SYSC 4907 – ENGINEERING PROJECT

Progress Report

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

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WIND TURBINE GROUND VIBRATION SIMULATOR

December 9, 2022

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1 Introduction ✓

The Davy Lab at Carleton University conducts conservation research to better comprehend how local environmental changes impact threatened species of bats, amphibians, and reptiles. One of these projects investigates how seismic vibrations from adjacent wind turbine activities affect the growth of turtle eggs. Additionally, ground vibrations caused by nearby roadways may have comparable impacts that need to be researched.

Engineering students Meia Copeland, Shawaiz Khan, Talal Jaber, Marwan Zeyada, and Ranishka Fernando are developing a tool that can simulate the ground vibrations near wind turbines so that the lab may investigate these impacts in a controlled environment.

1.1 Background ✓

The fastest-growing source of new energy in Canada over the last ten years has been wind power [1]. Wind power will be crucial to success as the nation works towards its climate objective of increasing the percentage of zero-emitting energy sources to 90% by 2030. Despite being a very helpful tool in the production of emission-free electricity, there are a number of potential adverse consequences on wildlife. The effects on flying species, such as birds and bats, have been examined the most. There have been reports of deaths from collisions with turbine rotors and widespread avoidance of locations around turbines [2]. The effects of wind energy on animals that live on the ground are less well understood.

It has been demonstrated that on-shore wind farms cause low-frequency ground vibrations for miles around the turbines [3]. The effects that these vibrations have on the stress levels and behaviour of ground-dwelling animals have been the subject of certain studies. Terrestrial animals have been the subject of most investigations so far. Reptiles and amphibians' influence on egg development have not been researched. Instead of simply the blades spinning, the entire turbine system, including the wind, interacts with the ground to produce the ground vibrations from wind turbines [4]. Typically, these frequencies fall between 0.1 to 100 Hz [3]. A shake-table will be required to reproduce these incredibly low frequencies in a lab setting. The incubator, which is affixed to the top of the shake-table, can hold the turtle eggs. The Low Frequency Portable Shaker Table by the Modal Shop [5], which can operate at frequencies as low as 0.7 Hz, is one example of a device that can operate at such low frequencies. The gadget is not, however, approved for continuous usage over the 65-to-95-day incubation period of snapping turtle eggs.

1.2 Motivation ✓

It is crucial to ascertain the effects wind turbines have on local animals that might reside or lay their eggs nearby as wind energy grows more prevalent throughout Canada and the rest of the world. The Davy Lab wants to investigate these impacts on turtle egg development, especially the ground vibrations brought on by wind turbine use.

Our objective is to develop a system that will enable the Davy Lab to measure environmental parameters like temperature and humidity while simulating and controlling these ground vibrations in a laboratory setting.

2 Recent Discoveries

2.1 Measuring Linear Displacement ✓

To ensure that the correct displacement is achieve, the movement of the surface must be measured. Since the device will only be vibrating the surface in the Z-direction, a linear displacement sensor can be used. These sensors come in many forms, such as potentiometers, capacitive sensors, or laser sensors.

Linear displacement 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. Technically, potentiometers have infinite resolution due to the analog nature of the changing voltage, however the digital conversion requires a significant number of bits for data transfer to get precision in the nanometer range. 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 42 million times (5 Hz for 95 days), any sensor used would have to be made of industrial uses.

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 withing the nanometer range were ~$1500 for the sensor, and an additional $5000 for the required signal processing unit and cables.

Another measurement tool that uses capacitance to measure displacement are calipers. Digital calipers are capable of measuring with extreme precision. However, these are generally used as diagnostic or testing tools, not for continuous measurement. Further, wear and tear is an issue since these measurement tools use contact to measure displacement.

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 millimeter 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.

2.2 Methods of Vibration Simulation

Over the course of the turtle eggs' 65 to 95-day incubation cycle, vibration treatment would need to be given continually [8]. The use of DC brushless motors was studied over the course of literature research and investigation on prospective vibration methods, and they will be presented here.

