Using Ocean Going Robots to Observe Wave Conditions
Computer Science Team

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Design Impact Statement

When considering the development of any engineering project, it is crucial to view the project through a critical lens and evaluate the interactions the project may have on the surrounding environment. This section aims to explore how the *Using Ocean Going Robots to Observe Wave Conditions* project impacts cultural, social, environmental and economic paradigms. The necessity of this assessment ensures that the development and implementation of this project upholds the engineering standards that it is bound by. Furthermore, this analysis is relevant to other researchers in the field of oceanography and data science, and to the academic community as a whole.

One of the foremost concerns of any project is the impact on human safety. When considering the impacts this project has on public health and safety, the primary concern is the autonomous glider itself. The glider is built out of aluminum and is 12 feet long, with sharp fins on its stern [1]. This physical object poses a threat to boats and swimmers, and could cause physical harm or damage if contact is made with the glider. Furthermore, the glider floats slightly below the water making it hard to spot, especially in poor visibility conditions. Although the glider floats low in the water, it is painted bright yellow, making it easy to spot and avoid. Despite the concerns raised by the physical nature of this system, the likelihood of a collision is very low. The gliders are deployed far away from the coast, so the chance a swimmer comes into contact with one is minimal.

Cultural and social impacts are also essential when assessing the design impact of a project. This project doesn't directly interface with the public, but potential social issues exist nonetheless. One of these concerns relates to political ocean boundaries, as tensions between nations could be exacerbated by a rogue glider. For instance, gliders launching out of Vietnam could potentially wander into Chinese waters where Oregon State University doesn't have the rights to research [2]. This would prevent the retrieval of the glider and would force the team to dive the glider until it implodes from the water pressure. One of the project leads, Kipp Shearman, has encountered this situation in the past and was forced to self-destruct a glider — an expensive loss for Oregon State University.

Another important consideration is interaction between the physical system and the surrounding environment. Since the glider system is deployed in the ocean, interactions with wildlife are common. The same dangers described in the public health and safety section above are also applicable to the environment in which the glider exists. For instance, fish and marine mammals could be struck and damaged or even killed by the glider's body and fins. It is hard to prevent such interactions but the bright coloring of the vessel should intimidate wildlife from approaching. Another environmental impact to consider is the manufacturing of the gliders themselves. Many of the electronics onboard (such as the PCB the team has created) have carbon footprints [3] that are important to consider. However, the glider is manufactured in small quantities so this carbon footprint is negligible when compared to other global sources of carbon emissions.
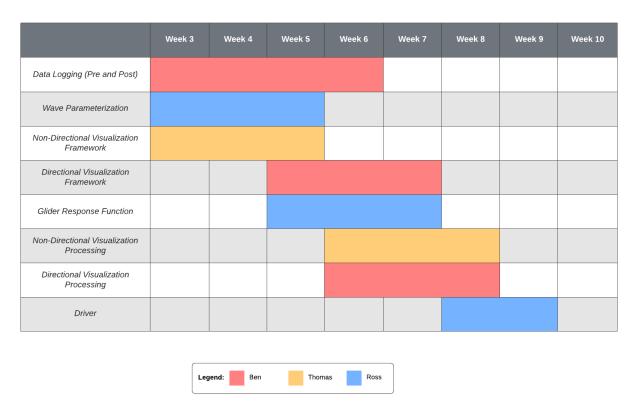
Finally, in an economic sense the price of a single ocean-faring, autonomous glider is around $150,00 to $250,000 [4], while the budget of this project is only $1500. The system the team has implemented is very cost effective considering the functionalities it provides to the scientific and academic community. Replicating this system in other applications is cheap and

could lead to greater understanding of wave phenomenon. However, the costly price of the glider alone could prevent other institutions from implementing a similar system.

