Sensor Networks Applications for Reefs at Racha Island, Thailand

Mullica Jaroensutasinee[1], Krisanadej Jaroensutasinee[1], Scott Bainbridge[2], Tony Fountain[3], Sirilak Chumkiew[1], Premrudee Noonsang[1], Uthai Kuhapong[1], Sornthep Vannarat[4], Amporn Poyai[4], Michael Nekrasov[3]

[1]CoE for Ecoinformatics, School of Science, Walailak University, Nakhon Si Thammarat 80161 Thailand
[2]Australian Institute of Marine Science, PMB 3, Townsville MC, QLD, 4810 Australia
[3]California Institute of Telecommunications and Information Technology, UCSD, CA, 92093 USA
[4]NECTEC, 112 Phahonyothin Road, Klong Luang District, Pathumthani 12120 Thailand
Corresponding author: jmullica@gmail.com

Abstract. Remote coral reef islands present a series of challenges for deploying coral reef sensor networks. This paper presents the experience of deploying sensor networks at Racha Yai Island in southern Thailand. Racha Yai Island is far offshore of Phuket and so the island suffers very little from sediment loads from Phuket. It is one of the most popular tourist sites for SCUBA/Snorkel activities in Phuket. It presents a logistically challenging environment for both researchers and instruments because it is characterised by large but shallow bays, storms, and occasional power and internet outages. The island's coral ecosystem consists of hard and soft corals with many marine resources. So far serious impacts on the ecosystem have included the 2004 tsunami, a major bleaching event in May 2010, and heavy tourist traffic from both snorkelling and SCUBA. In response to the bleaching event, a sensor network was installed in early 2011 to provide future real time information about events. The system installed includes an underwater camera, two shore cameras, a CTD, multiple HOBO temp/light sensors, G sensors and two Davis weather stations. Data are streamed through multiple DataTurbine servers and put into in-house data servers in several formats after cleaning with data quality tests including statistical ones. The data are then available on-line through a public outreach site. This site is part of CREON (Coral Reef Environmental Observatory Network) and is under consideration for inclusion in the International Long Term Ecological Research (ILTER) Network.

Key words: Coral sensor network, DataTurbine, CREON, Thailand.

Introduction

Climate change and increases in sea surface temperature (SSTs) are projected to be very likely in the coming decades (IPCC2007, Phinney et al. 2006). Combined with the acidifying effect of increasing dissolved carbon dioxide in the ocean (Keypas and Langdon 2006), there is a clear research need to understand the likely impacts of climate change on marine ecosystems.

Coral reef ecosystems are sensitive to climate changes in the physical environment. Coral bleaching caused by unusually high sea temperature has had devastating and widespread effects worldwide. Numerous physical factors reduce the incidence of coral bleaching such as low light (Mumby et al. 2001), high flow (Nakamura et al. 2003), lower temperature (McClanahan 2008) and higher nutrients (Grottoli et al. 2006). The link between physical conditions and the biological responses that lead to coral bleaching allows for the prediction of when corals may bleach based on measurements of the in-situ physical parameters. Monitoring of these parameters therefore becomes an important part of understanding and responding to coral bleaching events.

Sensor networks are envisioned to enable application for environmental monitoring (Pompili et al. 2009, Xie et al. 2010). They allow for the monitoring and detection of phenomena more accurately and rapidly in a variety of geographical areas. Recently, applying sensor networks in underwater environments has received growing interest (Akyildiz et al. 2004, Chitre et al. 2008, Liu et al. 2008).

Cameras have been extensively used in ecology by taking advantage of the camera's ability to provide unobtrusive observations over long time periods in inaccessible locations (Karanth and Nichols 1998, Silveira et al. 2003). Most camera deployments are only for short periods limiting the number of images that are captured and so the number and type of events recorded. A permanently installed network-connected web camera can capture a constant set of images and data indefinitely ensuring that even rare events are sampled. Similarly, networked sensors measuring physical characteristics of ecosystems can provide high-resolution records over long time periods. Integrated sensor suites for capturing numeric and image data can generate high data rates. These high data rates and the heterogeneity of the data types demand new approaches to networking, data management, visualisation, and analysis.

