The "Avalanche Detector", a new avalanche monitoring tool using distributed acoustic fibre optic sensing

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ABSTRACT: Information on avalanche activity is a paramount parameter in avalanche forecasting. When avalanches are released spontaneously, the risk of avalanches is very high. Therefore a new tool for avalanche monitoring, a distributed fibre optic system, is for the first time installed and adapted for the purpose of monitoring snow avalanche activity. The method is based on an optical time domain reflectometer system, which dates back to the 1970's and detects seismic vibrations and acoustic signals on a fibre optic cable that can have a length of up to 30 km. An appropriate test slope for this configuration has been found in the ski area of "Lech am Arlberg". In this work a description of the theoretical background, the system implementation, the field installation, realization of tests and an investigation of the recorded data is presented. We conducted 100 tests and triggered 52 avalanches so far with a runout distances ranging from a few meters to approximately 250 meters, all of which were detected by the system, as well as the 59 not successful attempts of artificial triggering. Moreover we measured properly if critical infrastructure (in our case a ski run) was reached by the avalanches or not. In conclusion we summarize that distributed acoustic fibre optic sensing is a precise method to monitor avalanche activity and runout distances

KEYWORDS: avalanche, monitoring, detection, fibre optic sensing.

1 INTRODUCTION

Information on avalanche activity is an important parameter in avalanche forecasting. When avalanches are released spontaneously, the risk of avalanches is obvious. Triggering avalanches by artificial means, such as explosives launched from helicopter or avalanche towers, can also give information on the stability of the snow pack. Hence, monitoring of avalanches released naturally or artificially, is an important quantity in avalanche forecasting. This information is also needed when deciding whether to close or not endangered ski runs, roads or railway lines.

So far monitoring systems lack certain benefits. Either they monitor only large avalanches, can only be used for single avalanche tracks or are weather/sight dependant. Snow avalanches are most commonly monitored by visual observations. This is not possible at night or when visibility is limited (Herwijnen and Schweizer 2011).

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So far, most approaches that are not visibility-dependent are based on the detection of acoustic, infrasonic or seismic emissions associated with avalanche activity or on radar technique. When reviewing measurements of infrasound induced by avalanche activity, Bedard (1989) mentioned that snow avalanches show unique acoustic signatures and for this reason proposed that the use of an algorithm for automatic identification might be promising. The studies of Comey and Mendenhall (2004) and Scott et al. (2007, 2004) investigated the potential of single and multiple infrasound sensors for the purpose of avalanche identification and stated that the use of multiple sensors improves the robustness of the approach against wind and noise and also allows to estimate the location of the avalanche. Kogelnig et al. (2011) combined infrasound and seismic sensors and highlighted the different strengths and limitations of both approaches.

Saint-Lawrence and Williams (1976) was one of the first who described that seismic signals associated with snow movement show specific characteristics, which allow to distinguish signals caused by avalanches from others. Seismic signals originating from snow avalanches, landslides and other mass movements were extensively analysed in the works of Surinach et al. (2000, 2001, 2005). Biescas et al. (2003) focused on the frequency evolution of the seismic

signals associated with avalanche events by investigating the running spectra of the signals. Navarre et al. (2009) presented data recorded at several stations of Seismic Detection of Avalanches in the French Alps. These stations were equipped with special software performing signal identification and signal analysis, regarding the time domain, the frequency domain, the polarization domain and the time-frequency domain. A unique, basin-scale avalanche activity dataset for an entire winter season, was collected by Herwijnen and Schweizer (2011), who compared data on avalanche activity recorded using a geophone (installed in the avalanche start zone) as well as automatic cameras and additionally considered meteorological data from nearby automatic weather stations.
Another approach for the detection of avalanche activity by means of a doppler radar is described in the work of Gubler (1986). The author used an oversnow vehicle based doppler radar to determine particle speed distributions in artificially released dense flow avalanches.

2 DISTRIBUTED FIBER OPTIC TECHNOLOGY

In the 1970's, some of the first experiments using optical fibers for sensing applications have been carried out (Grattan and Sun 2000). All fully distributed sensing system techniques are based on Optical Time (or Frequency) Domain Reectometry (OTDR) and allow measurements of distributed temperature, strain or pressure (Nikles 2007). Optical Time Domain Reflectometry first was used for fault detection in optical fibres and this technique was presented by Barnoski et al. (1976). The techniques employed for the purpose of distributed temperature, strain or pressure sensing make use of different characteristics of the backscatter signal and hence either focus on Raman-, Brillouin- or Rayleigh- Scattering.