The *Using Ocean Going Robots to Observe Wave Conditions* project has many key advantages to Oregon State University's scientific community and academic communities globally. These advantages, however, must be weighed against the cultural, social, environmental and economic impacts of the project. In this assessment these impacts are described and discussed. After analyzing the impacts of this project it can be concluded that this project is well designed to minimize negative outcomes. It is important to note that the physical nature of the glider poses a threat to vessels, swimmers and wildlife. To address this issue the glider's sharp fins could be redesigned to accommodate a more curved shape, reducing the potential damage that a collision with the glider could cause.

Project Timeline

The project was completed over 9 months. The first three months were used to research spectral analysis techniques and visualization methods. The implementation of our system occurred during months 3-6. The timeline is provided below. The final 3 months were used for testing, bug fixes and general improvements.

	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Data Logging (Pre and Post)	Ben	Ben	Ben	Ben				
Wave Parameterization	Ross	Ross	Ross					
Non-Directional Visualization Framework	Thomas	Thomas	Thomas					
Directional Visualization Framework			Ben	Ben	Ben			
Glider Response Function			Ross	Ross				
Non-Directional Visualization Processing				Thomas	Thomas	Thomas		
Directional Visualization Processing				Ben	Ben	Ben		
Driver						Ross	Ross	

Legend: Ben (red) | Thomas (orange) | Ross (blue)

Scope and Engineering Requirements

Cohesive Modular Subsystems
PR: We need to design, document, and implement each block so that they can work individually or within the scope of the system as a single program."
ER: The CS system will be implemented so that each individual sub-module can be run individually from the command line.
Testing Process (Demonstration):
1. Each module within the data pipeline will be run from the command line given a CSV or other data format file as input.
2. Each module should run with no error.

Test Passing Condition:
"For each module that is directly part of the data pipeline, the module can be run individually from the command line and produces no errors."

Glider Finite Element Analysis
PR: We need to design, document, and implement a finite element analysis framework.
ER: The CS system will use physical finite element analysis to calculate how the glider responds to waves (displacement, velocity, acceleration, pitch, yaw, etc) in under 60 seconds.
Testing Process (Analysis):
1. Three different meshes will be given to the potential flow solver for analysis (simple cylinder, glider mesh, and abnormal cone).
2. Coefficients of glider response are saved to the file system.

Test Passing Condition:
In all 3 cases the boundary values are calculated in under 60 seconds, and the coefficients are computed with no error."

Glider Visualization
PR: We need to design, document, and implement a finite element analysis visualization framework.
ER: The CS system will visualize a 3D image of the physical position of the glider relative to the ocean's surface using wave parameter data and finite element analysis of the glider's response.
Testing Process (Analysis):
1. Three different meshes will be given to the potential flow solver for analysis (simple cylinder, glider mesh, and abnormal cone).
2. The solver will display the mesh within the potential flow system.

Test Passing Condition:
In all 3 trials, the mesh is visualized with no errors and with reasonable (facing outward) normal vectors for each panel.

Directional Spectra Framework
PR: We need to design, document and implement an offline directional wave spectra framework.
ER: The system will analyze glider displacement readings and compute the directional spectra of these incoming waves.
Testing Process (Analysis):
1. Using data from the CDIP website, run the directional framework.
2. The directional framework will produce wave parameters.
3. Compare wave parameters with the expected outputs from CDIP.

Test Passing Condition:

In 3/3 trials the directional parameter ('Dpeak') is within 30 degrees of CDIP's output.

Non-Directional Spectra Framework
PR: We need to design, document and implement an offline non-directional wave spectra framework.
ER: The system will analyze glider displacement readings and compute the non-directional spectra of these incoming waves.
Testing Process (Analysis):
1. Utilizing the multi-wave simulator system, generate a set of 5000 wave sensor readings
2. Use the finite element analysis module to calculate the exact wave parameters
3. Display the non-directional wave parameters

Test Passing Condition:
In 5/5 trials, the calculated wave spectra are within the bounds originally defined by the multi-wave simulator, with no outliers.