DC Brushless Motor

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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).

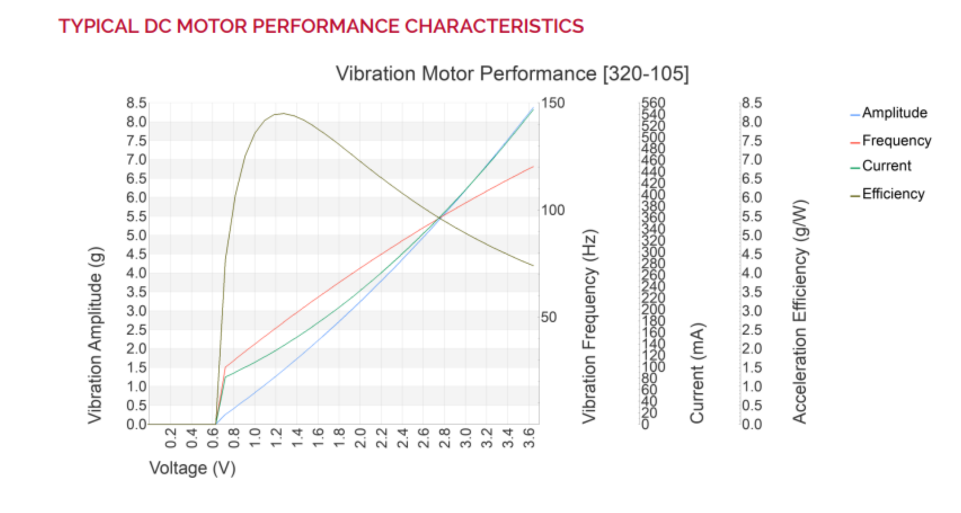

Figure 1 - DC motor frequencies [11]

The team settled on a three-phase brushless DC motor and the DRV10970EVM motor driver to control the motor using PWM. Testing of a stepper motor will still be held since a stepper motor turns in both directions which can make the amplitude of vibrations even smaller using just small steps in alternating directions.

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2.3 Database options to store data acquired

Provide Updates

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 [6] 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 [6]. NoSQL on the other hand offers flexible scalability and flexible data types [7]. 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 [8]. 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 [9]. 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 [9]. 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

Provide Updates

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 [10] 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 [11], 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.

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3 Vibration Simulator Design

3.1 Simulation of Linear Displacement

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 [12]. The specific components that will be used from the print are the frame, flexure, motor shaft, and camshaft.

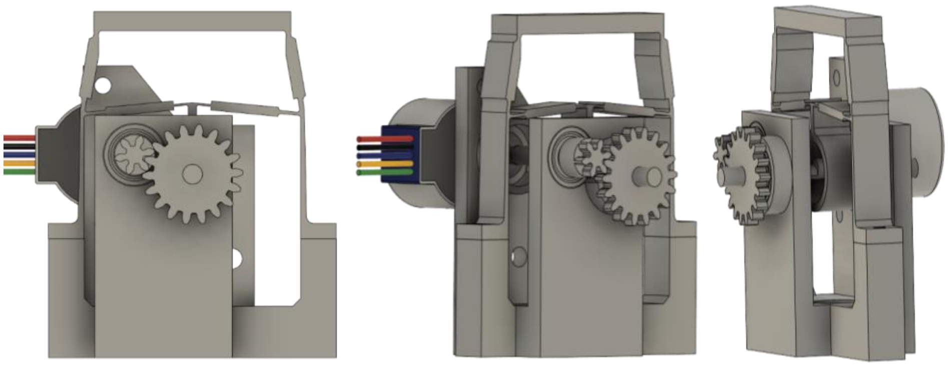

Figure 2 - Front and side views of the JWST Mirror fine positioning mechanism as designed by Polyfractal [12]

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 Fusion 360 [13] 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.