In snow and avalanche research, Tyler et al. (2008) used Raman-Spectra distributed temperature sensing for the measurement of snowpack base temperatures and Woerndl et al. (2010) investigated the ability of the distributed temperature sensing system to cover spatial and temporal variability of snow temperatures. Distributed temperature sensing is also employed for structural health monitoring, as for example in the case of dams (Aufleger et al. 2007). Another application of distributed fibre optic sensing is given by monitoring of long perimeters using a distributed pressure/ seismic sensor (Choi et al. 2003). Commercially available devices that perform distributed temperature, strain or acoustic sensing are employed in the fields of e.g. oil and gas, pipelines, power, structural health monitoring and security.

The goal of this work is to identify the potential of a distributed acoustic fibre optic system for the purpose of detecting and in a further step, monitoring snow avalanche activity. The system will be deployed in an avalanche slope for the first time. Several tests will show if this technique is suitable for detecting avalanche signals and if it is possible, to distinguish them from other sources of signal. The necessary technology of measuring acoustic disturbances with an optical fibre sensor system is nowadays commercially available. Several companies can be found on the market that are providing fibre optic sensing devices. A company has been found that provides an appropriate device as well as the required technical support. Regarding the fibre optic cable, a fibre optic specialist could be found for the production of the cable as well as support in the field work. The company is experienced in producing fibre optic cables for the use in sensing applications. Therefore the company could produce a fibre optic cable especially designed to fit our needs.

3 TEST SITE

An appropriate avalanche slope for testing the system was found in the ski area of Lech am Arlberg, Austria. The slope is situated on the lee side of a ridge on the east face of the Mohnenfluh and was used for different other research projects by the team in the past (e.g. Prokop 2008, Schneiderbauer and Prokop 2011) The summit of Mohnenfluh reaches up to 2544 m. The 'test-slope' extends from just beneath the blasting towers downwards, until the beginning of the ski run. The fibre line is shown in Figure 1. The start point is located at about 2337 m and its end point is located just before the beginning of the ski run, at 2245 m altitude. The length of the avalanche path within the test-slope is about 230 m. The slope itself is not part of the prepared skiing area, but can easily be accessed from Steinmaehder top station, which is situated at 2298 m altitude. The proximity to the infrastructure of the skiing area allows for easy transport of the entire instrumentation. Furthermore, fast access to the instrumentation is ensured. This is important so that measurements can be performed immediately after heavy snowfall and consecutive blastings. Steinmaehder top station is not only very useful in terms of transportation matters but also acts as housing for the measurement unit. There is a separate room where a secure installation location, power supply, heating and web access are provided.

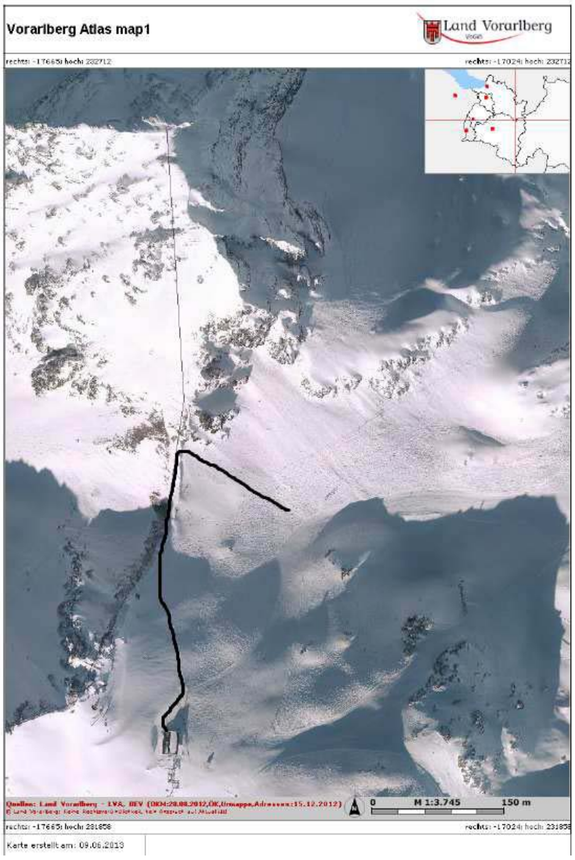

Figure 1. Map showing the location of the cable deployed in the test-area at Lech am Arlberg. The map has been produced using the software Vorarlberg Atlas 4 provided by Land Vorarlberg.

4 METHODOLOGY

4.1 Measurements

In order to identify the overall potential of this device as well as possible sources of error, diverse tests have been performed. In the most likely case, the system will be exposed to the following sources of signal: skiing on top of the fibre line, helicopters or even airplanes, groomers, lift stations, weather, explosions and snow avalanches. Recordings of these sources of signal were executed on different measurement days in order to scope different prevailing weather and snowpack conditions.

The measurement unit performs measurements continuously along the entire fibre optic cable with a spatial resolution up to 1 m. According to the selected system configuration and the applied settings, the highest detectable frequency is about 5000 Hz.

