Improvement of process identification and discharge measurement by the combination of different sensors

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Overview

Monitoring site Lattenbach

Debris flow 09.08.15
Debris flow 10.08.15
Debris flow 16.08.15
Warning System AMM-Detection
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Monitoring site Lattenbach

**Lattenbach:**
Grins, Tyrol; Catchment area 5.3 km²
Debris flow monitoring since 2004
Instrumentation:
ultrasonic sensors, weighing precipitation gauge, seismometer, video cameras, 2D laser scanner, debris flow radar, infrasonic sensors, geophones,...
Monitoring site Lattenbach

New installations on the test site:

**Debris flow Radar**
- surface velocity of a debris flow

**2D-Laser Scanner**
- cross sectional wetted area

**AMM-Detection**
- automatic detection of debris flows based on infrasound and seismic data
Debris flow Radar

High frequency pulse Doppler Radar

- Max. measurement distance 2,5 km
- Range gate length 15-250 m
- Velocities up to 300 km/h
- Alarming trigger in case of an event
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2D-Laser Scanner

SICK Laser-Scanner LMS511

- Resolution: 0.25°
- Sample frequency: 5 Hz
- Data acquisition and configuration: Raspberry PI 1 Model B
Automatic detection based on infrasound and seismic data

- System which detects alpin mass movements in real time directly at the sensor site and comes along with only one seismic sensor, one infrasound sensor and a microcontroller
- Warning system for debris flows / debris floods and snow avalanches
- Combination of seismic and infrasound sensors to get advantages of both technologies
- Identify magnitude and process type based on the seismic and infrasound signals
Debris Flow on 09.08.2015

Overall volume: 16000 m³
Max. discharge: 64 m³/s
Av. discharge: 4.5 m³/s
Max. velocity: 4.3 m/s
Average velocity: 1.9 m/s
Debris Flow on 09.08.2015

Discharge and total load of the debris flow on 09.08.2015
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Debris Flow on 09.08.2015

2D-Scan of the debris flow on 09.08.2015
Debris Flow on 09.08.2015

AMM-Detection:

Early detection: 53 s

Max. infrasound amp.: 776 mPa
Max. seismic amp.: 113 µm/s
Duration of event: 2671 s
Peak-frequency band: 5-15 Hz

(a) Infrasound time series; (b) Seismogram; (c) Average amplitude of the frequency bands of the infrasound signal; (d) Average amplitude of the frequency band of the seismic signal; (e) Running spectrum of the infrasound signal; (f) Running spectrum of the seismic signal; Lines: time of first detection based on infrasound and seismic data. Signals are represented with a common base of time.
Debris Flow on 10.08.2015

Overall volume: 26800 m³
Max. discharge: 53 m³/s
Av. discharge: 7.4 m³/s
Max. velocity: 4.4 m/s
Average velocity: 2 m/s
Debris Flow on 10.08.2015

Discharge and total load of the debris flow on 10.08.2015
Debris Flow on 10.08.2015

AMM-Detection:

Early detection: -14 s

Max. infrasound amp.: 859 mPa
Max. seismic amp.: 134 µm/s
Duration of event: 4561 s
Peak-frequency band: 5-15 Hz

(a) Infrasound time series; (b) Seismogram; (c) Average amplitude of the frequency bands of the infrasound signal; (d) Average amplitude of the frequency band of the seismic signal; (e) Running spectrum of the infrasound signal; (f) Running spectrum of the seismic signal; Lines: time of first detection based on infrasound and seismic data. Signals are represented with a common base of time.
Debris Flow on 09.08. / 10.08.2015

Precipitation and discharge of the debris flows on 09.08. and 10.08.2015

![Graph showing precipitation and discharge over time]
Debris Flow on 16.08.2015

Overall volume: 10000 m³
Max. discharge: 16 m³/s
Av. discharge: 2,8 m³/s
Max. velocity: 2,6 m/s
Average velocity: 1,6 m/s
Debris Flow on 16.08.2015

Discharge and total load of the debris flow on 16.08.2015
Debris Flow on 16.08.2015

AMM-Detection:

Early detection: 12 s

Max. infrasound amp.: 561 mPa
Max. seismic amp.: 75 µm/s
Duration of event: 2099 s
Peak-frequency band: 5-15 Hz

