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# MAMODIS - A low-cost monitoring system for debris flows based on infrasound and seismic signals

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**Abstract.** The automatic detection of sediment related disasters like landslides, debris flows and debris floods, gets increasing importance for hazard mitigation and early warning. Past studies showed that such processes induce characteristic seismic signals and acoustic signals in the infrasonic spectrum which can be used for event detection. The presented system MAMODIS (MAss MOvement Detection and Identification System) is a detection system for debris flows, debris floods and avalanches based on a combination of infrasound and seismic signals. The detection system consists of one infrasound sensor, one geophone and a microcontroller, where a specially designed detection algorithm is executed. This algorithm reliably detects events in real time directly at the sensor site. The setup can be easily installed beside a torrent or an avalanche path and therefore can be used as a low-cost and practicable solution for early warning. In addition, this system offers first information of the process-type and a rough estimation of the peak discharge and the total volume for debris flows and debris floods. These values are calculated from the infrasound and seismic signals. Currently the system is installed on several test sites in Austria, Switzerland and Italy.

## 1 Introduction

Automatic detection of alpine mass movements is an important tool for protecting people and property in the fast socio-economic developing mountain areas.

Alpine mass movements like debris flows and debris floods induce waves in the low-frequency infrasonic spectrum and characteristically seismic waves. These infrasound and seismic waves produced by the mass movement can be used for detecting events before a surge passes the sensor location and to monitor mass movements from a remote location unaffected by the process.

There have already been several approaches for automatic detection of debris flows based on seismic signals (e.g. [1,2]) and also infrasound signals are commonly used for detecting avalanches or debris flows (e.g. [3]). Seismic and infrasound waves have different advantages and disadvantages, so a combination of both technologies can increase detection probability and reduce false alarms (e.g. [4]).

However, up to date no system has been designed which uses a combination of low-cost seismic and infrasound sensors for an automatic detection of sediment related disasters of different types. So this work aims to develop a reliable automatic detection system for alpine mass movements, which is based on one infrasound and one seismic sensor and can detect different processes in real time directly at the sensor site. Further, the infrasound and seismic signals are used to identify the process type and to get an estimation of the event-magnitude.

## 2 System Setup

The MAMODIS system (MAss MOvement Detection and Identification System) is based on a modular setup to offer a inexpensive solution for different applications, like protection of traffic lines by controlling a traffic light, protection of construction sites inside the channel (e.g. for cleaning up a basin after an event) or at regions where a temporary protection is enough.

The infrasound sensor used for the MAMODIS system is a modified differential pressure sensor of the type Sensirion SDP816 with a measurement range from -12.5 to 125 Pa. As seismic sensors, we use the Sensor NL SM-6 with a sensitivity of 28.8 V/m/s and a natural frequency of 4.5 Hz. The system offers the possibility for a second geophone input, which can be used for an estimation of the mass movement velocity. The process velocity is calculated via cross-correlation of booth seismic signals [5]. This method is still under development and will be implemented in a future version of the system.

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The sensor signals have to be adapted for the input of the microcontroller, which is done by a non-inverting OPV circuit. This input circuit also has a band pass filtering with a lower cut-off frequency of around 150 mHz (for acoustic sensors) and an upper cutoff frequency of 150 Hz (acoustic and seismic sensors). These input signals are sampled by the microcontroller ADC (analog-to-digital converter) with a sample rate of 100 Hz.

A Texas Instruments development board with the microcontroller TM4C129X is used for the data processing and as data-logger. The software for the microcontroller is based on the open source runtime system FreeRTOS. The development board has two 12-bit ADC modules, eight UARTs (Universal Asyn-chronous Receiver Transmitters), several GPIOs (General Purpose Input/Output), which can be used as alarm outputs, and a Liquid Crystal Display (LCD) with touchscreen function. It also offers the possibility of an Ethernet connection. The data can be stored on a micro SD card where sizes of 8 GB, 16 GB or 32 GB can be used, and up to eight months (32 GB, one geophone) of data can be recorded continuously. Besides the input of the sensor signals, the free ADCs offer the possibility to log the flow height measured by a radar or ultrasonic gauge (input 4-20 mA), which can be used for event verification. In addition, the power supply voltage is monitored to check for low power. If the test site is equipped with a standard internet connection, the communication with the system can be conducted via the Ethernet interface. If there is no router available, we use a GSM module of the type Adafruit FONA. The system is designed to send a status message to a server every hour, whereby the date of the event detections or error messages are included. This server creates e-mail alerts in the case of an event. A web-server is installed on this server as well, where the status and events of all stations can be checked (http://mamodis.ddns.net/).

The time synchronization of the station is done by either a connection with a time server via Ethernet or GSM module, or by a GPS module, which is also connected via the UART. The alarm output can be done by Relays or via a radio link (RF-Module: GAMMA LoRA). An overview of the hardware components and the inputs and outputs of the system is given in Figure 1.