As is, the flexure design is capable of a 26 µm displacement (Figure 3). To decrease the displacement, increasing the height of the flexure is effective. Further, making the most flexible parts of the flexure stiffer will also decrease the displacement. So far, 14 µm displacement has been achieved upon increasing the height of the flexure by 37 mm, with further iterations necessary. However, to decrease displacement increasing the width of the flexure in the x-direction was not effective. A 0.02 mm displacement was recorded which is not ideal nor in the range.

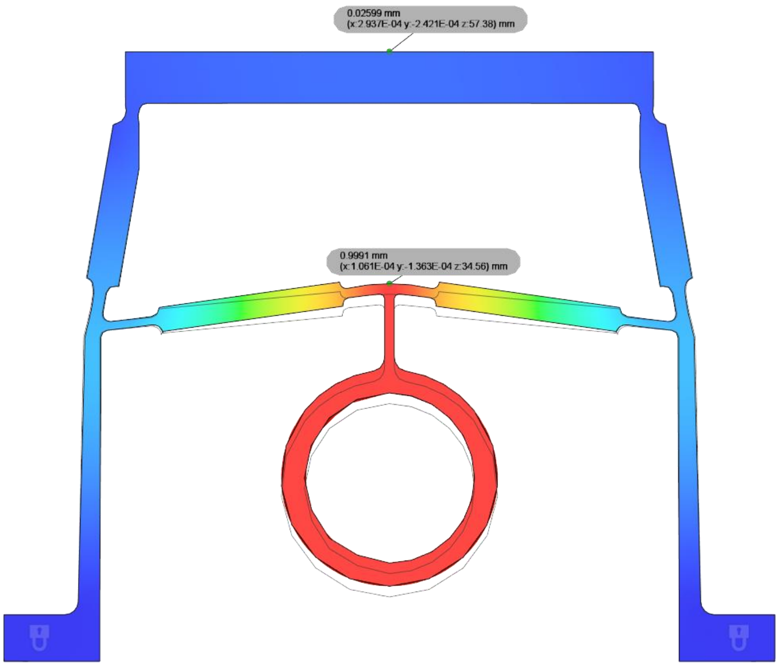

Figure 3 - Simulation result from Fusion 360. Simulation tested the original flexure design, with a 1mm camshaft offset. The displacement is measured to be 26µm.

Mechanical 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.

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To arrive at a conclusion, a vigorous analysis will be conducted after considering 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.

3.2 Database

Provide Updates: Progress made on the designing the database

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

Figure 4 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.

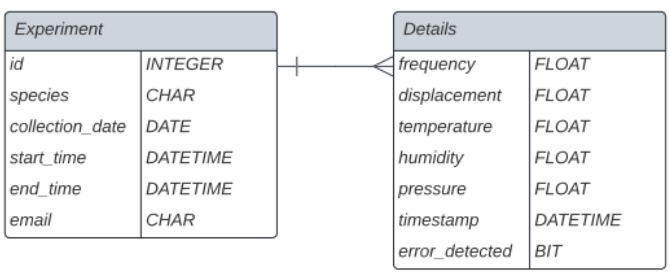

Figure 4 - Database Schemas

3.3 User Interface

Provide Updates: Progress made on designing the UI

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 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.