Access to near real-time data during bleaching events, using sensor networks, is essential in advancing our understanding. Early warning of local conditions likely to cause coral bleaching could enhance regional alerts. In this paper, we describe a coral reef sensor network at Racha Island, Phuket, Thailand.

Materials and Methods

Study Site

Racha Yai Islands is located at Phuket province, Thailand (Latitude 7.60488 °N, Longitude 98.37660 °E) (Fig. 1, Google Earth). Coral reefs in this area are typically shallow (1-15 m depth) fringing reefs. The Racha Island site is a logistically challenging environment for both researchers and instruments, characterised by large but shallow bays, storms, and occasional power and internet outages. The climate is tropical with mean monthly temperatures that range between 25-30 °C. Note that large scale bleaching was observed at this site in 2009-2010 with some of the HOBO loggers recording water temperatures of up to 33 °C.

Figure 1. Racha Island, Thailand.

This project is part of the Coral Reef Environmental Observatory Network (CREON), a group of international institutions made up of scientists and engineers whose goal is to develop tools for coral reef research. Building on CREON, this project is a collaboration between a diverse team of ecologists, computer scientists, and engineers from the California Institute of Telecommunications and Information Technology at the University of California San Diego (CalIT2 UCSD, www.calit2.net), the Australia Institute of Marine Science (AIMS, www.aims.gov.au) and the Centre of Excellence of Ecoinformatics, NECTEC-Walailak University. This deployment builds on the experiences of CREON members in establishing coral reef observatories that share and interchange data from multiple sites around the Pacific Rim. It is envisioned to be a living laboratory for long-term studies of marine ecology and as a test-bed for evolving technologies for environmental and biological sensing, communications and analysis.

Instruments and Infrastructure

The following description of the current deployment is organised into three areas: field deployment, cyber-infrastructure, and visualisation.

Field Deployment

At the field site, there are a variety of aquatic and terrestrial sensors that provide a comprehensive view of the environment for coral reef ecology. All of these instruments are commercially available and widely used by the marine sciences community (Table 1).

Table 1. Deployed sensors in real-time system.

Sensor	Sampling Interval	Measurements	Networked
Weather Station	1 min	Temperature, Rain, Wind, Humidity, Bar Pressure, Solar Radiation	Yes
CTD	5 min	Conductivity, Temperature, Depth	Yes
HOBO	10 min	Temperature, Light	No
EcoCam	Continuous	Video	Yes

On June 2007, HOBO Pendant temperature and light data loggers (UA-002-64) were deployed to measure water temperature and light intensity with a 10 min sampling frequency. These sensors are not networked and require a diver to collect data every three months.

In November 2009, a Davis Vantage Pro II Plus weather station for measuring air temperature, rainfall, wind, barometric pressure, UV index and solar radiation was installed on shore with a 1 min sampling frequency.

On February 2010, four EcoCams capable of real time video capture were deployed, two underwater on the reef and two on land. The cameras provide researchers and students with a real time view of the reef and surrounding environment.

In October 2010, a SeaBird SBE37 conductivity (salinity), temperature and depth (via pressure) sensor package, commonly referred to as a CTD, was deployed on the fringing reef in approximately 10 m water depth with five minute sampling frequency. The deployment uses inductive coupling technology to send the data back to the station on the shore. A 350 m plastic coated steel cable (mooring wire) runs from shore to the CTD, secured at 10 m intervals by three kg cinder bricks. The CTD is connected to the mooring cable via an inductive modem connection. In the future, additional sensors can be attached to this cable to provide additional measurements without needing to change the cabled network infrastructure. This system provides a scalable and robust foundation for communication between sensors and the on-shore data processing computer.

Cyber-infrastructure

The weather station, CTD, and EcoCams stream observations in real time to a Data Centre located at Walailak University (WU) and mirrored to UCSD and Nakhon Si Thammarat Rajabhat University (NSTRU). The system includes cyber-infrastructure for real-time streaming data acquisition, scalable event stream processing, and data publication services. Scientists at WU, UCSD, AIMS and other remote locations access the data and event streams via a suite of client applications for visualisation, modelling, and analysis. The system is engineered to be scalable, robust, extensible, and secure. It is built using state-of-the-art open-source software tools.