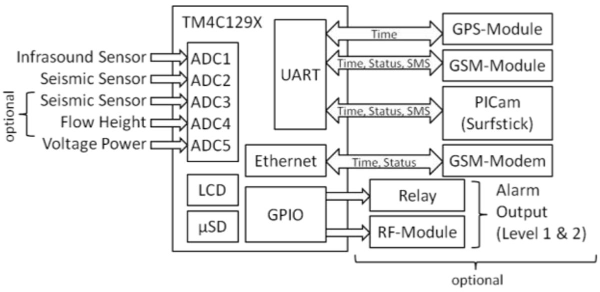


**Fig. 1.** Overview system setup and components.

The system operates at a voltage of 5 V, provided by a DC–DC converter, which needs a power connection at a voltage range from 6.5 to 32 V. The system has a power consumption between 0.7 to 1.2 W (depending on the equipment), which makes this system very suitable for stand-alone stations using a solar power supply, as is typically used. A typical system setup is shown in Figure 2.

**Fig. 2.** System setup at the sites Kühgraben (left) and Torrente Blé (right).

The MAMODIS System is currently installed on 12 sites in the Alps (Figure 3). Nine sites are debris flow catchments and at three sites the system is tested for snow avalanche detection. Data and further information of these sites are available at: http://mamodis.ddns.net


**Fig. 3.** Systems installed in 2021 (blue dots: snow avalanches, red dots: debris flow)

## 3 Detection Algorithm

The principle of the detection algorithm is already presented in [6] so only a short summary is given below. For the automatic detection of debris flows based on seismic and infrasound data, a detection algorithm had to be developed, which identifies events as early as possible, without false alarms, in a simple way, so that the algorithm can be used in real time directly at the sensor location without extensive requirements on computing effort (on a resource limited microcontroller).

The developed detection algorithm analyses the evolution in time of the frequency content from the infrasonic and seismic mass movement signals. To this purpose, different frequency bands are used to analyse the infrasound signal, whereby a 3 to 15 Hz band characterises debris flows and a 15 to 45 Hz band is used for debris floods. For the seismic signals a frequency band from 10 to 30 Hz is used for both event types. Different criteria has to be fulfilled for the Detection-Time $T_{det}$ (20 s) to identify events:

- The average infrasound and seismic amplitudes of the debris flow/debris flood frequency bands have to exceed a certain threshold (to distinguish between different event sizes, two limits are used for Level 1 and Level 2).

- The average infrasound amplitudes of the debris flow or debris flood frequency band has to be at least above a third (for debris flows) or a fourth (for debris floods) of the amplitudes of the frequency band below (1-2 Hz) This can avoid false alarms due to wind, that dominates this low-frequency band.
- The variance of the seismic and infrasound amplitudes have to be under a limit (to avoid false alarms from artificial sources, since this variance in the amplitudes of the broad-banded debris flow or debris flood signals is low, compared to narrow-banded signals from artificial sources).
- Because bedload transport processes as well as debris flows and debris floods can be detected, a further criterion is needed to enable identification of event type. For debris flow/debris flood detection, the seismic amplitude has to rise at least beyond the threshold used for the amplitude criterion during the detection time.

Using the combination of the seismic and infrasound signals, we achieve a high detection ratio and a strong reduction in the frequency of false alarms.

## 4 Magnitude Estimation

The system also offers a first estimation of the event size of debris flows or debris floods based on the infrasound and seismic data. The infrasound and seismic energy correlates passably with the discharge of an event (e.g., [7]), so we compared the maximum infrasound and/or seismic amplitudes with the peak discharge of an event (Figure 4).

The values for peak discharge and total volume used for this analysis are from Level 2 events at the Lattenbach, Gadria and Illgraben test sites (Table 1) and are calculated based on flow height measurements and velocity estimations.

**Table 1.** Peak discharge and total volume of used events.

| Test Site | Event-Date | Peak-Discharge [$m^3/s$] | Total Volume [$m^3$] |
|---|---|---|---|
| Lattenbach | 09.08.2015 | 50 | 11500 |
| | 10.08.2015 | 69 | 18500 |
| | 16.08.2015 | 12 | 5000 |
| | 10.09.2016 | 158 | 46000 |
| Gadria | 15.07.2014 | na | 10500 |
| | 08.06.2015 | na | 9850 |
| | 12.07.2016 | na | 1500 |
| Illgraben | 22.07.2015 | 17 | 8700 |
| | 10.08.2015 | 7 | 6100 |
| | 14.08.2015 | 7 | 25000 |
| | 15.08.2015 | 3 | 2000 |
| | 12.07.2016 | 15 | 10000 |
| | 22.07.2016 | 50-90 | >10000 |
| | 09.08.2016 | 29 | <10000 |

Since all monitoring stations used for this study are rather close to the channel (between 10 and 20 m) and the distances are nearly the same at every test site, we neglected attenuation of the signals in the air or in the ground, geometric spreading and the influence of topography or geology.

This analysis shows that, for peak discharge, a power curve fitting offers a good approach to find an initial relationship between the recorded signals and this event parameter.

