Avalanche Radar

Introduction

by

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2015

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1. Basic Considerations

For investigation and detection of rapid mass movements in alpine regions a reliable monitoring system is required. The system should be able to detect in all weather conditions on the one hand every single hazardous events and on the other hand it should value only the hazardous events as an alarming event. Only such a system could be used as passive protection and alarming system. Furthermore, structural measures in alpine regions are very expensive and always imply a massive intervention in the environment, so a practicable monitoring system should also need as low structural measures as possible. A lot of different systems are in use, but all known monitoring systems do not meet all these requirements at once (see also the comparison from different systems at the end).

The main parameters for detecting mass movements are the volume and the velocity. A well known technology to measure velocities is the RADAR-technology by measuring the Doppler shift of the used frequency. The RADAR cross-section of an object for a given wavelength is a function of the size, the material, the incident and the reflecting angle, etc. and it determines the measured scattered intensity. Therefore, the measured reflected intensity is a parameter which belongs to the cross section of the moving volume of the detected object.

The main objective of this document is to illustrate the principles and the potential of an innovative RADAR system and its versatility as an automatic detection system for alpine mass movements. The high frequency RADAR device was already successfully tested for snow avalanches in Sedrun/Switzerland (Lussi et al., 2012) and in Ischgl/Austria (Kogelnig et al., 2012) and is already launched as a product in the market.

2. Principles of the Radar Device

The RADAR operates according to the principle of the coherent pulse Doppler RADAR. A high-frequency generator produces a signal in the X-band (f_0 =10.425 GHz). This signal is pulse-modulated in a high-frequency switch, amplified to an output power of about 1 W and radiated from a parabolic Antenna to the detection area. The reflected beam from the area passes the parabolic Antenna again and goes through the receiver. In the receiver the reflected signal is sampled and goes to the analog-digital converters. Afterwords, a digital signal processor calculates the measured values from the signal, which then are edited and displayed on a user interface or go through an automatic alarm generating software.

Figure 1 shows the illumination of a mountain slope with a pulse-shaped electromagnetic wave packet limited to discrete points in time. The discrete time points 1-8 are located exactly at the distance of spatial pulse length corresponding to range gate length r_{RG}. It is assumed that an electromagnetic wave is emitted with duration τ. The speed of the pulse in the propagation medium air is the speed of electromagnetic waves c in the medium air.

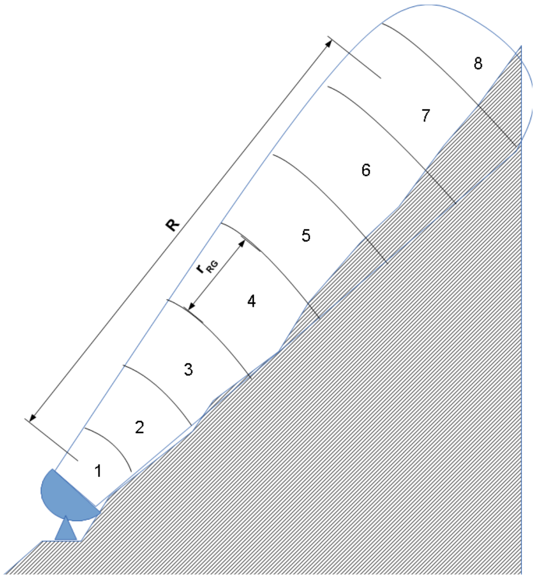

Figure 1: Scheme of typical detection situation with different range gates numbers n, range gate length r_{RG} and a range R.

Thus, one range gate length is

$$r_{RG} = \tau \cdot c \qquad (1)$$

and the discrete time points become $n \cdot \tau$ or in space $n \cdot r_{RG}$. This means, after the time t, the wave packet is at distance R from the antenna. From Figure 2.1 we get the conclusions that the beam direction of the antenna should be oriented almost parallel to the slope in order to illuminate the maximum range of the slope and get as many range gates as possible.

The space-resolution is equal to the range gate length r_{RG} and is therefore also a linear function of the duration time t. The duration time itself influences the signal to noise ratio of your data in the way the longer the duration time is the better the signal to noise ratio will be.

