AVALANCHE VICTIM SEARCH BY GROUND PENETRATING RADAR

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ABSTRACT: Ground penetrating radar (GPR) systems are used in many applications of snow and ice research. The information from the GPR is used to identify and interpret layers, objects and different structures in the snow. A commercially available GPR system was developed to work in the rough environment of snow and ice. The applied GPR is a 900 MHz system that easily reaches snow depths of ten meters. The system was calibrated in the course of several manual snow depth measurement surveys. The depth resolution is depending on the snow type and ranges around +/- 0.1 m. The GPR system is carried along a line of interest and is triggered by an odometer wheel at regular, adjustable intervals. The equipment is mounted in a sledge and is pulled by a snow mobile over the snow surface. This setup allows for efficient coverage of several kilometers of terrain profiles. The radar profiles give a real-time, two-dimensional impression of structures and objects and the interface between snow and underlying ground. The actual radar profile is shown on a screen on the sledge allowing the immediate marking of objects and structures by the operator. During the past three years the instrument was successfully used for the study of snow distributions and to search for avalanche victims in avalanche debris. The results show the capability of the instrument to detect persons and objects buried by snow. In the future, this device may be new a tool for avalanche rescue operations. Today, the size and weight of the system prevents accessing very steep slopes and areas not accessible by snowmobiles. Further developments will decrease the size of the system and make it applicable as a handheld search device in avalanches.

Keywords: ground penetrating radar, snow avalanches, search and rescue

1. INTRODUCTION

Manual methods for the search and rescue for deeply buried avalanche victims are limited to a snow depth of three to five meters. The results of such a search depend on the search grid and length of the applied snow probes. Searches are time consuming and demand large rescue teams to cover all possible search areas.

To improve the effectiveness of snow depth measurements and avalanche victim search, electronic devices can be used. The standards for avalanche victim location are active avalanche beacons carried by skiers and climbers that send out a signal at a given frequency. The victim can be located with receivers listening at the same frequency. Passive devices are also available and include magnetometers and radar.

Passive methods register reflections of an emitted signal for the detection of avalanche victims. While the magnetometer detects changes in the natural magnetic field due to the presence of a magnetic body, radar registers the reflection of electromagnetic waves from any kind of materials is the snow.

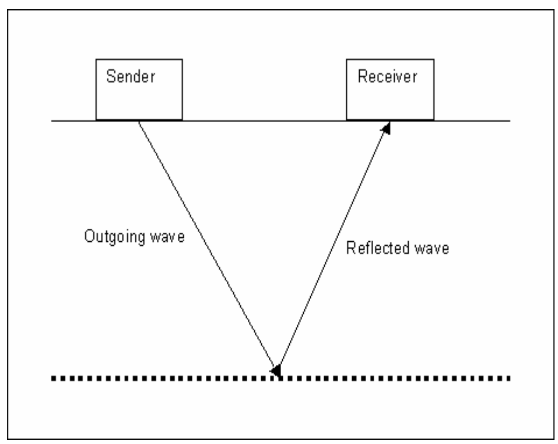

Figure 1: Technical principle of ground penetrating radar. The Sender antenna sends an electromagnetic wave into the ground which is partly reflected by an interface and detected by the receiver antenna

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1.2 *Ground Penetrating Radar (GPR)*

GPR is a well-known method to study subsurface structures. Examples for GPR application are detecting objects, pipes and cables in the underground, recording geological structures in the subsurface, detecting ground water tables, etc. GPR has been used successfully in archeology (Conyers and Goodman, 1997) and is a standard method to quantify the ice thickness of glaciers (Björnsson et al., 1996).

The technical principle of GPR is based on electromagnetic (EM) waves that are sent into the ground. They travel into the subsurface until they reach an object or a layer of a density different from the previous medium (Fig. 1). Parts of the EM wave will be reflected and detected by the receiver antenna, while the remaining energy will travel further into the ground. The radar itself detects the time needed for the EM wave to travel from the sender antenna into the ground and back to the receiver antenna. The strength of the detected signal depends on the electrical properties of the detected object or interface and the surrounding medium. If the difference between the two materials is large the radar will receive a stronger signal.

