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A Wireless Video Sensor Network for Autonomous Coastal Sensing

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Abstract

We describe an architecture and prototype for a low-power and low-cost video sensor unit suitable for deployment in remote coastal sensing applications. Our design is based on the premise that if a complete video sensor unit can be constructed for less then $50 then it is possible to deploy a very large number of units providing area coverage measured in kilometers.

1. Introduction

Video is an important medium for the observation of a variety of phenomena in the physical world. For example, in the coastal setting cameras can be used to monitor sea state including wave height and period, evaluate land erosion, and observe a variety of animal species. One of the severe limitations in deploying video cameras in these settings is their cost; in addition to sensing and processing electronics, they must be enclosed in weatherproof housings, provided with a source of energy, and, if live remote access is desired, must be supported by wired or wireless telemetry. Indeed, high-cost cameras limit the deployment to just a few camera nodes thus greatly restricting the potential for broad coverage of the coastal environment. Conversely, if a low-cost camera and telemetry capability can be created, then the opportunity to instrument wide-area or high-density visual sensing scenarios arises. This is the focus of our video sensor design effort.

There are many implications of this design operating point. To eliminate wiring for power and communication we must rely on low-power electronics and use wireless communications techniques. The benefit of many cameras yields fantastic area coverage but exposes the communication system to extreme overload if all cameras are expected to deliver continuous live video streams. However, by embedding intelligence into the collection of video sensors (the video sensor network), one can put limits on the number of features of interest that can be delivered simultaneously to a remote observer. This and other strategies for managing data overload and energy consumption define the scope of our research in video sensing.

The remainder of this paper is organized as follows: Section 2 describes a target deployment of our video sensor network. In Section 3, we describe the design of our video sensor prototype. Section 4 covers the research thrusts in in-network information processing. Section 5 concludes the paper.

2. Coastal Sensing: A Target Deployment

A video sensor network (VSN) is best represented schematically as a grid (Fig. 1). In this illustration cameras are assumed to be panoramic and thus capable of a 360-degree field of view (FOV). Depending on the camera visual range, resolution, and the targets of interest, the individual cameras can be arranged more deliberately. For example, for the study of nesting shore birds (e.g., Piping Plovers), one might deploy the units densely in a swath above the intertidal zone but below areas of dense beach grass. The resulting configuration continues to be mesh of irregular dimensions. Similarly, using cameras to identify marine mammal strandings or to monitor populations of seals is enabled by long strings of cameras spaced to maximize shore coverage.

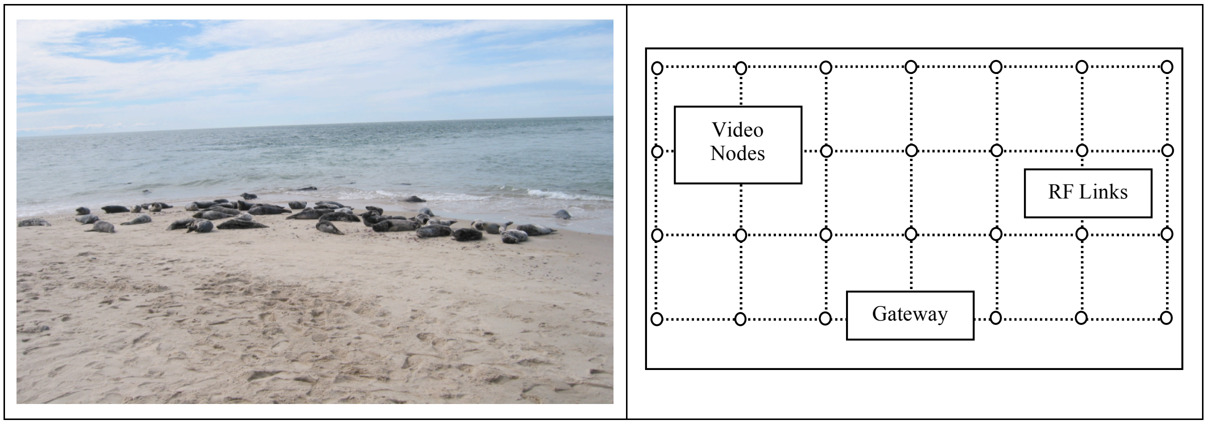

Fig. 1. Video Sensing Application (Grey Seals); VSN Grid Schematic

A network of these cameras would operate as follows. Each camera operates autonomously, but with similar instructions: wake up periodically and sample the image in the field of view. Compare the image with prior recordings and determine any changes. If there are none, go back to sleep to conserve energy. Otherwise, perform more advanced video processing to determine if the change in the image represents a target of interest (e.g., a stranded marine mammal). If a target is detected, the camera notifies a gateway to initiate telemetry and/or recording of the target. Neighboring units participate in routing live video from the source camera to the gateway for observation by a human. This is a representative application. We envision many other scenarios of this basic form supported by a VSN.

