Talanta 132 (2015) 520–527

Contents lists available at ScienceDirect

Talanta

journal homepage: www.elsevier.com/locate/talanta

A low-cost autonomous optical sensor for water quality monitoring

Kevin Murphy [a], Brendan Heery [a], Timothy Sullivan [a], Dian Zhang [a,b], Lizandra Paludetti [a,c], King Tong Lau [b], Dermot Diamond [b], Ernane Costa [c], Noel O'Connor [b], Fiona Regan [a,*]

[a] Marine and Environmental Sensing Technology Hub (MESTECH), NCSR, Dublin City University (DCU), Glasnevin, Dublin 9, Ireland
[b] CLARITY, Centre for Sensor Web Technologies, NCSR, Dublin City University (DCU), Glasnevin, Dublin 9, Ireland
[c] LAFAC Applied and Computational Physics Laboratory, University of São Paulo, Pirassununga, São Paulo 13635-900, Brazil

ARTICLE INFO

Article history:
Received 27 May 2014
Received in revised form
16 September 2014
Accepted 18 September 2014
Available online 7 October 2014

Keywords:
Optical sensor
Environmental monitoring
Low-cost sensors
Water quality
In-situ sensing

ABSTRACT

A low-cost optical sensor for monitoring the aquatic environment is presented, with the construction and design described in detail. The autonomous optical sensor is devised to be environmentally robust, easily deployable and simple to operate. It consists of a multi-wavelength light source with two photodiode detectors capable of measuring the transmission and side-scattering of the light in the detector head. This enables the sensor to give qualitative data on the changes in the optical opacity of the water. Laboratory tests to confirm colour and turbidity-related responses are described and the results given. The autonomous sensor underwent field deployments in an estuarine environment, and the results presented here show the sensors capacity to detect changes in opacity and colour relating to potential pollution events. The application of this low-cost optical sensor is in the area of environmental pollution alerts to support a water monitoring programme, where multiple such sensors could be deployed as part of a network.

1. Introduction

The monitoring of European water bodies has historically been limited but there has been a step change owing to the adoption of the Water Framework Directive (WFD) in Europe [1]. In response to this as well as other legislations including the Bathing Water Directive [2], the Birds Directive [3] and the Habitats Directive [4], the monitoring of water within Europe will increase in coming years. Additionally the pressures of climate change, which will lead to resource scarcity and water quality changes, give a strong scientific and economic argument for the expansion of aquatic monitoring. All of these factors will drive the increase in environmental monitoring by regulatory agencies, although it should be noted that the high cost associated with physical sample collection and the transportation to, and subsequent analyses in, laboratories is one of the reasons for the low level of monitoring over the years [5]. The precision and accuracy of these techniques, along with their adherence to standard techniques for legal and regulatory procedures has maintained the need for these methodologies. The initiative for more monitoring has not necessarily been matched by an increase in funding for these activities, which means that new technology should be employed to meet the desired increase in spatial and temporal monitoring.

The use of *in-situ* sensors, capable of continuously monitoring chemical and physical parameters, has been increasing in the recent past and offers a potential solution to some of the challenges outlined above. They can also provide real-time information and contribute to a better representation of long-term trends in aquatic environments [6]. It is now technologically conceivable to envision a network of sensors being deployed at key spatial locations, capable of autonomous operation in the field for a year or more and providing real-time alerts for key events [7]. The area of wireless networked sensors is fast becoming one of the most dynamic and important areas of multi-disciplinary research [8,9]. The communications and data gathering abilities of the network need to be of a high quality and suit the tasks at hand. The data from remote continuous monitoring of the environment can be, and is already being, used for a variety of applications, in addition to environmental protection [10,11]. Despite the promise of such a system many challenges remain using currently available technology, including a limitation in the analytes measurable, interferences, bio-fouling issues, expense, power requirements and the need for frequent calibrations. In essence the major issue for environmental sensing remains, in some instances, being able to accurately measure and detect environmental pollutants in laboratory conditions, but struggling to reproduce these results in the field with continuous *in-situ* monitors [12].

If these networks of sensors are to become not only a reality but commonplace it is necessary to produce reliable, inexpensive *in-situ* sensors. This means costs need to be considerably reduced

* Corresponding author.
E-mail address: fiona.regan@dcu.ie (F. Regan).

http://dx.doi.org/10.1016/j.talanta.2014.09.045
0039-9140/

but also, and as importantly, retain and increase the accuracy of the measurements. Some of the recent developments in the this field have included *in-situ* fluorometers for the measurement of phytoplankton [13], chemical sensors for pH measurements [14], and the use of optical refractive index measurements for generic water event detection [15]. While some of these sensors are less precise than laboratory techniques or some existing continuous monitoring sensors they can produce extremely useful data. A barrier to deployment of successful monitoring networks up to now has been cost and availability of analyte specific sensors. The sensor described here proposes to address the cost issue – enabling the development of a low-cost network to provide valuable qualitative information on water quality that can lead to more informed decisions. These devices can be used to inform grab sampling and lead to the desired quantitative analytical approaches at appropriate times and locations. They can give indications of pollution, as early warning systems, or observe trends in environmental conditions.