Directional Wave Spectra Visualization
PR: We need to design, document, and implement a visualization framework that can graphically represent directional wave spectra.
ER: The system will accurately depict directional wave spectra using polar plots. These plots illustrate the period, direction, and energy density of swells acting upon the glider.
Testing Process (Analysis):
1. For 5 trials a set of directional wave spectra will be passed into this sub-system for visualization through the command line.
2. For each trial, the input directional spectra will produce a directional polar plot.
3. For each trial, the output directional polar plot will be compared with a plot representing the same data from the CDIP website.

Test Passing Condition:
In 5/5 trials, the directional visualizations illustrate the major swells within the data. The visualizations do not need to be exact when comparing the CDIP plots, but should show the same swell pattern (period, direction, energy). This requirement must be validated by comparing the system's visualizations to example visualizations provided by CDIP.

Extensive Documentation for Usability
PR: We need to write documentation for our code so that future users can operate the system/modules or make adjustments as the need arises.
ER: The CS system will contain detailed documentation for every module as well as a short user guide that will allow users with no background experience in programming to run the system with no oversight.
Testing Process (Analysis):
1. Give a potential user the user guide and guide them to the correct file location on the command line.
2. Ask the user to generate directional and non-directional spectra from a given data file.
3. The user will successfully create both a directional and non-directional spectra

Test Passing Condition:
A user with no prior experience will be able to properly generate the spectral data using only the software documentation + user guide.

Non-Directional Wave Spectra Visualization
PR: We need to design, document, and implement a visualization framework that can display non-directional parameters (height, speed, etc) and wave spectra.

ER: The system will accurately (within 10% of verified data buoy spectra) visualize non-directional wave spectra and parameters (height, speed, etc).

Testing Process (Analysis):
1. A set of non-directional wave spectra data from a verifiable source (CDIP/NDBC) will be passed to the system.
2. The visualization framework will produce the non-directional wave spectrum as well as wave characteristics for the sample period.
3. The data displayed will be within an error of +/- 10% when compared to CDIP's data

Test Passing Condition:

In 10/10 trials, the non-directional visualizations and wave characteristics match the CDIP/NDBC plots with an error range of 10%, to account for unresolvable differences in data gathering/processing techniques.

Risk Register
(See next page)

Risk ID	Risk Description	Risk category	Risk probability	Risk impact	Performance indicator	Responsible party	Action Plan
R1	A programming error causes the glider to stop taking readings.	Technical	10%	H	Glider stops responding to the server.	Ben	Retain
R2	Purchased hardware is incompatible with existing systems onboard the glider.	Technical	25%	L	Keep track of which onboard hardware limits our compatibility.	Ross	Reduce
R3	Covid shutdowns prevent the team from using indoor wave facilities.	Legal	15%	S	Spikes in covid cases in corvallis.	Thomas	Avoid
R4	Incorrect calculations of correct data	Software	30%	M	The data that we collect is correct but the math regarding Wave Speed and Dispersion Relation is incorrect	Ben	Reduce
R5	High CPU usage	Software	20%	L	If cpu usage suddenly spikes or is at an elevated percentage for an extended period of time	Ross	Reduce
R6	Software stops fails to communicate with the offshore	Technical	15%	H	Glider does not check it when it is expected to	Thomas	Reduce

	buoys						

Future Recommendations

Directional Visualization Format
The directional visualization framework is a component of the system that allows for wave spectra to be visualized in a polar plot. These plots exemplify the direction, period and energy density of swells influencing the glider in the ocean. Although this component is completely implemented, the color map that defines the contour of the energy density levels is simplistic.
Recommendation
Many of our sub-systems are modeled after examples from CDIP, the *Coastal Data Information Program*. Currently the directional visualization framework defines a color space ranging from blues to reds. CDIP on the other hand uses a larger color space that ranges through blues and reds but ultimately ends with black to represent the highest energy densities [5]. By upgrading the color map our directional visualization uses, the system could more effectively represent small differences between energy densities within the data.

Real World System Test
Currently the software developed by the team can handle example data seamlessly, however, the system has yet to be tested in a real world environment. There is uncertainty to how the system would perform in real ocean conditions and there will be a need for further calibration to record wave parameters accurately.
Recommendation
The first step to deploying the system will be testing it in a controlled, simulated environment. One possibility for this testing space is the Hinsdale Wave Research Laboratory. This wave lab can simulate many different ocean conditions and would be the perfect place to calibrate the system to provide accurate readings. After the system has been thoroughly tested in the wave lab, it will finally be ready for its deployment in an autonomous glider.

