Drifter Challenge: A Low-Cost, Hands-On Platform for Teaching Ocean Instrumentation and Sensing

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1 Purpose of Activity

We present a curriculum based on the design, construction, deployment, and analysis of a low-cost ocean drifter platform capable of measuring ocean surface currents. Through the course, students explore various aspects of oceanography, hydrodynamics, and design. Students begin by understanding the fundamental requirements of oceanography and the challenges and limitations of ocean sensing and modeling. They apply principles of drag and lift to design a buoyant, durable drifter and learn how to set up a waterproof sensing suite for tracking surface currents in a wet environment. Through data analysis, students visualize flow on a more realistic scale than lab experiments, learning to translate Lagrangian drifter trajectories into Eulerian flow fields and match observations with external datasets. The curriculum can be adjusted to include a lesson on assessing and quantifying uncertainty in measurements and models. More generally, the course teaches students basic engineering skills, such as working with tools and assembling circuits, and emphasizes teamwork and problem-solving.

2 Audience

The curriculum was designed for the two-week MIT Portugal Marine Robotics Summer School in the Azores. Twenty students, undergraduate and graduate, were divided into six interdisciplinary teams of four to five, combining expertise in engineering fluid mechanics, robotics, marine biology, oceanography, and computer science. The course was taught through a series of lectures delivered by professors from these fields, with one head teaching assistant overseeing the drifter construction and deployment. The first week focused on designing, building, and testing the drifters, while the second week was dedicated to deployment, data collection, and modeling. Each student team was responsible for the successful deployment of their own ocean drifter, and one additional team consisting of program instructors also built and deployed a drifter.

3 Background

The ability to measure and model the speed and direction of ocean currents is necessary to monitor local and global circulation systems that affect important ecosystems and industries (McWilliams 2016). Currents can be described using a Lagrangian approach with GPS or inertial units on passively advected objects, or an Eulerian approach with electro-mechanical current meters, acoustic Doppler profilers, or HF radars.

One of the first surface ocean drifters was a simple "message in a bottle" (Lumpkin et al. 2017). From 1956 to 1972, scientists released 300,000 bottles along the East Coast of the United States, later recovering them to track the evolution of these passive Lagrangian particles (Monahan et al. 1974). Ocean drifters can be divided into two types of design: (1) a floating platform attached to a 5 to 60-meter long holey sock drogue, such as the surface velocity program (SVP) drifter (Niiler et al. 1995) or (2) a 0.5 to 1 meter long underwater sail that moves with near-surface currents, such as the drifter from the Coastal Ocean Dynamics Experiment (CODE) (Beardsley et al. 1987; Boydstun et al. 2015; Haza et al. 2018; Novelli, Guigand, Cousin, et al. 2017; Novelli, Guigand, and Özgökmen 2018).

The Consortium for Advanced Research on Transport of Hydrocarbon in the Environment (CARTHE) developed a biodegradable injected molded version of the CODE drifters to reduce economic and environmental costs (Novelli, Guigand, Cousin, et al. 2017; Novelli, Guigand, and Özgökmen 2018). More than 1,000 of these CARTHE drifters were deployed to measure near-surface flow in the Gulf of Mexico after the Deepwater Horizon oil spill (Haza et al. 2018). Some drifters are designed without underwater sails to reduce damage during grounding events, but these are less effective at tracking near-surface currents (Torsvik 2016). More recent drifter designs now include environmental sensors for other variables such as salinity, temperature, pressure, and acoustics (Areté 2024).

Educating marine scientists and engineers to be experts in the fields of ocean sensing, ocean modeling, and data assimilation is essential, but doing so can be challenging. The physical equations that describe ocean flow are complex, nonlinear, and high-dimensional. Visualizing the physics of the ocean can be difficult for students who are new to the field, and many of the existing high-precision sensors are too expensive to purchase in a classroom setting. We propose a curriculum that can be used to teach important topics about ocean fluid dynamics, ocean sensor design, and challenges in ocean sensing. The curriculum is inspired by similar projects, such as the ultrasonic water level sensor from Bresnahan et al. (2023) and the drifter platforms in Anderson (2015), Torsvik (2016), and Lant (2019).

