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Wireless Sensor Networks for Debris Flow Observation

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Abstract

This work is to augment a debris flow observation and early warning system with wireless sensor networks. Previously, the GIS at Fengchia University has constructed and deployed state-of-the-art, stationary and mobile types of observation systems at nearly 20 sites throughout Taiwan. These sites collect data from sensors ranging from rain gauges and tension cables to ultrasonic sensors and CCD cameras, and transmit them back to the GIS via a lower-orbit satellite uplink in real-time. A new wireless sensor network and middleware system are being designed and implemented to overcome several limitations with the current system.

Wireless communication capabilities are being incorporated to enhance the coverage. Previously, most connections between the sensors and the server before the satellite uplink are wired or Wi-Fi with fixed topology and limited range. New wireless interfaces with a 500m--1km range plus energy harvesting devices on the sensors reduces deployment effort and cost. More importantly, it is now becoming possible to construct and deploy brand new types of mobile sensor nodes that move with the debris flow along its path. Such sensor nodes are to be housed in pyramid-shaped, weather-proof capsules that contain motion sensors, GPS and other localization devices, energy harvesting and storage devices, and wireless transceivers. Normally in low-power or standby mode, these capsules would be deployed in the path of potential debris flows. They would stand steadily during normal weather conditions including wind, rain, and water flow. They would get triggered by a threshold motion detector or a rain gauge and start actively monitoring the flow. As it flows with the debris, these capsules transmit their sensor data wirelessly, via other relaying nodes if necessary. Based on the shape and mass of the capsule itself and the velocity, researchers can derive the direction and magnitude of the flow in brand new ways.

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1. Introduction

In the past two decades, debris flows have been occurring more in frequency and intensity in Taiwan and many parts of the world. Debris flows occur often in areas such as Taiwan, where the mountain terrain is characterized by fragile rocks and frequent seismic activities. Recent severe typhoons following the great 921 earthquake in 1999 have caused serious damages in central Taiwan. It is thus imperative to study debris flows and ways of monitoring them for early warning before disasters strike.

Techniques for debris flow monitoring have been proposed. They may be divided into contact vs. non-contact types. The former uses sensors such as wire sensors, induction blocks, pressure transducer gauges, etc. They can sense direct impact from debris flows, but they are more vulnerable and potentially more expensive. The latter uses geophones, image recognition, etc. to observe debris flow remotely. They are more likely to survive such events for successive or repeated monitoring. However, both are limited to a number of fixed locations of deployment. The cost for monitoring broader areas with these techniques would be prohibitive.

The recent advent of wireless sensor networks (WSNs) is bringing new possibilities to debris flow monitoring. WSNs are small electronic systems that can contain various types of sensors and wireless transceivers that can be programmed to form ad hoc networks. When housed in weather-proof casing and equipped with long-term energy sources, WSNs have the potentials for enabling broader areas effectively at an affordable cost. The purpose of this work is to augment an existing stationary debris flow monitoring infrastructure by Fengchia University with WSNs developed by National Tsing Hua University.

2 Previous Work

Previous monitoring systems track various environmental events that are likely to trigger debris flows. In Japan, geophones are used to detect volcanic activities. The rainfall index is measured with rain gauges, and the flow index is measured using wire sensors, water level meters, pressure gauges, and video cameras. In Europe, ultrasonic level transmitters and laser flow sensors are also used for measuring a mix of melted snow and soil. These systems can be further divided into long term, medium term, and short term ones. Long term sensors, including rain gauges and soil EC conductivity meters, are used to predict larger trends; short term ones, including image recognition, wire sensors, pressure transducer gauges, and photo interrupters, are for event detection and require short response times.

For transmitting data back to the command center, various technologies are used. Traditionally, analog modems over telephone lines are used, although the bandwidth is low and the telephone lines themselves are often broken during severe weather conditions. To address this problem, Feng Chia University in conjunction with the Soil and Water Conservation Bureau in Taiwan has set up two mobile monitoring stations and 13 fixed stations to use low-orbit satellites for transmitting data back in real-time. Wi-Fi technologies are used for transmitting data from the sensors themselves to a data aggregator before the satellite uplink. Then, the debris flow data may be viewed in real time by connecting to servers at the data center either via the world wide web or a cellular phone. In addition to the satellite uplink, the system may use ADSL, GSM, GPRS, or PSTN networks as backup uplinks when necessary.

What all of these systems have in common is that these sensors are relatively stationary. Although sensors may be installed on mobile stations, the stations are expected to be parked and remain stationary during the monitoring period. These stations cannot automatically follow the debris flow as it moves. The contributions of our work are two-fold: (1) upgrade existing wired links with our new wireless, networked links that support low latency, high data rate, low power, and high reliability; (2) demonstrate the feasibility of new mobile sensors that flow with the debris in an attempt to extract more accurate, real-time information in real-time.

3. Sensors

The new debris flow monitoring system will be based on the existing infrastructure with several new enhancements. The first is a new type of mobile sensor that will flow with the debris for new types of real-time tracking. The second is to add wireless capability to other types of sensors used in the existing infrastructure.

