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Wireless aquatic navigator for detection and analysis (WANDA)

Cormac Fay[a], King-Tong Lau[a], Stephen Beirne[a], Ciarán Ó Conaire[a], Kevin McGuinness[a], Brian Corcoran[a], Noel E. O'Connor[a], Dermot Diamond[a,*], Scott McGovern[b], Greg Coleman[b], Rod Shepherd[b], Gursel Alici[b], Geoff Spinks[b], Gordon Wallace[b]

[a] CLARITY: Centre for Sensor Web Technologies, Dublin City University, Glasnevin, Dublin 9, Ireland
[b] Intelligent Polymer Research Institute, ARC Centre of Excellence for Electromaterials Science, University of Wollongong, NSW, Australia

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ABSTRACT

The cost of monitoring and detecting pollutants in natural waters is of major concern. Current and forthcoming bodies of legislation will continue to drive demand for spatial and selective monitoring of our environment, as the focus increasingly moves towards effective enforcement of legislation through detection of harmful events, and unambiguous identification of perpetrators. However, these monitoring demands are not being met due to the infrastructure and maintenance costs of conventional sensing models. Advanced autonomous platforms capable of performing complex analytical measurements at remote locations still require individual power, wireless communication, processor and electronic transducer units, along with regular maintenance visits. Hence the cost base for these systems is prohibitively high, and the spatial density and frequency of measurements are insufficient to meet requirements. In this paper, we present a more cost effective approach for water quality monitoring using a low cost mobile sensing/communications platform together with very low cost stand-alone 'satellite' indicator stations that have an integrated colorimetric sensing material. The mobile platform is equipped with a wireless video camera that is used to interrogate each station to harvest information about the water quality. In simulation experiments, the first cycle of measurements is carried out to identify a 'normal' condition followed by a second cycle during which the platform successfully detected and communicated the presence of a chemical contaminant that had been localised at one of the satellite stations.

1. Introduction

It has been long recognised that the interaction between industrialised societies and the environment can be negative, in that concentrations of people in urbanised areas, with co-located industries will have a negative impact on the overall quality of the environment. An important aspect of this interaction is the release of pollutants into local water bodies, such as rivers and lakes, which can adversely affect the health of people and cause devastating fish kills [1–6]. Consequently, environmental protection is a priority in modern society, and an extensive, and growing, body of legislation exists that specifies the limits of key chemical and biological pollutants in various types of water (potable, drinking, ground, etc.) [7–9].

Arising from the enforcement of this body of legislation is a growing need to police these pollutant limits, through analytical measurements that are used to determine the water quality [10]. However, these measurements are almost always achieved by taking samples from a relatively small number of designated locations, and analysing the composition at a centralised laboratory facility equipped with sophisticated state-of-the-art equipment. There are good reasons for employing this strategy, principally because of the high precision and accuracy of the measurements, which are vital for obtaining legally binding decisions against polluters. However, because of the expense involved to manage the analytical facilities and monitoring programmes, this model is inherently not scalable, and measurements are very restricted in terms of the number of locations and sampling frequency [11,12].

In recent years, we have developed autonomous analyser platforms that can perform complex analytical measurements at remote locations, and make the resulting data globally available via websites. However, the cost base for these devices is still relatively high as it includes pumps, valves, microfluidics, optical detection, reagents, standards, electronics, power, and wireless communications, all housed within a robust enclosure [13–15]. In this paper, we present a radically different approach to remote water quality monitoring based on a low cost, biomimetic robotic fish, known as WANDA (wireless aquatic navigator for detection and analysis). The WANDA platform is capable of movement via a polymer actuator based tailfin [16], and can report what it 'sees' via an integrated

* Corresponding author.
E-mail address: dermot.diamond@dcu.ie (D. Diamond).

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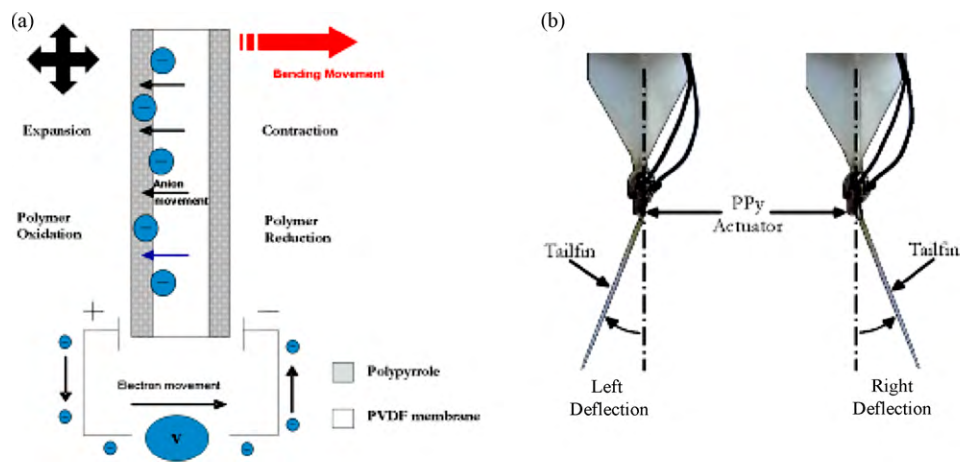