4 Design, Materials, and Assembly

The instructors provided students with a sample drifter design based on the CODE drifter, selected for its simple construction and the availability of readily accessible materials. Its shorter underwater sail reduces the risk of entanglement during testing and deployment. The electronic housing is designed separately from the float and weights, allowing for easy modifications and modularity. Overall, this design allows students to experiment with variations in sail geometry and length, as well as adjustments to float and weight balance.

4.1 Materials and Assembly

Each team was provided with basic materials that included (1) wooden dowels, cloth, and rope for the drifter frame and sail, (2) a commercial GPS/Cellular unit and a GPS/Cellular development board; (3) a shellac-coated bamboo container for housing the electronics; (4) cork for flotation. A detailed list of materials is provided in Table 1. Teams were encouraged to source locally produced materials as needed.

Table 1: List of Provided Materials with their Purposes and Cost

Part Name	Purpose	Cost
Lilygo T-sim7000g	Custom GPS cellular development board	$35
18650 Li-ion battery	Custom GPS unit battery	$4
BMP390 breakout board	Barometric pressure and altimeter	$13
NTC 3950	Waterproof temperature sensor	$2
Local SIM card	Cellular service provider	$20
LandAirSea GPS tracker	Commercial cellular GPS tracker	$28
Cellular antenna	Replacement antenna for Cellular GPS tracker	$8
Cotton canvas fabric	Underwater sail	$2
3 mm thick jute rope	Frame construction and parts attachment	$2
Cork	Surface flotation	$4
20 mm dia by 1.6 m wooden dowel	Frame construction	$5
4 x 8 mm dia by 0.5 m wooden dowel	Frame construction	$3
Fishing weights	Counter balance	$1
Cylindrical bamboo container	Electronic stack container	$8
Shellac	Waterproofing coating	$2
Coconut wax	Waterproof potting material	$2

The sample drifter's frame and sail (Figure 1) were made from wooden dowels, cotton canvas, jute rope, cork for buoyancy, and fishing weights. The sail was tensioned against the center dowel with hemp rope, threaded through the cork float, and tied to the attachment point, with grommets reinforcing the sail attachment points.

