Low-cost moored instrumentation for citizens' education and participation in environmental stewardship

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Abstract— One goal of the Círculo Europeo project is to approach citizens and improve their understanding of aquatic environmental observations and monitoring for the enhancement of community decision-making and cooperative planning. As a potential solution to estimate water transparency related parameters, a low cost instrument is proposed, integrating quasi-digital optical sensors in the open-hardware *Arduino* platform.

Keywords— *Buoy technology; Low cost sensors; Do it yourself; Oceanographic instrumentation and sensors*

I. INTRODUCTION

The great technological advances in embedded systems and sensor-riches have increased the interest of people in creating their own instrumentation equipment. Moreover, these new developers share the collected data with the community by using existing communication infrastructures (web pages). This is commonly known as citizen or participative science. In the particular case of marine environments, a widely adopted, scientific way to assess the status of water bodies is by measuring their optical properties (as indicators of, e.g., sewage impact, dissolved organic matter, sediment load or gross biological activity). With these ideas in mind, the Círculo Europeo project aims to develop systems to retrieve and use data on seawater optical properties using low-cost sensors combined with contextual information (e.g., georeferencing). Given the ubiquity of mobile devices and the high density of people in coastal areas, citizen science can achieve an unprecedented level of coverage in both space and time for observing events of interest in the, usually complex, coastal environments. The idea can be extended in open water as well, taking into account offshore activities (e.g. sailing and touristic cruises) and vessels of opportunity.

In this contribution, we analyze one of the Círculo goals: the development of low cost technologies to estimate optical parameters related to water transparency. The proposed technology is based on *Arduino* (1), an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software which could be considered a very good alternative to develop citizen science oriented sensors.

II. THE MEASUREMENT SYSTEM

A moored system for low-cost sensing, will obtain light (irradiance) measurements at different depths. These measurements will enable to estimate optical parameters related to water transparency such as light extinction or attenuation coefficients.

The target citizen community that will interact with the measurement system is people involved in aquatic activities such as sailing, artisanal fishing or sea-kayaking, carrying a mobile device with a dedicated wireless personal area network (WPAN) application.

The role of the participants is to act as “data carriers” (Fig. 3): whenever they are close enough to the moored sensor system (cBuoy hereafter), within the communication connectivity-range (Fig. 3-1), data will be automatically transmitted to their mobile devices (cCarrier hereafter). The mobile devices will automatically retransmit the data once they have the possibility to connect to a data center (Fig. 3-2). Thanks to this communication system, it will not be necessary to pay for any additional connection (3G, GPRS...).

Fig. 1. Example of low-cost moored sensor technology and the process to retrieve data from a sailing boat (1) the will be retransmitted and uploaded to internet once the boat is close to the land internet server.

The module structures of the cBuoy and the cCarrier are shown in Figure 2 and Figure 3 respectively.

The cBuoy is composed by 4 elemental parts:

Array of light sensors

Fig. 2. Basic Hardware structure of the moored system, the cBuoy

The hardware structure of the cCarrier is very similar to the structure of the cBuoy.

Fig. 3. Basic Hardware structure of the mobile device, the cCarrier

The system has been implemented using an open-source platform based on Arduino. One of the final goals to this project is also to offer hands-on workshops inspired by the idea of "create your own instruments", incrementing crowdsourcing capabilities.

The first cBuoy prototype allows to control up to 6 light sensors (see Figure 4, prototype photo). The light sensors are quasi digital-optical sensors that convert light irradiance measurements into frequency. With this simple conversion it is possible to obtain large time integrated measurement of irradiance values near the water surface, reducing the measurement variability derived from the large light fluctuations caused by focusing of sunlight by surface waves [3].

Fig. 4. cBuoy prototype, based on Ardiono platform. Six sensors connected with different length cable (1-10 m). Detail of the glass capsule and the sensor in the final sensor assembly (filling the capsule with semitransparent silicone)

This large time integration allows obtaining robust estimations of vertical light extinction without the need to take into account potential measurement systems caused by the state of the surface waves.

The sensors are assembled in a glass capsule filled with semitransparent silicone. The silicone acts as a waterproof isolator and also as a low cost light diffuser.