This paper presents a low-cost, robust and easily deployable sensor for the monitoring of aquatic environments. This multi-wavelength optical sensor has been designed so that it can be operated on an autonomous basis or in a network of sensors and thus is equipped with telecommunications. The sensor is capable of measuring the transmission of light emitted by five separate LED light sources through water, while simultaneously measuring the side-scattering of the light measured at right angles to the transmission path. The optical colorimetric sensor (OCS) is devised to give data on bulk water property changes, particularly opacity and colour changes.

The OCS is not a turbidimeter or a chlorophyll sensor, though it can clearly provide valuable data relating to turbidity events and primary productivity events. The analytical objectives of the OCS are the determination of qualitative variations in water quality based on opacity or colour changes due to pollution events or temporal environmental events. By qualitative it is meant that the optical responses observed using the system are related to opacity changes in the aquatic environment. This qualitative response is confirmed by co-deploying and correlating the trends of the OCS with a sensor sonde measuring multiple environmental parameters over the test period. The target water quality parameters are water opacity based on transmission measurements of different coloured LEDs. The advantages over existing devices include its autonomous nature, low cost and environmental robustness that could lead to multi-sensor deployments for a sensor network. The device can be used to detect pollution events that result in an increase in suspended solids, algal blooms or other environmental events.

Commercial water sensing equipment, in the form of either multi-parameter sondes or single parameter sensors, dominate the environmental sensing market. The cost of these sensors can be prohibitive and when anti-fouling measures and logging systems are taken into the account purchase costs can be further elevated. All sensors require cleaning and maintenance at regular intervals by well trained personnel, which makes the cost of ownership sometimes prohibitively expensive – particularly during the summer. The OCS described here would reduce the purchase and maintenance costs of the sensor (including anti-fouling and logging systems). This makes it possible to build a sensor network over a large spatial area of an interesting aquatic system with a high spatial resolution thereby allowing for the creation of a real-time pollution alert system.

This paper is structured as follows; an introduction of the topic of low-cost optical monitoring in a marine environment is given in this section. The Experimental section gives the details of all the materials and methods used in the construction and testing of the sensor in the laboratory and in field deployments. The Results and discussion section analyses and presents the data gathered in the laboratory and in the environment and discusses the outcomes. The Conclusions section reviews the paper, highlighting the ability of the low-cost sensor to detect shifts in water colour and opacity in both the laboratory tests and field trials.

2. Experimental

This section describes how the optical sensor is designed and built, as well as outlining all key elements of the sensor. Sections 2.3 and 2.4 delineate the tests carried out both in the laboratory to characterise the sensor and the field trials undertaken to observe the performance under real-life conditions.

2.1. Materials

The photodiodes were manufactured by Texas Instruments (OPT101P) and were purchased from Farnell electronics (www.farnell.com), as was the Raspberry Pi (Model B) and its accessories. The LEDs were obtained from Radionics via RS-online (www.rs-online.com) and were manufactured by Avago Technologies (Amber; HLMP-3850), Kodenshi (IR; OPE5685) and Knightbright (Red; L-7113EC, Blue; L-53MBC and Green; L-7113VGCK). The Wixel module was from Pololu Robotics and Electronics and was purchased via Cool Components (www.coolcomponents.co.uk).

The PVC-U tubing for the body of the sensor, the stainless steel parts and the copper plating were acquired from local hardware and marine boating suppliers. The clamps and O-rings were purchased from Alfa Laval (http://www.alfalaval.com/). The enclosures for the electronics were obtained through Radionics Ireland and Dexgreen (http://www.dexgreen.com/).

The food dyes used were E133 Brilliant Blue FCF (blue), E124 Ponceau 4R (red), E102 Tartrazine and E142 Green S (green) and E110 Sunset Yellow (yellow), from Goodall's of Ireland. The two turbidity standards were a Formazin solution (246142) from HACH and a Styrenedivinylbenzene copolymer solution (6073G) from YSI (a Xylem brand).

2.2. Design and construction

The complete sensor system, illustrated in Fig. 1, has the following features: an LED array light source, two photodiode detectors (90° and 0° to the light source), a low cost (Table 1), a robust re-deployable design, flexible electronic control, in-built antifouling measures, optional GSM communications, an optional integrated temperature sensor and a custom built data logger. Table 1 gives a breakdown of the components cost at the time of manufacture.

2.2.1. Sensor body

The OCS is constructed using low cost, robust materials (stainless steel 308 and 304, PVC-U, copper, rubber and IP 67 and IP 68 rated enclosures). It consists of a stainless steel sensor head protected by copper, a foam-filled floatation chamber, double sealed electronics housing, stainless steel mooring point and ballast chain.

Fig. 1(a) gives an exploded view of the device with the numbering corresponding to Table 2 which lists all of the labelled components and materials. Fig. 1(b) presents a schematic of the sensor head showing the configuration of the LED array, along with relative locations of photodiodes. The OCS can be moored in various ways, including standalone (floating), buoy integrated or pier attached. The OCS is positively buoyant; with the ballast chain attached and connected as a single point mooring, it floats at the surface. In this configuration the sensing elements are submerged to a depth of 1 m, with the electronic and communication housing above the surface.

2.2.2. Sensor head design and Optics

The sensor head is the part of the sensor which houses the optics and the detection abilities of the sensor. As the sensor is