Designing an Energy Harvesting Buoy

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Abstract

Ocean waves represent an enormous source of energy that is available to power technologies such as tracking endangered marine mammal migratory patterns, powering remote buoys for environmental ocean monitoring, and creating an interconnected network of wireless, battery-free ocean sensors for safety offshore. This project investigates ocean energy harvesting using nonlinear dynamics to enhance the amount of kinetic energy available to an electrostatic energy converter. In the system, harvested mechanical motion is converted into usable electrical power by means of a novel rotary parallel plate capacitor. The well known triboelectric effect is used to provide the initial charge on the harvester plates. This work represents a collaborative effort at Duke University between the Pratt School of Engineering, the Nicholas School of the Environment, and the Marine Laboratory.

Goals

The 3 distinct energy-harvesting components of the design include,

1 Buoy Design
- 3D print different buoy shapes and test in wave tank
- Manufacture a scaled horizontal pendulum with shaft to connect to capacitor plates
- Create an encasing within the buoy for the capacitor plates

2. Capacitive Energy Design
- Model plate designs for enhanced AC voltage swing
- Verify plate designs electrically using a rotary test stand
- Build and test rotary capacitive energy harvester design experimentally

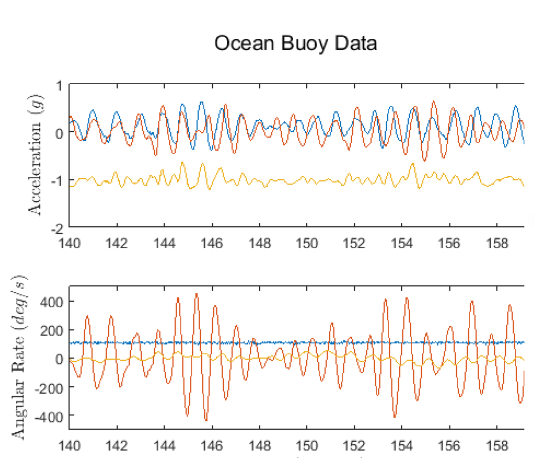
3. Triboelectric Design
- Test different materials for charge build up
- Create tubes of different materials for testing effects of water flow
- Design planar materials for attachment to buoy

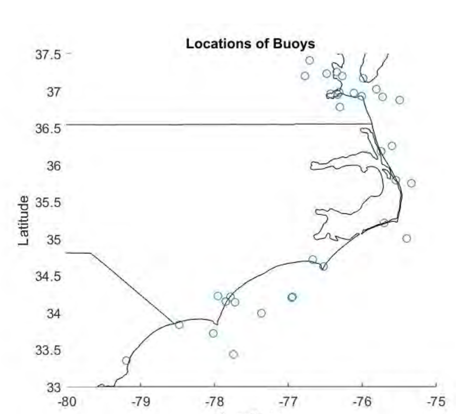
Outcomes

Current Status:
- A horizontal pendulum on a buoy can be used to generate the rotation of a vertical shaft given small perturbations.
- The buoy can be designed with a "soup can" insert to contain the capacitor plates and electronic components.
- Capacitive plates can be etched with copper in a design to maximize current generation when rotated about a vertical shaft.
- A voltage of approximately 3V can be created when tap water flows through a Teflon tube.

Ongoing Work:
- Buoy with capacitor plates that rotate about the vertical shaft of a horizontal pendulum—deployable in a real wave environment with measurable voltage
- Experimental circuit validation of plate design analysis to harvest voltage
- Planar triboelectric material to generate a charge build-up that can be measured and wired to connect to a rechargeable battery

