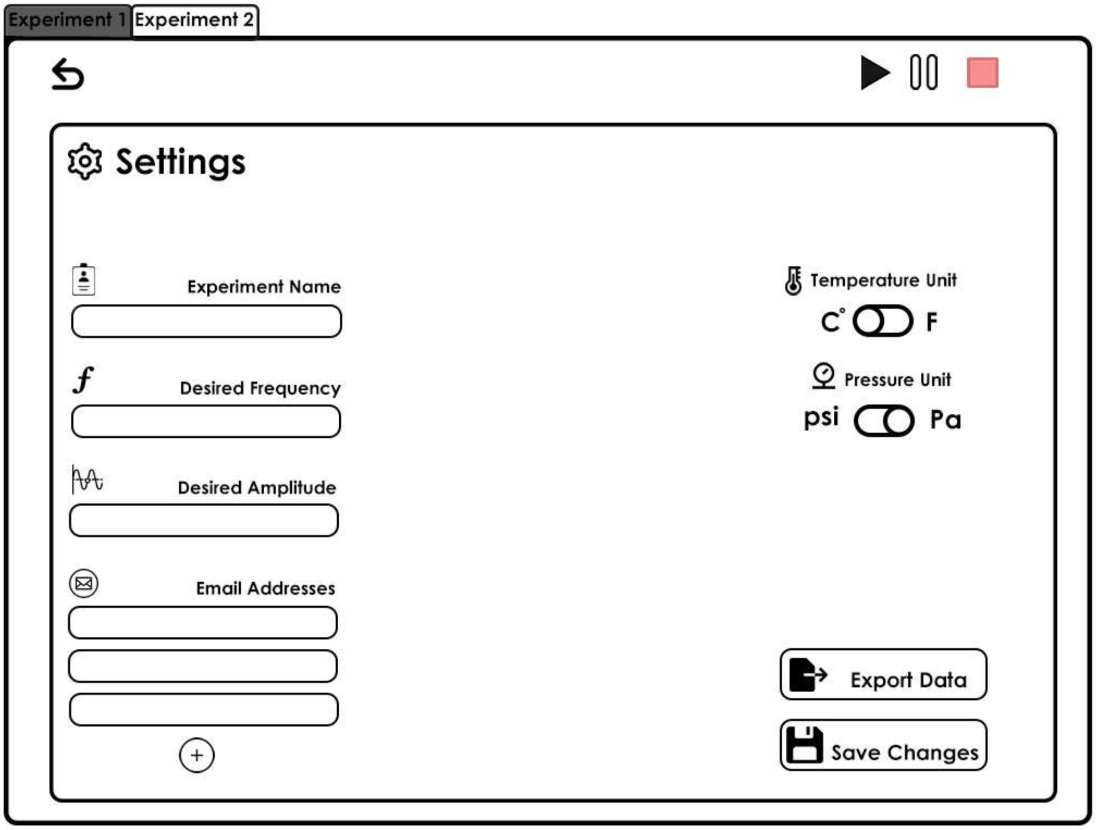

Figure 5: Settings UI Wireframe

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 5). 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.

3.7 Use Cases

A couple of use cases for the most common scenarios are posted below.

3.6.1 Use Case 1 – Begin New Experiment

Table 1

Intent	Setting up a new experiment.
Primary Actor	Biologist/Student
Precondition	The system is connected to power and turned on.
Postcondition	The user successfully sets up a new experiment. The parts operate at the intended settings.
Failed Postcondition	Either one of the actuators, accelerometer, temperature sensor or humidity sensor fails to operate.
Basic Flow	- Navigate through the touch screen interface. 1. Touch the "New experiment" UI button on the top left of the screen. 2. Enter an experiment name, desired frequency, desired amplitude, and email address in the given space. 3. Choose the units for Temperature and Pressure, review the details entered and touch the 'Save Changes' UI button.

3.6.2 Use Case 2 – Change the vibrational frequency.

Table 2

Intent	Changing the vibrational frequency applied by the actuator.
Primary Actor	Biologist/Student
Precondition	The system is connected to power, ON, and an experiment has been set up and is running; The UI displays the home screen.
Postcondition	The user successfully changed the vibrational frequency to the desired setting. The system uses the accelerometer to measure the change and display a confirmation notification.
Failed Postcondition	The accelerometer fails to detect a change or detects readings not intended by the user.
Basic Flow	- Navigate through the touch screen interface. 1. Touch the UI box/button displaying the current frequency value. 2. Enter the desired frequency in the pop-up textbox. 3. Touch "Save changes".
Alternate Flow	1. Touch "Settings" tool on the top right of the screen. 2. Touch the "desired frequency" text box. 3. Follow step 2 from the Basic Flow above.