If an object moves now in such a range gate with the velocity v, there is additionally a frequency shift f_D according the Doppler Effect.

The frequency of the reflected signal $f_{Doppler}$ becomes:

$$f_{Doppler} = f_0 - f_D \qquad (2)$$

with f_D:

$$f_D = f_0 \frac{2v}{c} \qquad (3)$$

The result is a speed proportional frequency shift. The sign is positive or negative, depending of the direction of the moving object in relation to the Radar. From frequency analysis of the reflected beam a velocity spectrum of the moving objects is obtained. Compact moving objects with a well-defined velocity (e.g. vehicles (Figure 2)) will therefore be measured with a very well defined peak in the velocity spectrum, objects without a defined surface such as avalanches, mudflows, water, etc. will have a wide range of different velocities(Figure 3).

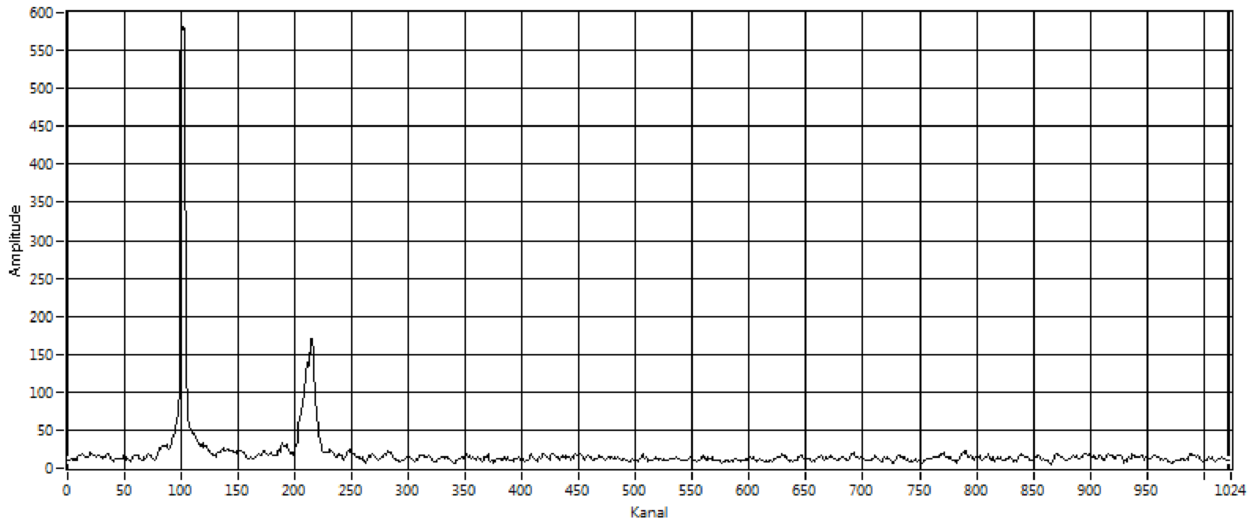

Figure 2: Typical velocity spectrum of a single moving object. Peak at channel 100 is the reflection of a static object (the hill itself) and the peak at channel 210 is the moving object (helicopter)

