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Design and implementation of a wireless video camera network for coastal erosion monitoring

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ABSTRACT

The short-term rate of coastal erosion and recession has been observed at island shoreline bluffs near waterways among Boston Harbor, Massachusetts, USA. This erosion has been hypothesized partially related to waves from high-speed wakes. Recording the physical erosion events during extreme high waves is significant to evaluate the dynamics of bluff erosion and to document these short-term processes. Still and motion imagery are important media to observe rare and extreme events in ecology, geology, and environmental condition. The study of coastal erosion requires recording devices for these modalities capable of long-term, low-cost, low-power operation with low maintenance, and with the ability to support a large dynamic range in both time and space. We describe recent work in the development of a wireless video camera network for an ecosystem observation platform. These cameras are enclosed in weatherproof housings and supported by solar energy harvesting. The cameras are Internet-enabled and thus live video can be accessed remotely. Video streams are transmitted via wireless network, and delivered to and stored at a remote server. This system has been functional as designed since installation in October 2012 on Thompson Island, Massachusetts, and is expected to operate indefinitely. To date, a number of erosion-related events have been successfully captured. This platform has shown the potential to be used in a large scale for a variety of environmental monitoring studies.

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1. Introduction

Global climate change is predicted to cause a rise of 50 cm in sea level in the next century (Solomon, 2007), and rising sea level in turn impacts the erosion of coastlines worldwide. In particular, rising sea level in the Northeast of the Unites States has changed sediment supplies and pathways, and altered patterns of erosion and deposition. The Boston Harbor Islands National Recreation Area, Massachusetts, USA shown in Fig. 1 is an exceptional geological system of 34 islands resulting primarily from the submergence of drumlins (Peri et al., 2010). The short-term rate of erosion and shoreline recession is predominately related to incident waves, high tides, ferry wakes and exposure to storms (Himmelstoss et al., 2006). Erosion rate varies from island to island. Between 1938 and 1977, Thompson Island (shown in Fig. 1) experienced bluff retreat of 18 m. The highest rates have been observed along a shoreline in coastal waterways, which is subjected to only moderate waves (Hughes et al., 2007). It has been hypothesized that this erosion is partially related to the high-speed wakes generated by passenger ferries and regional vessels. At high tide these waves may reach 0.3 to 0.6 m, and are able to reach the base of the bluff. Capturing the actual erosion events during extreme high waves is significant to understand the dynamics of slumping on the bluff and to document the short-term process of bluff erosion.

Still and motion imagery include a wealth of visible details for the observation of behavior of organisms, infrequent and extreme events in ecology, geology, environmental condition, and meteorology. They serve as important media to document both short- and long-term changes. For example, cameras have been used for census of bats emerging from shelters (Kunz et al., 2010), observing activities in bee colonies (Porter et al., 2010), tracking green-up forests (Richardson et al., 2007), monitoring polar environments (Newbery and Southwell, 2009), and nearshore ocean studies (Holman et al., 2003). Such uses of cameras enable unobtrusive and unattended observation over long time periods. Archived images and videos can be further analyzed using various advanced image/video processing algorithms (Samama, 2010; Spampinato et al., 2008; Wu et al., 2006) for modeling and understanding marine environment, such as summarizing hours of video down to a few short segments containing only targeted salient events (Cullen et al., 2012).

Traditional ecological cameras produce a relatively small number of still images. These images are either stored locally and downloaded manually, or packed and delivered to remote servers. Few of these cameras are deployed without wired power and network infrastructure. The physical environment of most studies in ecology and geology set severe limitations on such cameras as they need to be able to operate