3.7 Solution Evaluation

Our final solution would consist of a Beagle Board-Black microcontroller, designed actuators, temperature/pressure/humidity sensors, and a touch screen for User Interface. The microcontroller would be used to control the actuators to vibrate at a specific frequency.

A container filled with vermiculite substrate and turtle eggs would be placed on top of the actuator, exposing the eggs to the vibrations produced by the actuator for the incubation period of 65 to 95 days. The environmental sensors would monitor the environment to ensure that the eggs stay in optimal conditions. An accelerometer or vertical position sensor would be used to measure and calculate the vibrational frequencies and displacement at regular intervals of 30 to 60 minutes.

The data gathered above would be stored in a relational database management system using the MySQL tool which can be exported to a Microsoft Excel file for the lab to work with. A User Interface for the touchscreen would be created using PyQT6 which would allow the biologists to control the system.

4 Work Plan

4.1 Project Team

Table 3 - Description of project team members, experience, and relevant courses.

Team Member		Relevant Courses
Meia Copeland	Meia is a fourth year Computer Systems Engineering student and has a minor in Physics. Through seven co-op placements and internships, she has gained extensive experience in software development. Beyond software, Meia is very interested in software-hardware interfacing and control systems. She has taken electives in power engineering and control systems and will be working closely with the electrical engineering team to design the system and develop the signal processing necessary to control the electrical and mechanical components. Having the most industry experience in the group, she is also taking on a leadership position and will be acting as project manager.	**ECOR 1010** – Intro. To Engineering **ELEC 2507** – Electronics I **ELEC 3105** – Basic EM and Power Engineering **SYSC 3600** – Systems and Simulation **SYSC 3010** – Computer Systems Development Project **SYSC 4805** – Computer Systems Design Lab **SYSC 4505** – Automatic Control Systems I
Shawaiz Khan	Shawaiz Khan is a fourth year Computer Systems Engineering student. Working on previous and current projects during his studies, he acquired knowledge and skills in both hardware and	**ELEC 2507** – Electronics I **SYSC 2004** – OO Software Development

	software. Having a bit of experience in dealing with this before, he will mainly be working on setting up the database, as well as assisting in setting up the temperature and humidity sensors. Interested in learning more and gaining experience with front-end development, he will be assisting with the UI framework as well.	**SYSC 3010** – Computer Systems Development Project **SYSC 3020** – Intro. To Software Engineering **SYSC 4805** – Computer Systems Design Lab
Talal Jaber	Talal is a fourth year Electrical Engineering Student. Having developed most of his hardware experience from his co-op term where he worked in a power step-down transformer station. Talal had a lot of hands-on experience with motors and circuits throughout his studies and work term. Talal will be mostly responsible about the electrical design and the hardware design of the project.	**ELEC 2501** – Circuits and Signals **ELEC 3105** – Basic EM and Power Engineering **ELEC 3907** – Engineering Project **ELEC 3509** – Electronics II
Marwan Zeyada	Marwan is a fourth year Computer Systems Engineering student. He always had a passion for computers and anything tech related. Throughout his study years, he acquired a lot of technical skills in both hardware and software. Having worked on a lot of UIs and software in his projects, he will be working mainly on the graphical interface and the software side while also working on hardware to gain more experience.	**SYSC 2004** – OO Software Development **SYSC 3010** – Computer Systems Development Project **SYSC 4805** – Computer Systems Design Lab **ELEC 2501** – Circuits and Signals **ELEC 2507** – Electronics I
Ranishka Fernando	Ranishka Fernando is a fourth year Electrical Engineering student. Throughout his time at Carleton, he had the pleasure of not only gaining the academic knowledge required to move on past university years, but the soft skills required to be a successful member of the work force with more than 3 years of experience in the industry through various CO-OP positions related to research, hardware, software, construction, and project management. Ranishka will be mainly working on the electrical design of the project including integration and debugging of hardware and software.	**ELEC 2501** – Circuits and Signals **SYSC 2004** – OO Software Development **ELEC 3907** – Engineering Project **ELEC 3509** – Electronics II **SYSC 3600** – Systems and Simulation

4.1.1 Roles, Tasks, and Required Knowledge

Table 4 - Roles, tasks, and relevant experience for each team member.

