Engineering a Smartfin for Surf-Zone Oceanography

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***Abstract*—The surf-zone presents unique challenges and opportunities for observational oceanography. Physical and biogeochemical signals change quickly in and around breaking surface waves due to high magnitudes of momentum and mass transfer. Autonomous instruments can be challenging to deploy in this energetic zone. We are developing the Smartfin, a surfboard fin capable of measuring geolocated ocean chemistry data to enable surf-zone observations via a new citizen/surfer science initiative. The Smartfin collects GPS, temperature, and motion data; modules for measurements of pH, dissolved oxygen, and chlorophyll fluorescence are in development. The fin is used by citizen/surfer scientists with a goal of distributing over one hundred Smartfins in California in 2017 and rapidly expanding across the country and the world in coming years.**

Keywords—coast; surf-zone; near-shore; temperature; biogeochemistry; citizen science; internet-of-things

I. INTRODUCTION

The importance of the coastal ocean stems from the numerous goods and services that near-shore ecosystems provide human communities [1]. Yet coastal oceanography presents many unique challenges and opportunities. The coastal ocean's highly energetic, dynamic, and heterogeneous nature makes many processes uniquely hard to constrain, despite its ease of access. For example, estimates of coastal carbon budgets have uncertainties approaching 50 – 75% [2]. Despite the relatively small footprint of estuaries and continental shelves (~7.5% of the global ocean surface area) they can be disproportionality important to global material budgets. For example, continental shelves account for roughly 20% of global net air – sea CO_2 fluxes [3, 4]. Temperature plays an important role in understanding coastal dynamics as well, from its tight local correlations with nutrients due to upwelling [5] to its impact on mussel and barnacle growth rates [6] and coral bleaching [7], for example.

Here we describe the intended user experience as well as the development of the hardware and software infrastructure required to manage the Smartfin project. Engineering concerns include the fin's construction, the microcontroller/datalogger hardware and firmware, individual sensor components, database management, and web/mobile applications for data visualization. These components all have unique design considerations due to the fact that Smartfin's intended user community is not trained oceanographers, but rather everyday surfers.

The Smartfin is in many ways similar to the WavepHOx: a pH, dissolved oxygen, and temperature sensor package designed to be used by oceanographers on mobile platforms such as Wave Gliders and stand-up paddleboards, which the authors of this presentation developed [8] and have since deployed in several coastal and estuarine systems. The WavepHOx, while a powerful research tool in its own right, is too large, unwieldy, and complicated to operate for use in a citizen science program. As discovered in that work, biogeochemical "hotspots"—for example, places of disproportionately large photosynthesis/respiration—can be easily missed by static and sparse moored sensor deployments. Taking advantage of the surfing community as a data collecting channel will provide unique insight into changing patterns in environmental and chemical parameters in the near-shore environment.

Smartfin is designed to fill gaps in time and space in surf-zone oceanographic monitoring. Similar work has been achieved using small sensor tags attached to surfboard leashes and GPS units tethered to surfers [9]. Smartfin offers the advantage that no additional components beyond what a surfer typically uses are required; instead, a Smartfin can simply replace a standard surfboard fin. This relative ease-of-use will enable many surfers to contribute to this data collection effort.

II. METHODS

Current hardware, firmware, and web/mobile application software were developed by contractors of Lost Bird Project and Boardformula. Here we describe those components in terms of their specific functionality.

Smartfin is designed to fit into one of the most commonly used "fin-boxes," the slot into which fins are inserted in most surfboards. Specifically, the current fin fits into a standard Futures Fins side fin-box. When a surfer scientist is ready to deploy a Smartfin, he/she connects it to his/her surfboard, turns it on, and begins surfing as with any other fin. After the surf session, he/she recharges the Smartfin and uploads data (via a smartphone application) to a cloud database and views data visualizations on both mobile and web applications. Data will be made freely available following application of the

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QARTOD (quality assurance of real-time oceanographic data) protocols and incorporation into commonly accessed oceanographic database tools.

A. Hardware Design Considerations

Smartfin consists of an ATXMEGA64D4 microcontroller, SD memory card, a temperature sensor (MAX31725), inertial measurement unit (IMU: MPU9250), GPS receiver, and Bluetooth circuit. Smartfin is designed to operate without any direct electrical contact; it charges and transmits data wirelessly (inductive and classic Bluetooth, respectively). Temperature data are logged every 6 s while IMU data are logged at 5 Hz. Smartfin firmware is coded in Arduino sketches.