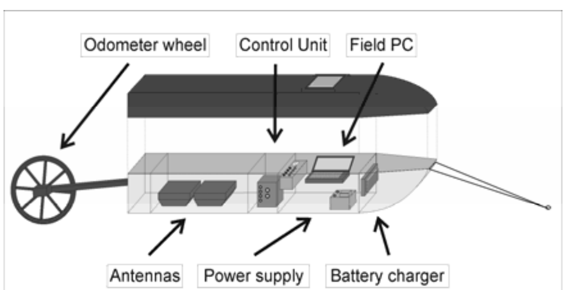

Figure 2: Setup of the radar system in the special designed sledge. All parts are firmly fixed in the sledge so that the sledge can roll over without damaging the electronics.

To calculate the depth to the object or interface detected, the velocity of the EM wave in the ground has to be known. This velocity depends on the density and electrical properties of the medium. In air the velocity of EM waves is V_{air} = 0.33 m/ns while it is V_{ice} = 0.16 m/ns in ice. In snow EM waves typically travel with a velocity near V_{snow} = 0.21 m/ns (Annan et al., 1995)

Direct calibration or a special method, which utilizes radar measurements itself, can be used to determine the velocity of EM waves in a


Figure 3: The radar behind a snow mobile during measurements on Spitsbergen spring 2000.

given media. Details about this "common mid-point method" can be found in Annan and Cosway, 1992.

In snow the velocity can be found by taking manual measurements of the snow depth at given locations and noting the travel time for the radar signal at the same locations.

The depth and vertical accuracy that can be reached with the radar depends on the frequency used. High frequencies will produce short wavelengths with a high vertical resolution but the energy of the waves is easily absorbed in the subsurface. Contrary, low frequencies produce long wavelengths that travel farther, but with a lower vertical resolution.

The resolution can be calculated for a given survey when the frequency, f, and the velocity of the EM wave, V, in the medium in known. For snow (V_{snow} = 0.21 m/s) and a 900 MHz radar system, the wave characteristic wave length, λ, is

$$\lambda = \frac{V}{f} = \frac{0.21 m/s}{900 MHz} = \frac{0.21 x 10^9}{900 x 10^6} = 0.23 m/s \qquad (1)$$

The accuracy is 1/3 of the wave-length e.g., 0.08 m (Annan, 1992).

The time window is the time that the receiver antenna "listens" to the reflections from the ground. For an average velocity of EM waves in snow V_{snow} = of 0.21 m/ns and a time window of 60 ns, the radar registers data down to a snow depth of 6.3 m.

The radar is triggered by an odometer wheel at a pre-set step size. The step size sets the distance between each measurement along a profile and can be adjusted from 0.1 to 9.9 m.

Both step size and time window decide how fast the system can be moved over the snow. For large areas a combination of 0.5 m step size and 60 ns time window allows travel speeds of 15-20 km/h.

This paper presents results from radar measurements on Spitsbergen, Norway. The

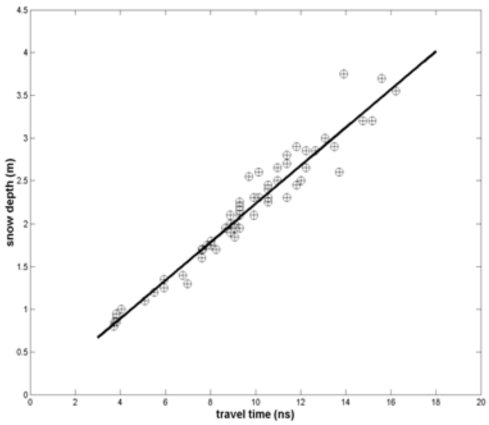

Figure 4: Scatter plot of snow depth versus travel time of the electromagnetic waves in the snow. The measured velocity is 0.223 m/ns (R^2 = 0.96)

objective of this paper is to demonstrate the capability of the radar system in snow mass quantification measurements and avalanche victim search. This paper (1) presents a general discussion of the applied radar system, (2) results from idealized experiments and (3) an example from a spring 2004case study.

2. MATERIALS AND METHODS

The radar system used was a pulse EKKO 1000 manufactured by Sensors and Software (Sensors & Software, 1995). The system can work with frequencies ranging from 225 to 900 MHz. For measurements in snow the 900 MHz antennas were used. The radar consists of the transmitter and receiver antennas, a control console, power supply and a PC to control the radar measurements. The system, as delivered, is not applicable for work under arctic conditions. A special sledge was designed to carry the instrument during measurements in cold and wet environments (Fig. 2). The power supply was designed to work in temperatures down to -30 °C. A field PC suitable for low temperatures controls the radar and stores all data in a raw data format. The measurements are triggered with the odometer wheel behind the radar sledge and the whole system is carried by a snow mobile (Fig. 3). With this setup, the radar can be moved at 15 - 30 km/h and cover large areas during one day. Sand and Bruland (1998) have used a similar system for hydrological studies on Spitzbergen.

