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Disasters, Risk, Forecast, Protection

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Automatic detection and identification of debris flows based on seismic and infrasound signals

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The automatic detection and identification of debris flows has been of increasing importance for mitigation measures in densely populated and intensively used alpine regions. Since these mass movements emit characteristic seismic and acoustic waves in the low frequency range, several approaches for detection and warning systems based on these signals have already been developed. Yet a combination of both methods, which can increase detection probability and reduce false alarms, is still used rarely and no method for an automatic identification of process type and magnitude based on these signals has been developed. This work presents an approach for a detection and identification system based on a combination of seismic and infrasound sensors, which can detect mass movements in real time directly at the sensor site, identify the process type and estimate the magnitude of the event. A first method to estimate the peak discharge and the total volume of debris flows based on infrasound data is presented and will be compared with discharge measurements made at the well-equipped test site Lattenbach (Tyrol, Austria). This system setup is low cost and easy to install and can therefore be extended to an early warning system for different applications.

infrasound, seismic signals, debris flow, detection system, process identification

Автоматическое обнаружение и идентификация селей на основе сейсмических и инфразвуковых сигналов

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Автоматическое обнаружение и идентификация селевых потоков приобретает все большее значение для разработки мер по смягчению их последствий в густонаселенных и интенсивно используемых альпийских регионах. Поскольку эти процессы излучают характерные сейсмические и акустические волны в низкочастотном диапазоне, уже разработаны несколько подходов к системам обнаружения и предупреждения на основе этих сигналов. Однако комбинация обоих методов, которая может увеличить вероятность обнаружения и уменьшить ложные тревоги, по-прежнему используется редко, и не был разработан метод автоматической идентификации типа и величины процесса на основе этих сигналов. В данной работе представлен подход к системе обнаружения и идентификации на основе комбинации сейсмических и инфразвуковых датчиков, которые могут обнаруживать сели в реальном времени непосредственно на месте установки датчика, определять тип процесса и оценивать величину события. Представлен первый метод оценки пикового расхода и суммарного объема селевых потоков на основе инфразвуковых данных. Результаты сопоставляются с измерениями расхода, выполненными на хорошо оборудованном испытательном полигоне Латтенбах (Тироль, Австрия). Оборудования является недорогим и простым в установке,

поэтому оно может быть использовано для систем раннего предупреждения различных модификаций.

инфразвук, сейсмические сигналы, селевой поток, система обнаружения, идентификация процесса

Introduction

The automatic detection and identification of sediment related disasters like landslides, debris flows and debris floods, is an important task for hazard mitigation and early warning. Although different warning systems like wire sensors, radar, ultrasonic sensors (flow depth) etc. already exists, most of the present methods need sensors placed in or above the process itself, which leads to expensive structures and continuous maintenance to ensure steadiness and stability. Past studies showed that such processes induce characteristic seismic signals [*Burtin et al. 2014, Arattano 2003*] and acoustic signals in the infrasonic spectrum [*Chou et al. 2007, Kogelnig et al. 2014*] which can be used for event detection from a remote location unaffected by the process. So already many works have been done on signal processing and detection methods based on seismic [e.g. *Coviello et al. 2015, Walter et. al. 2017*] or infrasound sensors [e.g. *Zhang et al. 2004, Marchetti et al. 2015*]. But the combination of seismic and infrasound signals has been researched rarely [*Kogelnig 2012, Hübl et al. 2013*] and up to date no system has been developed which uses a combination of both technologies for an automatic detection and identification of debris flows, debris floods or landslides.

So, this work presents an approach for a detection and identification system based on a combination of seismic and infrasound sensors for sediment related mass movements. The benefits of these methods include independence from weather conditions with regard to visibility, no structural need for sustainability, same system for different kind of mass movements [*Schimmel et al. 2016, 2017*] and monitoring from a remote location unaffected by the process. This approach offers a first estimate of the peak discharge and the total volume of the process based on the infrasound signal. The results of this method are presented in example of two debris flows at the test site Lattenbach in Tyrol, Austria.

