ABSTRACT: A new tool for avalanche monitoring, called „The Avalanche Detector“, a distributed fiber optic system, was for the first time installed and adapted for the purpose of monitoring snow avalanche activity. This tool was firstly presented at the ISSW2013 in Grenoble, France. 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 fiber optic cable that can have a length of up to 30 km. In winter 2013/14 the system was run in an operational mode as a warning tool and for the verification of avalanche events due to blasting actions in the ski resort of Lech am Arlberg, Austria. Both natural and by blasting triggered avalanches were recorded. 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 as well as the warning software that was programmed. So far we measured 60 avalanches with runout distances ranging from a few meters to approximately 250 meters, as well as the 90 not successful attempts of artificial triggering. Moreover we measured properly if critical infrastructure (a ski run) was reached by the avalanches or not. In conclusion we summarize that distributed acoustic fiber optic sensing is a very expensive but precise method to monitor avalanche activity and runout distances.

KEYWORDS: avalanche monitoring, seismic detection, acoustic fiber optic sensing, warning tool

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). 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 estimating 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 distinguishing signals caused by avalanches from others. Seismic signals originating from snow avalanches, landslides and other mass movements were extensively analyzed in the works of Surinach et al. (2000, 2001, 2005). Biescas et al. (2003) focused on the frequency evolution of the...
seismic manuscript deadlines 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 Reflectometry (OTDR) and allow measurements of distributed temperature, strain or pressure (Nikles 2007). Optical Time Domain Reflectometry first was used for fault detection in optical fibers 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 Woemdl 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 fiber 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 fiber optic system for the purpose of detecting and monitoring snow avalanche activity and develop a real time warning system. The system will be deployed in an avalanche slope for the first time. Several tests will show if the warning mechanism is suitable for detecting avalanche signals. The necessary technology of measuring acoustic disturbances with an optical fiber sensor system is nowadays commercially available. Several companies can be found on the market that are providing fiber optic sensing devices. A company has been found that provides an appropriate device as well as the required technical support. Regarding the fiber optic cable, a fiber optic specialist could be found for the production of the cable as well as support in the fieldwork. However a software had to be developed to the needs of an avalanche real-time warning tool.

3. SOFTWARE DEVELOPMENT

The Avalanche Detector software is composed of a JavaScript/HTML5 user interface and a Node.js based backend server. The JavaScript implementation deals with the parsing and the display of FDS (Fotech Data Stream) files and the real time data streams, produced by the Fotech Helios units. Both FDS files and the live data streams (offline/online mode) are displayed using waterfall visualization in the browser. Furthermore the UI enables the user to specify event criteria upon which the Avalanche Detector should take action and issue a warning (text message, email, alert on the screen). In offline mode the UI may be used to visualize previously captured FDS files. Overall the UI comes in the form of a single page app with several modal windows, for the specification of event criteria and configuration options, adhering to the model view controller design pattern (MVC) on the basis of AngularJS. The CSS is based on the Twitter Boostrap standard. The Node.js based backend server communicates with the UI using web sockets (Socket.IO) and serves as a watchdog for the Fotech live data streams. User specified criteria are persisted on the server using a lightweight key/value store (nStore). The server is constantly monitoring the live data stream coming from the Helios units and looping it through to the UI. As soon as the user specified criteria for an event of interest are fulfilled warnings in the form of text messages and emails are issued and the live data stream for the event is written into an FDS file - such files may later be viewed on the
client, which may request recorded files using a simple REST API.

4. METHODOLOGY

4.1 Test Site

An appropriate avalanche slope for testing the system was found in the ski area of Lech am Arlberg, Austria. 5 avalanche tracks were surveyed by the system (Figure 1), as the multipath monitoring possibility of the system is one major advantage of the device. For a detailed description of the test site the reader is referred to Prokop et al. (2013).

Fig. 1: The 5 surveyed avalanche tracks at the test site in Lech am Arlberg

4.2 Measurements

The measurement unit performs measurements continuously along the entire fiber 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 fiber optic cable. The test measurements should mainly show if our newly developed software is capable to warn accurately if an avalanche was released or not.

4.3 Data post processing

In Prokop et al. (2013) we explained how the signals of avalanches were analyzed. Depending on frequency and intensity of the signal related to the location on the cable the algorithm warned, if an avalanche was released. So in the results section we focus within these analyses if our warning algorithm successfully detected the avalanches.

5. RESULTS

First we looked if we can detect avalanches that are triggered due to blasting and determine if our devise is capable of this task. We measured 60 avalanches with runout distances ranging from a few meters to approximately 250 meters, as well as the 90 not successful attempts of artificial triggering. The time frame from 11.12.2014 till the 06.02.2014 is reported in figure 2. The system was capable to detect blasting signals with and without avalanche initialization.

Fig. 2: Avalanches triggered (green) and not successful blasting attempts (brown) measured by the avalanche detector

To go into detail we show first an example of an avalanche triggered by blasting. In the waterfall diagram we see first the signal related to blasting along the whole cable length and than at 325 m cable length the first avalanche occurring (Figure 3). The extracted time series of signal intensity shows again the signal of blasting and the consecutive avalanche (Figure 4)

Fig. 3: Waterfall diagram of signals observed from blasting and consecutive avalanches at 05.01.2013. White line shows location of time series in Figure 4.
Fig. 4: Time series of signal intensity, first on the left the blasting signal and then about 5 seconds later the signal of the avalanche at 05.01.2013.

The system was also run in operational mode to detect natural avalanche occurrence. Luckily for our research goal at the 27.01.2014 an avalanche occurred at our slope under observation, it was recorded by the system and a warning signal could be transferred. Figure 5 shows the waterfall diagram of the avalanche (obviously no blasting signals are visible before the avalanche signal). A visual inspection of the site at the same date verified the avalanche event and the proper determination of the location and size of the avalanche.

6. DISCUSSION AND CONCLUSIONS

We recorded both natural and by blasting triggered avalanches with the „Avalanche detector“ under all weather conditions. We monitored several avalanche spots simultaneously, as the cable length can be chosen in the range of several tens of kilometers. So far we measured 60 avalanches with runout distances ranging from a few meters to approximately 250 meters, as well as the 90 not successful attempts of artificial triggering. Moreover we measured properly if critical infrastructure (a ski run) was reached by the avalanches or not. 1 very small (less than 20 m length) avalanche with a large powder content could not be detected. All blasting attempts that were not successful were detected, except for one, where due to bad visibility the small avalanche measured with the system could not be identified in the movie. Here we trust our measurement more than the visual inspection of the movie material. The received signal intensity is dependent on snow height and snow properties above the cable, while dense flow avalanches create higher intensity values in higher frequencies than powder snow avalanches. The signal to noise ratio is very satisfying as snow pack insulates noise sources such as wind that are usually problematic for seismic sensors. Potential noise sources such as cable damages or skiers, can be easily detected, therefore our newly developed software worked properly. In conclusion we summarize that distributed acoustic fiber optic sensing is a very expensive (for our setup about 250000, - Euros) but precise method to monitor avalanche activity, avalanche size and runout distances. In important cases of avalanche detection it might be still worse to install such a system.

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REFERENCES


