WANDA: A Radically New Approach for Low-Cost Environmental Monitoring

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Introduction

The cost of monitoring pollutants within natural waters is of major concern. Existing and forthcoming bodies of legislation continually drive the demand for spatial and selective monitoring of key pollutants within our environment. Although research and commercial entities continue to drive down the cost of the infrastructure involved in environmental sensing systems (with an aim to increase scalability), the realisation of deploying a number of such systems even now remains out of reach. High cost and maintenance continue to persist as the major limiting factors.

The aim of this work is to combine recent advances in robotics with chemical sensing techniques to remove all but the chemo-responsive material from each sensing node, and package the sensing element within a low cost, mobile, biomimetic robotic fish for effective water quality monitoring. Consequently, this approach is believed to radically reduce the systemic cost and maintenance per node and in doing so it will increase the scalability for spatial and selective monitoring of key pollutants within our environment.

Background

Current and forthcoming bodies of legislation brings with them a growing need to police pollution limits within our environment at a higher sampling and temporal rate than ever before. Here, a brief description is given to the current (or manual) sensing model, followed by the promising approach based on wireless sensor networks (WSNs) and finally an experimental sensing model presented in this work is examined that may address the disadvantages of WSNs.

Current Sensing Approach: The current method for determining chemical concentration levels of the environment is almost always achieved through laboratory based analysis of manually collected sampled using sophisticated state-of-the-art equipment and highly trained personnel. It has now become apparent that the current sensing model is no longer viable to comply with increasing legislative demands mainly due to its cost, spatial and temporal sampling rate. Thus, a more autonomous approach is needed.

Conventional Sensing Model: In recent years the emergence of key technologies capable of performing complex analytical measurements 'in situ' have been seen in the literature. These have almost always been based on emerging communication protocols such as ZigBee for WSNs. Fig. 1a depicts a typical WSN system architecture showing the progression of sensor information to data coordinators. Each End Device, and indeed Routers/Coordinators alike, requires many individual sub units for this model to function, see Fig. 1b. This means that each node requires regular maintenance visits and/or replacement parts and as a result its cost base increases dramatically limiting the spatial sampling frequency of our environment.

Proposed Sensing Model: The work presented herein aims to address the key issues associated with the conventional sensing approach by removing all nodal sub elements except the chemo-responsive material (Fig. 1b) and using a single mobile, autonomous sensing platform to perform the in situ analysis of many sensing nodes. The ultimate findings of this work are expected to reduce the overall cost base significantly and increase the spatial sampling frequency.

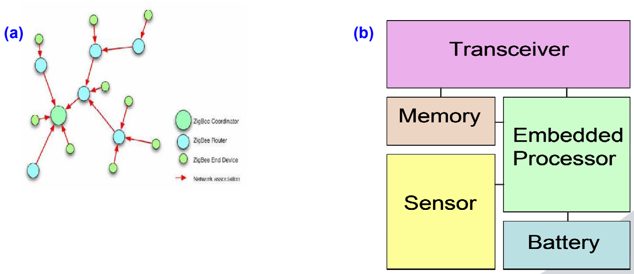

Figure 1. (a) A generic wireless sensor network system architecture based on the ZigBee communications protocol. This shows the typical infrastructure necessary for a WSN and interactions thereof. The Coordinator communicates the sensed data from the End Devices (relayed via Routers) to another tier such as sensor network servers and ultimately for storage on databases. (b) Typical composition of an End Device requiring a minimum of a power source, processing capabilities, the sensor and a radio/transceiver.

Proof of Principle Study

Our efforts to date have resulted in a criteria for proving the principle of the new sensing approach. Firstly, the mobile sensing platform used in this study was equipped with a wireless camera, electronics control via radio and propelled by conducting polymer actuators that results in a fish like movement of the platform (Fig. 2). The function of the camera is two fold; 1) for navigation and 2) for colorimetric sensing of chemo-reactive materials affixed to the sensing stations (Fig. 3a). To this end, we chose pH as our target chemical species because of its importance in water quality and the wide availability of colorimetric pH indicators.

Next, the platform was set to patrol along a fixed patrol route within a water area consisting of 3 sensing stations (Fig. 3b) where an image stream was constantly (25 fps) being streamed wirelessly to a laptop PC. Two patrols were carried out:

Patrol # 1: Normal condition; all landmark stations were green in colour.

Patrol # 2: Event occurred; the environment surrounding station L2 was acidified and the station indicated a yellow colour.

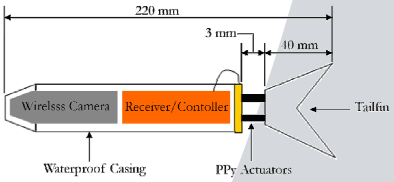

Figure 2. Diagram showing the wireless camera, controller, casing, PPy actuators, and tailfin arrangement on the WANDA device.

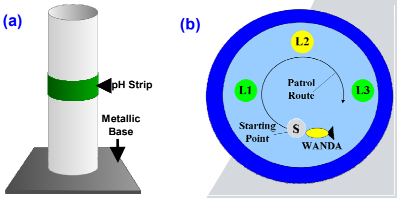

Figure 3. (a) Diagram showing the construction of a pH sensing station used during patrols. One strip of universal pH indicator coated with ethyl cellulose is attached around the centre of the vial. (b) Layout of pH stations and patrol route within the water container. 'S' starting and ending point of the patrol route, 'L1' pH station 1, 'L2' pH station 2, 'L3' pH station 3.

Three frames of each sensing station were analysed for both patrols and processed using appropriate image processing algorithms using the HIS colour space. Fig. 4a and 4b shows the results of the image analysis for Patrol 1 and 2 respectively. For comparison, Fig. 4c shows the ratio of each patrol where a single value of the three frames (average) is take as representative for each station. These results shows that it is possible to qualitatively determine the presence of a chemical contaminant using the approach proposed in this work.

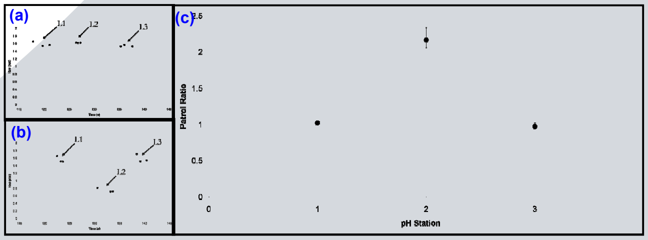

Figure 4. (a) Image analysis of Patrol#1. (b) Analysis of Patrol#2. (c) Comparison of Patrol#1 (stations uncontaminated) and Patrol#2 (station L2 contaminated). A single hue value is taken to represent each sensing station. Points represent the average hue ratio of station's L1, L2 and L3. Upper and lower error bars represent the max and min hue ratio respectively.

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