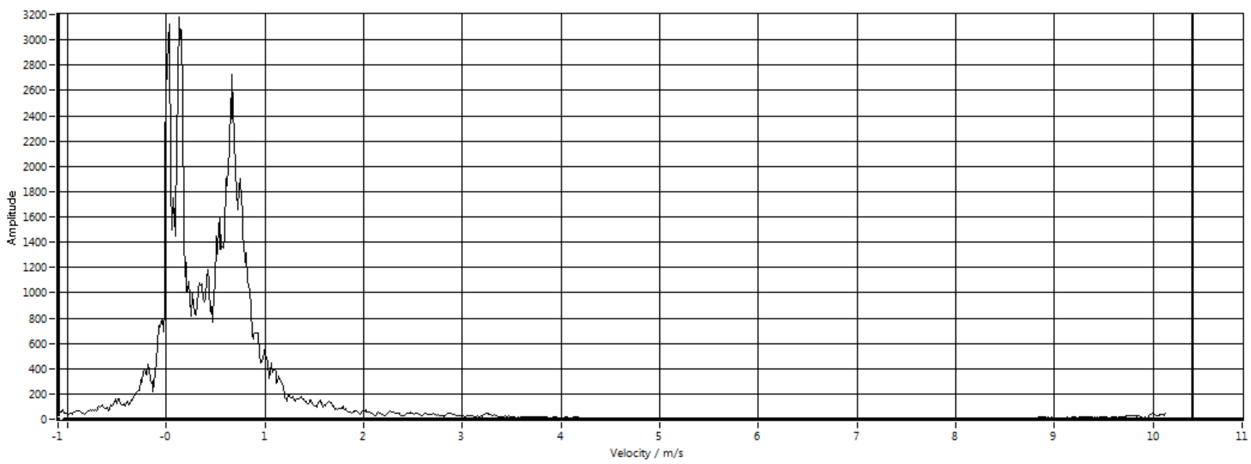

Figure 3: Typical velocity spectrum of water in a river

The amplitude of the spectrum depends on the surface of each moving object for each speed. The integral of the spectrum corresponds therefore to the magnitude of the moving mass.

The pulse repetition frequency of the RADAR device is up to 90 kHz, this means that every second data from 90000 pulses are processed, which gives about 3 frames per second for the analysis. The maximum range for detecting moving objects (even snow) with a cross section of 1m² in heavy weather condition (rain/snow) is 2 km. The range gate length could be chosen between 15 m and 250 m and it is possible to measure velocities between 1 km/h and 300 km/h.

