# Design and Implementation of Non-Autonomous Mobile Wireless Sensor for Debris Flow Monitoring

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*Abstract*—**This demo presents a mobile wireless sensor system for debris flow monitoring. The objective of this system is to realize long-term and effective debris flow surveillance using low cost wireless sensors. In the system, a set of robust wireless sensors are designed to deploy on riverbed and cooperatively observe the moving debris flows. Our mobile sensors are intended to be carried along by the debris flow. As the sensors move along, they are able to measure the internal parameters, such as vibration frequency, amplitude, moving direction and velocity, of the debris flow. By utilizing the proposed energy-saving mechanism on the WSN platform, the mobile sensors can continuously operate up to six months with merely two alkaline D cell batteries. The proposed system provides the abilities to collect high-fidelity data for civil engineering applications to analyze and determine the occurrence of debris flows, as well as estimate the damage.**

## I. INTRODUCTION

The invention of wireless sensor network (WSN) explores a new methodology to observe the natural phenomenon with fewer constraints, as well as less budget. Wireless sensor network has been used to study the environmental activities of volcano [3] and ocean [2], etc. In traditional natural disaster monitoring scenarios, most monitoring equipments rely on AC power and expensive communication infrastructures. Therefore, the monitored area is usually limited by the availability of existing facilities and only a few sample locations are able to be examined. The situation becomes more difficult for applications such as debris flow monitoring, because the fast-moving debris flow cannot be effectively observed using stationary equipments. For these applications, mobile wireless sensor system provides a viable solution to understanding debris flows.

In this demo, a mobile wireless sensor system prototype is introduced for monitoring debris flows and collecting related environmental parameters. In general, a moving debris flow is composed of water, sand, gravel and cobblestones, destroying everything on its way. Current technology has enabled civil engineers to install sensors on fixed locations on riverbank and hillside to measure the debris flow indirectly. For example, geophone can be used to collect the low frequency vibration generated by moving debris flow. However, the signal strength of vibration might relatively weak as the debris flow is far from the sensors. Moreover, the immobile sensors can only track the moving debris flow as it passes by, but not all the way through. This demo proposes a sensor that can be carried along with the debris flow. The advantages of this system are listed as follows:

**Fig. 1. A group of wireless sensors are scattered deployed on the riverbed for debris flow monitoring.**

1. Multiple wireless sensors are scattered and deployed in the riverbed. This allows the signals of the debris flow to be picked up easily and directly.
2. The sensor is designed with robustness in mind to resist clashes and move along with the debris flow for continuous in-situ measurement.
3. The cost of equipment, deployment labor, and maintenance of the proposed system are low, because it does not need fixed infrastructure for power supply and communication links.
4. The dual power source design enables our wireless sensor to use the alkaline battery as the major power source, and solar panel to harvest additional energy in the daytime. Even only with the alkaline battery, this wireless sensor system can continuously operate for six months without charging.
5. The price of each mobile sensor is about 200 USD. To set up a motioning site using six mobile sensors and riverbank receivers, the cost is below 2000 USD. Our system has a very good cost-efficiency ratio in comparison with conventional apparatus.

## II. EXAMPLE WORKING SCENARIO

This system is composed of two types of devices, *INSIDER* and *COORDINATOR*. INSIDER is a cone-shaped robust wireless sensor designed to sit on riverbed or hillside, to be carried along with the debris flow and measure its parameters. COORDINATOR is a wireless data receiver installed on riverbank to get data from INSIDER. We explain how this debris flow monitoring system works using an example scenario, as shown in figure 2.

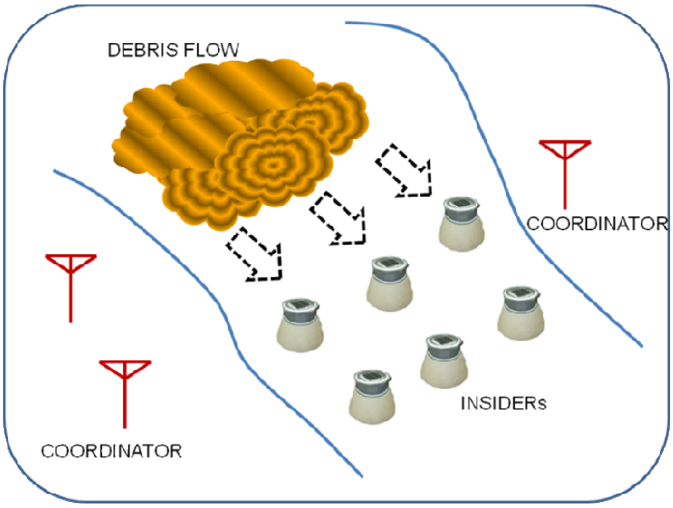

**Fig. 2. Debris flow advances close to the INSIDERs.**

When the debris flow advances close to the INSIDERs, any INSIDER receiving the low frequency vibration generated by the moving debris flow will change its operational mode to ACTIVE. It then sends alarm messages to COORIDNATORs on the riverbank. In the monitoring vicinity, more than one COORDINATOR may be installed to increase the data receiving probability. Once the COORDIATOR receives the alarm message, it analyzes the alarm message and decides whether to wake up the other INSIDERs. An INSIDER has two operation modes: ACTIVE mode and SLEEP mode, which define different timeslot length and energy-saving operational schedule to reduce power consumption. In the ACTIVE mode all the INSIDERs send out the raw data to COORDINATORs, as opposed to the size-reduced, processed data sent out in SLEEP mode.