Fig. 1. The Smartfin, front and back. The top shows an unilluminated LED in the center and a small cut-out for future sensor integration. The black carbon fiber tip covers the temperature sensor. The bottom shows the PCB, rechargeable battery, and inductive charging pad.

Circuitry is potted in epoxy and then laid into a Futures Fins F6 fin template with cutouts for the custom circuitry. The full assembly is coated with fiberglass cloth and again epoxied and placed into a vacuum bag. Finished Smartfins (Fig. 1) have been evaluated by Futures Fins to ensure they match the overall performance characteristics—especially flex and weight—of their commercial fins.

B. Software Design Considerations

A web application (hosted at surf.smartfin.org) was programmed and deployed with the primary goal of creating a PostGIS database and an application programming interface (API). The API, in turn provides read/write access from/to the database such that data can be uploaded via Bluetooth using the mobile application and time-series can be viewed on the web's front-end. The web application was written using Python's Django framework with additional JavaScript and HTML on the front-end; iOS and Android mobile applications were written in native languages, Objective-C and Java, respectively, and are currently available for beta testers only (*i.e.*, not yet available on app stores).

C. Calibration

Smartfins are calibrated in batches of ten by submerging them in a twenty-gallon insulated cooler with recirculating seawater pumped through a heat exchanger. The heat exchanger has a counter-current flow which is temperature controlled by a Thermo Scientific NESLAB RTE7 circulating bath/chiller. Temperature is ramped from 15 °C to 30 °C in 5 °C increments; each temperature step is held for four hours. The voltage output from the Smartfin temperature sensor is calibrated against a Seabird MicroCAT CTD by averaging 5 minutes of data from each 5 °C step and calculating coefficients from a linear regression. Using this protocol, precision and accuracy of the Smartfins are better than 0.1 °C.

D. Smartfin Beta Test

In the Spring of 2017, fifty fins were produced and distributed, including twenty-five to members of the San Diego Surfrider Chapter. At the time of writing this article, several were in use with the remainder being shipped; data from the deployed fins are shown below. For example, two Smartfins were used concurrently on two different surfboards on 11-May-2017 in the surf break 500 m south of Scripps Pier, La Jolla, CA. Additionally, 24 surf sessions with one fin occurred across South San Diego County over six weeks in May and June, 2017. Data analysis and visualization was performed with the Anaconda 4.2.13 installation of Python 3.5 and matplotlib, pandas, numpy, folium, and cmocean packages.

III. Results

On 11-May-2017, two individuals with Smartfins surfed simultaneously. Fig. 2 shows the temperature and acceleration time-series from the two Smartfins. Largescale features show two instances when temperature changed by 0.4 °C during the session: one decrease in the first 30 minutes and a subsequent increase over the following hour. Smaller scale features can be seen in the time-series as well. The authors anticipate that these smaller scale features will prove particularly meaningful in the identification and analysis of biogeochemical patches through subsequent studies. For example, these comparatively smaller features, likely indicative of internal wave breaking and mixing of differentially heated shallower water, will likely have heterogeneous biogeochemical signals corresponding to the temperature changes seen here. Note that the sharp decrease in the beginning and increase at the end of each surfer's time-series correspond to those surfers entering and exiting the water, respectively, and will be filtered out in the publicly accessible database.

Acceleration and rotation data (rotation not shown) will be useful in reconstructing the surfer's location via dead reckoning as well as aiding in quality control of the oceanographic data (for example, when acceleration in the direction normal to the board is negative, it can be determined that the board is upside down). Additionally, motion sensor data will be useful in filling in gaps in time and space between high quality buoy records as well as providing information about wave shoaling closer to shore than most wave buoys. It is unlikely that the motion sensor data will prove capable of providing wave spectral data (swell size, period, direction) of the same quality as, for example, a Datawell Directional Waverider (http://www.datawell.nl/Products/Buoys.aspx) due to a large number of interferences from a surfer's/surfboard's inertia and non-wave-induced motion, even when not riding a wave, but we anticipate that the motion sensor data will prove useful to the project's goals nonetheless.

