DRONE-MOUNTED UWB RADAR SYSTEM FOR MEASURING SNOWPACK PROPERTIES: TECHNICAL IMPLEMENTATION, SPECIFICATIONS AND INITIAL RESULTS

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ABSTRACT: Airborne ground penetrating radar systems allow for carrying out snowpack surveys in complex terrain. Ultra wideband radars operate within the lower part of the microwave band and are suitable for measurements of snow depth and layering in a time-saving and safe manner. We have developed a complete radar system based on a commercial UWB radar sensor, custom designed antennas and a single board acquisition computer in all weighing 4 kg and fitting (without antennas) into a 30 x 25 x 15 cm^3 box. The radar is capable of measurements with a frequency range from 0.95 - 6 GHz, giving roughly 5 cm slant range resolution and an unambiguous range in air of 5.75 m. The radar can be carried by an octocopter drone with a wingspan of 1.5 m, flying autonomously at an altitude of 1 m above the snow surface. In this paper we present the characteristics and specification of our drone-borne radar system and show results from two different campaigns. We were able to resolve snow stratigraphy in great detail in a dry snowpack, identifying the most prominent layers. Our second example shows the system's capabilities of detecting a person buried under 1.5 m of wet snow.

Keywords: UWB radar, Ground penetrating radar, UAV, drone, Snow stratigraphy

1. INTRODUCTION

Ground penetrating radars (GPRs), especially ultra wideband radars (UWB) operating in GHz-bands have penetration capabilities and range resolutions that enable information extraction of snowpack structural features (e.g. Marshall et al., 2007). Thus, such systems provide a practical alternative to traditional point-scale measurements that are time consuming and influenced by the choice of measurement location. However, GPRs are conventionally deployed on the ground, by dragging an antenna with direct ground contact or at a small standoff distance. In complex terrain, such as rough avalanche debris, an airborne GPR is of significant advantage (e.g. Yankielun et al., 2004), as it increases accessibility and decreases deployment time.

We have developed a UWB radar system that is mountable on a remotely piloted aircraft (RPAS) (Figure 1), commonly referred to as a drone. By doing so, we solved the problems of 1) constructing a light, compact and portable radar system, with 2) high range resolution and the ability to penetrate the snowpack from an airborne platform, as well as 3) an autonomously flying drone with high payload capabilities and engine redundancy.

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Figure 1: UAV-borne radar system. The UWiBaSS is the grey box mounted beneath the drone, with the transmitting antenna (grey plate) and both receiving antennas (black sheets) visible.

2. DRONE-BORNE UWB RADAR SYSTEM

2.1. UWB radar

The UWB radar, or ultra wideband snow sounder (UWiBaSS), is a GPR that we have developed for drone-mounted surveys of layered snowpacks over ground or sea ice (Jenssen et al., 2016). The radar consists of an m:sequence UWB radar sensor developed by the German company Ilmsens (https://www.uwb-shop.com/), custom designed spiral and Vivaldi antennas, and a single board acquisition computer with processing software. Besides weight, size and range resolution, unambiguous range and incident power impinging the target were central design parameters. Unambiguous range describes the range from which a transmitted radar pulse can be reflected and received before the next pulse is transmitted. Incident power at target depends on antenna gain, height above target (snow surface) and radar system amplification parameters. These properties dictate how high the drone can fly above the lowest surface of interest (typically ground), in our case currently at a maximum of 5.75 m. Additionally, the unambigeous range of the system inherently affects the measurements speed of the radar system, which in turn affects the speed the drone can fly above the snow surface. In the presented cases, the maximum speed is about 2-3 m/s due to the current configuration of the radar. However, this speed can be increased significantly with asynchronous data acquisition, which has been implemented and is ready for use in future campaigns. The radar has a total of three antennas, of which a planar spiral antenna is the transmitting antenna and two Vivaldi antennas act as receiving antennas. The Vivaldi antennas are mounted in 90 degree offset to each other to provide reflection polarization capabilities of the target (Figure 1).The described radar properties are summarized in Table 1.

Table 1: Main characteristics of the UWiBaSS

Characteristics	**Value**
System bandwidth	5.05 GHz (0.95-6)
Range resolution	$\approx$ 5 cm
Unambiguous range in air	5.75 m
Weight	$\approx$ 4 kg
m-sequence clock	13.312 GHz
Measurement rate	32 Hz (max 1000 Hz)
Max power consumption	$\approx$ 12.7 W (Radar $\approx$ 9 W)
Field of view (from 1 m above surface)	0.35 m diameter

2.2. RPA

The drone currently in use to carry the UWiBaSS is an octocopter. The ‘Kraken’ octocopter can lift a maximum payload of 11.5 kg. Each of the eight engines has a maximum rated thrust of 8.45 kg using 18 x 6.1 inch propellers. ’Kraken’ uses 6 cell Li-Pol batteries (currently at 30 Ahr). For navigation and control, a ‘pixhawk2’ autopilot running ‘arducopter’ is used. A laser rangefinder, mounted on one of the eight arms accurately measures the distance to the ground. It is set up with a ‘Here+’ GPS system this allows for the use of RTK and very accurate positioning. ‘Kraken’ can be set up with a ‘MBR 144’ radio system to operate a 15 Mbps radiolink.