(a) Infrasound time series; (b) Seismogram; (c) Average amplitude of the frequency bands of the infrasound signal; (d) Average amplitude of the frequency band of the seismic signal; (e) Running spectrum of the infrasound signal; (f) Running spectrum of the seismic signal; Lines: time of first detection based on infrasound and seismic data. Signals are represented with a common base of time.
Debris Flow on 16.08.2015

Precipitation and discharge of the debris flows on 16.08.2015

Precipitation

Discharge
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AMM-Detection

“Automatic Detection and Identification of Alpine Mass Movements based on Infrasound and Seismic Signals”
Infrasound and seismic waves of debris flows

Infrasound:
- Signal source is the collision of stones (vibrations)
- Sound pressure between 0.1-10 Pa
- Peak frequencies
  - 5-15 Hz (debris flow)
  - 15-30 Hz (debris flood)

Seismic waves:
- Signal source is the collision of stones with the channel
- Amplitudes between 5-500 µm/s
- Peak frequencies 10-30 Hz

(Kogelnig 2012)
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Used components

- **Microcontroller:** Luminary LM3S8962
  - 50 MHz ARM-Cortex-M3 Processor
  - 4 ADC-Channels – 100 Samples/s

- **Infraschall sensor:** Chaparral Model 24
  - Sensitivity 2 V/Pa, frequency range 0.1 Hz – 50 Hz
  
  or **MK-224**
  - Sensitivity 50 mV/Pa, frequency range 3 Hz – 200 Hz

  or **Electret Condenser Micophone** KECG2742WBL-25-L
  - Sensitivity -42±3 dB, frequency range -20-20000 Hz

- **Seismic sensor:** Geophone Sercel SG-5
  - Sensitivity 80 Vs/m, Natural frequency 5 Hz
Functions of the warning system

**Display:**
Display of current values, system settings and parameters detection-alg.

**SD-Card:**
Max. 16 GB memory card
Recording time 148 days (3560 hours-files)
Log-Files (3 types)

**Network:**
100 Mbit Ethernet
Web server (remote control)
Time from time server
E-Mail alert

**Input:**
- Infrasound signal
- Seismic signal
- Level (ultrasonic or radar gauge)

**Power supply (12 V, consumption <1.5W!; supervision possible)**

**Signal adaptation:**
Filtering by RC-network
Adapting the input signals with an inverting amplifier circuit

**Output:**
Alarm 3 V (relay control)
2 Alarm levels (magnitude)
Modem control (timed switch on/off)
Camera - triggering on alarm
**Signal processing**

- Removing the DC-component by RC-high-pass with a cutoff frequency of ~1 Hz
- Adaptation of the signal to ADC input with an inverting amplifier circuit → Infrasound: 400 mV/Pa; Seismic: 8 mV/µm/s
- Sampling at 100 samples/s, transforming into physical dimensions (Anti-aliasing: 32x Hardware oversampling)
- Calculation of the frequency spectrum using Fast Fourier Transformation per second, 100 FFT samples (FFT Bluestein algorithm)
- Detection-Algorithm
Current Detection-Algorithm

Infrasound Signal:

Amplitude-Criteria - Level 1 / Level 2:
Amplitude of the debris flow / debris flood frequency band exceeds a limit for a certain time-period

\[ avAmp_{DFlow} \geq AmpLimit_{L1} \quad \text{or} \quad avAmp_{DFlood} \geq AmpLimit_{L1} \]

\[ avAmp_{DFlow} \geq AmpLimit_{L2} \quad \text{or} \quad avAmp_{DFlood} \geq AmpLimit_{L2} \]

Distribution-Criteria:
Amplitude of the debris flow / debris flood frequency band is greater than the amplitudes of the frequency bands above and below

\[ avAmp_{DFlow} > \frac{avAmp_{high}}{avAmp_{low}} \quad \text{or} \quad avAmp_{DFlood} > \frac{avAmp_{high}}{avAmp_{low}} \]

Variance-Criteria:
Variance of the amplitudes below a certain value (to eliminate artificial noise)

\[ AmpVar_{DFlow} \leq VarLimit \quad \text{or} \quad AmpVar_{DFlood} \leq VarLimit \]
Current Detection-Algorithm

Seismic Signals:

Amplitude-Criteria - Level 1 / Level 2:
Amplitude of the debris flow / debris flood frequency band exceeds a limit for a certain time-period

\[
\text{avAmp}_{DFlow/DFlood} \geq \text{AmpLimitL2} \\
\text{avAmp}_{DFlow/DFlood} \geq \text{AmpLimitL1}
\]