The acquisition and transfer of data is accomplished using DataTurbine, a real-time streaming data engine (Drollet et al. 1994). It is an open-source middleware product supported by NSF, NASA, and private industry managed by the NSF-sponsored Open Source DataTurbine Initiative at CalIT2 (www.dataturbine.org). The DataTurbine middleware satisfies a core set of infrastructure requirements that are common in environmental observing systems, including reliable data transport, a framework for integrating heterogeneous instruments, and a comprehensive suite of services for data management, routing, synchronisation, monitoring, and visualisation (Tilak et al. 2007, Fountain et al. 2009). From the perspective of distributed systems, the DataTurbine middleware is a "black box" to which applications and devices send and receive data. DataTurbine handles all data management operations between data sources and sinks, including reliable transport, routing, scheduling, and security. DataTurbine accomplishes this through the innovative use of flexible network bus objects combined with memory and file-based ring buffers. Network bus objects perform data stream multiplexing and routing. Ring buffers provide tuneable persistent storage at key network nodes to facilitate reliable data transport.

In addition to DataTurbine, a secondary system for storing video data is used. In conjunction with the cameras, the submersible underwater monitor system (CR110-7) and Recorder DVR (FK-RJ2604) provide a high frequency feed for live observation, with periodic archiving of images for retrospective analyses. Live online feeds provide updated images every 5 s, which is a compromise between researcher needs and camera capabilities. Archive images are typically taken every three hours. Files are transferred real-time online into an FK-RJ2604 DVR device.

Data from the DataTurbine server are extracted and uploaded to a database on a regular basis (daily) and this forms the long term data store for the project. Data from the logging HOBO sensors are manually uploaded to this database after every download (three monthly) to produce a final integrated data set. The time codes stored in the database can be manually matched to the video to link the visual data to the physical data; work is underway to automate this process so that for any set of physical measurements the video can be automatically viewed.

Visualisation

This site uses a variety of techniques to visualize and share data. Our primary objective in creating this site was to make information freely and easily accessible both to ecological researchers and school students. All the research work is documented and photographed, and activities, as well as results of research are published to http://www.twibl.org/virtualsites/ for use by schools. The video streams are accessible through a website by researchers and students.

All data are also accessible through the DataTurbine as well as a number of client applications that interface with DataTurbine that can be run remotely. Some of these operate on real-time data streams; some operate on the archived data. These include the DataTurbine Real-time Data Viewer (RDV), a utility for creating embedded web page graphs, a MATLAB interface, and a Google Earth plug-in.

Through DataTurbine, users can see temporally synchronised streams of both video and numeric data allowing researchers to match environmental variables on air and water with pictures, providing context. There are also plans to utilise the DataTurbine services to build a web site for the Racha Island observatory to make it easier for the public to interact with the data in real time.

Results

Since becoming operational the system has provided scientists with significant new insights into the coral reef ecosystem at Racha Island. Physical parameters at coral reef site (i.e. temperature, salinity and depth) were shown in Fig. 2a-d. Meteorological conditions were collected (Fig. 3a-d). Video images underwater and on the beach were captured (Fig. 4a-d).

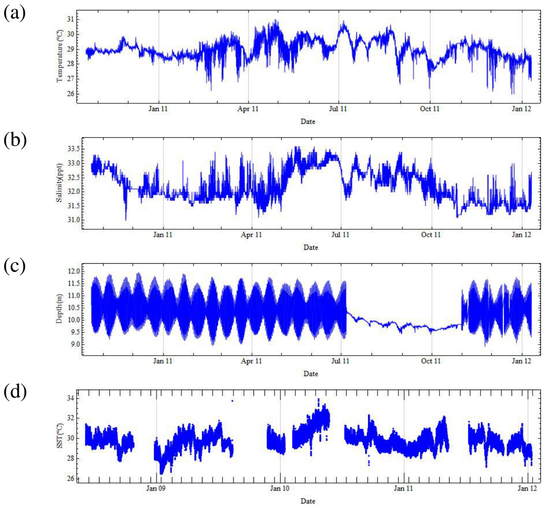

Figure 2. Physical conditions at Racha Island, Thailand from Oct 2010-Jan 2012. (a) water temperature at 10 m (°C), (b) salinity (ppt), (c) depth (m) and (d) water temperature from HOBO sensor from Jun 2008-Jan 2012.