3. METHODS

3.1. Campaign setup

Preparatory work on site before mission deployment takes roughly 15 min, including mounting propellers and batteries on the drone, antennas on the UWiBass and setup of the ground control station as well as radio communication to the airport tower.
Currently, the drone can only be flown in visual line-of-sight mode (VLOS) as the drone does not have a camera mounted and lacks obstacle detection sensors. VLOS missions, however, can be flown both manually and autonomously, the latter scheme following a pre-defined flight path.
The UWiBass can be operated via switches mounted on the outside (radar on/off, radar control arm/start/stop). Survey data has to be downloaded after each mission with a WLAN cable and processed for a first quick look. The radar system can also be operated via secure shell (SSH) and Near Real-time (NRT) data visualization can be achieved using the MBR radiolink.

3.2. Postprocessing of radar data

An inherent property of antennas is that all spatial components of the incident field at the receiving antenna are integrated. As a consequence, a single measurement illuminates a 3D volume of snow, about 0.35 m wide and as deep as the snowpack is above ground, when the radar is 1 m above the snow surface. However, only a 1D average of the returned energy is imaged.
During postprocessing of data, the radar traces are stacked together to form a 2D image of the snowpack. Each pixel intensity is represented in terms of voltage returned to the antennas. By squaring each pixel, they are presented in terms of power, which helps in analysing the data, as some noise is suppressed from the image. For radar images with low signal-to-noise-ratio (SNR), often due to wet snow, thresholding further suppresses low level pixels and thus reduces noise further, while histogram equalization evenly distributes the pixel intensities in the image to amplify weak returned signals in the snowpack.

4. RESULTS

We present data from two different campaigns. Campaign 1 shows our system’s capabilities to resolve snow stratigraphy while campaign 2 focuses on the detection of a metal object and a buried person within the snowpack.

4.1. Campaign 1 - Snow stratigraphy

Campaign 1 took place in central Svalbard in May 2018 during dry snow conditions. The radar was mounted on a snowmobile sledge, 50 cm above snow surface to simulate airborne data acqusition. The snowpack had variable depths up to a maximum of 155 cm. It consisted of wind-deposited snow at the surface and a gradually more coarse-grained snowpack at depth with a thick layer of depth hoar above ground. Three relatively hard layers (P - K) characterized an otherwise rather soft snowpack. The radar intensity image (Figure 2)

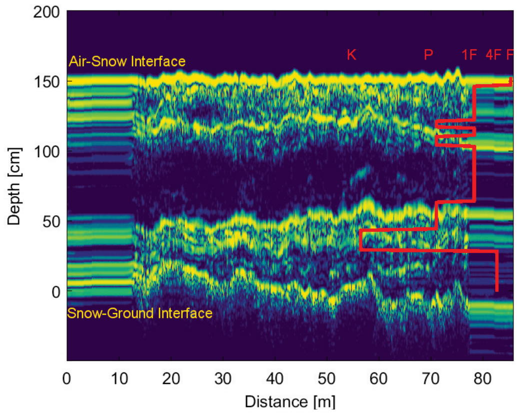

Figure 2: Radar image showing intensity variations in backscattered energy (yellow means more energy) through snow depth (y-axis) and distance (x-axis). In-situ measured snow hardness from a pit dug in the transect is superimposed.

shows high back scattered energy from the snow surface (air-snow interface) as well as from the undulating snow-ground interface. The three relatively harder snow layers, as well as the bottom part of the snowpack, reflected more energy back to the radar then the softer middle part.

4.2. Campaign 2 - Buried person

Campaign 2 took place on the island of Andøya in Northern Norway in April 2018 during wet snow conditions. A person was buried under 1.5 m in a road embankment, together with a metal plate at 1 m depth (Figure 4). With less than 1 m/s, the drone was flown over both the metal plate and the buried person. Below the clearly visible snow surface showing a strong reflection, two hyperbolic reflections are visible, indicating the metal plate and the person buried in the snow (Figure 3). During this campaign, the snow had up to 8 % liquid water content and therefore a thresholding procedure was used to improve visualization of the targets.