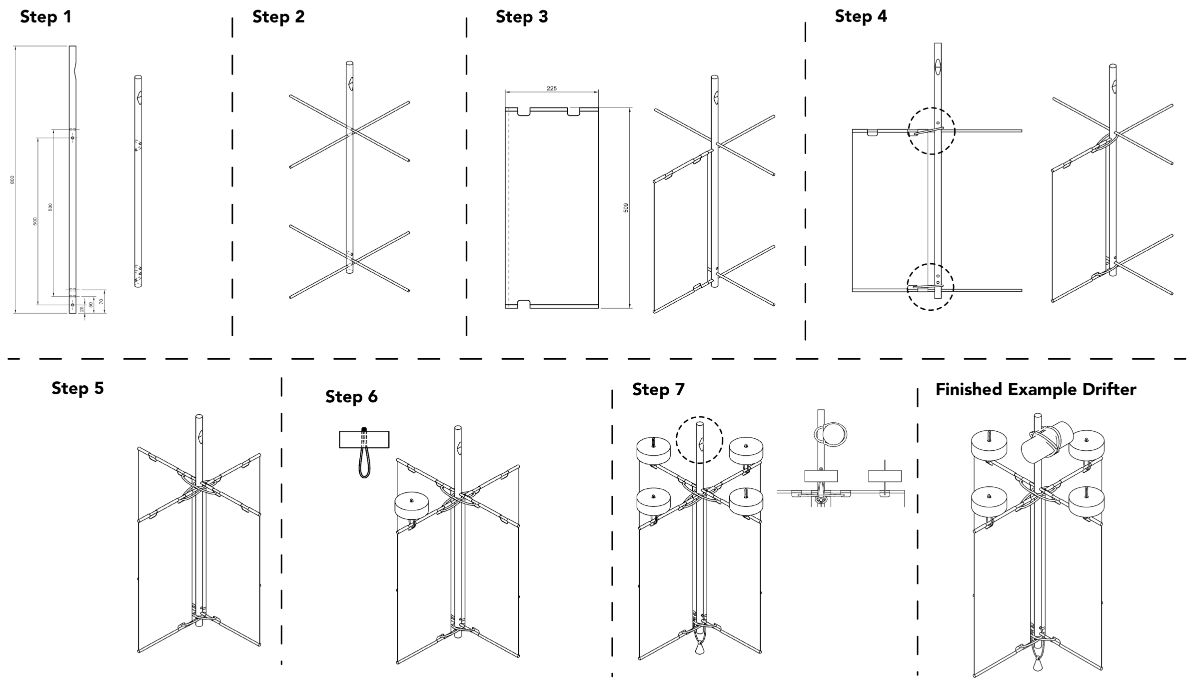

Figure 1: Example step-by-step assembly instructions for constructing a drifter frame and sail given the provided materials.

4.2 Electronic Setup and Housing

The main wireless communication method used was the LTE-M cellular network, chosen due to its ease of implementation, cost, and performance. Each student team was offered two GPS/Cellular communication systems: (1) a commercial off-the-shelf option and (2) a custom-built option. Two GPS units were used to ensure redundancy, enable comparison, and increase hands-on experience with communication technologies. The custom-built GPS systems also allowed students to integrate additional environmental sensors, such as temperature and barometric pressure sensors.

The commercial tracker requires a monthly subscription for data transmission and storage. The custom tracker consisted of (1) an ESP32 board development with SIM7000G GPS/Cellular modem, (2) 18650 Li-ion battery, (3) GPS antenna, (4) cellular antenna, (5) global SIM card, (6) optional sensors: barometer and temperature. The GPS electronics stack had an estimated 48 hours of operation. GPS location data were transmitted through 4G cellular network to Silvercloud (commercial) and Blynk IoT Platform (custom). The electronic block diagram and code flow chart are shown in Figure 2.

The electronic stack was enclosed in a bamboo container coated with water-resistant shellac resin (Figure 2). This housing was designed to keep the electronics dry during splashing and brief submersions, with the expectation that it would remain at least 10 cm above the waterline for most of the deployment. To improve waterproofing, students could use coconut wax to encase the electronics, excluding the antennas.

5 Field Application

5.1 Student Design and Deployment

The seven teams (six student teams and one instructor team) explored various design approaches, with key differences including the shape of the underwater sail (cross-shaped vs. square-shaped), the sail depth (ranging from just below the surface to 15 meters deep), and the placement and distribution of weights