3. Specifications of the Radar-Module and Overall System Structure

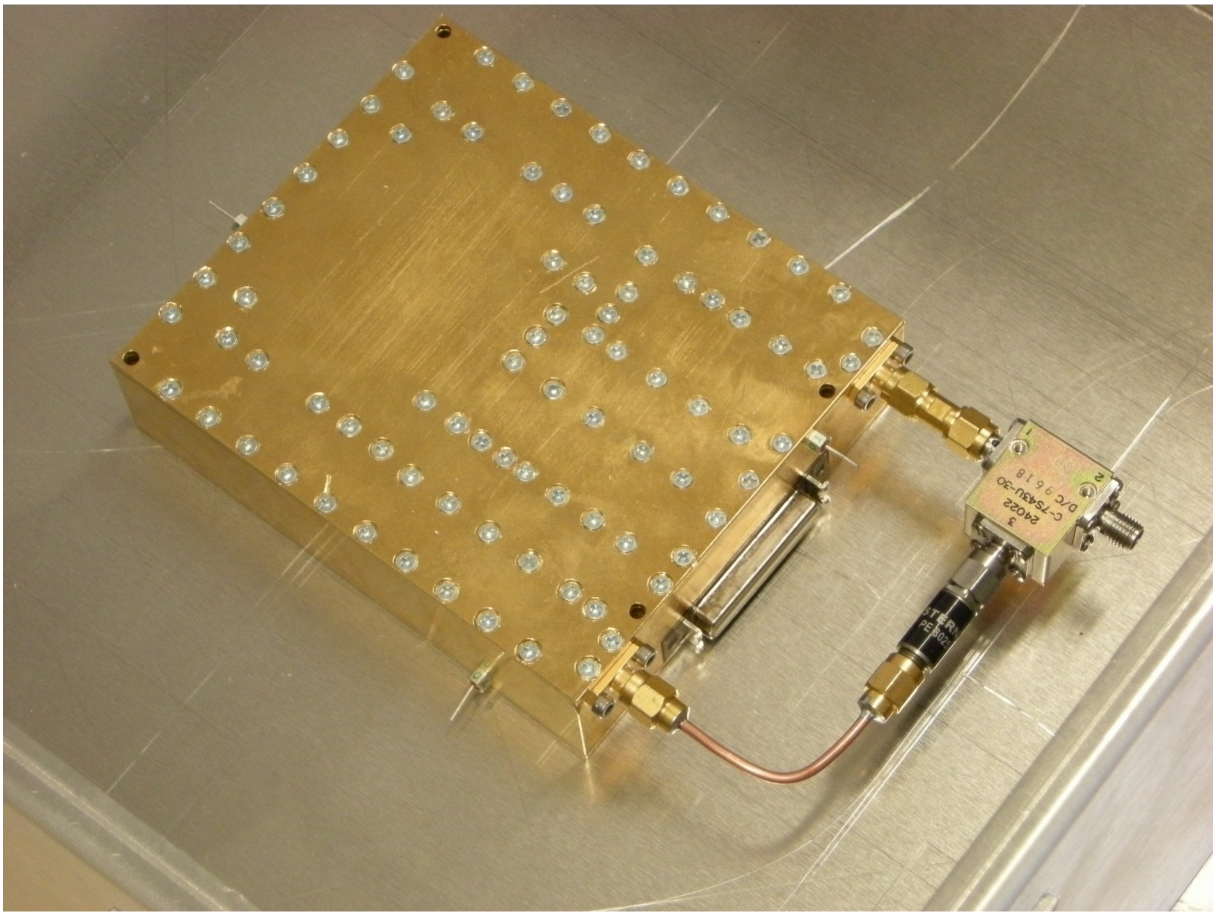

Figure 4: Picture of the Radar Module

The Radar module itself (Figure 4) is about 12x12x4cm³ in diameters and has a power consumption of 15W. The technical specification are listed in Table 1 and Table 2.

Table 2: Technical specification of the Module

parameter	value	tolerance	unit
Power consumption	15	max 15	W
Operating voltage	+5	+/-5 %	V
Current input	3	max	A
Temperature range	-40 - +85	min/max	°C
Humidity	0 - 100 %	min/max	Rel. Hum.
Frequency range	10.1 - 10.5	min/max	GHz
Frequency resolution	5		MHz
DDS- resolution	0.15		mHz
Frequency drift	+/-	30	ppm
Output power (circulator)	+25	+/- 1	dBm
Spurious emission (SFDR)	-80		dBc
Spurious emission 0-9 GHz	< -100		dBm
Spurious emission 11-26 GHz	< -90		dBm
Modulation	Pulse, PSC		
Pulse width	0.105 - 30		µs
Pulse width resolution	105.263		ns
Pulse compression	Barker 3- 13 BPSC		
Modulation correlation mode	Puls 50% duty cylce QPSC		
Band width (all operation modes)	25	max	MHz
Noise figure (circulator)	3.5	typ	dB
Compliance	CE, ROHS		
Pulse repetition frequency	0.001 - 1		MHz
Connections	USB, RS232, Ethernet		
Rangegates	1-128		
Rangegate resolution	1024 FFT		lines

Table 3: Technical specification of the overall system

Parameter	**Quantity**	**Tolerance**	**Unit**
Mode	Pulse/PCM		
Frequency	10,0-10,5		GHz
Power C.	40	<	W
Range	30-2500		m
Targetsize	1	min > at 2km	m^2
	0,25	min > at 1km	m^2
Velocity	0,2-100	min/max	m/s^2
RG	128	max	
RG-length	15-250	min/max	m

The natural hazard radar consists mainly of this module and is installed with the appropriate antenna, power supply, operating computer and communication unit in a weatherproof enclosure (see Figure 5 and Figure 6). The construction is totally modular so that any additional measurement sensors can be integrated. The overall system has a power consumption between 30-50 Watts (depending on additional integrated measurement sensors).

Installation Requirements and Service:

To install the Radar only a straight view to the monitoring area, a mast a power-supply of about 50 Watts and an Internet connectivity (via LAN, WLAN, Mobile-Net, radio relay etc.) is required. The system can trigger any kind of alarming system, if the interface description is given (see for example Figure 7)

The Radar system is monitored over the Internet and all system-parameters can also be adjusted without being on site. Nevertheless, it is recommended to make a visual inspection once a year.