3.1 Capsules for the Mass Flow Sensor

We envision a mobile sensor, called the Mass Flow Sensor, to be a pyramid-like capsule that normally stands idle along possible debris flow paths and housed in a weather-proof, sturdy

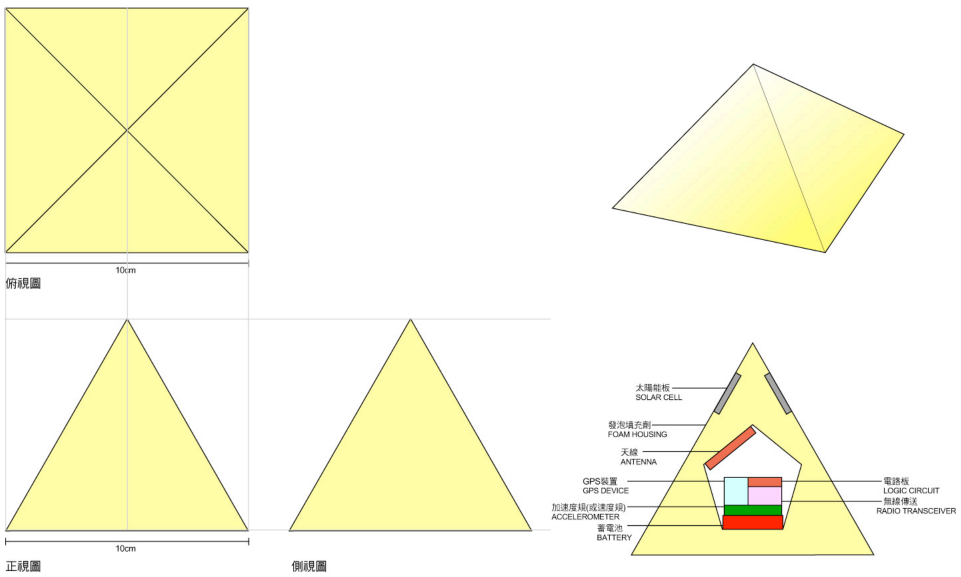

Fig. 1: Capsule design.

enclosure. This capsule is shown in Fig. 1.

The capsule has a square bottom and four triangles. It is made of waterproof material that blocks out moisture but allows radio signals and light to pass through. Solar cells are mounted on top of the capsule to harvest energy. The antenna is fixed in the interior of the capsule near the top. The electronics inside the capsules include a GPS, an accelerometer, a radio transceiver, and additional circuit boards for control and signal processing. A rechargeable battery, which is the heaviest component, is mounted at the bottom of the capsule for stability.

Normally, the mass flow sensor is expected to stand still while harvesting energy from sunlight and transmit minimal messages to indicate its condition and location. Because the capsule has a known mass, the speed of the capsule would enable us to infer the momentum of the debris flow based on the mass and speed.

We also envision the capsules to act as not only mass flow sensors but also as either wireless relays or hubs. Unlike stationary sensors whose transmission distance is known, these mobile sensors are expected to move beyond the range of base stations during their initial deployment. They will rely on relaying among capsules in order to transmit sensor data back to the data center.

3.2 Integration with Current Infrastructure

The capsule will serve as an initial platform on which different types of sensors can be attached either directly or indirectly. Different types of sensors require different interfaces detailed as follows:

- water level meter: the output current is 4—20mA, to be sampled at 1Hz.
- geophone: ±50mV to ±10V, to be sampled at 500Hz for each of three channels.
- rain gauge and cable sensor: on/off signal to be sampled at 1Hz.
- CCD camera: live video streaming at 30fps.

4. Wireless Sensor Networks

What distinguishes this work from the previous deployment is the networking capability supported by the wireless sensor platform. This section describes the hardware and software features.

4.1 Hardware

Currently we are evaluating several platforms. The first is based on the commercially available Tmote Sky, but we added another amplifier board to increase the radio's range. The second is a family of platforms of our own design. The specification of this suite is given by the National Science Council (NSC) of Taiwan and consists of three types of systems: a

SimpleNode, a SuperNode, and a Gateway, and they are required to be Zigbee compatible. Zigbee is an industry standard networking protocol built on top of the 802.15.4 MAC protocol. Both the Tmote and ours are compatible at the MAC layer, but the Tmote requires a Zigbee stack in order to join a Zigbee network. The SimpleNode consists of a RadioPulse MANGO, an integrated 8051 core with an 802.15.4 MAC and radio. The SuperNode consists of an MSP430 microcontroller similar to the Tmote but uses the MANGO chip as its Zigbee coprocessor. The Gateway consists of an ARM9 network processor interfaced to a MANGO module. In addition to being compatible with 802.15.4 at 250Kbps and supporting Zigbee, this chip also supports faster data rates. With proper antennas, the transmission distance can be up to 1km in direct line-of-sight according to the manufacturer's own tests.

4.2 Software

The software can be divided into the firmware running on each system and software on the host. The Tmotes currently run a custom protocol on 802.15.4 for a number of features, including localization based on heterogeneous signals, high data rate transfers, and ad hoc networking. The SimpleNode, SuperNode, and Gateway run a Zigbee compliant protocol stack with additional management software tools running on the Gateway. Specifically, the Gateway supports web-based configuration and XML-RPC for platform-independent management. The support for IPv6 and 6loWPAN enables nodes in the Zigbee network to be bridged to the Internet. Moreover, since the Gateway runs Linux 2.4 with a complete flash-based file system (256MB), it is able to run many new applications for data aggregation and distributed processing in the field.

5. Conclusions

This paper summarizes the current work on augmenting a comprehensive debris flow monitoring system with new capabilities offered by wireless sensor networks (WSN). The existing debirs flow monitoring contains stationary sensors that can report weather and geological conditions back to the center over satellites and other communication lines. The new, relatively low cost, mobile WSN will serve the purpose of actually flowing with the debris for much wider area monitoring. The ability to relay messages will also add another option for making the communication more robust. At this writing, the hardware has been designed and being tested for a limited scale deployment.

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List of multimedia data (if available) (10pt Times)

1) Example of Standard Image Animation #187_1, (Movie of color pictures, 1.0MB)

2) Example of Standard Image Animation #187_2, (Movie of color pictures, 1.5MB)