The next figure shows the mobile device prototype. The data retrieval procedure has been designed as simple as possible for non-expert users: when the button is pushed, the cCarrier sends a message to the cBuoy asking the measurement data that it is saved onto memory.

Fig. 5. cCarrier prototype, based on Arduino platform.

III. THE MEASUREMENT DATA AND THE DOWNWELLING DIFFUSE ATTENUATION COEFFICIENT

The light-to-frequency converter used is the TSL230RP-LF (3). According to the sensor specifications, the output frequency has a linear dependence with the light intensity. obtain averaged irradiance measurements at different depths. The measurement time integration was set to 10 s.

Fig. 6. Test of the cBuoy system.

Beer's law states that intensity of light decreases exponentially as a function of depth in the water column and is described mathematically as:

$$E = E_0 e^{-K_d z} \quad (1)$$

where:

E Irradiance at given depth

E_0 Irradiance at the surface

K_d Diffuse attenuation coefficient

z depth

The instantaneous output frequency from the light sensors may change according to the light fluctuations caused by the surface waves. However the number of the pulses generated by the light sensors during the integration interval should be proportional to the averaged irradiance. According to (1), there should be a linear relationship between the measurement depth and the natural logarithm of pulses.

Figure 7 shows the linear relationship between $\ln(\text{pulses})$ and the depth measurement (the estimated K_d is 0.65 m^{-1} , with a regression coefficient of 0.94).

Fig. 7. K_d calculation with the cBuoy system with six sensors at different depths. In vertical, the value of the logarithm of the number of pulses counted during the integrating time interval (10 s) sensors. the number of the sensor.

It's important to note that in this test result and there was not any correction procedure to reduce the sensor measurement variability. The sensibility may change due several factors (capsule orientation in the water, internal sensor position within the glass capsule ...). Even without this factor correction, the linear relationship between the $\ln(\text{pulses})$ and sensor depth is very high. This result indicates that the design is very robust to potential construction or assembling errors when the system is built by non-expert participants.

The overall system cost less than 150 euros, so it is possible to design monitoring areas covered with this measuring system at very high spatial resolution. An example of a potential application is shown in Alfacs Bay (Ebro Delta, Spain) one of the tests sites in Citclops project.

Fig. 8. Hypothetical distribution of several cBuoys in the Alfacs Bay, Spain, to measure the continuous changes of K_d in this area.

This low-cost solution could complement other volunteer programs to monitor water transparency. For example the Secchi Dip-in initiative is a volunteer monitoring program initiated on 1994. The volunteers estimate the water transparency using simple instruments and manual methods. Now, the Dip-In database has grown to more than 41,000 records. The use of low cost systems to retrieve automatically similar information may allow increasing the data flow and simplifying the data quality control procedures.

IV. ONGOING WORK

This project is starting now. There is a lot of work to do. In the following list there are some points to improve on:

- 1) To make an efficient Arduino algorithm in terms of power consumption.
- 2) To make an algorithm to do the calibration of the sensors.
- 3) To improve system mechanics.
- 4) To try other light sensors.
- 5) To compare the data measurement of the cBuoy with the data measurements of the commonly used measurement systems and come to conclusions about errors associated with the cBuoy system.

V. SUMMARY

With the instrument proposed, based on quasi digital-optical sensors and an Arduino platform, we have obtained a low cost and easy-to-use system to measure of light (irradiance) values near the water surface, reducing the measurement variability derived from the large light fluctuations caused by surface waves. The instrument could transmit the measured information to the citizens' mobile devices via WPAN and finally, they will act like "data carriers" to transmit the data measurement to a data center.

With the measurement data, it is easy to calculate the downwelling diffuse attenuation coefficient (K_d) a parameter related to water transparency.

The project is in the initial face. Further improvements are planned, but the results of the first prototype are promising and encourages us to continue developing one of the first open-hardware system that supports the Citclops project, an initiatives for marine environmental participative science.

ACKNOWLEDGMENT

The research described in this paper is supported by the Citclops European project (FP7-ENV-308469).

We would like to thanks to Marta Ramírez and Manuel Morón for help us with the prototype validation test.

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