Figure 5: System for mudslide and debris flow with Radar-antenna, UMTS-antenna, housing and IP-camera

Figure 6: Electrical supply components of the Radar and the Radar module (15)

1. *1x 230 to 24V power supply*
2. *1x 24V UPS*
3. *2x 12V batteries*
4. *1x 12V power supply for PC*
5. *1x 5V power supply for radar module*
6. *1x Network switch*
7. *1x main fuse*
8. *1x Electric meter kWh*
9. *1x Schuko plug socket*
10. *1x UMTS mobile internet connection device*
11. *1x Intelligent relay control device*
12. *1x PC: fit-pC2i – with OS Debian Linux Wheezy*
13. *1x Temperature controller for the 24V fan*
14. *1x Radar Interface board*

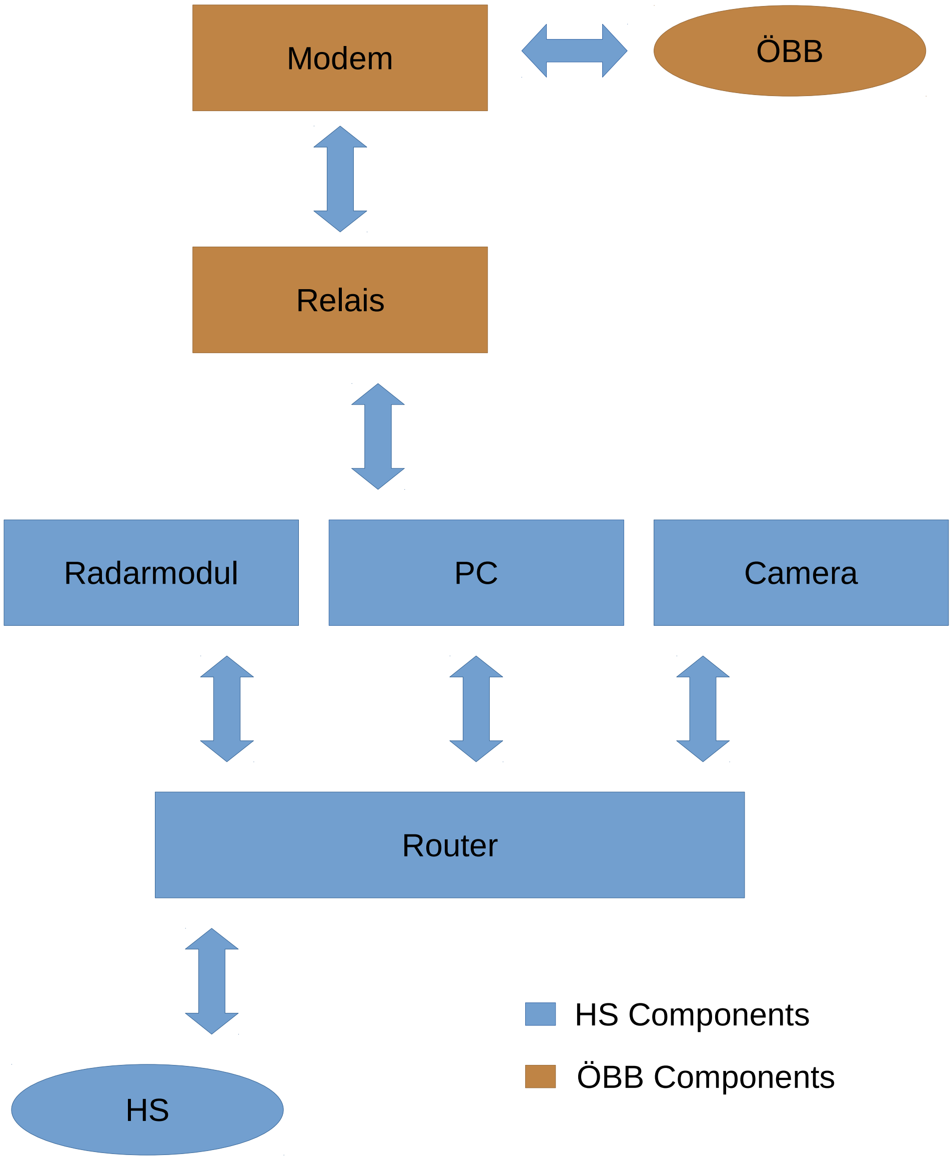

Figure 7: Scheme of an integration of an alarming system from the Austrian rail company ÖBB

4. Software-Architecture and Data-Handling

The Software architecture is dictated by different tasks. These include data acquisition, processing and archiving of the raw data, analysis and detection of events and triggering of alarming units. Parallel, there is a monitoring system that monitors all components on failures and faults and possibly settle messages.