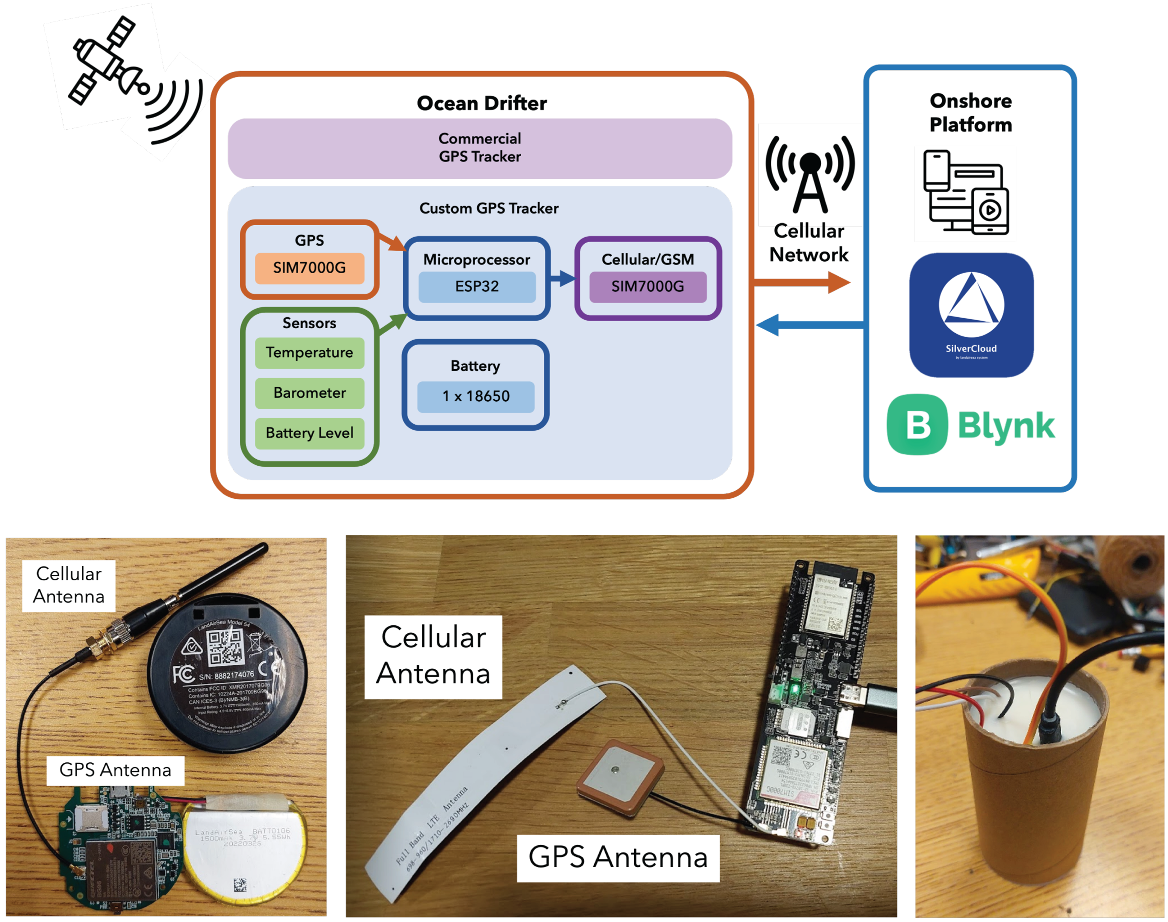

Figure 2: Top Row: Electronic system block diagram for the drifter. Bottom Left: Tear down of the commercial GPS tracker electronics component. Bottom Center: Custom GPS tracker electronics components. Bottom Right: Coconut wax potting example. The code for the custom GPS is available on `https://github.com/xialing95/OceanDrifter-Lilygo`.

and buoyant materials. Additionally, some students incorporated store-bought coconut shells and locally sourced cane as supplementary buoyancy materials (Figure 3). During testing, students adjusted buoyancy by modifying the float and weight, assessed the drifter's self-righting stability in case of capsizing, and validated the commercial and custom GPS tracking systems.

The drifters were dropped from the same location at the same time along the coast of Faial Island, Azores, Portugal as in Figure 4. As the drifter moved further away from the island, the LTE-M signal got weaker. The drifter communication lasted between 12 hours to 36 hours; either the signal went out of range or the device lost power.

5.2 Data Analysis

Students compared and analyzed the drifter observations to tides, bathymetry, and wind forecasts from weather stations. In the following analysis, the bathymetry was obtained from EMODnet Bathymetry Consortium (2022). Students were also introduced to the operational numerical model engine, MOHID Water System, from +ATLANTIC CoLAB (Neves 1985; Santos 1995). This platform uses a system of models to cover the Azores archipelago with different resolutions by downscaling the Copernicus Marine Global model (European Union-Copernicus Marine Service 2016). The MOHID modeling systems also provide an accurate