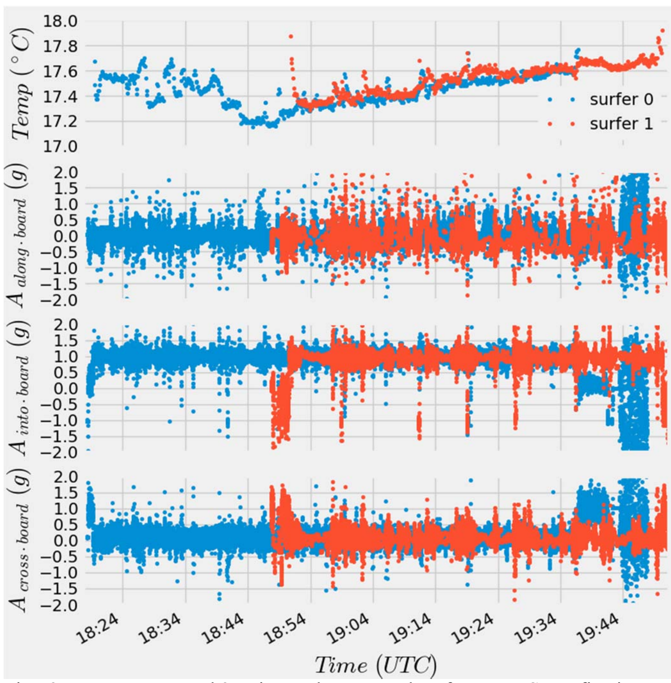

Fig. 2. Temperature and 3-axis accelerometer data from two Smartfins in concurrent use.

Fig. 3 shows 24 surf sessions using the same Smartfin at Scripps Pier, La Jolla, CA, over the course of six weeks. The majority of the observed heterogeneity occurs on an inter-session basis: across all sessions mapped here, there was a > 4 °C range in comparison to the < 1 °C changes during a given session. As more Smartfins are in use in more locations, these types of maps and time-series animations will be instructive in locating small scale features than are observable with current observational networks. Additionally, we anticipate that the data will be valuable in the validation of remotely sensed data which are notoriously imprecise in the coastal ocean due to a number of interfering signals [9].

