Automatic detection of avalanches using infrasound and seismic signals.

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ABSTRACT: The ability to detect avalanches as they occur is essential for avalanche management and avalanche forecasting. Past studies have shown that avalanches generate signals in the low-frequency infrasonic spectrum and induce characteristic vibrations in the ground and this signals can be used to build up a warning system. The benefits of this method include independence from weather conditions with regard to visibility, no structural need for sustainability, same system for different alpine mass movements (snow avalanches, debris flows,...) and monitoring from a remote location unaffected by the process. Several approaches to monitor avalanches with infrasonic or seismic sensors are existing, but to date the combination of seismic and infrasound sensors for an automatic detection has not been considered. Previous studies have already shown that seismic and infrasonic signals of avalanches are correlated and complementary and that the combination of these two sensor types can serve as a basis for an error resistant warning system. So the goal of this work is to build up a warning system that is based on a minimum of one seismic and one infrasound sensor, which are co-located, to detect mass movements with high accuracy directly on-site. Therefore a detection algorithm has been developed and the system was extended by a microcontroller, which can do the necessary calculation in real time and directly at the sensor site. The algorithm has been tested with avalanche signals monitored at the Vallèe de la Sionne test site in Switzerland and a first version of this new system was tested last winter at Kaprun in Salzburg.

KEYWORDS: Avalanches, Warning systems, Infrasound, Seismic

1 INTRODUCTION

Monitoring systems based on seismic signals are quite common and have been used to study avalanches and debris flows for many years. Various previous studies on avalanches (e.g. Surinach et al. 2000; Biescas et al. 2003; Bessason et al. 2007) have already shown that it is possible to detect these processes with geophones and that it is possible to distinguish them from other seismic sources. The first attempts of infrasound monitoring of avalanches (Sommerfeld et al. 1977, 1983; Bedard et al. 1989, 1994; Chritin et al. 1996; Scott et al. 2002, 2004, 2006) have already proven the viability of infrasonic waves for detection and monitoring of these types of mass movements. Although there are many research work done, no reliable universal usable warning system, based on the combination of only one infrasound and one seismic sensor has been considered. Previous studies conducted at the Institute of Mountain Risk Engineering (e.g. Kogelnig et al. 2011, 2012) have already shown that seismic and infrasonic signals of alpine mass movements are correlated and complementary, and that the combination of these two sensors can provide a basis for the development of a innovative warning system, because advantage can be taken of both technologies and the disadvantages can be minimized. (e.g. seismic: lower disturbances due to wind and weather but strong dependency on the geology of the site and high attenuation with increasing distance between mass movement and sensor; infrasound: little attenuation in the air at local distances, but high background noise induced by wind).

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2 DETECTION PRINCIPE

This section describes a first version of a detection method to automatically detect avalanches based on seismic and infrasound data. The requirement on this detection algorithm is to identify events as early as possible without many false alarms in an uncomplex way, so that the algorithm can be run in real time directly at the sensor site without high computational effort (e.g. on a microcontroller). This leads to an approach of analyzing the development of the amplitudes of the signals in a time-frequency range. The automatic detection of an event is limited by a minimal event size, weather condition, distance and background noise.

The infrasound signal and the seismic signal is processed by fast Fourier transform (FFT) and analyzed with respect to time, time-frequency and amplitude. This approach of a detection algorithm compares the development of the signal over time in three frequency bands. For the infrasound signals the three frequency bands are defined from 2 to 5 Hz, 7 to 10 Hz and 12 to 15 Hz; for the seismic signal this bands are: 7 to 10 Hz, 12 to 15 Hz and 17 to 20 Hz. The distribution of this frequency bands was chosen to represent the whole characteristic spectrum of infrasound and seismic signals produced by avalanches. Interfering signals are often distributed evenly over this three relevant frequency bands on the contrary to avalanches which presents a typical divergence over time at these frequency bands. So the difference between the average amplitudes of this different frequency bands can be used as a detection criteria. At the current version a mass movement is detected if the difference between this three frequency bands exceeds the limit of 3 mPa for infrasound signals and 0,01 µm/s for seismic signals, for a specific time span which is set to 10 s. As an additional criteria the peak frequency of the infrasound and seismic signal is used to avoid high frequency disturbances. For a detection of an event this peak frequency has to be below 28 Hz for the infrasound signal and below 40 Hz for the seismic signal during the time span. This limits and time span has been determined in an analysing process of different avalanche and interfering signals. Only if this criteria is met by the seismic and the infrasound signal a detection of an event is indicated, which results in a strong reduction of false alarms. This method has been tested for different avalanche signals and seems to be a promising approach. The applicability of this detection algorithm is shown at section 4 in example of two events at the Vallèe de la Sionne test site in Switzerland.