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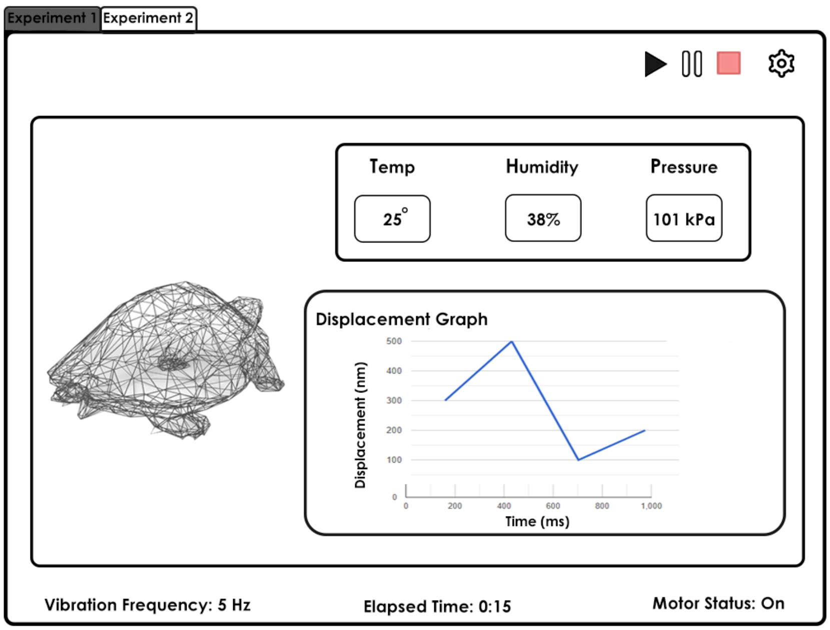

Figure 5: Home screen UI Wireframe

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 5) 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.

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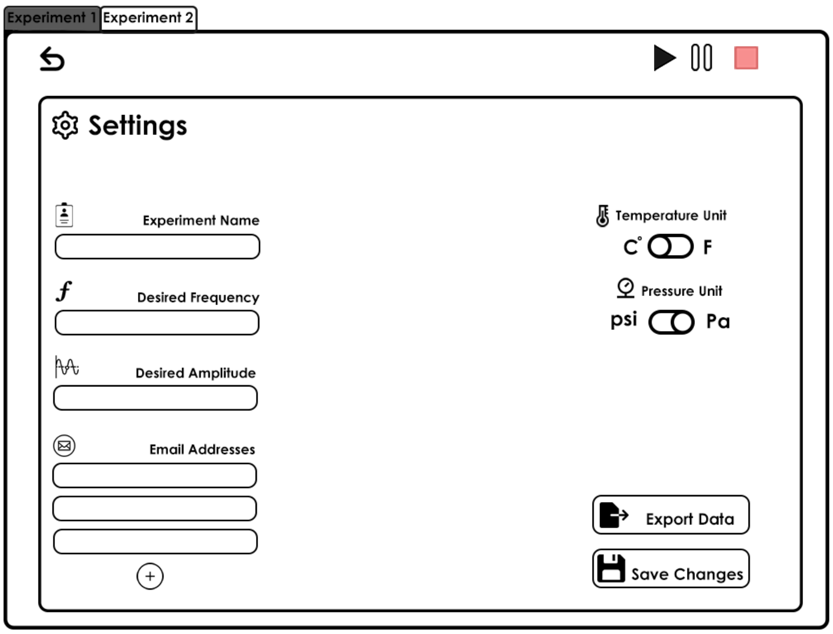

Figure 6: Settings UI Wireframe

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 6). 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.

4 Work Plan

4.1 Roles, Tasks, and Required Knowledge ✓

Table 1 - 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

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After, a full section on how the team as a whole has the skills to do the project

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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	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 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

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Commented [MP21]: @Talal Jaber please fill out this section

Commented [MP22]: @Marwan Zeyada please fill out this section

Commented [MP23]: @Ranishka Fernando please add justifications

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.

4.1.1 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.

4.2 Contributions ✓

4.2.1 Project Contributions

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

Component		Contributor
Linear Actuator	3D modelling	Meia Copeland and Ranishka Fernando
	Simulation Testing	Meia Copeland and Ranishka Fernando
	3D printing	Meia Copeland and Ranishka Fernando
	Motor Control	Talal Jaber
	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 Progress Report Contributions

To be completed

Table 3 - Contributions from each team member to project documents.

Proposal	Contributor

Introduction		
Research		
System Design		
Work Plan		
Project Requirements		
Budget Breakdown		

4.3 Project Milestones ✓

Table 4 - Milestone descriptions and completion dates.

Provide Updates: Description??