Variance-Criteria:
Variance of the amplitudes below a certain value (eliminate artificial noise)

\[
\text{AmpVar}_{DFlow/DFlood} \leq \text{VarLimit}
\]

Detection:
All criteria for both signals (seismic and infrasound) are met.
Current Detection-Algorithm

Scheme of the event detection - debris flow infrasound signal:
Current Detection-Algorithm

Current parameter values:

<table>
<thead>
<tr>
<th></th>
<th>Infrasound signal</th>
<th>Seismic signal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency band 1</strong></td>
<td>$\text{FB}<em>{1\text{low}} - \text{FB}</em>{1\text{high}}$</td>
<td>3 to 5 Hz</td>
</tr>
<tr>
<td><strong>Frequency band 2 - debris flow</strong></td>
<td>$\text{FB}<em>{2\text{low}} - \text{FB}</em>{2\text{high}}$</td>
<td>5 to 15 Hz</td>
</tr>
<tr>
<td><strong>Frequency band 3 – debris flood</strong></td>
<td>$\text{FB}<em>{3\text{low}} - \text{FB}</em>{3\text{high}}$</td>
<td>15 to 35 Hz</td>
</tr>
<tr>
<td><strong>Frequency band 4</strong></td>
<td>$\text{FB}<em>{4\text{low}} - \text{FB}</em>{4\text{high}}$</td>
<td>35 to 50 Hz</td>
</tr>
<tr>
<td><strong>Limit for Amplitudes - Level 1</strong></td>
<td>$\text{AmpLimitL1}$</td>
<td>10 mPa</td>
</tr>
<tr>
<td><strong>Limit for Amplitudes - Level 2</strong></td>
<td>$\text{AmpLimitL2}$</td>
<td>30 mPa</td>
</tr>
<tr>
<td><strong>Limit for Variance</strong></td>
<td>$\text{VarLimit}$</td>
<td>0,6</td>
</tr>
<tr>
<td><strong>Time span for detection</strong></td>
<td>$T_{\text{det}}$</td>
<td>12 s</td>
</tr>
</tbody>
</table>
Test sites since 2013

- **Debris flow** (Illgraben, Marderello since 2015)
- **Avalanches**
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Example for detection

Debris flow on 1.9.2008
Lattenbach (Tyrol)
Early detection: 111 s
Example for detection

Debris flood on 9.7.2013
Dristenau (Tyrol)
Early detection: -4 s
Example for detection

Comparison infrasound spectrum
Debris flow Lattenbach – Debris flood Dristenau
Example for detection

Debris flood on 28.7.2009
Illgraben (Wallis, Switzerland)
Early detection: 89 s
Example for detection

Debris flood on 31.7.2014
Farstrinne (Tyrol)
Early detection: 99s
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Example for detection

Debris flood on 9.8.2015
Marderello (Italy)
Example for artificial interfering noise

30.6.2014
Farstrinne (Tyrol)
Aeroplane
## Results - Test sites

**Debris flow / debris floods, season 2013 – Number events / detections**

<table>
<thead>
<tr>
<th>Test Site</th>
<th>Number events</th>
<th>Detections</th>
<th>False alarms</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>very small &lt;100 mPa</td>
<td>small &gt;100 mPa &lt;400 mPa</td>
<td>medium &gt;400 mPa</td>
</tr>
<tr>
<td>Lattenbach</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Warschenbach</td>
<td>8</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Farstrinne</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Dristenau</td>
<td>18</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Schüsserbach</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td><strong>Overall:</strong></td>
<td><strong>50 %</strong></td>
<td><strong>70 %</strong></td>
<td><strong>100 %</strong></td>
</tr>
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Results - Test sites

Debris flow / debris floods, season 2014 – Number events / detections

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<tr>
<td>Lattenbach</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Farstrinne</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Dristenau</td>
<td>10</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Schüsserbach</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Overall:</td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>
Further points of research

- Estimation of event size (magnitude, deposit) *
- Determination of process-type (viscosity) *
- Determination of the duration of the event
- Localization of the event (sensor array)

*) ÖAW ESS-Project:
„Identification of sediment-related disaster based on seismic and acoustic signals“
Debris flow - Test sites