3 SYSTEM SETUP

As described above the detection system is based on a combination of two sensors, a infrasound and a seismic sensor. A microcontroller is used to run a detection algorithm and detect events directly on site. A overview of this setup is shown in figure 1.

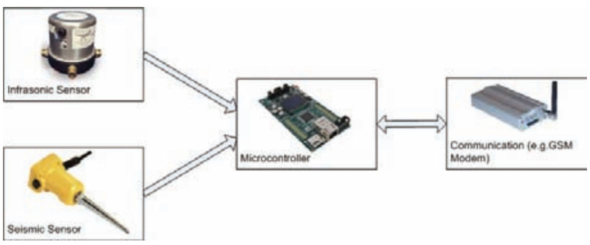

Figure 1. System setup

Currently the system consist of a Chaparral Physics Model 24 Infrasound Sensor which has a resolution of 2 V/Pa and a seismic sensor of the type SM-4 with a resolution of 28.8 Vs/m.

For the data processing the Stellaris Luminary Evaluation-board LM3S8962 with a 50 MHz ARM Cortex-M3 microprocessor is used. The input signal is adapted to the microcontrollers ADC input range by an operational amplifier circuit. For this input circuit an inverting amplifier with a gain of 0.2 for the infrasound signal and a gain of 110 for the seismic signal is used, which results in a final resolution of 400 mV/Pa for infrasound and 3168 mVs/mm for the seismic signal. For the input from the infrasound sensor a high-pass filter based on a RC-circuit with a cutoff-frequency of 1.17 Hz is used. This high-pass filter is specially needed to reduce the noise if the infrasound sensor location is very exposed to wind, since the disturbances caused by wind are usually located mainly in the range of 1-2 Hz.

The Evaluation-board offers the possibility to store the data on a micro-SD card for up to two month and it also provides Ethernet access for remote control and download of data. A great advantage of this system is, that the microcontroller makes it very flexible and adaptable for the special requirements of a warning system and the setup is low cost, highly effective and applicable in harsh alpine environments.

Also the energy consumption of this system is very low which makes this setup very useful for stand alone stations with solar power supply. The current setup needs an electrical power of 1,5 W and a power supply with 12 V DC is used.

A fist version of this system setup has been tested last winter at the test site Kaprun in Salzburg. This test site is located at the pumped-storage power plant of the electricity company Verbund with high frequency of naturally released avalanches. For the next winter two systems will be installed there and it is also planed to install further systems at the nearby ski resort for detecting artificial triggered avalanches.

4 DETECTION EXAMPLE

This approach for the detection algorithm has been applied to the seismic and infrasound signal of several events recorded at Vallèe de la Sionne. This avalanche dynamic test site is located in central Valais (Switzerland) above the city of Sion and is operated by the WSL Swiss Federal Institute for Snow and Avalanche Research, SLF. Two naturally released avalanches with typical seismic and infrasound signals have been chosen as an example for the application of the detection algorithm. Detail information of both avalanches and the recorded infrasound and seismic signals can be found in Kogelnig et al. 2011.

The first event occurred on 07.12.2010 and was released naturally after a snowfall of 0.50 m on a snow cover of 0.8 m. The classification size of the avalanche was approximately 4 (mass 10^4 t; path length 2000 m) and the duration based on infrasound and seismic data was approx. 495 s (40 s to 535 s).

