Real-time Detection of Water Pollution using Biosensors and Live Animal Behaviour Models

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INTRODUCTION

Victoria faces a number of significant issues related to the quality of its inland waterways and estuaries with 80% of them being reported to be in a very poor to moderate condition [1]. Catchment management authorities and water authorities are responsible for the condition of waterways and estuaries; however, existing monitoring systems are expensive, limited and consequently in many cases cannot identify the substances causing the damage. As a result, many once-popular waterholes and rivers have experienced degraded in-stream habitat and declining fauna populations. This has resulted in a negative effect on the many industries that rely heavily on waterways for productivity. Recreational activities on Victoria waterways alone are worth $368 million per year, whilst tourism and fishing expenditure, also dependent on river health, generate of the order of $533 million annually [2].

Existing processes for monitoring the health of the waterways and contamination events are expensive and human resource intensive requiring individuals to go to rivers and collect samples for chemical analysis and measurement of toxicity. This is very much after the fact. In contrast, behavioural and physiological responses of wildlife to pollution are sensitive, immediate and relatively simple to monitor. However, they require transmission and analysis of high volumes of data, which has so far limited their utility in field applications. In contrast to these approaches, catchment managers require affordable diagnostic tools with rapid response times to effectively identify and manage pollution events. The Victorian Department of Business and Innovation (DBI) has funded the ALARM project (http://capim.com.au/index.php?page=prac) to develop such a real time detection infrastructure.

AIMS

This project has developed biosensors comprising a BeagleBoard- and Arduino-based biosensor unit that automatically monitors animal behavioural responses to pollution in the field along with a rich variety of other information, e.g. temperature, turbidity, pH. BeagleBoard-based sensors have been used successfully in projects like the Acoustic Sensor Networks for Environmental Monitoring project [3], which has similar intent to the ALARM project. These units will be deployed in a variety of Victorian waterways, and potentially Australian waterways; creating flexible, integrated networks of biosensors that provide a sensitive and robust method of monitoring water quality. Each unit measures pollution impacts at spatial and temporal resolutions well beyond what is currently feasible. Algorithms will be developed to automatically raise warning signals when the changing behaviour of the monitored organisms indicates pollution-induced stress. By enabling a more rapid, targeted and appropriate response, the product will deliver significant health, productivity and environmental benefits to the Victorian community by immediate warning of declining water quality.

High Capacity Broadband – eventually through the National Broadband Network (NBN) once it is ubiquitous - will be used to transfer high-resolution data from each biosensor unit to a central database where an integrated perspective on the state of Victorian waterways can be ascertained. This will be used to develop automated pollution detection mechanisms based on the behaviour of a range of organisms in the presence of pollution. Such a capability is unique and urgently required by a variety of water and environmental agencies, government organisations, e.g. Department of Primary Industries, VicRoads, as well as industrial organisations, e.g. mining.

APPROACH

Recognising that existing monitoring regimes cannot sufficiently identify and isolate the causes and impacts of aquatic pollution, this project has developed affordable, robust biosensors. Each sensor captures both behavioural and physiological response of stream biota to pollution-induced stress through built in video capture systems. Suitably sized animals, e.g. shrimps, snails or other small vertebrates, are confined in flow-through cages (see Figure 1), and their behaviour monitored in real time. Physio-chemistry data such as turbidity, conductivity, pH, temperature and dissolved oxygen are collected in parallel by a set of standard water quality probes associate with each biosensor. Behavioural data can be combined with water physio-chemistry to capture both the normal animal responses as well as abnormal responses in real-time. Such abnormal behavior can be an immediate sign of potential water contamination.
Each biosensor unit consists of multiple cages and a set of physiochemical sensors; all contained in a robust, compact housing suitable for immersion. Data collected is streamed in real-time via a wireless link to a local router, then on to a central repository for analysis and storage. Multiple biosensor units will be deployed at a single site to allow for intra-sensor variation and to provide redundancy in the event of sensor malfunction. The range of behavioural responses of each biosensor unit can then be compared to infer the seriousness of the observed stress in relation to background variability. The test set-up and animal behavior models are shown in Figure 1.

![Figure 1: Test Environment and Animal Being Monitored](image)

The combination of an in-situ biosensor, physical water quality parameters, and diagnostic algorithms will grant catchment managers unprecedented access to real-time toxicity data. Deployment of a network of biosensor units in multiple locations along a stream will provide sensitive and robust diagnostic monitoring of water quality, at spatial and temporal resolutions well beyond what is currently feasible. To support this, seamless integration with advanced geospatial data processing capabilities and high-resolution maps of the Victoria waterways are required. The ALARM infrastructure currently uses Geoserver with Postgis (Postgres with GIS extensions) at the back end. The current user interface to the ALARM project is shown in Figure 2. This shows sensor networks deployed across Victorian waterways and the various sets of information that is currently streamed to the central database.

![Figure 2: Prototype ALARM User Interface](image)

**DISCUSSION**

This work is still very much ongoing, however the proof of concept biosensors and the analysis and visualization of data sets has already been demonstrated. The presentation will cover the implementation of the biosensors and the data streaming and visualization. One particular challenge that will be discussed is on the water catchment areas and how geospatial queries have been developed to understand which upstream tributaries could potentially have given rise to a pollution event. A further extension to this work is to apply machine-learning approaches (Bayesian neural networks) for automatic detection of abnormal animal responses in the presence of certain pollution events. Data Provenance techniques [4] can also be investigated to reduce the storage cost of data being streamed by the biosensors to the central server. The ALARM project began in October 2011 and will run for 2 years.
REFERENCES

About the Authors
Gerson C. Galang is a software developer (e-Enabler) at the Melbourne eResearch Group. He was formerly with the Victorian eResearch Strategic Research Initiative. He is a member of the Melbourne eResearch Group (MEG) and involved in the ALARM and AURIN projects.

Christopher Bayliss graduated from the University of Glasgow in 2005 with an MSci (Hons) in Computing Science, and then joined the National e-Science Centre in Glasgow in 2006 as a research associate where he worked on projects covering bioinformatics, cheminformatics, electrical engineering and e-Science infrastructure. He is a member of the Melbourne eResearch Group (MEG) and involved in the ALARM and AURIN projects.

Stephen Marshall is the manager of the ALARM project at the Center for Aquatic Pollution Identification and Management (CAPIM), based at the Zoology Department of the University of Melbourne. He has studied the effects of stormwater from highways and industrial areas on aquatic invertebrates. As part of this research, he has been involved in developing new sampling technologies to improve measurement of common pollutants such as hydrocarbons and heavy metals. He has also researched the use of field-based microcosms to investigate the ecological significance of pesticides commonly found in urban stormwater and sediments.

Prof. Richard O. Sinnott is Director of eResearch at the University of Melbourne. Before this he was the Technical Director of the National e-Science Centre at the University of Glasgow; Deputy Director of the Bioinformatics Research Centre (also in Glasgow) and the Technical Director of the National Centre for e-Social Science. He is the Technical Architect of the AURIN project. He has been involved in an extensive portfolio of e-Science projects in the UK, Europe and now in Australia.
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Title:
Real-time detection of water pollution using biosensors and live animal behaviour models

Date:
2012

Citation:

Publication Status:
Published

Persistent Link:
http://hdl.handle.net/11343/32699

File Description:
Real-time detection of water pollution using biosensors and live animal behaviour models

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