Coral sensor network at Racha Island, Thailand

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Abstract

Environmental observation stations are systems which allow researchers to observe rare events and to document long-term changes in ecological systems. Here we describe a system used for acquiring and sharing numerical data and imagery with ecological researchers that is deployed at the Racha Island, Phuket, Thailand. This is a new observatory that aims to provide publically accessible scientific data for researching the environmental changes of coral reefs. This project is part of the Coral Reef Environmental Observation Network (CREON).

1. Introduction

Sensor networks are envisioned to enable applications for environmental data collection, pollution monitoring, disaster prevention, tsunami and seaquake warning [1, 2]. They empower us to monitor and detect phenomena more accurately and rapidly in a variety of geographical areas. Recently, applying sensor networks in underwater environments has received growing interests [3-8]. To improve the understanding of coral reef ecosystems, it is essential that studies are conducted over a wide range of temporal and spatial scales. Cameras have been extensively used in ecology including observations of the nocturnal behavior of coral reef fishes [9] and the study of large cryptic animals [10-11]. Such applications take advantage of the camera's ability to provide unobtrusive observations over long time periods in inaccessible locations. Traditional uses of field cameras produce a relatively small number of images. A network-connected web camera can capture that same number of images in less than 2 s, and continue to do so indefinitely. Similarly, networked sensors for measuring the physical characteristics of ecosystems, e.g., temperature and pressure can also provide high-resolution records over long time periods. Integrated sensor suites for capturing numeric and image data can generate high data rates, e.g., XXX). These high data rates and the heterogeneity of the data types demand new approaches to networking, data management, visualization, and analysis [12]. In this paper, we describe a sensor network for monitoring a coral ecosystem at the Racha Island, Phuket, Thailand.

2. Materials and Methods

2.1. Study site

Figure 1. Racha Island, Thailand

This study was undertaken at Racha Yai Islands, Phuket province, Thailand (Latitude 7.60488 °N, Longitude 98.37660 °E) (Figure 1). Coral reefs in this area are 1-5 m depth. The Racha Island site is a logistically challenging environment for both researchers and instruments, characterized by salt water, large but shallow bays, storms, occasional power and internet outages, and blood-sucking insects. The climate is tropical with mean monthly temperatures that range between 29-30 °C.

2.2. Collaboration

This project is part of the Coral Reef Environmental Observation Network (CREON) [13], a loose group of independent institutions made up of scientists and engineers whose goal is to develop tools for coral reef study. 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, http://www.calit2.net/), the Australia Institute of Marine Science (AIMS, http://www.aims.gov.au) and the Center of Excellence of Ecoinformatics, NECTEC-Walailak University. This deployment builds on the experiences of CREON members in establishing coral reef observatories that can easily 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 a testbed for evolving technologies for environmental and biological sensing, communications, and analysis.

2.3. Instruments and Infrastructure

The following description of the current deployment is organized into 3 areas: field deployment, cyberinfrastructure, and visualization.

A. 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).

On June 2007, we deployed HOBO Pendant temperature and light data loggers (UA-002-64) to measure water temperature and light intensity. We placed 1.5 kg weight at 1 m^2 empty area and tied these four data loggers to the weight in four diagonal corners. This allowed each data logger to receive an accurate and maximum light intensity. These sensors are not networked and require a diver to collect data every 10 min reading interval.

In November 2009, a Davis Vantage Pro II Plus weather station for measuring 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 sensor package commonly referred to as a CTD (SBE-37IM) measuring the conductivity, temperature, and depth was deployed on the fringing reef at approximately 10 m water depth with 5 min sampling frequency. The deployment uses inductive coupling technology to send the data back to the station on the shore. A 350 m mourning cable runs from shore to the CTD, secured at 10 m intervals by 3 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.