Dynamic CDIP Data Link
One of the stretch goals mentioned by the project leads was the capability for our system to dynamically access CDIP archives and compare readings done by our system with buoys operated by CDIP. This capability would allow our system to validate its own recordings by comparing them with the closest buoy to the glider.
Recommendation
Our recommendation is to use the API CDIP provides as a means for pulling data for the purpose of comparison. A user of this subsystem should be able to choose between different buoys and run their data through the visualization frameworks. An example of this datalink can be seen in the *ND_Visualization.py* script in the project GitHub.

Web/Desktop Application
 At the current state of the system, the only way to display the data is through the command line. While the python modules that we created are available on our GitHub page, the user must have a working understanding of how to clone a repository, install required python packages, and run python code. We document how to do this on our Github extensively, but it can still be daunting to a user with no GitHub or coding experience.
Recommendation

Our recommendation is to create a website that includes all of our plots, documentation, and GitHub. This site will allow any researcher to access the data collected from our experiments regardless of their experience. It would also be beneficial to include data from trusted sources (CDIP) to show any discrepancies in our findings.

Wave Spectrum Database
The system currently provides no additional file system support for the input and output of spectral data. The software pipeline takes in a single input data file from the file system (command line) and then outputs the spectral data to the same directory that the software itself is contained in. While the data is successfully processed, the onus is entirely on the user to properly categorize and organize both input and output files on their own machine. However, almost every institute that records real time wave data keeps a database of the most recent data from their buoy measurement systems.

Recommendation
Our recommendation is to host a web server that allows for the automatic categorization and storage of acceleration data and its spectral output. Any time the system is run with valid data, the system would save the input and output to a database organized by date that the data was collected and/or the location the data was collected from. That way users could more easily compare and contrast spectra between different days or locations. Moving the file management responsibility from the user to a server would also be a big quality of life improvement.

Slope Measurement System for Greater Accuracy
The system currently samples wave data by measuring accelerations with 6 degrees of freedom. These measurements work fine for calculating wave heights, peak direction, etc. However, calculating the directional spread for visualization requires the use of statistical estimation techniques in order to derive a spectrum as close as possible to the real spectrum.

Recommendation
Our recommendation is to use an array of wave gauges instead of a single point system. The current single point system returns a set of accelerations in the x/y/z direction, as well as quaternions for rotations (yaw, roll, sway). A set of wave gauges would provide the wave slope data as well as the wave surface elevation. There are a number of estimation techniques from the literature that can use the wave slope to estimate a more accurate wave surface signal. This could be as simple as mounting two single point systems on both ends (tip and tail) of the glider.

Different Visualization Frameworks
The directional and nondirectional plots are created using Matplotlib. While this is a very extensive visualization library, it is by no means the only one. Currently, we are only displaying our data using two graphs, a polar lot and a histogram. This type of visualization suits our needs well, but there are other options to display the data.

Recommendation
Our recommendation is to extensively research other types of data visualization for both directional and nondirectional data. A differentiation in our plots will ensure that the most significant number of scientists and researchers can understand our findings. To accomplish

this, the team should document the plots used by top research institutions such as the UCSD Scripps CDIP site.

Additional Measurements
The main objective of this project was to calculate ocean characteristics using spectral analysis of point measurements taken from a slocum glider deployment. These characteristics are common among wave measurement groups such as CDIP or NDBC. However, these groups also record additional wave information. Things like wind speeds and temperature are common.

Recommendation
Our recommendation is to include an additional sensor for temperature measurement. In theory, measuring wind would be the most useful. However, we're limited by the glider shape itself, which tends to sit mostly below the surface of the waves, with less than a foot of the structure above the surface. This makes the glider unsuitable for wind measurements. Temperature however would be fairly easy to implement.

References

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