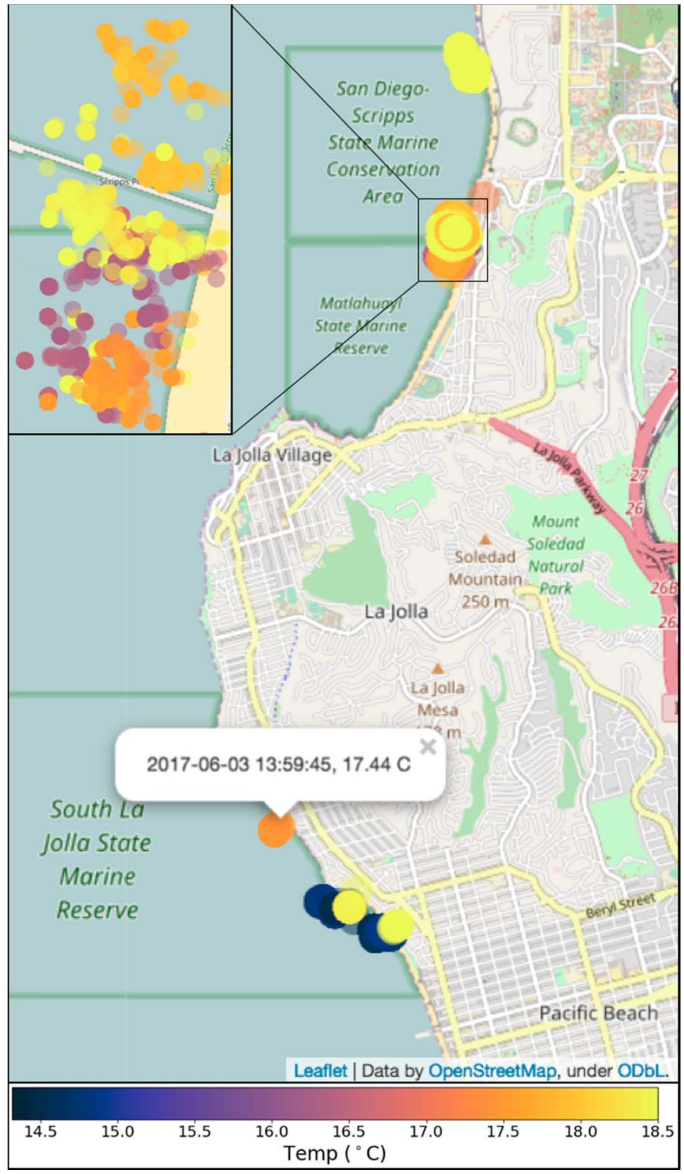

Fig. 3. Screenshot of interactive web map displaying preliminary data collected in San Diego in May/June of 2017. Dots represent a single temperature record with a corresponding GPS fix. Inset shows zoomed in area around Scripps Pier, La Jolla, CA.

IV. Conclusions and Future Directions

In this work, we describe the current state of development of the Smartfin, including hardware and software engineering and present preliminary results from tests during the Spring of 2017. Smartfin currently comprises a temperature, motion, and position sensing package integrated into an otherwise standard surfboard fin designed so that any surfer can become a citizen scientist and contribute to oceanographic research. While the temperature sensing version of the Smartfin is valuable in its own right, we anticipate that Smartfin's true contribution will be realized with the development of additional sensors and incorporation of this technology onto additional platforms. Table I shows a list of prospective sensors and their applications. Once the Smartfin concept has been proven on surfboard fins, it will be readily adaptable to stand-up paddleboards, kayaks, and sailboats.

We intend to implement standardized quality assurance algorithms, such as those described in the Quality Assurance of Real Time Oceanographic Data (QARTOD) package [10]. Integration of such automated routines, as well as hardware solutions (*e.g.*, a wet/dry detector circuit) and machine learning approaches (*e.g.*, clustering), will greatly enhance data quality.

Smartfin enables a unique method of science communication and ocean stewardship. Non-scientists are able to contribute to the collection of research-quality oceanographic data and are empowered to describe the state of science and their direct experiences in the pursuit of scientific knowledge. Smartfin also hopes to add to conversations around global climate change and exposes a community that relies heavily on the coastal ocean for recreation to the scientific process as it relates to the ocean.

TABLE I. PROSPECTIVE SENSOR SUITE

Parameter	***Technology Readiness***	***Potential Applications***
Temperature	Functional on Smartfin	Local patterns, upwelling, currents, extended time-series will generate data related to natural and anthropogenic variability
pH	In development	Local variability, related to ocean acidification on long timescales, can be used to observe photosynthesis/ respiration-driven processes
Chlorophyll	Future integration	Phytoplankton abundance, particularly hard to estimate coastal concentrations from satellites, can be related to fertilizer run-off
Dissolved oxygen	Future Integration	Can be used to observe photosynthesis/ respiration-driven processes, decoupling between CO2 and O2 air – sea transfer
Conductivity	Future integration	Used to measure freshwater inputs (river/storm runoff, direct rainfall), used to calculate other important ocean characteristics (*e.g.*, density) and characterize large scale features
Fluorescent dissolved organic matter	Future integration	Potential proxy for run-off from land which can be related to input of pollutants, better constraint on organic matter influx during storm events
Turbidity	Future integration	Proxy for suspended sediment concentration, helpful for estimating interferences to other optical signals, such as chlorophyll and fDOM
Fecal indicator bacteria	No sensors currently available	Of direct importance to human health. Current analytical techniques take 24 hours to get response and are spatially patchy. Dire need for fast-response, high-resolution sensing.

Lastly, in addition to the contributions that Smartfin will make to coastal oceanography, it is a uniquely powerful communication and education tool. The Smartfin project equips local surf communities with the tools necessary to talk about changes to ocean health, including sea level rise (and associated shifting or complete destruction of surf breaks) and coral bleaching and ocean acidification (which could have dramatic effects on reef breaks). Smartfin allows surfers, frequently among the strongest groups of ocean health advocates, to become more informed and proactive stewards of the marine environment. We have presented the Smartfin project to numerous school and service organizations as well as attended surf trade shows, frequently as the only science-focused exhibitors, allowing for multiple avenues for outreach. We are also developing a more formal STEM outreach plan in coordination with the Birch Aquarium at Scripps, the Surfrider Foundation, and others. The Smartfin project's tightly integrated research and outreach missions are mutually beneficial and offer a powerful combination of tools to learn and teach about ocean science.

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