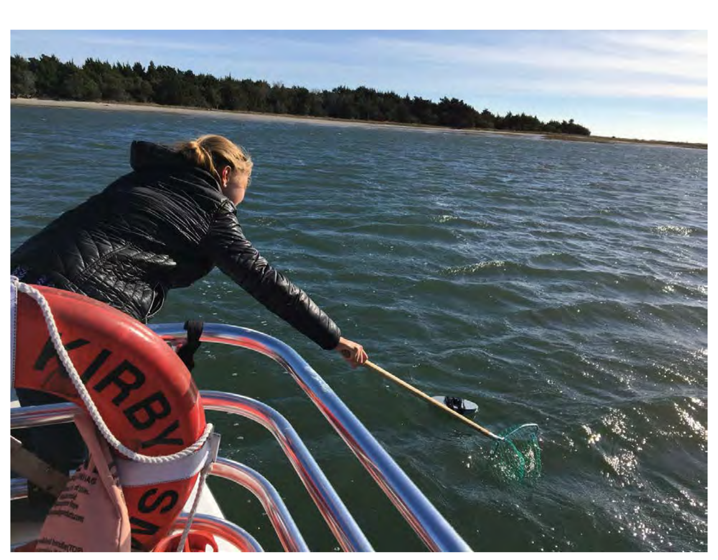
Buoy Design Results



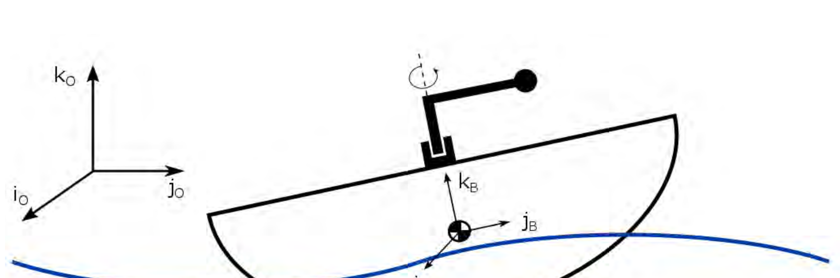


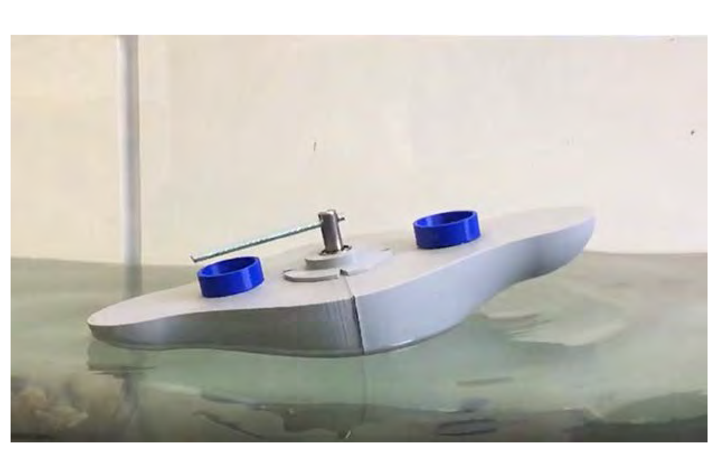
Several different buoy shapes were printed for testing. Width and the curvature of the bow of the buoy were adjusted to increase/decrease stability. A Loggerhead OpenTag was used during test deployments in the Beaufort Inlet to measure acceleration in 3 planes. The frequency of waves could be extracted from this data and relative wave amplitude.

After initial deployments in the Fall of 2016, a horizontal pendulum was added to the design. This buoy was tested in the Duke Wave Tank to visualize the perturbations to the buoy and reactions of the horizontal pendulum.



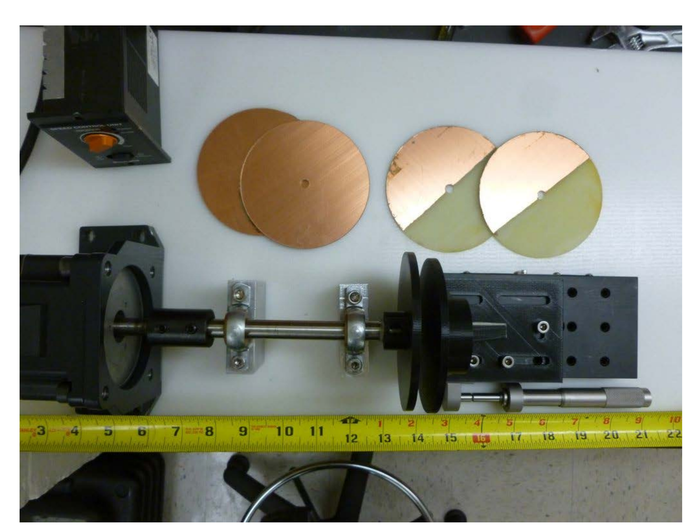
Finally, an internal casing for a hollow buoy design was 3D printed and outfitted with the capacitor plates and a battery for coupled testing of the buoy, horizontal pendulum, and capacitor plate as a unit. The pendulum generated large rotations of the shaft and the capacitor plates rotated enough to generate a measureable voltage.