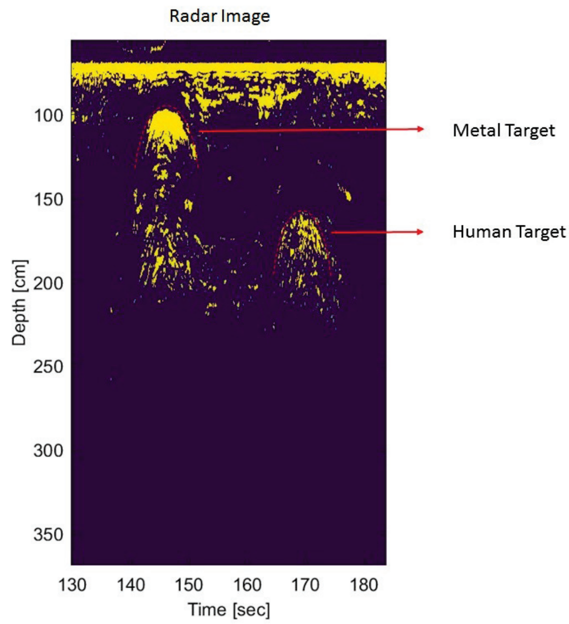

Figure 3: Radar image showing variations in backscattered energy (yellow means more energy) through snow depth (y-axis) and time (=distance on the x-axis). The red dashed lines indicate the target hyperbolas typical for strong point reflectors.

5. DISCUSSION

5.1. (In)Capabilities of the UWiBaSS

The UWiBaSS is optimized to resolve detailed snow stratigraphy as well as to detect buried objects in a variety of snow conditions. Thus, high vertical resolution has been traded off against high penetration depth in wet snow conditions, which could be obtained using lower radar frequencies (at the cost of bandwidth).

Weak snow layers are in the order of 1 cm thick; thus their detection is very difficult. Nevertheless, distinct layer differences are detectable. Weak snow layers are often found adjacent to harder layers or right above or below ice layers. Thus, detecting distinct hardness changes or ice layers can be used to infer the presence of a weak snow layer.

The UWiBaSS, as demonstrated above, is also capable of penetrating wet snow, with liquid water content of up to 8 %, like in the case of the buried person. It should be noted that the human target was only visible in one of four passes across the transect. This can be explained by the low measurement speed of the radar which needed a very low flight speed to detect the targets.

A limiting factor is that with a current field of view of about 0.35 m in diameter, a very tight grid needs to be flown at a distance of 1 m above the snow surface in order to cover an avalanche debris with a missing person or car. To overcome this problem, we are currently developing a radar with an ambiguous range in the air of 42 m. This allows to raise the field of view to 7.14 m and thereby opening up the grid without changing the range resolution of 5 cm.

5.2. *(In)Capabilities of the 'Kraken' octocopter*

The 'Kraken' octocopter has been designed to test the UwiBaSS under controlled conditions, having enough redundant power to lift the radar also during an engine failure. It has not been optimized for operational use in regard to flight time or for particular operational scenarios where real-time sensor navigation, data processing and visualization are needed. However, we have developed tools for operational use of drones that are currently used for other applications such as iceberg tracking. These tools can easily be adapted to provide NRT visualization and mapping of the UWiBaSS data.

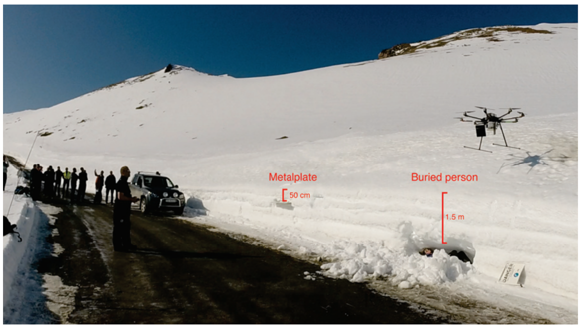

Figure 4: Setup of the object burial test with a metalplate and a buried person 50 cm and 1.5 m below the snow surface. The drone is hovering over the buried person.

6. CONCLUSION

We have developed a drone-based UWB radar system capable of resolving snow stratigraphy and detecting a buried person in a range of snow conditions. Our system can be deployed within roughly 15 min. For a fully operational system, however, we are currently developing a UWB radar that can be flown higher above ground, thereby also flying BVLOS missions. We are also currently testing a real-time radar processing unit and live transmission to an operator screen.

For any of the described applications, a radar expert is currently needed to interpret the radar data. Automatic detection of buried persons could possibly be remedied using an artificial intelligence approach for on-board machine learning interpretation of the radar signals followed by automatic flagging and geotagging of objects.

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