3. Design of a Video Sensor Node Platform

There is a great deal of prior work in the development of video sensor systems (e.g., video cameras [1-6], sensor networks [7-9], video streaming [10], energy harvesting, imaging, and image processing [10-14]). Our challenge is to exploit this work and the advances in device technology to yield a low-cost unit satisfying the coastal monitoring requirements. We approach this design based on the overall needs and then a translation to each subsystem. The general requirements of the video camera unit, or video node (VN) are listed below:

- ***Wireless.*** The VN must be deployable in remote unattended locations without access to wiring infrastructure. This implies operation on batteries and/or environmental energy harvesting. Data logging must be performed in the system or communicated out of the system to a gateway or to the Internet.
- ***Broad visual field of view.*** To maximize utility, each VN should have a flexible directionality and zoom. Ideally the field of view is matched to the range of the wireless communication used (e.g., a FOV supporting ranges from 0—100m corresponding to the RF range of 802.11b).
- ***Variable-resolution imagery.*** The VN should support sub-sampling in both temporal and spatial dimensions to vary the volume of data generated.
- ***Capable of streaming video to a gateway.*** An important goal is to deliver full video streaming to an end-user once an event or object of interest has been identified.
- ***Infrequent maintenance.*** Access to remote locations is inconvenient and potentially costly. The system must operate without need for service for long periods. For example, to

study breeding birds can require installation without service for several months. Services to minimize include battery replacement, lens cleaning, data download (if not performed in real time). This requirement puts difficult constraints on the energy used by the camera, communications, and microcontroller (MCU).

- ***Weatherproof and low impact.*** The mechanical enclosure including energy harvester (solar panel) must be robust to survive in the harsh coastal environment. It must also be non-invasive with respect to studied phenomena and must not cause significant harm to the environment in which it is installed.
- ***Inexpensive.*** The VNs must be designed for low cost when produced in quantity.

We have prototyped a VN using commercial components including an Axis 207w wireless network camera as part of a camera network hosted at Boston University. This network has been the basis for experimentation leading to the design of our next generation VN. The components of this VN and the motivations for the selection of components are described below.

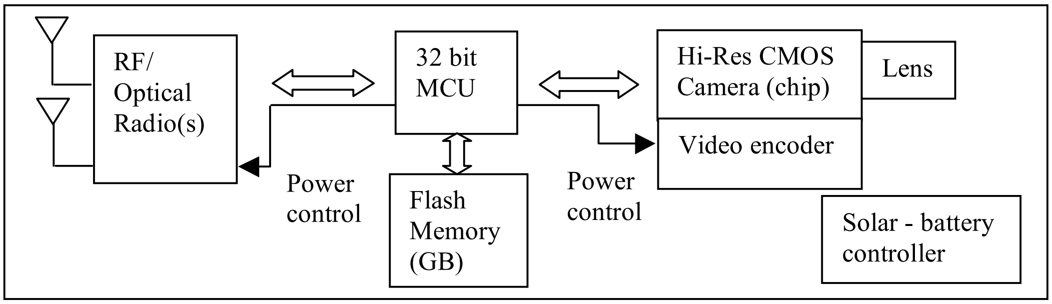

Fig. 2: Major Components of our Video Node Design

- ***Camera optics.*** To achieve a wide field of view we will use a catadioptric configuration using an omni directional mirror fabricated to yield a panoramic image. This approach eliminates the moving parts of most pan-tilt-zoom configurations, reduces corresponding energy use, and reduces directionality challenges.
- ***Image sensor.*** Advances in single-chip cameras based on CMOS technology have led to the ubiquity of camera phones. We will select a 3-5Mpixel CMOS chip that can provide flexible temporal and spatial sampling, and low active current.
- ***MCU and data storage.*** There are many options here. Specific desirable options here are: very low sleep current for periods of inactivity, multimedia instruction sets (for image manipulation), 32 bit architecture, programmable clock rate, access to large amounts of flash memory.
- ***Communications and networking.*** Two modes of communication are anticipated – inter-VN communication to support collaborative processing and target tracking, and video streaming via multihop communications to the gateway. The former is suitable for low-power, low-data rate technologies such as 802.15.4 whereas the latter is appropriate for intermittent WiFi (802.11a,b,g) or other technologies (e.g., optical or IR). We anticipate multiple network interfaces to support concurrent data exchange. Each will be under power control to minimize communication energy costs.
- ***Energy harvesting and control.*** The energy required for video sourcing and streaming is approximately 2500mW for the Axis camera. We target 500mW per VN in the active (streaming) state and less than 5mW when asleep. Energy at an intermediate VN serving to relay to a gateway will be approximately 250mW. Longevity on stored energy is highly

dependent on the duty cycle of these states. The energy harvesting unit, a solar panel and supercapacitor bank is sized to encompass a nominal load profile/duty cycle of 5% over a 24-hour period, and an energy source model that can tolerate up to 30% reduction in incident solar radiation. Thus the design is one of daily energy input to supercapacitors with conventional disposable batteries to bridge periods of cloud cover.