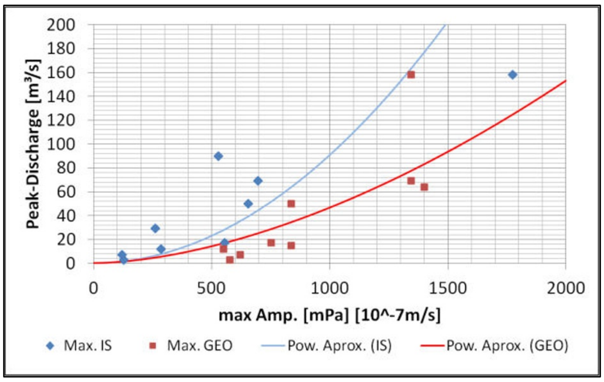


**Fig. 4.** Peak discharge over maximum seismic (Max GEO) and infrasound amplitudes (Max IS) and the approximation based on infrasound data (Pow. Approx. (IS)) and seismic data (Pow. Approx. (GEO)).

This curve fitting provides a $R^2$ of 0.76 for peak discharge based on infrasound data and a $R^2$ of 0.65 for the seismic data. The approximation for peak discharge $Q_{peak}$ (in $m^3/s$) can be calculated based on the maximum infrasound amplitudes $A_{IS(max)}$ (in mPa) and the maximum seismic amplitudes $A_{GEO(max)}$ (in $10^{-7}$ m/s) according to Equation (1).

$$Q_{peak} = \frac{1}{2}\left(0.0001019598\, A_{IS(max)}{}^{1.982999} + 0.000332\, A_{GEO(max)}{}^{1.715603}\right) \quad (1)$$

The peak discharge is calculated as the mean of both relations and this overall calculation offers a $R^2$ of 0.967. For an estimation of the total volume, we integrate the discharge calculated with the relationship for peak discharge (Equation (1)) over the entire detection time of an event. Figure 5 and 6 compares the calculated values (vertical axis) for peak discharge and total volume to the observed values (horizontal axis). The line represents the one-to-one relationship.

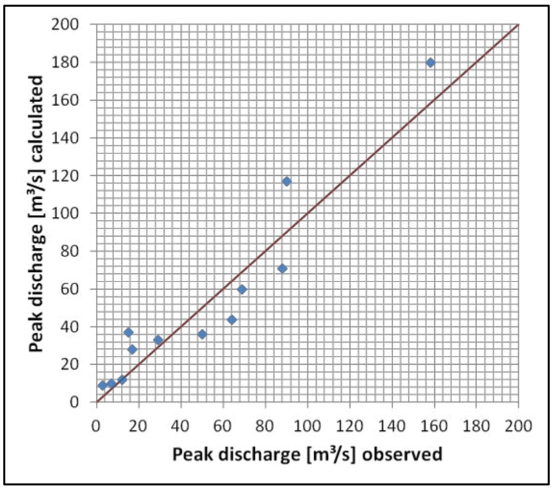


**Fig. 5.** Comparison of the calculated peak discharge to the observed values;

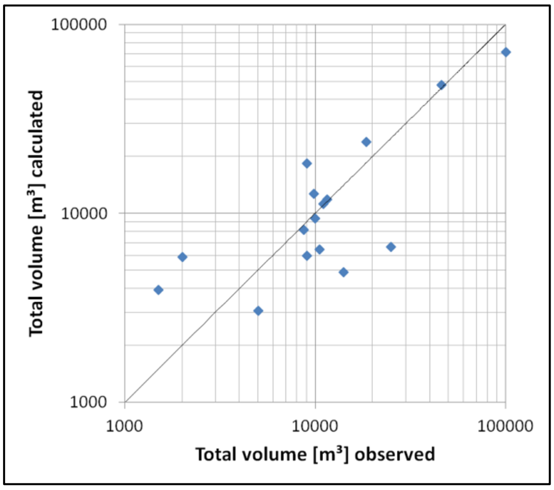


**Fig. 6.** Comparison of the calculated total volume to the observed volume.

Both diagrams suggest that it is possible to obtain first-order estimates of the peak discharge and the total volume for debris flows and debris floods at different sites based on the infrasound and seismic amplitudes. The calculation of the peak discharge based on a combination of infrasound and seismic data offers a good approximation ($R^2$ = 0.912), for the total volume, this method shows a larger variance ($R^2$ = 0.880).

## 5 Conclusions

This paper presents an approach for a detection system for different kinds of alpine mass movements based on one infrasound sensor, one co-located geophone and a microcontroller. The system consists of widespread low cost sensors and components (differential pressure sensor, standard geophone, microcontroller board) in a modular setup, so it is inexpensive, portable and easy to install and can be extended to an early warning system without much effort. The combination of infrasound and seismic signals can increase the detection probability and reduce false alarms. However, sensor equipment and installation location have to be chosen carefully and parameters of the detection algorithm may have to be adapted to the particular application and the background noise of the site.

Initial analyses of different event types and different magnitudes have shown a dependency of the peak frequency range on the viscosity and a relation of the maximum infrasound and seismic amplitudes to the event magnitude. So it is possible to estimate peak discharge and total volume from the infrasound and seismic signals, but there are still high uncertainties. In fact, beside the magnitude, flow velocity and the sediment concentration have also a large influence on the seismic and infrasound amplitudes of a debris flow, so including them in a next step in the magnitude estimation could lead to more accurate results.

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