Detection and Identification System

The developed system is built up on a minimum of one seismic and one infrasound sensor which are co-located and a microcontroller which runs a detection algorithm to detect debris flows and debris floods with high accuracy in real time directly on-site [*Schimmel et al. 2016, 2018*]. Due to the use of a microcontroller for data processing, the system has a power consumption below 1.5 W which makes this system very useful for stand-alone-stations with solar power supply like it is commonly used in its field of operation. The use of low-cost sensors like standard geophones and Electret microphones in combination with a microcontroller for data processing and as datalogger and the easy installation of this system opens the possibility for several applications. So future applications of this system could be the protection of traffic lines by controlling a traffic light, the protection of mines and pipelines in remote locations, or protecting construction sites inside torrents like cleaning up a retention basin after a debris flow. Since the material cost of such a system is below 1000 € this setup may be used especially at sites, where the necessary founding for expensive torrent and avalanche barriers are not available.

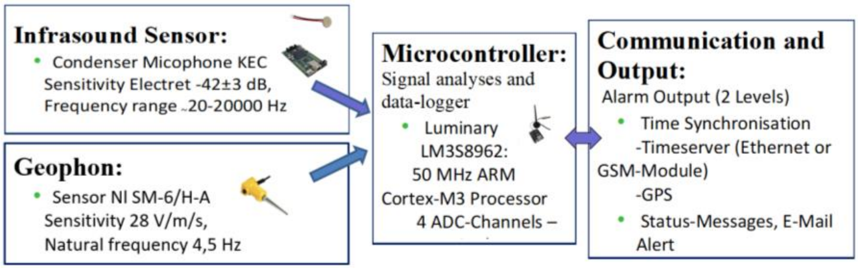

Fig. 1. Overview of the used system components, their technical specifications and functions

The developed detection algorithm analyses the evolution in time of the frequency content from the infrasonic and seismic mass movement signals. Therefore, 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.

Three different criteria have to be fulfilled for the Detection-Time Tdet (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: 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 (to avoid false alarms due to wind).
- The variance of the seismic and infrasound amplitudes has to be under a certain limit (to avoid false alarms from artificial sources)

Analyses of different events on several test sites showed, that the infrasound and seismic energy correlates passably with the discharge of an event and can therefore be used to estimate the peak discharge and total volume of an event. The values for peak discharge and total volume used for this analysis are from Level 2 events of three different test sites (Lattenbach (Austria), Gadria (Italy) and Illgraben (Switzerland)) and are estimated by flow height measurements and velocity estimations. This analysis shows that for peak discharge, the infrasound amplitudes with a power curve fitting offers a good approach to find a first relationship between the recorded signals and this event parameter [*Schimmel et al. 2018*]. The approximation for peak discharge Q_{peak} (in m³/s) can be calculated based on the maximum infrasound amplitudes $A_{IS(max)}$ (in mPa) according to Equation (1):

$$Q_{peak} = 0{,}000732\, A_{IS(max)}^{1{,}644}. \tag{1}$$

For an estimation of the total volume we integrate the discharge calculated with the relationship for peak discharge over the entire detection time of an event.

Test Site Lattenbach

The Lattenbach creek, is a very active torrent located in a geologic fault zone in the western part of Austria (Landeck, Tyrol) with a catchment area of 5.3 km². The channel separates the Northern Limestone Alps in the North from the Crystalline Alps in the South. The highest elevation of the catchment is around 2900 m above sea level (asl), the confluence with the river Sanna at 840 m asl. Due to the frequent debris flows and debris floods events the torrent is monitored by the Institute of Mountain Risk Engineering since several years [*Hübl et al. 2006*]. The parameters that are currently measured during an event include meteorological data (rainfall, temperature, etc.) in the upper part of the catchment (Station "Dawinalpe") and run-off data from the middle (Station hm 13.25 and hm 12.78; village Grins) and lower reach (Station hm 1.5; villages Pians) of the torrent (Figure 2). In the last years the monitoring equipment has been constantly improved. Additional to the standard sensors like several radar gauges for water level measurements, the detection system consisting of a Chaparral infrasound sensor and a SM-4 geophone (changed in 2014 to a SG-5 geophone) has been installed at the test site near the monitoring Station hm 12.78 closed to Grins in 2013. In 2015 the infrasound sensor was changed to an Electret-microphone and a second system, also based on a Electret-microphone and a SG-5 geophone, has been installed around 90 m upstream at Station hm 13.25, which can therefore be used to measure the surge velocity.