- **Data Collection**

This is done by the software 'radard', which provides the interface between the actual radar hardware and the control computer. The control computer can configure over standard TCP / IP connections the measurement, starts, pauses and makes status inquiries. Data are sent in real time from the radar module. The same format is used for both, the data transport over the network and for the storage of the Data in files.

- **Data Analysis**

The data analysis is performed separately for following reasons from the data acquisition.

1. Calculations: The radar module is limited in computing power and so the compute-intensive analysis can be outsourced.
2. Modularity: It can be easily tried out new methods of analysis parallel and this without disturbing the data collection and the alarming function.
3. Archiving: The raw data can be recorded easily.

The basis of the evaluation is a temporal observation and comparison of the radar signals. There are 3 different algorithm for different hazards running:

1. Detection of avalanches / debris-flows:

The algorithm compares a data base with the current frame. This is formed on a running average calculation of Radar data and constantly updated to slow environmental changes, such as snow, wet and dry offset. An avalanche is the opposite, a rapid change with a wide speed range, which is moving toward the Radar. Comparing current frame with the average value a statement about the avalanche can be made on the basis of these difference.
The existing algorithm can recognize and exclude thinkable sources of false alarms, such as wind, rain and statistical noise and can trigger an alert within 1 seconds

2. Detection of rainfall

Nevertheless, rain has not the best reflectivity at the used frequency it is possible to detect heavy rainfalls. The radar data of rainfall differ from those of an avalanche in particular in that they are more stable over time and have a rather narrow range of speeds.
In contrast to the avalanche detection algorithm, the base must not be constantly updated, because the reflectivity of the air itself does not change.

3. Detection of water levels

If there is a river in the illuminated area, there will be also a velocity spectrum of the flowing water (see again Figure 3). The change of the Integral of the spectrum corresponds proportional to the change of the water level.

- **Alert Algorithm**

The calculated values are categorized and sent to the appropriate location. The 2 main categories are:

1. Internal alarm:

There has been an unusual result but it does not meet the criteria of avalanches /debris flow/rainfall Triggers can be for example helicopters, small moving objects etc.

2. External alarm:

An avalanche/debris-flow/rainfall was detected.

Depending on the application and the customer requirements there are different notification groups and methods (SMS, email). Each event is recorded and stored on a central server for verification and documentation. These alerts can also be put out on site (audible signal, warning light) and/or can be transmitted to specific centers (regional emergency management agency, ambulance and road patrol) via mobile communication technology (GSM/GPRS/WLAN).

Additionally to triggering an alarm, video surveillance is activated and records the monitored area. The video is transmitted to a remote station for later analysis which can be helpful e.g. to locate buried disaster victims.

- **Data-Viewing**

There are two levels of Data-Viewing. One for the trained and professional user and one for the customer.

