8 Years of X-Sense and X-Sense2

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New scientific knowledge about geophysical processes

Development of early warning systems

Wireless Sensor Network Technology

- allows to quantify mountain phenomena at diverse modalities and scales,
- provides information for process understanding and modeling
- can be used for safety critical applications in hostile environments.
X-Sense - Detecting Large-Scale Mass Movements in Mountain Permafrost Slopes
Detecting Millimeter-scale Process Dynamics

Objectives of this work

• Accurate point measurements (surface)
• High temporal resolution intra annual – intra day
• Long-term autonomous operation
• High spatial coverage
• Process understanding – knowledge
• Decision making for natural hazard mitigation (warning)
Standard Approach: Repeat Manual Surveys

- Low temporal resolution; limitations for process understanding
- Repeat exposure to natural hazards

Wireless L1-GPS Sensors

- Wireless communication
  - Wireless sensor network cluster
  - 868 MHz ultra low-power radios
  - Up to ~7km range

- Sensors
  - ublox LEA-6T L1-GPS
  - Trimble Bullet III active antenna
  - 2-axis SCA830 inclinometer
  - Ambient temp/hum/battery

- Standalone data logger functionality
  - Local 2GB data buffer

- Remote configurable
  - Duty-cycle (1-24h)
  - Sampling rate (30 sec)

- Data transfer in near real-time

GPS Logger
Large-scale, early access data

GPS CoreStation
Experimentation, variable use

Wireless GPS Sensor
Fully integrated, low-power

Short-term Variability of Rock Glacier Surface Velocities in the Swiss Alps Revealed by Continuous GPS
Real-time Experimentation at Valley Scale
Intra-annual Variability of Horizontal Velocities

Movements In the Context of Meteorological Factors

<table>
<thead>
<tr>
<th>snow cover</th>
<th>zero curtain (GST)</th>
<th>hor. velocity</th>
<th>velocity peak</th>
<th>low SNR</th>
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**RG Breithorn**

**RG Dirru**
Access to Real-time Data for Early Warning Decision-making

**Bielzug Debris Flow, June 2013**
- Critical natural hazard event
- Herbriggen partial village evacuation
- Closure of road and railway to Zermatt

![Bielzug/Breithorn rock glacier, C. Graf, WSL, Switzerland](image1)

**Längschnee, Fall 2014**
- Constructive measures securing rock boulders above Herbriggen
- Extension of sensor coverage in collaboration with authorities

![Längschnee, Stalden, Switzerland](image2)
Technology Transfer

PERMOS Continuous GPS Pilot

• Pilot program to make L1-DGPS sensors developed in a research project available to PERMOS partner on their field sites

• First sensor installation in summer 2013, extensions in 2014, 2015, 2016
  (Valais: Herbriggen Bielzug, Breithorn + Längschnee, Grächen Distelhorn + Ritigraben, Saas-Balen Gruben + Jäggihorn, Wysse Schije, Randa Grossgufer)
X-Sense2
A New Seismic and Acoustic Emission Experiment is Taking Shape
Why?

[Randa rockfall incident, April 22, 2015, blick.ch]
Sensors cover the Hörnligrat from first couloir up to Eisloch
The clefts at Hörnliridge move in distinct patterns.

What is preventing wide applicability?

- sensing movement events (GPS, images, crackmeters) and/or micro-seismic and acoustic activities
- high sensing rate, signal amplification
- big data
- high energy
- high cost

*Improve the energy efficiency* of the sensor network by several order of magnitude and *expand sensor modalities.*
sensors
pre-processing
communication
data cleaning & processing
geophysical processes
geo-science
society & early warning
X-Sense2 – From Tera To Nano

- Sensor
- Pre-processing
- Communication
- Data cleaning & processing
- Geophysical processes
- Decision

Nano

Tera
The X-Sense2 MEMS Acoustic Sensor Concept

Acoustic emission signals

A crack in the rock creates a vibration signal
The X-Sense2 MEMS Acoustic Sensor Concept

Acoustic emission signals

The sensor picks up the vibration and amplifies it mechanically like a shoaling wave
The X-Sense2 MEMS Acoustic Sensor Concept

Acoustic emission signals

If the signal has the target spectrum and threshold amplitude: the device triggers a switch

Events

Idle power needed only for DC voltage sourcing

Current detection
Proof of Concept Devices

Simulation of amplification mechanism...

...with 4 masses...

...with 6 masses...

...with 10 masses!

...and fabrication of devices...

Combination with pull-in trigger
10-mass mechanical amplifier fabricated with 3-D Silicon-on-Insulator (SOI) technology

Our Event-driven System Architecture

DPP – The Dual-processor Platform

Acoustic Sensor Interface
\[ P_s = 6.2 \, \mu W \]

Acoustic Event Characterization
\[ P_s = 2.5 \, \mu W \]

Multi-hop Event Dissemination
\[ P_s \ [11.0, 49.6] \, \mu W \]

BOLT
\[ P_s = 1.3 \, \mu W \]


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Computer Engineering and Networks Lab
Geodesy and Geodynamics Lab
Micro and Nanosystems
Federal Office for the Environment
University of Zurich
Department of Geography

Demo at nano-tera.ch booth