In this case, suppose the leader COODINATOR, which is pre-assigned to make the final decision, decides to wake up all INSIDERs and asks them to send out the raw data. Meanwhile, the debris flow hits these INSIDERs and carries them along. The INSIDERs keep measuring the debris flow's internal parameters. The data sent out by the INSIDERs are gathered by the COORDINATORs. In this example, all the INSIDERs perform one-hop communication with COORDINATORS. These data are fused and analyzed in the back-end data center, so the final decision whether to issue warnings to public can be made very soon and the local authority can take preventive measures, such as evacuating the downstream inhabitants near the hazardous region and closing dangerous bridges.

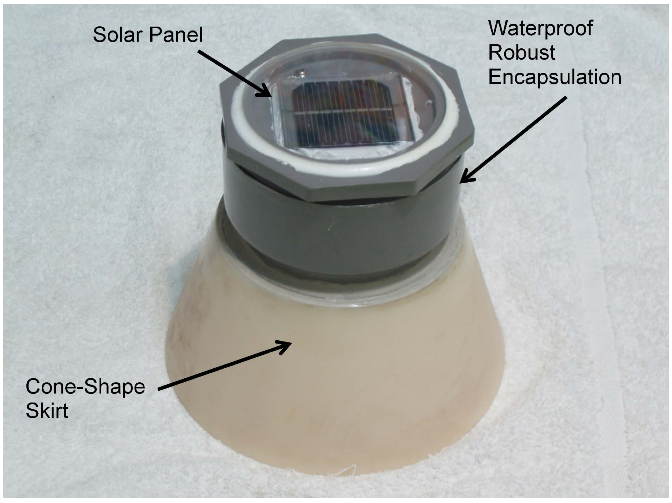

**Fig. 3. INSIDER**

## III. SYSTEM DESIGN

In this section we show the system design details.

### *A. Packaging and Hardware*

As shown in Figure 3, INSIDER is tightly encapsulated. Its shape is specially designed to make it streamlined to lessen the water resistance, and to prevent it from moving by fresh water flows. The packaging is waterproof and weather resistant to guarantee that it can shield the internal electronics.

**Fig. 4. INSIDER stands in floodwater.**

The wireless sensor of INSIDER is based on Telosb WSN platform from [1] with TI MSP430F1611 and TI CC2420. For the sensing components, INSIDER integrates a small and lower power accelerometer (ADXL330, ADXL335Z or ADXL321, depending on different requirements). The accelerometer in our design always keeps sensing, so once the readings vary significantly INSIDER can change to ACTIVE operation mode immediately. GPS, gyroscope and other special sensing components, e.g. for measuring suspended sediment concentration of flows, are also available for integration. The overall hardware cost for an INSIDER is about 200 USD.

### *B. Energy-Saving and Maximal Response Time*

The energy source of INSIDER is primarily from two D cell alkaline batteries, with a small solar panel (4V/75 mAh) as the secondary energy source. Energy consumption is the most critical factor to make INSIDER to work for a long time. The RF transceiver CC2420 is the most energy-hungry component in INSIDER. The CC2420 current draw for actively receiving and sending messages is about 19 mA, and the total system current draw is 27.5mA. To reduce RF power consumption, using the CSMA-based protocols with low-power function (i.e., B-MAC[4] with low-power listening) cannot guarantee deterministic message delivery and response time of sleeping sensors. We define a m*aximal response time* (*MRT*) of sleeping sensors, which is the maximal delay time when the COORDINATOR sends out the wake up message until the sensor in SLEEP mode is waked up. Note that in most of time, INSIDER turns off its RF transceiver to save energy. So the precise timing for the COORDINATOR to send out the wake up message as INSIDER turns RF transceiver on is crucial. A small MRT is very important to turn all INSIDERs to ACTIVE mode when debris flow is approaching.

To achieve the energy-saving requirement and satisfy the MRT, each INSIDER is assigned a time-divided multiple access (TDMA) schedule, which defines the exclusive time-slot and communication schedule in both SLEEP and ACTIVE mode. By setting the timeslot length to 50 ms in SLEEP mode and cycle length to 22 timeslots in a 6 INSIDERs group, each INSIDER wakes up at 3 predefined timeslots for bidirectional wireless communication and time-synchronization with COORDINATORs. Under this configuration, the average current consumption is 4.25 mA, which indicates the lifetime of INSIDER is about three months using a pair of D cell alkaline battery. The estimated MRT is 850 ms under this setting. If we loosen the upper bound of MRT to 2 seconds, the setting of cycle length could be 40 timeslots and average current consumption is further reduced to 2.53 mA. The lifetime of INSIDER is extend to about six months. All the above lifetime estimation is conservative, as it is known that the typical alkaline D cell battery is about 10000~12000mAh. Such a low duty cycle design certainly helps to reduce the cost of system maintenance and human intervention, and also keep the MRT low to quick response to external events.

## IV. DEMOSTRATION SCENARIO

In this demo, we present the model of debris flow monitoring system, including a real INSIDER and a scale-down COORDINATOR. For interactive demonstration, the simulated debris flow approaching the INSIDERs will trigger the INSIDERs into ACTIVE mode. The INSIDERs then start to send out the measured raw vibration data and these data are display on the PC. We will also show the video of INSIDER trial deployment and related debris flow footages. The space we need is a 100 cm x 50 cm clean table with AC power supply. Required setup time is about 30 minutes.

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