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.	Completed
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.	Completed
Finalize Part Orders	Oct. 21	Parts required for the final designs can be ordered to enable development as soon as possible.	Partially Completed
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.	In Progress
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.	In Progress
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.	N/A
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

4.4 Schedule of Activities/Gantt Chart ✓

Table 5 - Schedule of activities for project completion, documentation, and presentations.

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

Provide update Gant Chart?

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Figure 7 - Gantt chart

5 Budget Breakdown ✓

5.1 Hardware

Note, hardware does not include 3D-printed components or manufactured items, as costs for those items have not yet been finalized. Also does not include measurement device, which is to be determined.

Table 6 - Hardware required to complete project, with sources and pricing.

Item	Source	Price	Acquired/ Not Acquired
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	☒
MSP430 LaunchPad MCU	Digikey.ca	$22.94	☒
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	☐
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	$0	☐
Raspberry Pi 4, 4GB	Digikey.ca	$80.95	☒
Temperature & Humidity sensor	Amazon.ca	$16	☐
Touch screen for interface	Amazon.ca	$80	☐
	Total	$479.23	☐

Commented [MP27]: Need to source

Commented [MP28R27]: @Talal Jaber and @Ranishka Fernando can you guys find a placeholder for this one?

Commented [MP29]: Need to figure out a placeholder or finalized motor driver. Preferably from TI

Commented [MP30]: Another option: https://www.amazon.ca/Prime-Line-Products-SP-9706-Compression/dp/B008RG3P7E/ref=asc_df_B008RG3P7E/?tag=googleshopc0c-20&linkCode=df0&hvadid=346147627168&hvpos=&hvnetw=g&hvrand=2314713433565455132&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9000681&hvtargid=pla-335274182084&psc=1

6 Conclusion ✓

The main objective of this project is to provide a tool that the Davy lab may use to investigate the effects of ground vibrations from wind turbines on the growth of turtle eggs. There are numerous shaking table designs that can produce frequencies of 2 to 10 Hz, but none have been discovered that can produce the

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minuscule vertical displacement observed in tests of wind turbine ground vibrations. Extreme precision in displacement can be attained by utilizing the James Webb Space Telescope Mirror Actuators' elegant yet straightforward design. By April 2023, the team hopes to have a research-ready model of this device available so that the Davy lab may start conducting research and share its findings with other labs that also require such a device.

7 References

To be updated

Commented [MC32]: When adding references, please use MS Word tools (check the 'References' tab). This will keep things much more organized, and will allow for dynamic updates to citations.

[1] "By The Numbers," Canadian Renewable Energy Association, January 2022. [Online]. Available: https://renewablesassociation.ca/by-the-numbers/. [Accessed 18 September 2022].

[2] C. B. Thaxter, G. M. Buchanan, J. Carr, S. H. Butchart, T. Newbold, R. E. Green, J. A. Tobias, W. B. Foden, S. O'Brien and J. W. Pearce-Higgins, "Bird and bat species' global vulnerability to collision mortality at wind farms revealed through a trait-based assessment," *Proceedings of the Royal Society Biological Sciences,* vol. 284, no. 1862, 2017.

[3] W. N. Edwards, "Analysis of measured wind turbine seismic noise generated from the Summerside Wind Farm, Prince Edward Island," Natural Resources Canada, Prince Edward Island, 2015.

[4] P. He, J. González-Hurtado, T. Newson, H. Hong, M. Postmann and S. Molnar, "Field monitoring of the ground vibrations adjacent to an," *Canadian Geotechnical Journal,* vol. 58, no. 4, pp. 595-602, 2019.

[5] "Low frequency portable Shaker Table: 9200D," The Modal Shop, [Online]. Available: https://www.modalshop.com/industrial-vibration/products/portable-shaker-tables/9200D-low-frequency-calibrator. [Accessed 21 09 2022].

[6] A. Panwar, "C-Sharpcorner," 17 01 2022. [Online]. Available: https://www.c-sharpcorner.com/UploadFile/65fc13/types-of-database-management-systems/. [Accessed 21 10 2022].