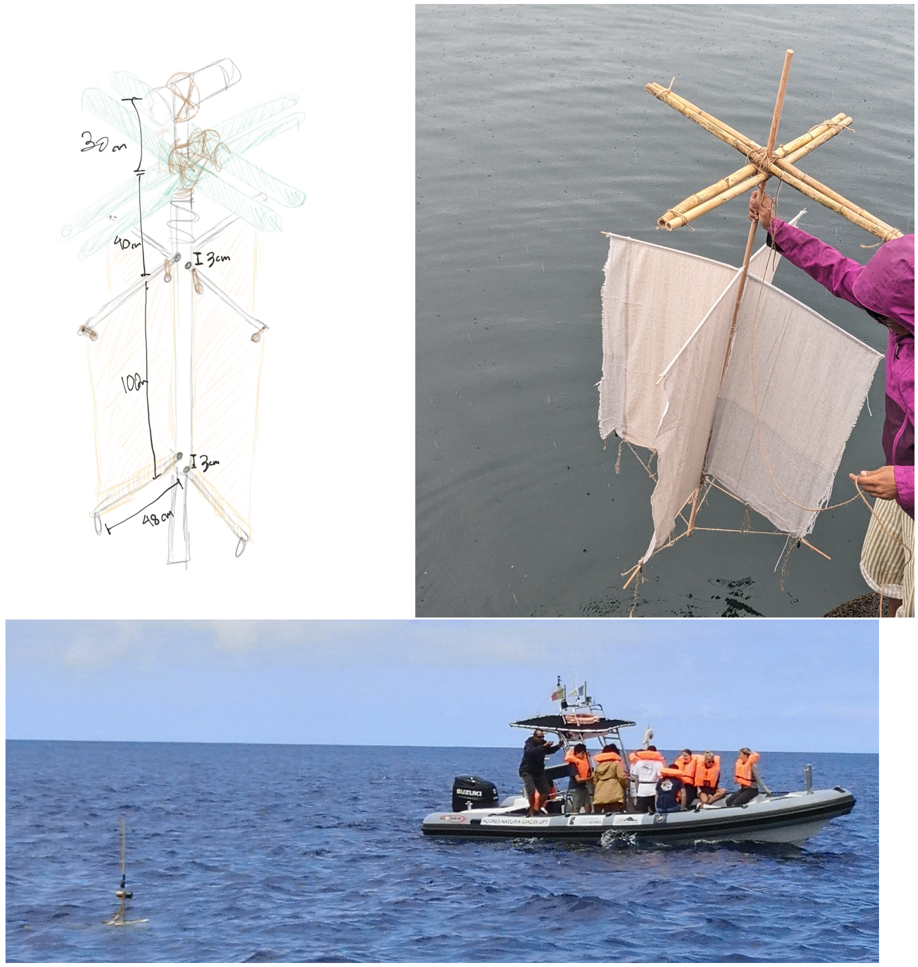

Figure 3: Before building, teams worked on planning and designing the attributes of their drifter. The top left figure shows an initial sketch of a student drifter design that uses natural locally-sourced cane found by one of the students living on Faial. The top right figure shows the corresponding drifter during the testing phase. This drifter was built according to the sketch. The bottom figure shows the drifters being deployed at sea.

estimate of the local tides.

The top row of Figure 4 shows the GPS observations of the deployed drifters. Team 6 was never able to record any measurements. Some drifters lost GPS connection earlier than others. Only the drifter from Team 1 obtained GPS measurements from both the commercial and non-commercial GPS units, with the non-commercial GPS unit collecting measurements at a faster rate. The measurements from Team 1 indicate a strong agreement between the two GPS units. In general, most drifters followed similar patterns. The drifter built by the instructors had a sail depth of 15 meters, which may explain its different trajectory at the start of the release. The drifter from Team 3 had a larger surface area protruding out of the water, which may explain why it deviated from the other trajectories, potentially being more strongly carried by wind.

The other rows of Figure 4 show the location of the drifter from Team 1 with the non-commercial GPS at three timestamps. The top row shows the position over a contour plot of the bathymetry with a red arrow denoting the tide height. From these visualizations, it appears that the drifter trajectory was most influenced by the ebb and flow of the tide, expected in this coastal region where the tide produces strong currents. While the effect was smaller, it also appears that the drifter tended to follow contours of constant bathymetry, providing insights into local circulation patterns. In the bottom row, the position is shown over the flow field obtained from the +Atlantic CoLAB MOHID model. While the temporal resolution of the