Alternatively the tests were filmed to validate if an avalanche occurred and if and when it has reached the berried fibre optic cable. Laser scanning campaigns using Riegls LPM-321 laser scanner were carried out when a scanner was available to measure the mass displacement after avalanche events. For laser scanning the method of Prokop (2008) and Prokop and Panholzer (2009) was applied.

4.2 Data post processing

The data post processing is performed with MATLAB, a software developed by Math Works. The data is analysed concerning different characteristics. In order to get an overall impression of the dataset, first a Soundfield image was produced. The Soundfield plot displays the recorded data in dependence of time and depth. So, the signal intensity is analysed in terms of time and location. This means that now time series can be produced for different locations in order to find out whether an event has been detected and to what extent the fibre has responded to it. This is very helpful to get a quick overview and then study the data in detail. Whenever an event is found, its spatial and temporal extent can clearly be identified. An example of a time series is shown in Figure 2.

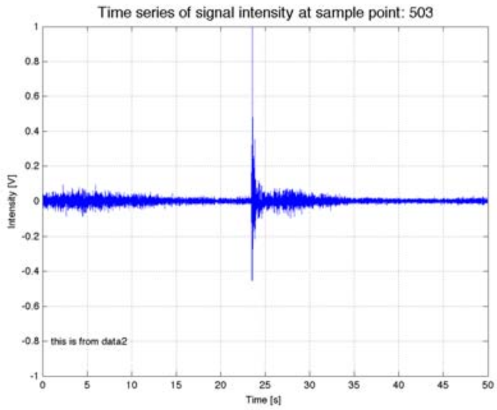

Figure 2. A time series at sample point 503, where some event occurred. The vertical axis refers to voltage (intensity of the signal). The horizontal axis refers to time in seconds.

Another approach for analysing the data is to focus on its spectral characteristics. The different recorded events will probably show altering signal intensities in different spectral bands. These characteristics can be investigated in detail by producing spectrograms of the desired data. Therefore, it is crucial to define the temporal and spatial extent of the event first in order to prevent averaging the spectrogram over sample points and periods where only standard noise was recorded but no event. This would not lead to the desired the results. In Figure 3, an example of a spectrogram is shown. The figure presents the frequency distribution of the signal's energy. The data shown is already filtered from 1 up to 80 Hz. This means that frequencies higher than 80 Hz and frequencies below 1 Hz are cut. There are different filters that can be applied to the datasets. So far, the utilized filters are kind of edge filters. The procedure when filtering data, in this study, is to first take a filter that almost reaches up to the highest detectable frequency. Then, if there is no significant intensity in the higher bands, the data gets filtered step by step, until the relevant frequency range is determined.

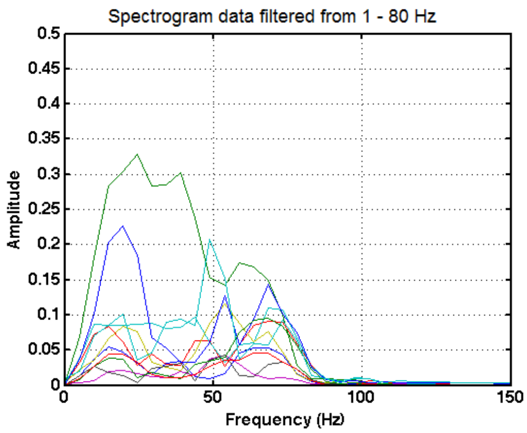

Figure 3. Spectrogram where input data has been filtered from 1 - 80 Hz.

5 RESULTS

In this result section the signals of the detected events are shown and their characteristics are highlighted according to the responsible source of signal. These sources comprise: stamping and skiing on top of the cable, environmental noise, explosions and snow avalanche activity. In this chapter, the basis for the investigation whether the system is practicable for the purpose of detecting snow avalanche activity is given and possible errors sources are revealed.

5.1 Avalanches and explosions

The first detectable avalanches were triggered on April 9th 2012. A video analysis of the blasting showed that the explosion at tower number 1 triggered several small avalanches within the test-slope, as can be seen in Figure 4.

One of them was within the reach of the fibre line. This small avalanche is indicated by the red arrow in the photograph. It has partly been propagating on top of the fibre line.

Figure 4. Avalanche measured on April 9th 2012, the location of the avalanche is indicated by the red arrow.

Hence, when looking at the Soundfield plot, a signal directly following the first explosion is evident. This signal is most likely caused by the snow movement of the small avalanche that occurred on top of the fibre line. Also, the small spatial extent of the signal, comprising roughly the sample points 435 - 490, is in good agreement with the spatial extent derived from the video analysis. There, the avalanche event started at the top of the test-slope, just beneath blasting tower number 2 and was reaching just a few tens of meters into the test-slope. The amount of snow associated with the release of the small avalanche has been very limited. This points out the high sensitivity of the distributed acoustic sensing system.