Team Member	Tasks	Justification
Meia Copeland	Linear Actuator Design	CAD experience from ECOR 1010 and personal projects
	Signal processing	Knowledge of signal processing from SYSC 3600 and SYSC 4505
	Hardware-Software interfacing	Experience in multiple hardware-software projects in SYSC 3010 & 4805
	System integration	Significant experience through degree program and professional experience
	Project management	Extensive experience working on projects through co-op, and knowledge from SYSC 3010 &4805
Shawaiz Khan	Database	Experience in projects in SYSC 3010
	User Interface	Experience in projects in SYSC 3010 and an intro in SYSC 2004
	Hardware Integration Software Integration and testing	Experience in multiple hardware-software projects in SYSC 3010 and SYSC 4805 Experience in multiple hardware-software projects in SYSC 3010 and SYSC 4805
Talal Jaber	Electrical design	Designing required PCB for the system.
	Hardware integration	Choosing the right motor and driver for the project. Elec 3907
	Simulation	Using ANSYS to simulate the flexure displacement. SYSC 3501
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
	Software integration and testing	Great experience in software integration and testing due to working on multiple projects of that nature
Ranishka Fernando	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 – Hardware Consultant
	Debugging	Extensive experience in development and operations through CO-OP and knowledge acquired from ELEC 2607 and ELEC 3500

Collectively, the team has all the necessary skills and knowledge to be successful on this project. Requirements for this project mostly involve electronics or computer systems techniques previously learned, with some very basic mechanical engineering and CAD that was learned in first year.

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

4.1.2 Collaboration

The team has leveraged multiple collaboration tools to keep each other, supervisors, and the Davy lab up to date with progress. Microsoft Teams is used for communication and document sharing. GitHub is used as a code, document, and design repository. The repository will be an open source for all work done, so that other labs can use the work for research in the future. Progress meetings are held every Monday at 2:30 pm, and include the team members, supervisors, and Dr. Davy. Further client meetings with Dr. Davy are scheduled on an as-needed basis to go over user interface, software, and hardware designs such that they fulfill the Davy lab's requirements.

The team is also collaborating with Jelena Nikolic-Popovic, a Senior Member of Technical Staff at Texas Instruments Canada (TI). She is providing the team with expertise on TI hardware being used for the project and donating some hardware. Communications with Jelena are conducted through email, with all team members included.

4.2 Contributions

4.2.1 Project Contributions

Table 5 - Contributions of each team member to project components.

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

	Assembly	Meia Copeland and Talal Jaber
Motors	Step Motor testing	Talal Jaber
Environmental Sensors	Hardware connection	Shawaiz Khan and Marwan Zeyada
	Software Integration	Shawaiz Khan and Marwan Zeyada
	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

4.2.2 Report Contributions

Table 6 - Contributions from each team member to project documents.

Proposal			Contributor
Introduction	Background		Meia Copeland
	Motivation		Meia Copeland
	Project Objectives		Meia Copeland
Research	Vibrations to be Simulated		Meia Copeland
	Methods of Simulation	Earthquake Shake Table	Meia Copeland
		Sub-woofers and Haptic Transducer	Meia Copeland
		DC Brushless Motor	Meia Copeland, Talal Jaber, and Ranishka Fernando
		Stepper Motor and Fine Control Linear Actuator	Meia Copeland
	Software	Database Options	Shawaiz Khan
		User Interface Framework	Marwan Zeyada
System Design	Actuator Test Plan		Meia Copeland
	Motor Test Plan		Ranishka Fernando and Talal Jaber
	Shake Table Test Plan		Meia Copeland
	Measurements		Meia Copeland
	Database		Shawaiz Khan
	User Interface		Marwan Zeyada
	Use Cases		Shawaiz Khan

	Evaluation		Shawaiz Khan
Work Plan	Project Team	Roles and Tasks	All Members
		Collaboration	Meia Copeland
	Contributions		Meia Copeland
	Project Milestones		Meia Copeland and Shawaiz Khan
	Schedule of Activities/Gantt Chart		Meia Copeland and Shawaiz Khan
	Risks and Mitigation Strategies		Meia Copeland and Shawaiz Khan
Project Requirements	Project Requirements		Ranishka Fernando, Shawaiz Khan, and Marwan Zeyada
	Stretch Goals		Meia Copeland and Shawaiz Khan
Budget Breakdown	Hardware		Meia Copeland
	Services		Meia Copeland
Conclusion			Meia Copeland

4.3 Project Milestones

Table 7 - Milestone descriptions and completion dates.