Further a high frequency Pulse Doppler Radar (IBTP-Koschuch; [Koschuch et al. 2015]) has been installed at Station hm 12.78, which provides the opportunity to measure the surface velocity of a debris flow in different range gates. Together with a installed 2D-Laser scanner this setup provides the possibility to determine a very precise approximation of the discharge with a high temporal resolution by multiplying the scanned cross sectional wetted area with the surface velocity of the related range gate [*Hübl et al. 2017*].

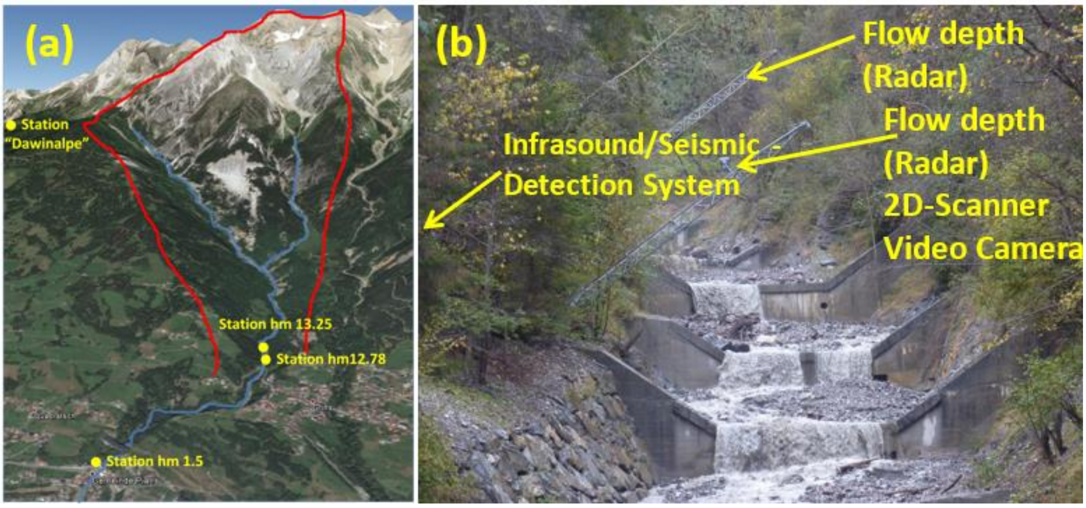

Fig. 2. (a) Overview of the test site Lattenbach (red line: catchment area; source: Google Maps); (b) Closer view of the monitoring Station hm 12.78 and sensor setup

Results - Magnitude Estimation

To evaluated this method for the magnitude estimation we analyzed two events which occurred at the Tyrolese test site Lattenbach in the last years.

This first event is a small debris flow with a total volume of 5000 m³ and a peak discharge of 12 m³/s, which occurred on 16.08.2015. It had a maximum infrasound amplitude of 471 mPa at 6 Hz and a maximum seismic amplitude of 55 µm/s at 25 Hz. The detection algorithm could identify this event 40 s (Level 1) and 14 s (Level 2) respectively, before passing of the main surge at the sensor site. The diagram in Figure 3 compares the calculated discharge (Q_{is}) and calculated volume (V_{is}) based on infrasound data to the measured discharge (Q_m) and measured volume (V_m) which has been determined by the debris flow Puls-Doppler Radar and the 2D-scanner. The peak discharge calculated on the infrasound signal based on the method presented in Section 3 was 18 m³/s which overestimate the measured peak discharge, but the estimation of the total volume with 4738 m³ fits very well with the measured total volume.