Table 1 Deployed Sensors in Real-Time System

Sensor	**Sampling Interval**	**Types of Measurement**	**Networked**
Weather Station	1 min	Temperature, Rain, Wind, Humidity, Bar. Pressure, Solar Radiation	Yes
CTD	5 min	Current, Temperature, Depth	Yes
HOBO	10 min	Temperature, Lux	No
EcoCam	Cont.	Video	Yes

B. Cyberinfrastructure

The weather station, CTD, and EcoCams stream observations as they are received to a Data Center located at Walailak Univeristy and mirrored to UCSD and Nakhon Si Thammarat Rajabhat University (NSTRU). The system includes cyberinfrastructure 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 visualization, modeling, 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 [14]. It is an open-source middleware product supported by NSF, NASA, and private industry. It is 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, synchronization, monitoring, and visualization [14, 15]. 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 tunable 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 3 hours. Files are transferred real-time online into an FK-RJ2604 device.

C) Visualization

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 facebook for use by schools. The video streams are accessible through a website by researchers and students.

All the data is also accessible through DataTurbine as well as a number of client applications that interface with Data Turbine and 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 GoogleEarth plug-in, as well as on OptIPortal a large-scale visualization system that can be deployed on a variety of hardware platforms (wiki.optiputer.net/optiportal/).

Through DataTurbine, users can see temporally synchronized 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 utilize 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.

3. Results and Discussion

The system has been operational since coming on line in October 20th 2010. The Data Center services have been very stable. The only interruptions were for scheduled system maintenance and power outages. The field data acquisition system has also been stable, although as the system is new occasional user interaction has been required. The system has been robust to occasional power and network outages, even during through several very heavy storms in early November 2010.

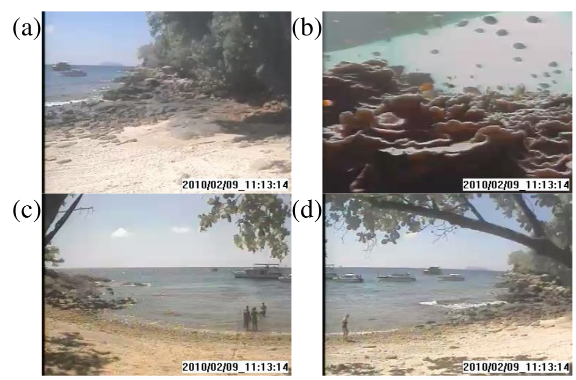

Figure 2. Racha Islands. (a, c, d) Racha Island beach and (b) coral reef site

Observation of the coral reef using the Coral Virtual Site System started on 8 February 2010 (Figure 2). In one application of the imagery, researchers plan to sample images every 10 min to count the number of coral reef fish, and to determine the results of the interactions between coral and coral reef fish (feeding rate, aggressive behavior, tourist impact and etc).

The camera systems as described here provide new capabilities for ecologists studying a wide range of phenomena. They 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 dirt collects on the lens of a remote camera. However, if such challenges can be surmounted it opens additional opportunities for automated or semi-automated data collection using web cameras.

Understanding the processes that impact reefs, such as temperature, requires high quality data at a range of spatial scales on a regular basis. Autonomous smart sensor based systems provide one way to obtain this data from the scale of oceans to the scale of individual corals. The development of a suite of technologies to deliver a robust, simple but effective technology platform to support sensor webs has become a high priority for a number of marine and environmental agencies. This project looks to take this goal forward for coral reefs using a number of technologies and a number of partners. Some of the technical obstacles are similar for any marine based monitoring system and mainly revolve around fouling, powering equipment and the general problems of maintaining equipment in a remote and hostile (at least to electronics) environment.

There are, however, a number of new challenges that need to be addressed. This include being able to store and deal with the large amounts of data that the system will generate (which may include video feeds), the integration of the data into modeling and visualization systems and the ability to manage and maintain a system that is inherently more complex than the simple passive systems deployed currently. We hope our efforts will create a valuable technology knowledge base for the further deployment of reef monitoring systems in remote environment.

The cost of sensor networks should be considered. While the individual elements are not expensive, systems of this type will realize their true potential if they are replicated in large numbers. We are as far as possible employing off the shelf or simple to fabricate hardware and software solutions. There is considerable potential to reduce the costs and even consider mass production of the component sensors.

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