Milestone	Completed	Description
Hardware Design	Oct. 21	Research will be used to come up with final designs for the vibration mechanism and measurement to be implemented.
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.
Finalize Part Orders	Oct. 21	Parts required for the final designs can be ordered to enable development as soon as possible.
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 amplitudes.
Software Development	Feb. 1	Various components will be implemented such as GUI, database, communication 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.
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.
Integration Testing	Feb. 15	Final integrations between the hardware and software will be thoroughly tested.
Acceptance Testing	Feb. 28	Tests will be conducted to ensure the project works as is required by the Davy lab.

4.4 Schedule of Activities/Gantt Chart

Table 8 - Schedule of activities for project completion, documentation, and presentations.

Task	Begin	Draft	Completed
Kickoff meeting between engineering team and lab	-	-	Aug. 26
Research	Summer	Sept. 7	Sept. 30
Proposal	Sept. 7	Sept. 30	Oct. 21
Hardware & Software Designs	Sept. 7	Oct. 8	Oct. 21
Finalize Part Orders	-	-	Sept. 30
Hardware Test Phase	Oct. 1	-	Dec. 10
Test Plan	Oct. 31	-	Dec. 10
Development – Software & Hardware	Sept. 30	Jan. 1	Feb. 1
Software-Hardware Integration	Feb. 2	-	Feb. 15
Progress Report	Nov. 1	Nov. 18	Dec. 9
Oral Presentations	Jan. 9	Form – Dec. 9	Jan. 23-27
Integration Testing	Feb. 15	-	Feb. 28
Acceptance Testing	Feb. 28	-	March 10
Poster Fair	March 1	-	March 17
Final Report and Video	Jan. 15	1st – Feb. 17 2nd – March 24	April 12