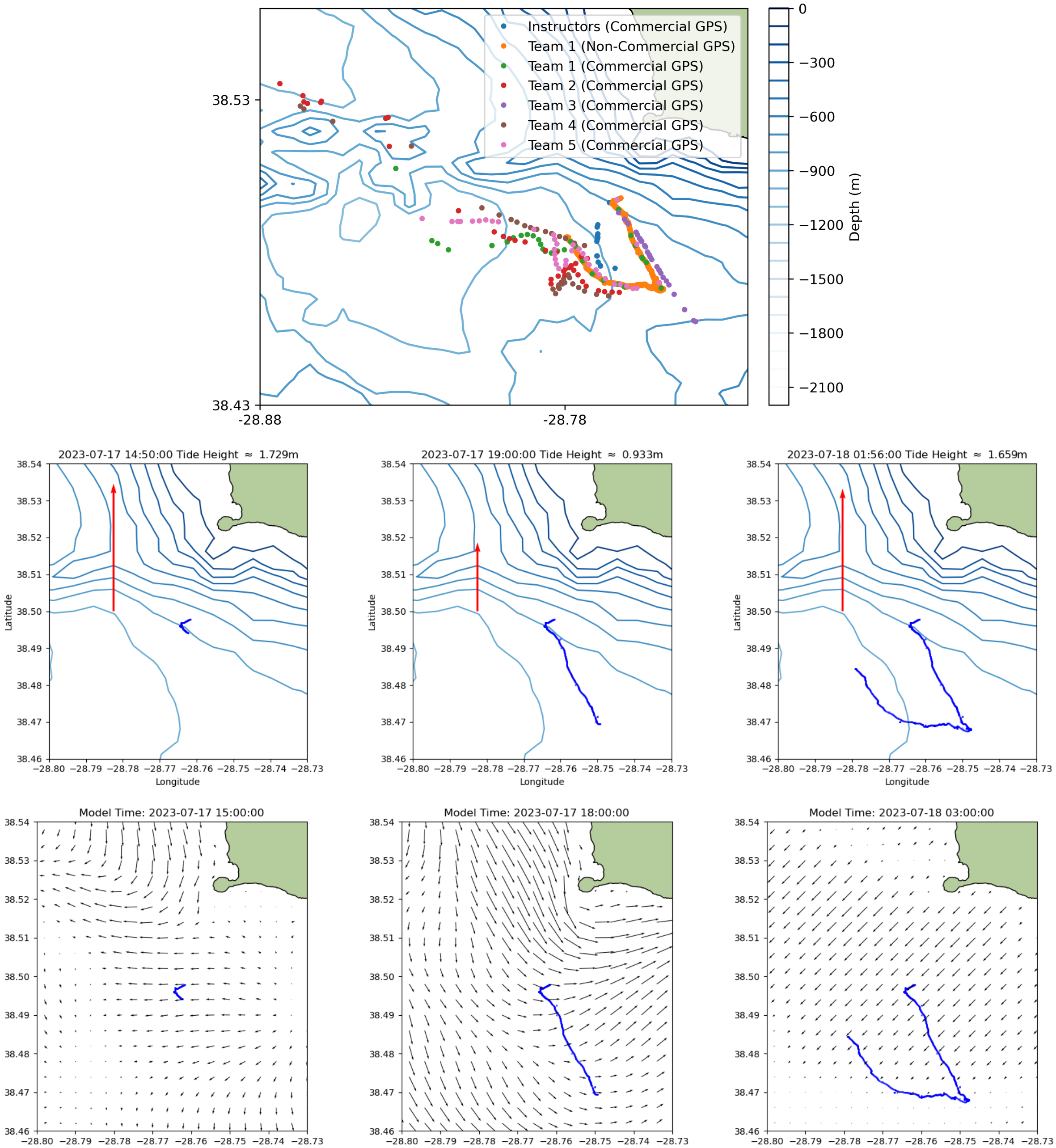

Figure 4: Top figure: Complete trajectories obtained from all teams. Snapshots of the observations are provided at three timestamps between July 17th, 2023, and July 18th, 2023. In the middle row, the red arrow shows the relative height of the tide at that instant, and the blue contour lines represent the bathymetry. In the bottom row, the arrows represent the surface velocity field that was determined by the numerical simulation, but the temporal resolution of the model is three hours, so the snapshots do not capture the full dynamics of the drifter. Corresponding movies can be found at `https://github.com/xialing95/OceanDrifter-Lilygo`.

model is low (one snapshot every three hours), it is still a helpful tool for estimating the trajectory of the drifter and teaching students about data assimilation.