1. Live Viewer for the Customer

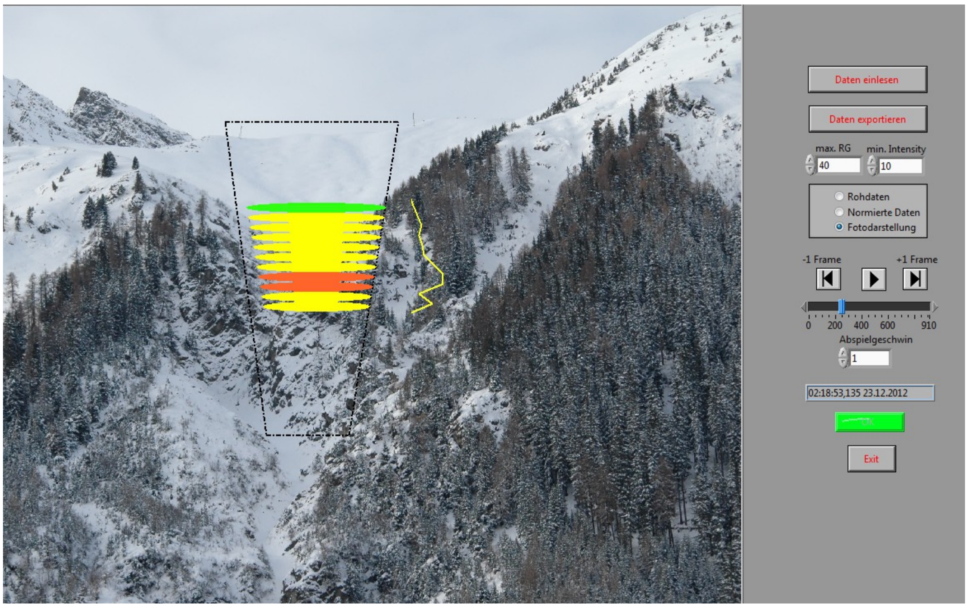

Figure 8: Live Viewer for the customer

Normally, the customer just want to see if an avalanche was triggered by a blasting-system or not. For this purpose we have developed a Live Viewer, where you can easily see an avalanche running down the mountain in real time. The different colors represent different amount of snow.

2. Data Viewer for Professionals

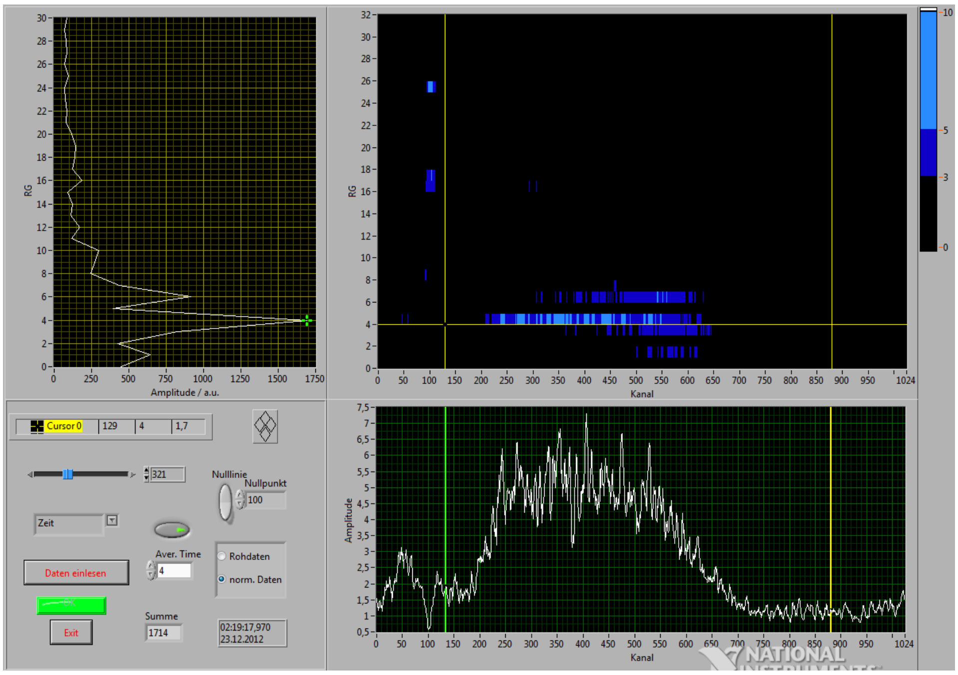

Figure 9: Data Viewer for Professionals

The Data Viewer for Professionals is more complex but for trained people it enables to get more information out of an event. For example the velocity distribution, the postion, the intensity etc.

5. References

There are more then 10 Radars installed, here some examples:

Ischgl; Tirol; Austria

Distance: 900m-2000m
Radar surveillance area:

Sedrun; Swizerland

Distance: 1100m-22000m
Radar surveillance area:

Kaunertal; Tirol; Austria

Distance: 1700m-2300m
Radar surveillance area:

Grins; Tirol; Austria

Distance: 30m-250m
Radar surveillance area:

Umhausen; Tirol; Austria

Distance: 30m-800m
Radar surveillance area:

6. Compression with other Detection Systems

There are 2 scientific evaluations from 2 independent institutions known so far. One is the project “Avalanche detection” from the Institute of Snow and Avalanche Research SLF; Switzerland. (Lussi et aI., 2012) and the other one is the Master Thesis “Evaluation of Avalanche Detection Systems and Development of a Plan for a Simple Detection System” from Christian Kienberger at the Institute of Mountain Risk Engineering, Department of Civil Engineering and Natural Hazards, University of Natural Resources and Life Sciences (BOKU), (Peter Jordanstraße 82, 1190, Vienna, Austria). There it says in the abstract:

“Since artificial avalanche releases are used more and more often for the protection of infrastructural and touristic objects, the importance of avalanche detection systems is ever increasing. These detection systems offer the possibility to determine spontaneous and artificial released avalanches. Some detection systems are already on the market, but until the end of winter 2011/2012 **only the avalanche radar could satisfy the standards for availability and reliability**. It was one aim of the study to find out, if there have been any advancements between winter 2011/2012 and 2012/2013. This was made by a comparison of the different detection results which are mentioned in the final report of the project avalanche detection from the institute of snow and avalanche research - SLF (Lussi et aI., 2012) with the results from the detection applications of the winter 2012/2013. Finally, no substantial improvements have been found**...”**

The tested systems were (there were some more at the beginning, but they are not, of some not known reasons, listed in the report):

- **ARFANG (IAV)**
  The system is based on the principle of infrasonic goniometry. An array of four infrasonic sensors (Microphones) are used within a radius of about 50 meters. The data according to different criteria (correlation, azimuth, duration, frequency components) are evaluated.

- **UHU (SLF)**
  Infrasound pressure variations is recorded by a mass-flow-ensor, which measure the air flow between the atmosphere and a pressure reservoir (thermos). The sensors are installed in distances of several hundred meters. It is a system in development not a finished product.

- **Avalanche-Radar (H&S Hochfrequenztechnik)**

The Radar is an Puls-Doppler-Radar and measures directly the velocities of moving objects.

- **Seismic-Sensor-System (AlpuG)**
  An avalanche causes underground seismic waves. The waves can break in the spread, bent, scattered, absorbed and be converted. The propagation velocity of seismic waves depends from shaft type and the material that is passed by the waves. The seismic waves are detected by geophones (electromechanical transducers convert ground vibrations into analog voltage signals) and recorded and evaluated in a data logger.

The results of the evaluations are listed in the Tables 4-6. “Standort” means location. There were at the beginning about 9 locations, but it seems that again, of some reasons, the results are not listed. The location “Levin” is equal with the location “Gonda”

“a” means: There was an avalanche, but it was not detected by the system.
“b” means: There was an avalanche and it was detected by the system.
“c” means: There was no avalanche, but the system detected one.
“POD” means: POD = b/(a+b).................detection efficiency (should be 1)
“FAR” means: FAR = c/(c+b).................. false alarm rate (should be 0)

Table 4: Results for 2011/12 (project avalanche detection; SLF; Lussi et al., 2012)

Standort	System	*a*	*b*	*c*	POD	FAR
Täsch	ARFANG	*3*	*10*	*138*	0.77	0.93
Belalp/Blatten	ARFANG	-	-	-	-	-
Lavin	ARFANG	*10*	*40*	*205*	0.8	0.84
Lavin	Geophone AlpuG	*28*	*9*	*0*	0.24	0
Sedrun	Radar H&S	*0*	*11*	*7*	1	0.39
Ischgl	Radar H&S	*0*	*17*	*0*	1	0

Comment: The 7 false alarm in Sedrun of the Radar were all within 1 hour and were caused by a large truck at the parking-place, where the Radar was installed.

Table 5: Results for 2011/12 (Master Thesis; Boku; Kienberger,2013)

Standort	System	a	b	c	POD	FAR
Gonda	ARFANG	38	33	216	0.46	0.87
Gonda	AlpuG	28	9	0	0.24	0.00
Gonda	UHU	-	-	-	-	-
Ischgl	IDA	-	-	-	-	-
Ischgl	Lawinenradar	0	17	0	1.00	0.00

Table 6: Results for 2012/13 (Master Thesis; Boku; Kienberger,2013)

Standort	System	a	b	c	POD	FAR
Gonda	ARFANG	11	6	128	0.35	0.96
Gonda	AlpuG	9	5	20	0.36	0.80
Gonda	UHU	-	5	-	-	-
Ischgl	IDA	7	7	7	0.50	0.50
Ischgl	Lawinenradar	1	6	0	0.86	0.00