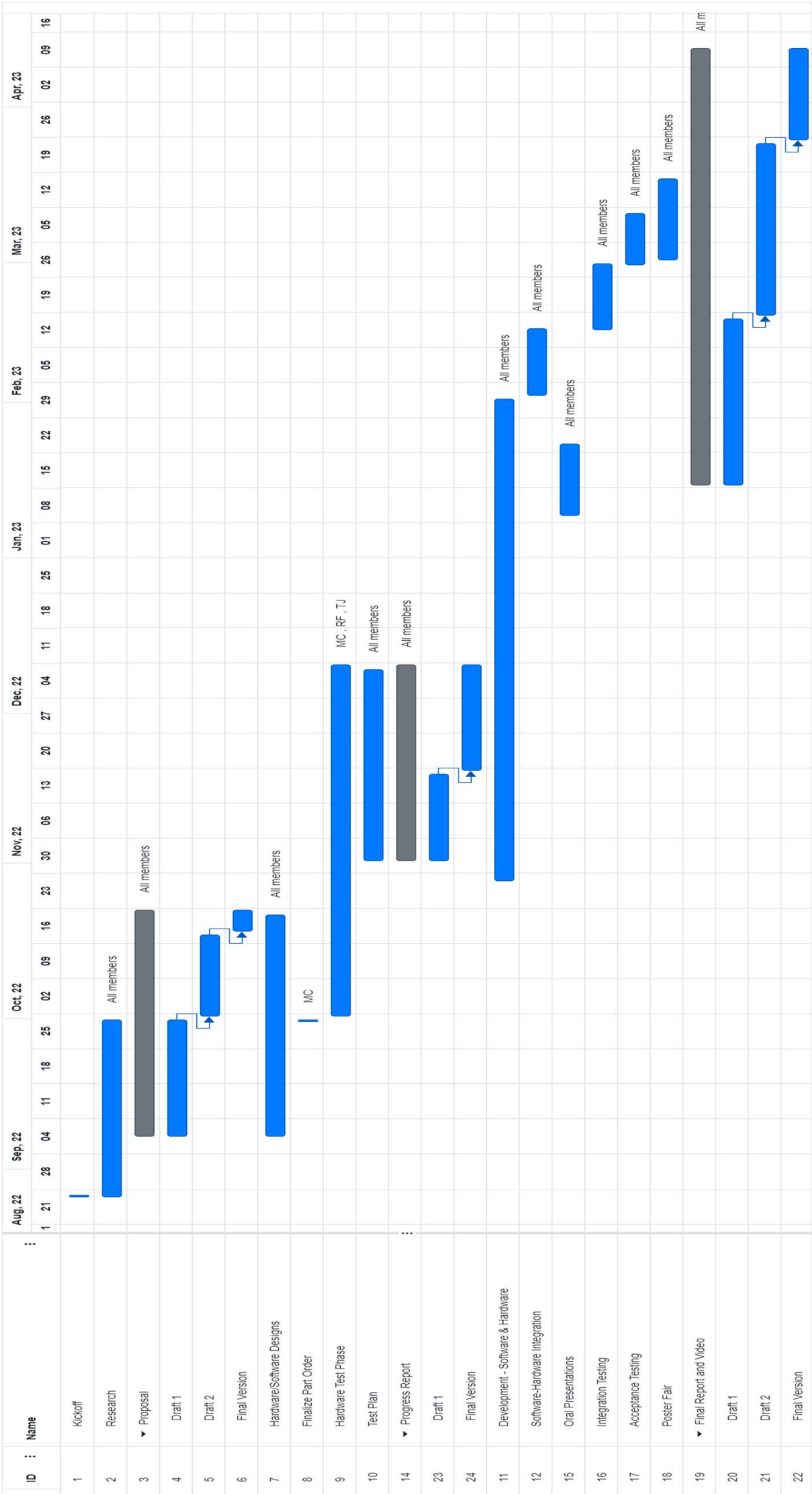

Figure 6 - Gantt chart

4.5 Risks and Mitigation Strategies

Risks with this project are mostly related to the execution and scheduling of the tasks, as well as some external factors regarding sourcing of components.

The biggest risk involves the execution of the vibration mechanism, since the success of the entire project hinges on this one component. Not being able to generate the correct frequency is the most important aspect, and creating the correct displacement is a close second. To mitigate this risk, a significant amount of time went into researching how this mechanism would be designed. Many options were looked at, and elements from each option are still being considered. Further mitigation will come from thorough testing of the current design, through simulated and physical testing.

Another crucial risk involves sourcing of some components. While some components can be 3D printed, therefore allowing for infinite customizability, other components cannot. Parts such as the motor shaft and camshaft are custom designs that will need to be manufactured in extremely durable material, preferably metal. Other parts such as gears are also extremely expensive and time consuming to have milled. To mitigate these risks, out-of-box components will be used as much as possible. In the case of gears, differential gear trains for RC cars can be utilized as their size and ratio can be leveraged. Mounting of these gears can be compensated for in 3D printed designs. Regarding more custom elements, alternate materials will be examined for the motor shaft and camshaft. Design aspects will also be considered, to eliminate the need for especially durable components. For example, reducing the amount of torque needed to create vibrations could allow for a 3D resin-printed shaft to be durable enough for long-term use.

Sourcing also involves risk regarding the supply chain. Issues have been rampant in the last few years, especially in semiconductors. This project requires the sourcing of many electrical components that rely on semiconductors, such as sensors, microcontrollers, and single-board computers. The team will use caution when finalizing a parts list and will try to find alternatives when possible. For example, the Raspberry Pi computer is a very useful and commonly used computer in projects like this. However, getting a Raspberry Pi is incredibly difficult. Instead, the team has partnered with Texas Instruments and will be using their widely available BeagleBoard. Just like the Raspberry Pi, the BeagleBoard is compatible with many Linux distributions, has pins for connecting sensors and powering components.

Unforeseen circumstances may arise at any time whether of a health or personal concern. With the project being roughly divided into two parts (Hardware/Software), the team members are tackling each part in groups, two for software and three for hardware. If a situation arises where one team member is unable to complete a task, other team members working on that part can temporarily cover for those tasks.

Due to all team members being in many other classes during the school year, difficulty in following the project schedule may arise. By carefully determining a timeline and tasks, these risks can be mitigated. Well-described tasks eliminate any confusion as to success criteria that could cause a loss of productivity. Well-planned tasks with the appropriate amount of time allocated to them will allow for team members to schedule their time accordingly and understand their responsibilities.

5 Project Requirements Checklist

Table 9 - Requirements for project to be considered complete.