6 Possible Modifications

To prolong the deployment, we recommend using more durable materials, such as coated aluminum or fiberglass tubing. Battery life can be improved by incorporating additional batteries and solar cells or by reducing the sampling rate. Additionally, environmental sensors — such as those for salinity, temperature, and pH — can be integrated into the drifter's custom electronic stack. Using a commercial GPS tracker with satellite data communication (SPOT 2025) instead of LTE-M can increase network coverage and enable data collection in remote areas without cellular networks. The curriculum can be modified by challenging students to optimize the design for compactness, making it suitable for large-scale deployments, with each team deploying 10 or more drifters.

7 Ocean Drifter Development as a Teaching Tool

We developed and tested a curriculum to teach undergraduate and graduate students in oceanography and engineering about ocean sensor design, ocean sensing, and ocean fluid dynamics. The project challenged students to design, build, and deploy a fully operable platform for measuring near-surface ocean currents, as well as analyze and compare the measured data. Students from different disciplines learned to (1) design, construct, and deploy a biodegradable ocean drifter to follow ocean surface current; (2) assemble and deploy simple electronics for GPS tracking, cellular communication, and environmental sensing; (3) connect drifters to an IoT network for collecting and analyzing GPS data; (4) understand the relationship between ocean current velocity and tide, bathymetry, wind, up-welling, etc.

This project provided valuable lessons for both students and instructors alike. Across the different teams, drifters with more buoyancy were capable of sending GPS signals for a longer time, suggesting the importance of protecting the electronics from oncoming waves. Most drifters followed the same trajectory, and these trajectories correlated with tides and bathymetry. However, the drifter with a deeper sail and the drifter with a larger surface area exposed to above-surface wind followed different paths. Students learned that the GPS and LTE-M signals were difficult to obtain at regular intervals, reinforcing the challenges of remote sensing. Most drifters only had success with the commercial GPS units, which might suggest that the custom-built GPS units were incorrectly set up or the waterproof cases were insufficient. This shortcoming could be due to salt water and wind erosion on the shellac coating or the internal coconut wax.

The design challenge was an engaging and educational experience for the students. One student shared that "It was a great experience to learn material outside of my degree classes. I feel like I have a much more holistic understanding of marine robotics now that I understand oceanography and some marine biology" (course evaluation Marine Robotics Summer School student, anonymous).

References

Anderson, T. (Dec. 2015). "Educational Experiences in Oceanography through Hands-On Involvement with Surface Drifters: an Introduction to Ocean Currents, Engineering, Data Collection, and Computer Science". In: 2015, ED21A–0823. URL: https://ui.adsabs.harvard.edu/abs/2015AGUFMED21A0823A (visited on 07/26/2023).

Areté (Dec. 10, 2024). *STRIDR® - Sea-Trekking Rechargeable Instrumented DRifter*. URL: https://arete.com/products/stridr/ (visited on 11/26/2024).

Beardsley, R. C. and S. J. Lentz (1987). "The Coastal Ocean Dynamics Experiment collection: An introduction". In: *Journal of Geophysical Research: Oceans* 92 (C2), pp. 1455–1463. DOI: https://doi.org/10.1029/JC092iC02p01455. URL: https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/JC092iC02p01455.

Boydstun, Daniel et al. (2015). "Drifter Sensor Network for Environmental Monitoring". In: *2015 12th Conference on Computer and Robot Vision*, pp. 16–22. DOI: 10.1109/CRV.2015.10.

Bresnahan, Philip et al. (2023). "A Low-Cost, DIY Ultrasonic Water Level Sensor for Education, Citizen Science, and Research". In: *Oceanography* 36.1. ISSN: 10428275. DOI: 10.5670/oceanog.2023.101. URL: https://tos.org/oceanography/article/a-low-cost-diy-ultrasonic-water-level-sensor-for-education-citizen-science-and-research (visited on 10/09/2024).