Figure 2 a and b shows the seismic and infrasound signal of this avalanche and the diagram below depict the average amplitudes of the respective frequency bands. The lines over the diagrams indicates the point in time of the first detection based on the particular data.

The detection algorithm identifies the event in the infrasound signal 93 s after the start of recording and the detection based on seismic signal is some time later at 115 s. The diagram of the average amplitudes shows that the frequency band with the highest amplitude of the infrasound signal is the band from 2 to 5 Hz. The main amplitudes of the seismic signal are located in the 7 to 10 Hz band, however, the difference to the other frequency bands is much smaller than in the infrasound signal. So the detection based on the seismic signal is more complicated which results in a 22 s delayed detection compared to infrasound.

The second avalanche was recorded on 11.02.2009 after a snow precipitation of 0.4 m on a snow cover of 2 m. This event was a little bit smaller as the previous presented avalanche

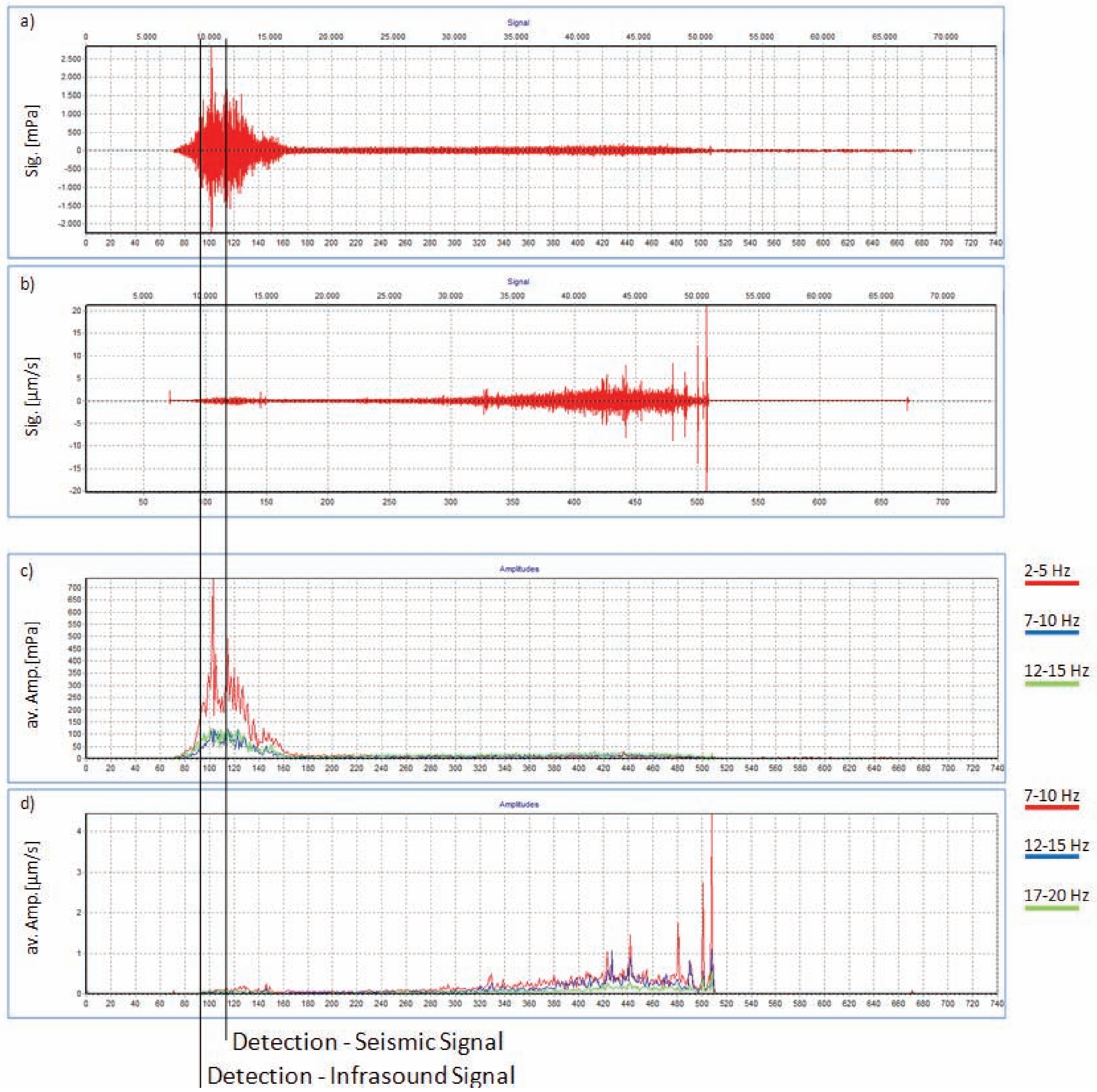

Figure 2: Infrasound and seismic data of the avalanche monitored at the Vallèe de la Sionne test site on 07.12.2010. Signals are represented with a common base of time. (a) Infrasound time series; (b) Seismogram; (c) Average amplitude of the three frequency bands of the infrasound signal; (d) Average amplitude of the three frequency bands of the seismic signal; Lines: time of first detection based on infrasound and seismic data.

with a classification size of approximately 3 (mass 10^3 t; path length 1000 m). The duration of the event can be estimated with about 80 s (70 s to 150 s).

Figure 3 shows the result of the detection algorithm applied on the seismic and infrasound signal of this avalanche.

Similar to the previous presented avalanche the detection based on infrasound data is some time earlier (at 91 s) then the detection based on seismic signal (121 s) which also results from the low differences between the frequency bands at the first part of the seismic signal. The signals of the two avalanches have in common that the main frequency at the infrasound signal is in the 2 to 5 Hz band and that the peak amplitudes are reached some time earlier the in the seismic signal, where the peak amplitudes are located at the end of the signal. This results from the flow regimes of the avalanches and the different sources of the signals. As signal source is assumed that, the acoustic signal is generated by the turbulent snow air flow (powder cloud) (Firstov et al. 1992) and that the main sources of the seismic energy generated by snow avalanches are the basal friction produced