Requirement	Description
5.8 Hz Frequency in vertical direction	Achieve using a stepper motor or brushless DC motor 3D printed design used to convert motion to linear motion
Low-weight flat surface	Flat, light-weight acrylic sheet
Power to drive the stepper motor	Achieved using the VCC pin of the BeagleBoard and driver or direct power
Measure vertical displacement	Slider Potentiometer or linear position sensor
Measure frequency	Accelerometer
Suspend surface and be able to move it	Use of stiff springs
Control speed and RPM of the motor	Use of shaft and gears
Keep gears and shaft in place and provide ability to move	Use of bearings to keep gears and shaft in place and have smooth motion. 3D printed frame to fasten everything together.
Environmental sensor setup	All the environmental sensors should be setup and running, with tests proving they operate within the advertised range and output accurate readings.
Data collection	Every specified interval, the details of various sensors should be saved in a database file successfully.
Data export	The database file should successfully be converted to an excel file and sent to the email address associated with the specific experiment.
UI Stability	The user interface should never fully crash and should always display if there is a problem
UI Functionality	UI should always be able to display and configure all devices connected to it

5.1 Stretch Goals

WEB PORTAL – Access databases from device through a web portal. View and download data from portal.

MODULAR LINEAR ACTUATOR DESIGN – Design multiple flexures with different displacement capabilities and allow for swapping of flexures to customize experiments further. Could also implement a swappable camshaft instead.

GROUND VIBRATIONS FROM HIGHWAYS – Research and include settings to simulate ground vibrations from nearby highways.

CLOUD DATABASE WITH NOSQL– Store and access data using a remote server preferably using NoSQL as a tool.

6 Budget Breakdown

6.1 Hardware

Note, hardware does not include 3D-printed components or manufactured items, as costs for those items have not yet been finalized.

Table 10 - Hardware required to complete project, with sources and pricing.

Item	Source	Price
NEMA 17 Stepper Motor	Amazon.ca	$18.99
DC Brushless motor	Amazon.ca	$23.53
Motor driver	TexasInstrument.com	$54.53
MC3479 Accelerometer	Digikey.ca	$21.47
LMC8 Linear Motion POT	P3America.com	$50
Differential Gears 64T, 17T, 21T, 26T, 29T	Amazon.ca	$16.29
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	Amazon.ca	$22.41
Melamine surface	Homedepot.ca	$26.75
Incubator	Provided by lab	FREE
BeagleBone Black Board	Digikey.ca	$106
Temperature & Humidity sensor	Amazon.ca	$16
Touch screen for interface	Amazon.ca	$80
		Total $503.22

6.2 Services

During the testing phase, access to 3D extrusion printers will be required. 3D printing services are offered for free by the MacOdrum Library, with a lead time of 4-7 business days. Services are also available at the Maker Space of the Ottawa Public Library, Centrepoint branch.

Over the course of the project, laboratory space will be needed to assemble and test components. The team has been given access to the fourth-year project lab and will be looking into getting storage there.

Some manufacturing capability may be needed when the final design is ready. These services involve PCB printing and shaft manufacturing. Materials for the shaft manufacturing will be examined to determine the most cost-effective solution, with 3D printing being considered as a first option. The final frame and flexure will be 3D printed using high-quality filament.

7 Conclusion

The primary goal of this project is to create a device which can be used by the Davy lab to study the effects of ground vibrations from wind turbines on the development of turtle eggs. While many shake table designs exist that can reach frequencies between 2 and 10 Hz, no solutions were found to exist that could create the extremely small vertical displacement as seen in studies of wind turbine ground vibrations. By utilizing the elegant, yet simple, design of the James Webb Space Telescope Mirror Actuators, extreme precision in displacement can be achieved. The team plans to have a research-ready version of this device ready by April 2023, so that the Davy lab can begin research, and be able to share the work done with other labs also in need of such a device.

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Appendices

Relevant Courses

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

Table 11 - Cumulative relevant courses for required knowledge and experience.

Course Codes	Title
ECOR 1010	Introduction To Engineering
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 System I
ELEC 2501	Circuits and Signals
ELEC 2507	Electronics I
ELEC 3105	Basic EM and Power Engineering (2018), Electromagnetic Fields (Current)
ELEC 3907	Engineering Project
ELEC 3509	Electronics II
CCDP 2100	Communication Skills for Engineering
ECOR 4995	Professional Practice