[7] MongoDB, "NoSQL vs SQL databases," 28 12 2021. [Online]. Available: https://www.mongodb.com/nosql-explained/nosql-vs-sql. [Accessed 21 10 2022].

[8] Statista Research Department, "Ranking of the most popular relational database management systems worldwide, as of January 2022," Statista, 23 05 2022. [Online]. Available: https://www.statista.com/statistics/1131568/worldwide-popularity-ranking-relational-database-management-systems/. [Accessed 21 10 2022].

[9] E. S, "SQLite vs MySQL – What's the Difference," 23 08 2022. [Online]. Available: https://www.hostinger.com/tutorials/sqlite-vs-mysql-whats-the-difference/. [Accessed 21 10 2022].

[10] ActiveState, "ActiveState," 9 August 2022. [Online]. Available: https://www.activestate.com/blog/top-10-python-gui-frameworks-compared/#:~:text=1%E2%80%93PyQt5,about%20any%20kind%20of%20application..

[11] L. P. Ramos, "RealPython," 2021. [Online]. Available: https://realpython.com/qt-designer-python/.

[12] Polyfractal, "JWST Mirror Actuator," Thingiverse, 7 02 2022. [Online]. Available: https://www.thingiverse.com/thing:5232214. [Accessed 1 10 2022].

[13] "Fusion 360," Autodesk, [Online]. Available: https://www.autodesk.ca/en/products/fusion-360/overview?term=1-YEAR&tab=subscription. [Accessed 20 11 2022].

[14] R. Łopucki, D. Klich, A. Ścibior, D. Gołębiowska and K. Perzanowski, "Living in habitats affected by wind turbines may result in an increase in corticosterone levels in ground dwelling animals," *Ecological Indicators,* vol. 84, pp. 165-171, 2018.

[15] R. Łopucki and I. Mróz, "An assessment of non-volant terrestrial vertebrates response to wind farms—a study of small mammals," *Environmental Monitoring and Assessment,* vol. 188, no. 122, 2016.

[16] B. Serralheiro-O'Neill, "Snapping Turtle," The Canadian Encyclopedia, 6 05 2021. [Online]. Available: https://www.thecanadianencyclopedia.ca/en/article/snapping-turtle. [Accessed 15 10 2022].

[17] P. Botha, "Ground Vibration, Infrasound and Low Frequency Noise Measurements from a Modern Wind Turbine," *Acta Acustica united with Acustica,* vol. 99, no. 4, pp. 537-544, 2013.

[18] R. Schofield, "Seismic Measurements at the Stateline Wind project," LIGO, 2002.

[19] S. Borowski, "Ground vibrations caused by wind power plant work as environmental pollution - case study," *MATEC Web of Conferences,* vol. 302, no. 01002, 2019.

[20] "What is an Earthquake?," Seismology Research Centre, [Online]. Available: https://www.src.com.au/earthquakes/seismology-101/what-is-an-earthquake/. [Accessed 15 10 2022].

[21] "BUTTKICKER LFE," ButtKick Haptics, [Online]. Available: https://thebuttkicker.com/products/buttkicker-lfe-haptic-transducer. [Accessed 20 08 2022].

[22] E. S. Corporation, "Tactile FAQ," Auralinear, 2022. [Online]. Available: http://www.earthquakesound.eu/info/faq/tactile-faq.aspx. [Accessed 1 October 2022].

[23] R. Warden, "Cryogenic Nano-Actuator for JWST," in *Proceedings of the 38th Aerospace Mechanisms Symposium*, Hampton, Virginia, 2006.

[24] D.-P. Nguyen, K. Hansen and B. Zajamsek, "Human perception of wind farm vibration," *Journal of Low Frequency Noise, Vibration and Active Control,* vol. 39, no. 1, pp. 17-27, 2020.

[25] "DC motors and mechanisms," Precision Microdrivers, 2022. [Online]. Available: https://www.precisionmicrodrives.com/. [Accessed 1 October 2022].

8 Appendices

8.1 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 7 - 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