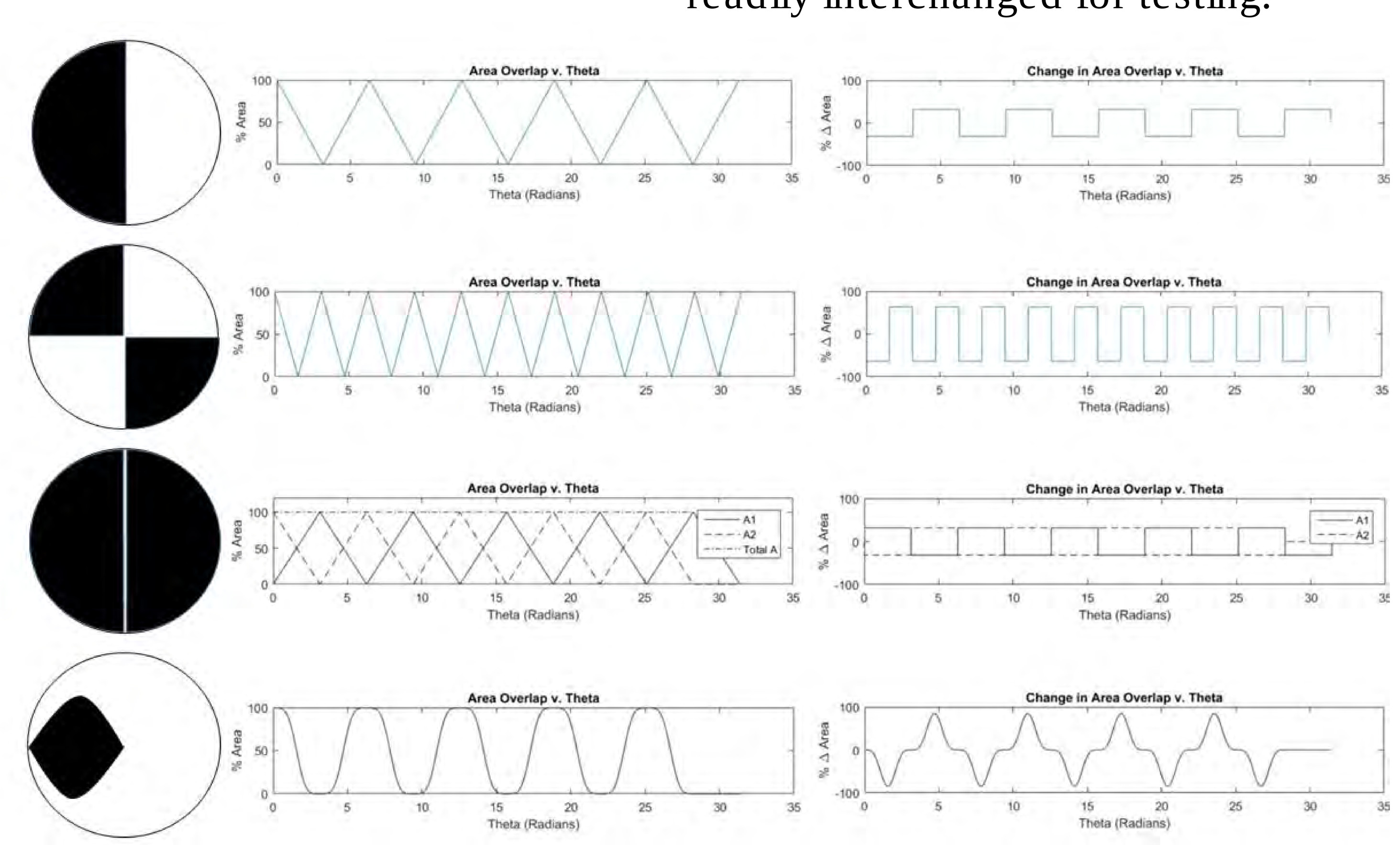


Capacitive Energy Design Results

In the integrated system, harvested mechanical motion of ocean waves is converted into usable electrical power by means of a novel rotary parallel plate capacitor designed for optimal change in overlapping plate area (dA/dt) per rotation which also upconverts the inherently low-frequency ocean waves to usable, more efficient higher frequencies for electrical conversion.



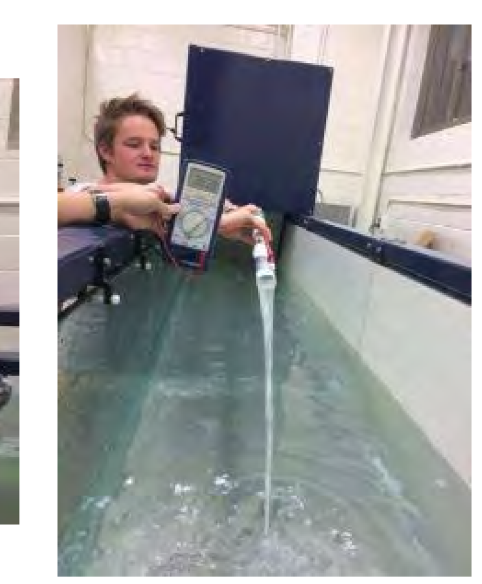
The rotary capacitive energy harvester is shown with printed plate holders and a micrometer stage on one side for fine adjustment. The capacitive plates that hold electrical charge have been chemically etched from copper-clad printed circuit board material, FR4. Full-plate and 1/2-plate designs are shown. Other physical plate geometries can be readily interchanged for testing.



Rotary capacitor configurations depicting the effect of plate geometries. By designing capacitive plate geometries appropriately, optimally up-converted AC voltage frequencies can be engineered. An initial voltage bias is added using triboelectric charge.

Triboelectric Design Results

The well known triboelectric effect where two material interfaces—in this case ocean water colliding with a buoy—build-up the charge that initially biases the harvester plates. Recently, experimental work at GA Tech in 2012 [3] successfully demonstrated that triboelectricity could be widely used to power various sensors. The materials required to generate a charge based on this concept are inexpensive, however, the fabrication process requires nano-scale surface alteration so that electrons can flow under optimal conditions.



Based on early results, significant voltage increases have been seen when running water through Teflon tubes and taking advantage of the charge gradient between the two materials. When a high voltage is maintained then planar materials will be tested.

Revised experiments moving forward include a basin partially submerged in water that at rest will not interact with the energy harvester. However, when an external force is applied, the friction will produce a measurable charge.

References

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