EMODnet Bathymetry Consortium (2022). *EMODnet Digital Bathymetry (DTM 2022)*. DOI: 10.12770/FF3AFF8A-CFF1-44A3-A2C8-1910BF109F85. URL: https://sextant.ifremer.fr/record/ff3aff8a-cff1-44a3-a2c8-1910bf109f85 (visited on 12/12/2024).
European Union-Copernicus Marine Service (2016). *Global Ocean 1/12° Physics Analysis and Forecast updated Daily*. en. DOI: 10.48670/MOI-00016. URL: https://resources.marine.copernicus.eu/product-detail/GLOBAL_ANALYSISFORECAST_PHY_001_024/INFORMATION (visited on 01/15/2025).
Haza, A. C. et al. (Apr. 2018). "Drogue-Loss Detection for Surface Drifters during the Lagrangian Submesoscale Experiment (LASER)". In: *Journal of Atmospheric and Oceanic Technology* 35.4, pp. 705–725. ISSN: 0739-0572, 1520-0426. DOI: 10.1175/JTECH-D-17-0143.1. URL: https://journals.ametsoc.org/view/journals/atot/35/4/jtech-d-17-0143.1.xml (visited on 12/06/2024).
Lant, Karla (May 20, 2019). *Learning With the Student Drifter Program*. Environmental Monitor. URL: https://www.fondriest.com/news/learning-with-the-student-drifter-program.htm (visited on 07/26/2023).
Lumpkin, Rick, Tamay Özgökmen, and Luca Centurioni (Jan. 3, 2017). "Advances in the Application of Surface Drifters". In: *Annual Review of Marine Science* 9.1, pp. 59–81. ISSN: 1941-1405, 1941-0611. DOI: 10.1146/annurev-marine-010816-060641. URL: https://www.annualreviews.org/doi/10.1146/annurev-marine-010816-060641 (visited on 12/06/2024).
McWilliams, James C. (May 2016). "Submesoscale currents in the ocean". In: *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* 472.2189, p. 20160117. ISSN: 1364-5021, 1471-2946. DOI: 10.1098/rspa.2016.0117. URL: https://royalsocietypublishing.org/doi/10.1098/rspa.2016.0117 (visited on 12/06/2024).
Monahan, Edward Charles, Peter C Hawkins, and Elizabeth A Monahan (1974). *Surface Current Drifters: Evolution And Application*. URL: https://repository.library.noaa.gov/view/noaa/45944 (visited on 07/26/2023).
Neves, R.J.J. (1985). "Bidimensional model for residual circulation in coastal zones: application to the Sado estuary." In: *Annales Geophysicae* 3, pp. 465–471.
Niiler, Pearn P. et al. (Nov. 1995). "Measurements of the water-following capability of holey-sock and TRISTAR drifters". In: *Deep Sea Research Part I: Oceanographic Research Papers* 42.11, pp. 1951–1964. ISSN: 09670637. DOI: 10.1016/0967-0637(95)00076-3. URL: https://linkinghub.elsevier.com/retrieve/pii/0967063795000763 (visited on 12/06/2024).
Novelli, Guillaume, Cédric M. Guigand, Charles Cousin, et al. (Nov. 2017). "A Biodegradable Surface Drifter for Ocean Sampling on a Massive Scale". In: *Journal of Atmospheric and Oceanic Technology* 34.11, pp. 2509–2532. ISSN: 0739-0572, 1520-0426. DOI: 10.1175/JTECH-D-17-0055.1. URL: https://journals.ametsoc.org/view/journals/atot/34/11/jtech-d-17-0055.1.xml (visited on 12/06/2024).
Novelli, Guillaume, Cédric M. Guigand, and Tamay M. Özgökmen (Nov. 1, 2018). "Technological Advances in Drifters for Oil Transport Studies". In: *Marine Technology Society Journal* 52.6, pp. 53–61. ISSN: 0025-3324. DOI: 10.4031/MTSJ.52.6.9. URL: https://www.ingentaconnect.com/content/10.4031/MTSJ.52.6.9 (visited on 12/06/2024).
Santos, A. J. (1995). "Modelo hidrodinâmico tridimensional de circulação oceânica e estuarina". PhD thesis. Portugal: Technical University of Lisbon.
SPOT, Saved by (2025). *Spot trace®. SPOT Trace Satellite Tracker with GPS*. URL: https://www.findmespot.com/en-us/products-services/spot-trace (visited on 03/12/2025).
Torsvik, Tomas (Jan. 2016). "Data processing and performance testing of a low-cost surface drifter design for use in coastal waters". In: *Proceedings of the Estonian Academy of Sciences* 65, p. 58. DOI: 10.3176/proc.2016.1.06.