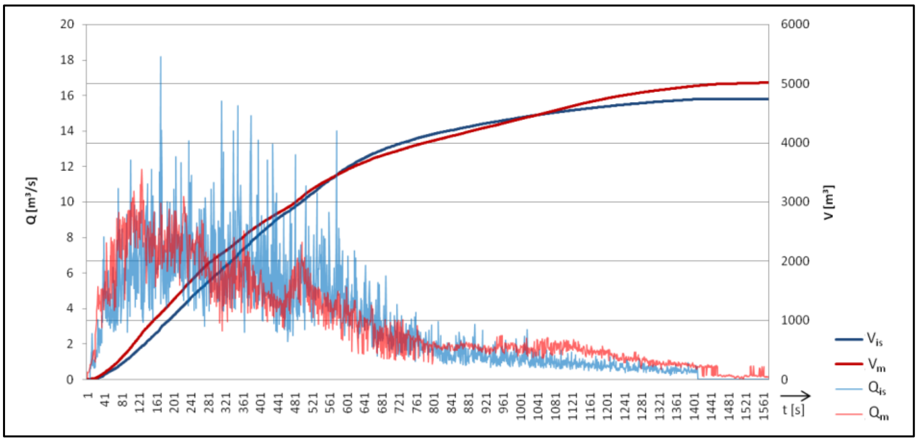

Fig. 3. Calculated discharge (Q_{is}) and calculated volume (V_{is}) based on infrasound data compared to measured discharge (Q_m) and measured volume (V_m) of the debris flow on 16.08.2015.

The second event presented here occurred on 10.09.2016 at 18:54 CET. This event with a duration of 4000 s consists of more than 40 surges and had a total volume of 46100 m³. The event was detected by the warning system 16 s (Level 1) and 4 s (Level 2) before the first surge arrived at the sensor site. The maximum infrasound amplitudes of 1776 mPa was recorded at 12 Hz and the maximum seismic amplitudes of 185 µm/s occurred at 25 Hz. If the measured discharge and its resulting total volume is compared to the calculated discharge and total volume it shows a good correlation for the first turbulent part of the debris flow, but the discharge calculation based on the infrasound signal overestimates the discharge for the second smother part of the event (Figure 4). So the resulting overestimation of the total volume is about 8000 m³ However, the peak discharge estimated based on the infrasound signal of 161 m³/s fits very well with the measured peak discharge of 158 m³/s.

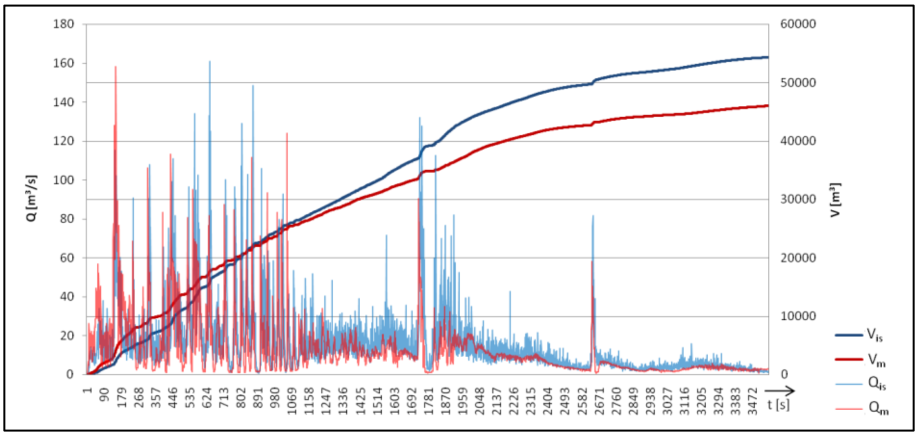

Fig. 4. Calculated discharge (Q_{is}) and calculated volume (V_{is}) based on infrasound data compared to measured discharge (Q_m) and measured volume (V_m) of the debris flow on 10.09.2016.

Conclusion

This work shows that the combination of infrasound and seismic sensors can offer a good approach for an automatic detection system for different alpine mass movements. The combination of both technologies can increase the detection probability and reduce false alarms. So, the presented system could detect all larger debris flows and debris floods in the period from 2013 to 2016 at nine different test sites, while only seven false alarms were registered in this time period. The test on very different sites with diverse types of sensors shows that the sensor equipment and installation location have to be chosen carefully. Also, the parameters of the detection algorithm may have to be adapted to the particular application and the background noise of the site. This work also presents a first approach for an identification of the process type and the magnitude of sediment related mass movements. So a method for the estimation of the peak discharge and the total volume based on the infrasound data of an event is introduced, which shows promising results. However, further research based on a large databases of different well categorized events at various test sites will be necessary for a reliable event identification.

In summary this work shows, that the combination of one infrasound and one seismic sensor and the use of a microcontroller can offer a good basis for an easy to install, and inexpensive warning system for different kind of alpine mass movements.

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