- ***Software control.*** Software control includes image capture, processing, analysis, data routing, and energy management. The activities rendered in software are described in the next section.
- ***Packaging.*** Our initial prototype uses conventional PVC plumbing for a weather housing. The next generation unit will be smaller with a stiffer mast material (PVC is quite flexible). The prototype and the next generation design are illustrated in Fig. 3.

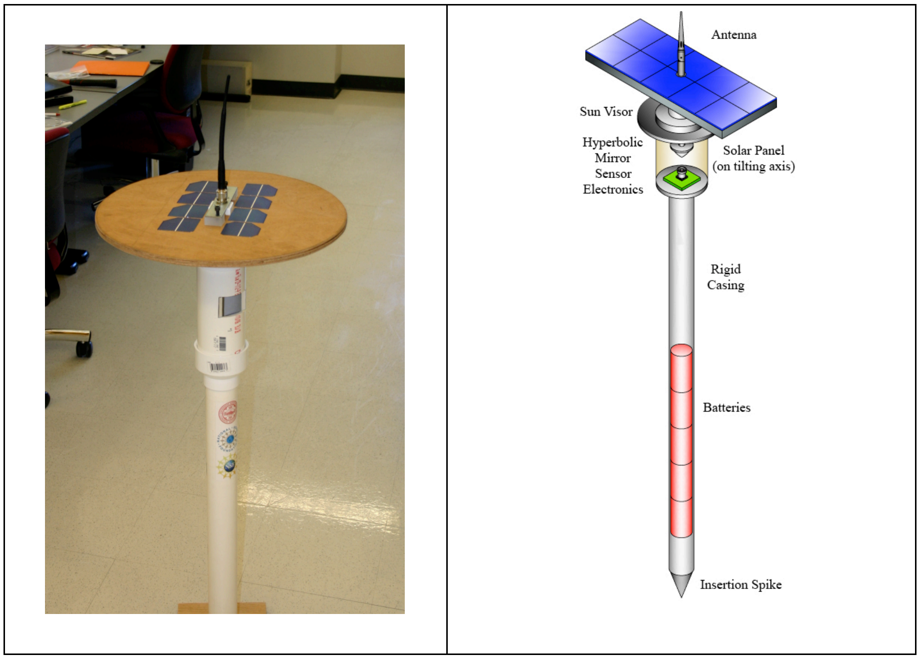

Fig 3. Prototype VN Using Axis Camera; Next Generation Panoramic VN in Development

4. In-Network Information Processing

In order to support duty cycling of each VN, robust image change detection algorithms will be developed on the target platform. Particular attention will be applied to low-complexity algorithms with minimal memory requirements (the so-called "fast and lean" algorithms [8]) because the available computing power and on-board memory are severely limited. Since VNs are stationary, the algorithms will be based on the concept of background subtraction [1]. The background will be statistically modeled over time and each new image will be tested against this statistical model. For cameras with overlapping fields of view, inter-node collaboration will be permitted by means of message passing (e.g., communicating partial change detection results). If a change is detected, a video stream from the node will be transmitted to the gateway using standard video compression techniques (e.g., MJPEG, MPEG-4, H-264).

The above scenario does not account for the type of change occurring, i.e., whether it is a shadow from the clouds or an appearing animal. Therefore, as part of our ongoing research agenda, more advanced algorithms are anticipated that attempt to discover the nature of the change based on prior knowledge about the phenomenon being monitored (e.g., shape and color of a group of gray seals on the beach). Such algorithms will be based on color histograms and shape descriptors.

5. Conclusion

In this paper we presented a design for a video sensor unit to support deployment in applications in which wide area visual sensing is required such as coastal environments. The design is believed feasible based on advances in camera chip, microcontroller, and radio communication technology. Following our work in prototyping an off-the-shelf camera unit in a weatherproof enclosure with solar panel, we anticipate final component selection of the more compact design this summer. The resulting design provides a platform on which to explore a variety of research problems in wireless sensor networking and ecological study.

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