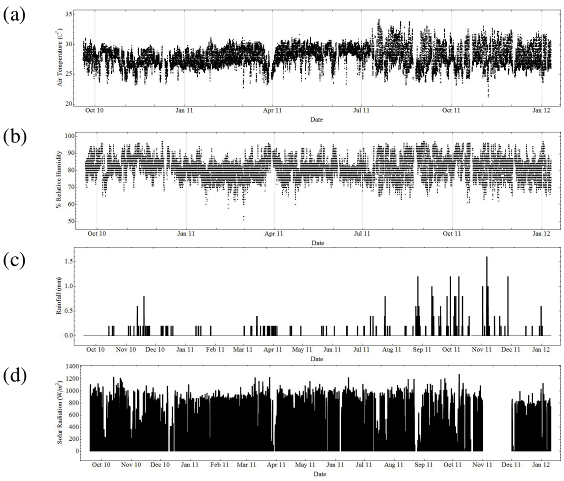

Figure 3. Weather conditions at Racha Island, Thailand from Sep 2010- Jan 2012. (a) air temperature (°C), (b) relative humidity, (c) rainfall (mm) and (d) solar radiation (W/m^2).

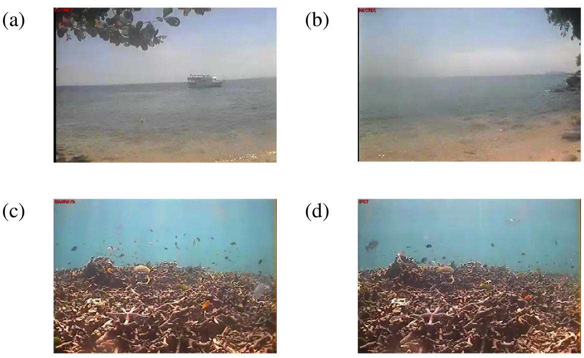

Figure 4. EcoCams stream observations at Racha Islands, Thailand. (a, b) Racha Island beach and (c, d) coral reef sites.

Discussion

The system has been operational since coming on line since October 2010. The Data Centre services have been very stable. The only interruptions were for scheduled system maintenance and power outage. The field data acquisition system has also been stable, although as the system is new occasional user interaction has been required due to some initial growing pains that come with deploying a new system. The system has been robust to occasional power and network outages, even during through several very heavy storms in early November 2010.

Racha Island has extensive coral bleaching in 2010 when the HOBO temperature loggers recorded temperatures over 33 °C (personal observation, authors MJ and KJ). The data from 2011 shows much lower temperatures (maximum of 30.6 °C) with a result that no bleaching has been observed this year at this site.

In one application of the imagery, researchers plan to sample images every 10 min to count the number of diving boat and tourists. The camera systems facilitate high-frequency monitoring over long time spans which allowed them to capture infrequent events that would otherwise have gone unobserved. The infrequent events would have been impossible using a human observer both due to the cost of paying the observer and because the presence of a human so close to the observing site would have altered the dynamics of animal interactions.

Although the camera systems presented here have proved useful for ecological research, there remain many additional challenges and opportunities. Some specific challenges that need to be overcome include variable lighting intensity and angle, plasticity in the size, configuration and orientation of features of interest, the wide diversity of possible features of interest and even mundane problems such as environmental fouling as algae collects on the lens of the remote camera. However, if such challenges can be surmounted it opens additional opportunities for automated or semi-automated data collection using web cameras.

The infrastructure allows for adaptive sampling in that sampling rates can be altered based on the data being collected. While this was possible the lack of standard interfaces to each of the instruments and the need to write considerable code to automate this meant that the adaptive sampling functionality was achieved by manually re-programming the instruments. This is cumbersome and while it can be done remotely it is time consuming and only practical in a small scale deployment such as Racha Island. This is an area that is still unresolved and where common instrument interfaces and programming protocols would help.

The work being done fits within the larger CREON group and within this group solutions for higher level data management are being investigated. These include a single cloud-based data store for data from each of the CREON sites, metadata for all sensors in ISO-19115 format and web based access and analysis tools. While this work is on-going the outcome will be a single system that will allow for comparisons to be done across the CREON sites and an ability to better understand the factors impacting coral reefs and responses such as coral bleaching.