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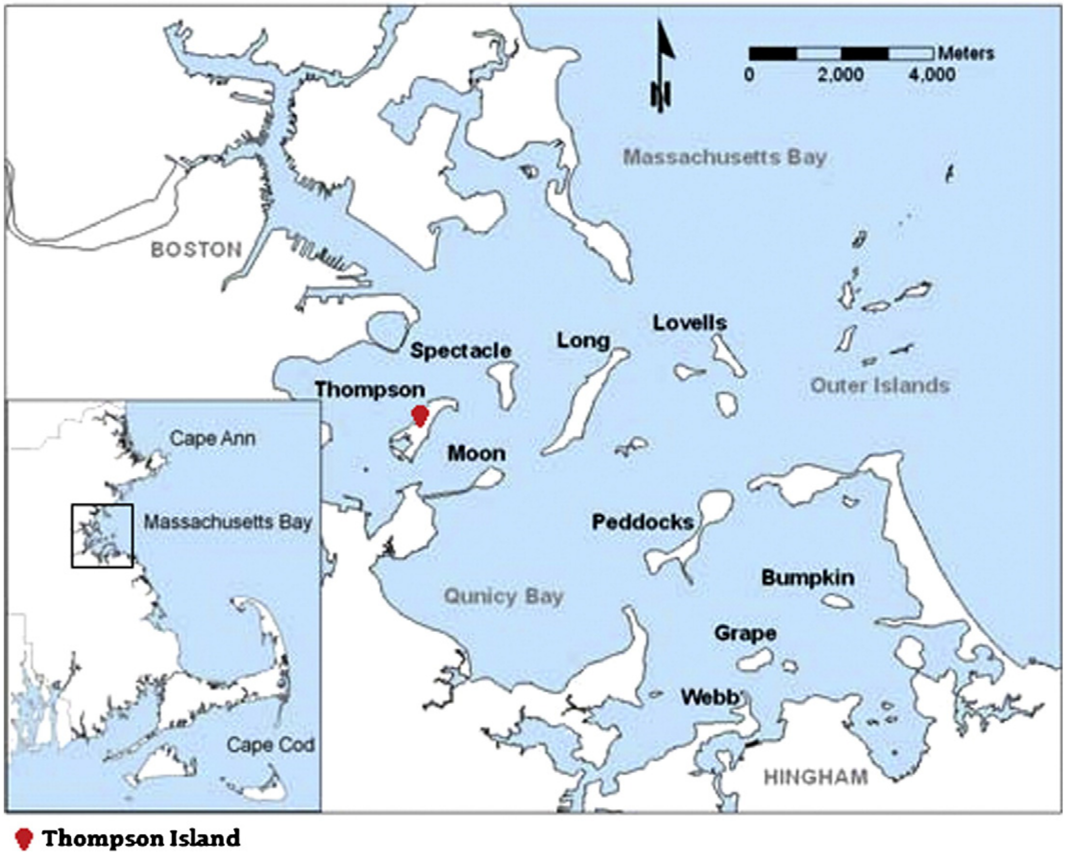

Fig. 1. Boston Harbor Islands.

long-term, low-cost, low-energy, and low-maintenance, and to support a large dynamic range in both time and space. In addition, these cameras must be enclosed in weatherproof housings, and be able to harvest energy if needed. As videos are increasingly being applied to continuously monitor dynamic processes, there is a desire for remotely accessible live video solutions in ecological studies, which must be supported by wired or wireless telemetry. The rich visual details in video data require significant energy resources to sustain recording, communication, and storage.

Based on our preliminary work of a low-power and low-cost video sensor unit prototype (Little et al., 2007), we designed a wireless video camera network to facilitate monitoring and studying coastal retreat. The design demonstrates low-cost, long-term, low-power, energy-harvesting, autonomous operation, wireless network for video delivery, remote access, and live video. A wireless network system with two cameras is implemented to assess the impact of ferry wakes, waves, and high tides on shoreline erosion on Thompson Island, Massachusetts. One camera is studying the 20-foot bluff at the northeast tip that is undergoing rapid erosion. The second camera has been alternately focused on a tidal pond and a low sand and clay beach. These cameras will help to understand the possible driving factors for erosion and will also evaluate the usefulness of video cameras in coastal environmental science. The result from this system can lead to further studies in other parts of Boston Harbor and has already led to reapplication of remote video cameras for other environmental processes.

2. Camera system design

This section presents major strategies for the camera system design, including the design requirements, network nodes, network setup, power management and energy harvest.

2.1. Design requirements

The camera system is aimed to operate unattended in the field to support studies of ecology, geology, and environmental sciences. The physical world poses challenging requirements on the system design, ranging from extreme weather to accessibility difficulties and to needs for alternative power. Our approach was to exploit advances in technology to fulfill coastal monitoring requirements as follows.

- *Low-cost*. The camera network for coastal and other ecological monitoring requires supporting a large dynamic spatial range, and thus supporting the potential to be deployed over large scales. The system must be designed for low cost when produced in quantity.
- *Long-term*. Most coastal erosion is episodic and infrequent. Studies generally last for years to decades. The system must work for long time periods to support the large dynamics in temporal ranges.
- *Low-maintenance*. Typical study areas offer limited access, for example nature reserves and conservation areas. A minimal impact on the studied phenomena is desired, and the system must not cause any significant impact on the environment where it is installed. The mechanical packaging must be robust to survive different, sometimes severe weather conditions in the harsh coastal environment, such as lightning and extreme storms.
- *Low-power and energy replenishment*. The rich visual details in video data require significant energy resources to sustain recording, communication, and storage. Wired power is usually not available along shorelines. The camera system must be designed to run on batteries with a conservative power budget, and it must be able to harvest energy from the environment such as solar or wind power.
- *Remote access and live view*. Due to limited access to study area, cameras are required to be accessible remotely to configure imagery and video parameters such as resolution, frame rate, and compression rate. To meet such challenges, the cameras are designed

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