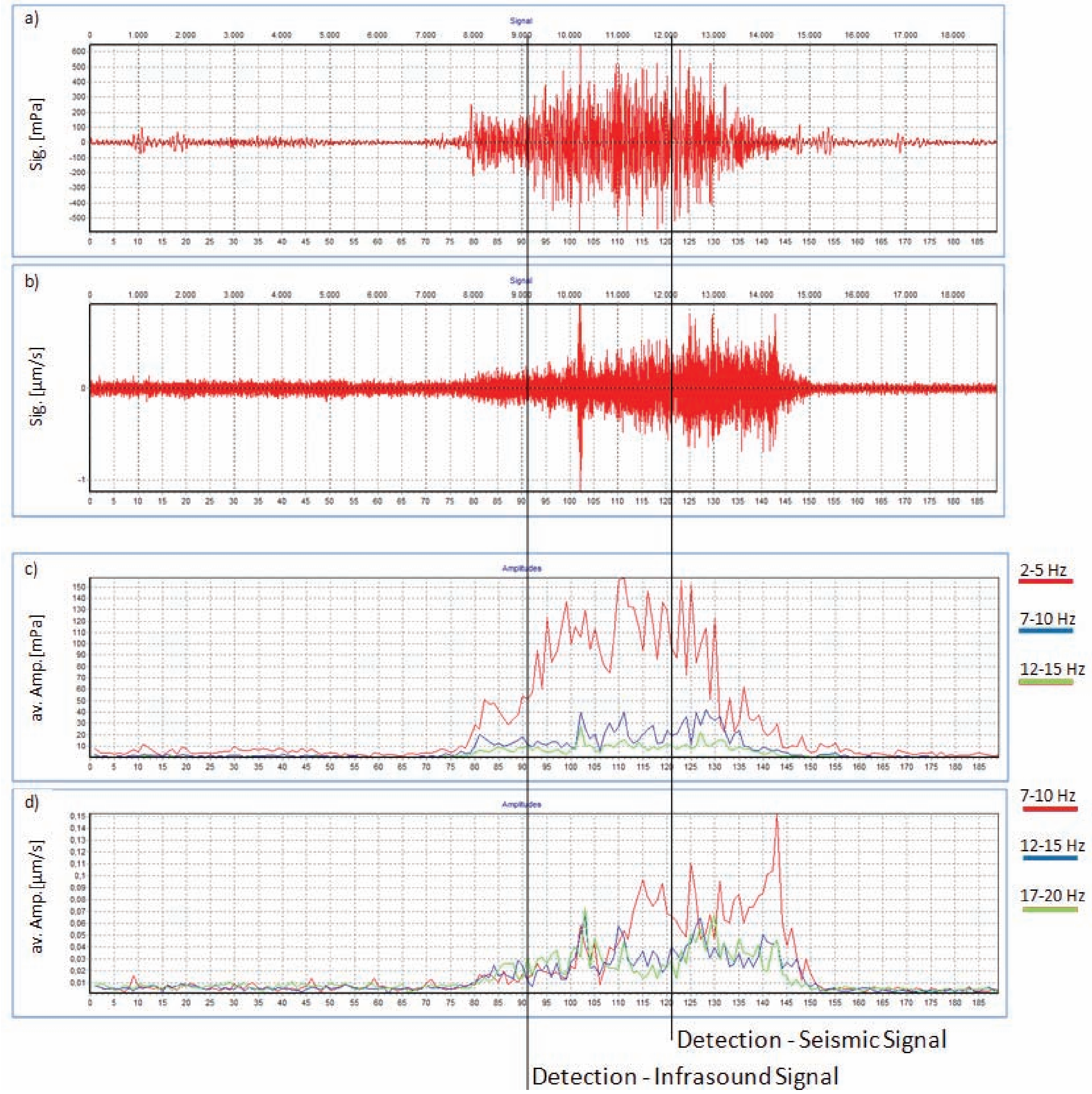

Figure 3: Infrasound and seismic data of the avalanche monitored at the Vallèe de la Sionne test site on 11.02.2009. Signals are represented with a common base of time. (a) Infrasound time series; (b) Seismogram; (c) Average amplitude of the three frequency bands of the infrasound signal; (d) Average amplitude of the three frequency bands of the seismic signal; Lines: time of first detection based on infrasound and seismic data.

by the dense body inside the flow in contact with the ground or snow cover and the changes in the slope of the path (Surinach et al., 2000; Biescas et al., 2003; Vilajosana et al., 2007; Schneider et al., 2010).

4 CONCLUSION

This paper presents a first approach for an avalanche warning system based on a combination of seismic and infrasound sensors. The combination of both sensor technologies increases the detection probability and minimizes false alarms.

So with these complementary technologies it will be possible to build up a reliable warning system which can detect avalanches as well as debris flows in real time directly at the sensor site and comes along with only one seismic and one infrasound sensor (co-located). The use of a microcontroller for the calculation of the detection algorithm makes the system very flexible, low energy consuming and cost-efficient.

However, the application of seismic and infrasound sensors for monitoring and detection of alpine mass movements is not a straightforward task. Understanding the propagation and attenuation mechanisms of seismic and infrasonic waves and the background noise characteristics in the study conditions is crucial for the interpretation of the recorded seismic and infrasonic signals and the development of a detection algorithm. The equipment and the placement of the sensors have to be chosen carefully. So the tests last winter at the test site Kaprun in Salzburg has shown that some interfering signals from the pumped-storage power plant are recorded as event, which could have been avoided by proper site selection.

In summary, the analysis confirmed that avalanches produce seismic and infrasonic signals characteristics that are reproducible at very different experimental sites and under different environmental conditions and so the combination of infrasound and seismic sensors for monitoring alpine mass movements and use this signals for an automatic detection, showed promising results.

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