Acknowledgements

We thank Jim Hendee from NOAA for comments on previous versions of this manuscript, Damien Eggeling and Geoff Page from AIMS for the CTD installation, and Banraya Resort and Spa staff for providing the research facilities at Racha Island. This work was supported in part by the United States National Science Foundation, AIMS, the Centre of Excellence for Ecoinformatics, the Institute of Research and Development, NECTEC/Walailak University, Thailand Research Fund through the Royal Golden Jubilee Ph.D. Program (Grant No. PHD/0307/2550).

References

Akyildiz IF, Pompili D, Melodia T (2004) Challenges for efficient communication in underwater acoustic sensor networks. ACM SIGBED Rev 1:1

Chitre M, Shahabudeen S, Stojanovic M (2008) Underwater acoustic communication and networks: recent advances and future challenges. Mar Technol Soc J 1:103-116

CREON (2012) The Coral Reef Environmental Observatory Network, http://www.coralreefeon.org/

Drollet JH, Faucon M, Maritorena S, Martin PMV (1994) A survey of environmental physic-chemical parameters during a minor coral mass bleaching event in Tahiti in 1993. Aus J Mar Freshw Res 45:1149-1156

Fountain T, Tilak S, Hubbard P, Shin P, Freudinger L (2009) The Open Source DataTurbine Initiative: Streaming data middleware for environmental observing systems. Proc 33rd Int Remote Sensing of Environment Symp, Stresa, Italy, 4-8 May 2009

Grottoli AG, Rodrigues LJ, Palardy JE (2006) Heterotrophic plasticity and resilience in bleached corals. Nature 440:1186-1189

IPCC (2007) Climate change 2007: The physical science basis, Summary for policy makers, Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. http://www.ipcc.ch

Karanth KU, Nichols JD (1998) Estimation of Tiger densities in India using photographic captures and recaptures. Ecology 79:2852-2862

Keypas JA, Langdon C (2006) Coral reefs and changing seawater carbonate chemistry. in Phinney JT, Hoegh-Guldberg O, Kleypas J, Skirving W, Strong A (eds) Coral Reefs and Climate Change: Science and Management. Coastal and Estuarine Studies 61, American Geophysical Union, Washington DC, pp 73-110

Liu L, Zhou S, Cui JH (2008) Prospects and problems of wireless communication for underwater sensor networks. Wireless Comm Mobile Comp 8:977-994

McClanahan TR (2008) Response of the coral reef benthos and herbivory to fishery closure management and the 1998 ENSO disturbance. Oecologia 155:169-177

Mumby PJ, Chisholm JRM, Edwards AJ, Andrefouet S, Jaubert J (2001) Cloudy weather may have saved Society Islands reef corals during the 1998 ENSO event. Mar Ecol Prog Ser 222:209-216

Nakamura T, Yamasaki H, van Woesik R (2003) Water flow facilitates recovery from bleaching in the coral *Stylophora pistillata*. Mar Ecol Prog Ser 256:287-291

Phinney JT, Hoegh-Guldberg O, Kleypas J, Skirving W, Strong A (2006) Coral reefs and climate change: science and management. in Coastal and Estuarine Studies 61. American Geophysical Union, Washington DC

Pompili D, Melodia T, Akyildiz IF (2009) Three-dimensional and two-dimensional deployment analysis for underwater acoustic sensor networks. Ad Hoc Networks 7:778-790

Silveira L, Jácomo ATA, Diniz-Filho JAF (2003) Camera trap, line transect census and track surveys: a comparative evaluation. Biol Conserv 114:351-355

Tilak S, Hubbard P, Miller M, Fountain T (2007) The Ring Buffer Network Bus (RBNB) DataTurbine Streaming Data Middleware for Environmental Observing Systems. Proc 3rd IEEE Int Conf E-Science and Grid Computing (e-Science)

Xie P, Zhau Z, Peng Z, Cui JH, Shi Z (2010) SDRT: a reliable data transport protocol for underwater sensor networks. Ad Hoc Networks 8:708-722