Since the radar only measures the travel time of the electromagnetic waves in the snow, the velocity of the waves in the snow being scanned has to be known. Both snow density and free water content of the snow influence the velocity (Annan, 1992). A high free water content will slow the electromagnetic wave in wet snow. The velocity of the radar wave in snow can be found by taking manual measurements of snow depth between the radar antennas.

A special calibration survey was done to demonstrate the linearity of snow depth versus travel time (Fig. 4). The result yields a mean velocity of V_{snow} = 0.223 m/ns for the snow pack, in this case cold, dry, wind packed snow. The radar system was successfully applied in different snow research projects on Spitsbergen and in two rescue operations after avalanche accidents on Spitsbergen and in the French Alps (Moe, 2001, Nordlys, 2001, Jaedicke 2001, Instanes et al. 2004).

3. AVALANCHE VICTIM SEARCH

Deeply buried avalanche victims are often difficult to find, since manual methods only reach to a snow depth of 3 - 4 m. GPR can easily reach down to 10 m snow depth, improving the range and also the efficiency of the search operation.

In winter 2001 the radar was applied successfully in two rescue operations where the victims' bodies could be recovered after other measures failed. Encouraged by these results, the radar system was tested for its ability to detect objects and persons in the snow cover. The objectives of the test were to achieve radar profiles from different objects in the snow and to test different step sizes for their performance in detection of the objects.

For this purpose a two-meter deep snow pit was dug in the firn area of Slakbreen on Spitsbergen. The snow cover consisted of dry, cold and windblown snow, which formed a hard snow pack (density 200 kg/m^3). At the snow / firn interface a 20 cm layer of cup-shaped depth hoar allowed digging of a horizontal tunnel into the pit wall. In this tunnel a backpack and a person were placed. The section was then scanned with the radar at step sizes of 0.5 m, 0.25 m and 0.1 m.

3. 1 *Results and discussion*

The achieved radar profiles can be seen in Figure 5. All profiles cover the same horizontal section. The objects (air void, backpack, person) give the strongest signal at 0.1 m resolution. At a resolution of 0.25 m, the person and the backpack can still be detected while the air void is rather difficult to see. At 0.5 m, only the person gives a