Fig. 1. (a) Cross-sectional diagram showing bending principle of the tri-layer conducting polymer actuators. Applying a low electrical potential 'V' causes oxidation of one polypyrrole layer and reduction of the other resulting in a bending movement. (b) Images showing the resulting bending movement of WANDA's polymer actuators when a rigid tailfin is attached.

low-power wireless video camera. The biomimetic fish can be used in conjunction with very low cost, dispersed, colorimetric 'satellite' sensors integrated into an easily recognised 3D form that enable very effective shape-identification algorithms [17] to be employed to distinguish the sensor from its surroundings. Once the sensor has been located, the camera is used to interrogate its condition and make the resulting data available via a wireless link. In this manner, a single, low-power robotic platform can harvest analytical information about the local chemical and/or biological environment at multiple locations using very low cost sensors.

In this paper, we demonstrate the principle of this approach using dispersed colorimetric sensors to probe changes in the local pH at several locations. Specifically, a water container of sufficient size (to allow for manoeuvrability) is setup within a laboratory setting. Several colorimetric sensors are then dispersed within the water container whereby an initial sensing patrol by WANDA allows for reference measurements of the sensors in uncontaminated conditions. A subsequent sensing patrol takes place whereby the water surrounding one station is acidified, resulting in a colorimetric change that is sensed by the camera. The results of the two patrols are compared showing that a change in pH has occurred in the water surrounding the station.

2. Robotic fish platform

The mobile wireless sensor platform used combines many disciplines into one practical device including materials science, wireless communications, vision systems, chemistry, systems control, biomimetics and robotics. However, in this paper, we will focus on three of these:

- the biomimetic novel propulsion method;
- the ability to navigate and sense chemical events;
- system construction and control.

2.1. Propulsion method

Conducting polymer actuators (or artificial muscles) based on polypyrrole (PPy) [18] have been utilised within the propulsive element of the tailfin of WANDA. With the application of an oscillating voltage (e.g. a low voltage square wave, ±1 V 1 Hz), a bi-directional bending movement is derived from the actuators as one side becomes oxidised, and the other side is reduced. This oxidation/reduction process is accompanied by swelling/contraction of the respective polymer layers, due to movement of anions and water of hydration associated with the maintenance of overall charge neutrality, see Fig. 1a. In such a system, the direction of bending is controlled by the polarity of the applied voltage. If a rigid tail fin is attached to a pair of actuators (Fig. 1b) the force generated can enable a transfer of energy from the bending motion of the actuator to the water.

2.2. Navigation and sensing

The WANDA platform is equipped with a wireless video camera for two main purposes. The first is for navigation as, through the video images, one can estimate the location of the device while building a map of the environment. This technique, known as simultaneous localisation and mapping (SLAM), has received continuous attention for the last two decades [19,20].

The second purpose of the onboard camera is to harvest information about the chemistry of the water body it moves through. In this study, we achieve this through the use of a number of sensing stations fitted with a chemo-responsive dye which responds colorimetrically to changes in the chemistry of the local environment. By using the onboard camera, a mobile device can easily detect differences in colour and, in turn, this can be related to the levels of certain chemicals in that region of the water body. Previous works [21–25] have shown that it is possible to monitor changes of pH in a laboratory using a colour camera, and we have therefore selected this measurement as the proof of principle test for the platform.

2.3. System construction and control

A primary goal for the research was to control the movement of WANDA using a biomimetic polymer actuator. Fig. 2 shows the assembly of the WANDA fish platform presented in schematic (Fig. 2a) and photographic (Fig. 2b) formats for clarity. The main components, i.e. wireless camera and control circuitry, are housed within a waterproof container (a truncated 50 ml syringe). Connected to the casing's bung are the PPy actuators to which the tailfin (cut from a thin plastic sheet) is attached. The range of the WANDA device is dictated by the wireless camera allowing for a transmission length of 100 m [26]. The control circuitry is powered from the wireless camera's battery allowing for a continuous operation (PPy bi-directional actuation of 1 Hz with wireless video transmission) of WANDA for a period of ca. 3.5 h in its current configuration.

By coupling the propulsion method with machine vision techniques, autonomous control is achievable. Further, by interpreting the scene with data captured by the onboard camera using a