In order to further investigate the snow avalanche signal, time series have been analysed. An example showing the time series at sample point 473 (320 m) is presented in Figure 5. The signal consecutive to the explosion signal, which is present in the Soundfield plot, is also present in the time series.

Looking at a larger avalanche event (still less than 100 m in length) at the 12th of April 2012 the signal of the avalanche is even more obvious. An explosion at blasting tower number 3 successfully triggered an avalanche within the test-slope. The small avalanche was partly propagating on top of the fibre line. A photograph of this event is shown in Figure 6. The outlines of the avalanche are indicated by the pink line. Again the time series shows the explosion and consecutive signals of the avalanche which were verified by film material (Figure 7). This time series shows more than one sample point. it includes the measurements of 10 sample points (sample points 515-525).

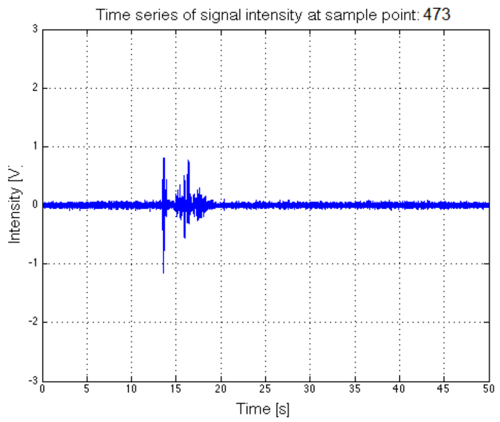

Figure 5. Time series at sample point 473, showing the first explosion and the consecutive avalanche signal on April 9.

Figure 6. Avalanche released on April 12th 2012. Snow was propagating on top of the fibre within the test-slope until approximately the second ski path crossing the slope.

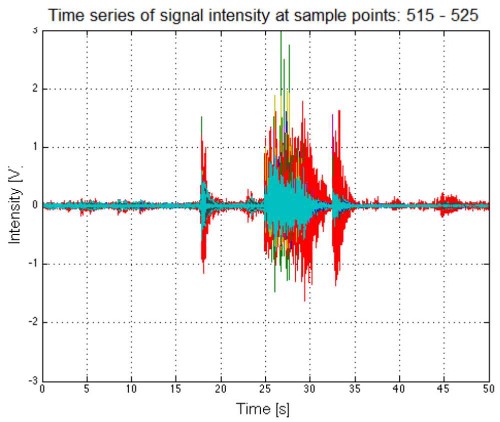

Figure 7. Time series at sample points 515 - 525 showing the explosion and consecutive signals of the avalanche.

In this manner we conducted 100 tests and triggered 52 avalanches so far with a runout distances ranging from a few meters to approximately 250 meters, all of which were detected by the system, as well as the 59 not successful attempts of artificial triggering. Moreover we measured properly if critical infrastructure (in our case the ski run) was reached by the avalanches or not.

5.2 Disturbing signals

The disturbance signals, for example when a skier crossed the fibre line, showed different characteristics than those originating from avalanche activity and have a as well a very defined spatial extend (approx. up to 4 sample points). Energy is distributed in a narrow frequency range compared to avalanche signals. So, the disturbance signals can clearly be identified and do not pose any confusion regarding the detection of snow avalanche events. Lift stations in action create a constant noise onto the fiber and can be easily identified, As the fibre optic cable is buried under the snow pack, wind and snowfall do not create any disturbing noises, as it is the case for seismic and infrasound recordings.

6 CONCLUSIONS

The distributed acoustic sensing system was able to successfully detect avalanche events if they occurred within the system's reach. Furthermore, the system proofed its suitability for explosion control, as all the explosions affecting the testing-area were successfully recorded. The skiing and stamping tests allowed to investigate the sensitivity of the system in more detail. Regarding these tests as well as the results from analysing the avalanche signals recorded on April 9th, the system shows its high sensitivity as even very weak impacts, either induced by skiing or stamping action or the propagation of very limited amounts of snow on top of the fibre line, were detected by the system. The system's high sensitivity is rather unique on the market of avalanche detection systems. However, the tests also showed that impacts of this low size can only be detected if they occur within the direct vicinity of the fibre. This implies that impacts have to be applied directly on top of the fibre or depending on their size, within a range of meters away from the fibre. In addition, the system can be applied almost anywhere if an appropriate housing for the measurement unit is ensured. Another big advantage of the system is the possibility to monitor several avalanche spots simultaneously, as the cable length can be

chosen in the range of several tens of kilometres. There is also the possibility to
connect more than one fibre to the measurement unit, which then will continuously be sampled one after the other.
A significant drawback of the method is ist current price. A ready installed device with a cable length of several kilometeres costs about 250.000 Euros. In important cases of avalanche detection it might be still worse to install such a system.

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