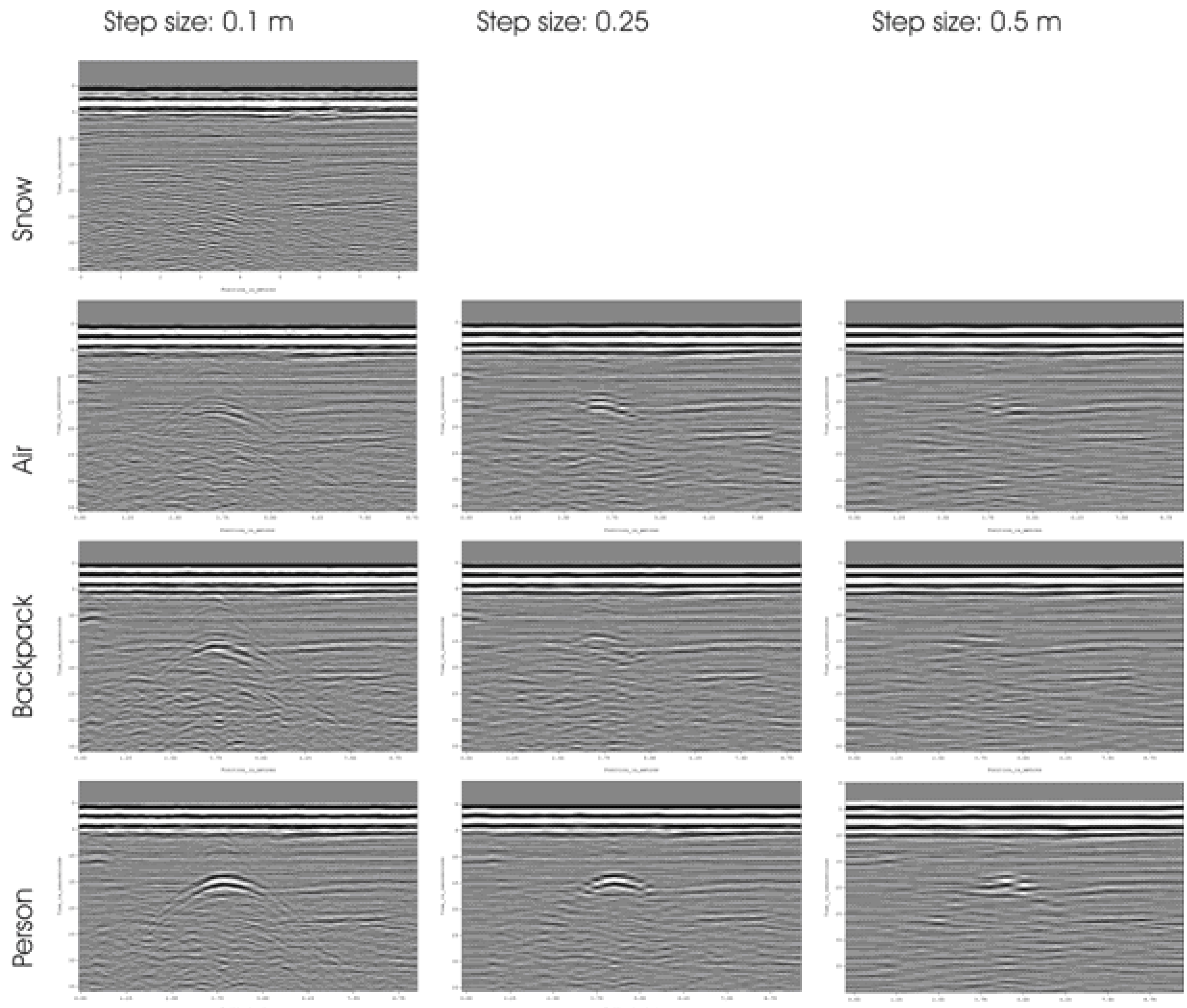

Figure 5: Results from the detection of objects in the snow pack. The profiles show the resulting signals for the detection of an air void, a backpack, and a person under two meters of snow. Profiles were recorded at 0.1 m, 0.25 m and 0.5 m step size

significant signal. A profile of the snow without the horizontal tunnel is given as a reference.

These plots can be created after a successful data handling in the office. Considering the conditions on site in a real emergency situation; where the need to hurry, and cold will affect the operator's judgment; the signal from a person at 0.5 m resolution is too weak to ensure detection. On the other hand, the system works too slowly, if it is applied at the high resolution of 0.1 m step size. Therefore a faster system, or a maximum step size of 0.25 m should be used in search and rescue operations. Larger objects like cars and snowmobiles could also easily be detected at 0.5 m resolution.

The test was done on dry and cold snow of medium density. Further tests are necessary on real avalanche debris and wet snow with high free water content. Free water in wet snow will slow down the radar signals and decrease the density difference between a human body and the surrounding snow. This would lead to a weaker signal.

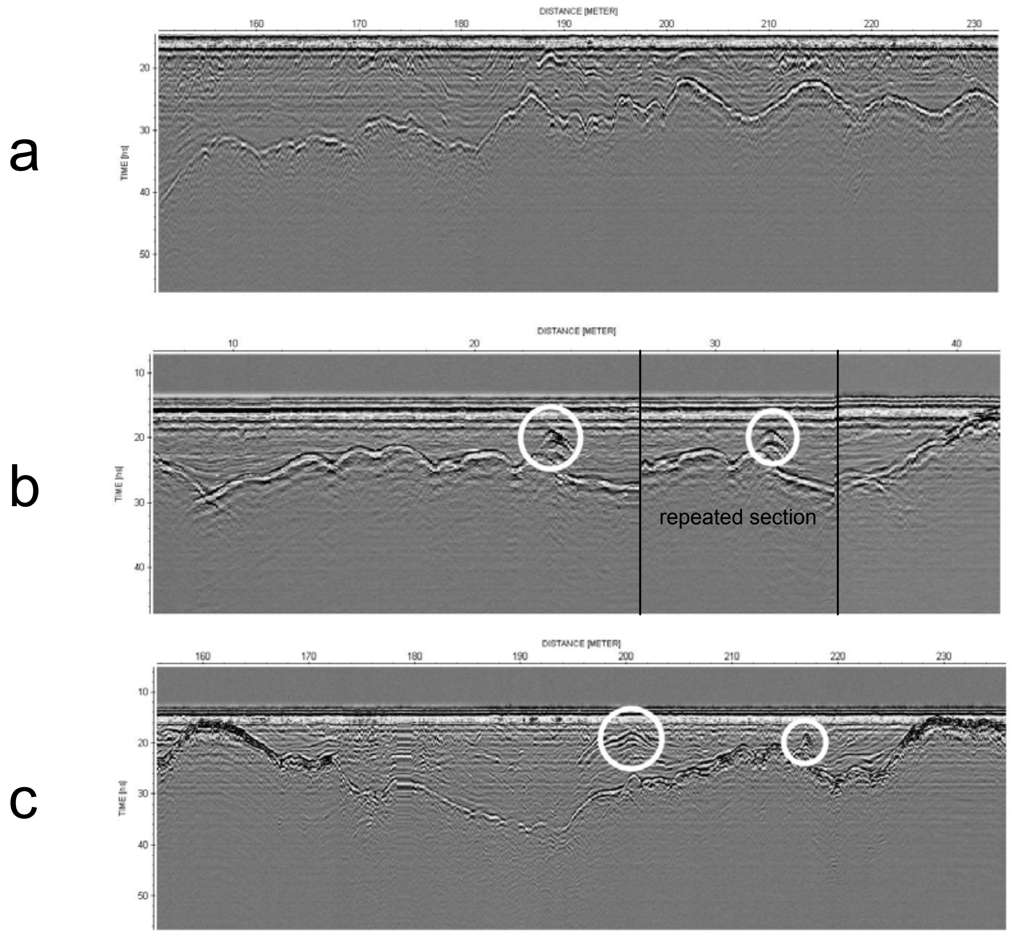

Figure 6: Example profiles from operation 22 March 2004 the rescue on Spitsbergen.
a) Undisturbed snow
b) Clear reflections of an object in the snow. The profile is repeated once
c) Reflections from snow blocks in the avalanche deposits

Additionally the technical solutions for search and rescue operations must be improved, leading to a small and easy to operate radar system that can be transported in a backpack.

4. RESCUE OPERATION MARCH 2004

On 22 March 2004, the radar was acquired for a rescue operation on Spitsbergen. A snowmobiler was buried by a large avalanche. Eye witnesses did not capture the point where the victim last was seen. Therefore, the search area was extensive and the radar was used to help in the search.

The radar was applied with 900 MHz antennas, 0.25 m step size, and 100 nm time window. The avalanche deposits were more than 10 m maximum depth and covered an area of ca. 200 x 100 meters.

In comparison to the idealized case described in Section 3, the real emergency situation caused several problems in the radar operation. While the radar has been previously used with success to recover bodies several days after the avalanche, in this case there was hope to find the person alive. The radar was operative after only a few minutes and searches stared immediately. The following problems occurred:

a) The avalanche surface consisted of large and very hard snow blocks, such that following a straight line was impossible
b) The radar profiles displayed in real time are much less legible than highly processed images as shown in Figure 6.

The radar operator has to follow the results in real time on the screen, while assistants pull the sledge through the snow. Avalanche snow is highly inhomogeneous especially the blocks of very hard snow typical for Spitsbergen. Distinguishing between reflections from snow blocks and features caused by the victim is very difficult. The results improved significantly when the avalanche surface was levelled by a snow cat. Figure 6 illustrates different profiles from the operation after levelling. Figure 6a shows a sample profile from undisturbed snow, while 6b and 6c shows features in avalanche snow. In 6b, the profile was repeated to rescan the reflection in detail. Unfortunately, the avalanche victim was not seen on any of the surveys.

The victim was finally found after 17 hours by manual sounding in an area not covered during the radar surveys.

5. CONCLUSION

The presented radar system is working with 900 MHz antennas and can achieve a vertical accuracy of approximately 0.1 m in snow. The system can collect large amounts of data in a short period of time, allowing the survey large areas. The field data can be used to create three dimensional snow distribution maps for the use in hydrological and research applications.

During two earlier rescue operations the radar proved its capability to detect the bodies of avalanche victims under deep snow. A systematic study showed that a test person as well as a single backpack could be detected under two meters of snow. A horizontal resolution of 0.25 m yields a suitable compromise between desired resolution and survey efficiency for the equipment used.

In a rescue operation in spring 2004 the experiences from the idealized study helped to apply the radar in an emergency situation.

The system has to be improved technically to allow easy operation and reduce its size and weight. A small and light version of the system could be located at any skiing area and become standard equipment for professional search and rescue operations.

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7. ACKNOWLEDGEMENTS

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