REPORT

8/2018
ISBN 978-82-7492-407-9
ISSN 2535-3004

UAV-BORNE UWB RADAR FOR SNOWPACK SURVEYS

Authors: Markus Eckerstorfer, Rolf Ole R. Jenssen, Ándre Kjellstrup, Rune Storvold, Eirik Malnes, Svein K. Jacobsen

P.O. BOX 6434, TROMSØ SCIENCE PARK
N-9294 TROMSØ, NORWAY
TEL: +47 77 62 94 00, FAX: +47 77 62 94 01
post@norut.no
www.norut.no

norut
NORTHERN RESEARCH INSTITUTE

PROJECT: Demonstration of UAV-borne UWB radar for snowpack surveys

PROJECT NR.: 755

CONTRACTOR: Statens Vegvesen

Document number: 8/2018 | Type of document: Report | Status: Open

ISBN 978-82-7492-407-9 | ISSN 2535-3004 | Number of pages: 13

Project leader: Markus Eckerstorfer | Date: 08.04.2018

AUTHORS Markus Eckerstorfer, Rolf Ole R. Jenssen, Ándre Kjellstrup, Rune Storvold, Eirik Malnes, Svein K. Jacobsen

TITEL: UAV-BORNE UWB RADAR FOR SNOWPACK SURVEYS

Summary:

In this report we summarize the capabilities and technical characteristics of our UAV-borne UWB radar system, designed for conducting snow surveys. We developed an ultrawideband snow sounder that is capable of imaging snow stratigraphy with a 5 cm range resolution. The radar can be carried by an octo-copter UAV in order to carry out airborne snowpack surveys.

During a demonstration on Andøya, we showed that the radar was capable of resolving snow stratigraphy in wet snow conditions, as well as detecting a buried person under 1.5 m of wet snow. In this report, we present the results of the demonstration in detail. We furthermore discuss capabilities and incapabilities of our radar system and offer a list of future steps to bring it to an operational status.

Keywords: UWB-radar, snow survey, UAV

Notes: -

Published by: Norut, PB 6434, 9294 Tromsø, Norway

Table of contents

1. Introduction

Ground penetrating radars (GPR's) have a wide range of applications, spanning from subsurface surveys to high-resolution object detection. Especially ultra-wideband (UWB) systems that operate in the GHz-band have penetration capabilities and range resolutions that are able to extract information from complex stratigraphical targets.

However, GPR's are conventionally deployed on the ground, by dragging an antenna with direct ground contact. Mounting the GPR and its antenna onto a snowmobile or carrying it by person works well for surveys of an undisturbed, flat snowpack. However, in more complex terrain or over rough avalanche debris, an airborne GPR is of significant advantage.

We have therefore developed an UAV mountable GPR (Figure 1). During the development process we were solving the problems of 1) constructing a light, compact and portable device, with 2) high range resolution and the ability to penetrate the snowpack from an airborne platform, as well as 3) an autonomous flying UAV with high payload capabilities and engine redundancy.

2. UAV-borne radar system

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

2.1.1 Radar

The ultra-wideband snow sounder (UWiBaSS) is a ground penetrating radar (GPR) that we developed for UAV-mounted surveys of a layered snowpack over ground or sea ice (Figure 1). The focus of the radar development was therefore on constructing a light, portable device with cm range resolution, to detect prominent snow layers.

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 at 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. This property dictates how fast the UAV can fly above the snow surface, in our case at a maximum speed of 2-3 m/s. Incident power at target depends on antenna gain, height above target (snow surface) and radar amplifier parameters. These properties dictate how high the UAV can fly above the snow surface, in our case currently maximum 5.75 m. These described radar properties are summed up in Table 1, describing the UWiBaSS key characteristics.

Table 1: Characteristics of the UWiBaSS.

Characteristic	***Value***
System bandwidth	5.05 GHz (0.95 - 6 GHz)
Range resolution	~5 cm
Unambiguous range in air	5.75 m
Weight	~4 kg
Field of view (from 1 m above surface)	0.35 m diameter
M-sequence clock frequency	13.312 GHz
Measurement rate	32 Hz (max 1000 Hz)
Total power consumption	~9 W

The radar has a total of three antennas, of which a planar spiral antenna is the transmitting antenna and two Vivaldi antennas, mounted in 90 degrees offset to each other are the receiving antennas (Figure 1). This experimental setup is used to detect potential phase differences between the targets radar cross section. These phase differences might become a problem with increased flight elevation above snow and thus an increased footprint of the radar signal. Larger antennas would solve such problems, however, are due to their size and weight not desirable.

2.1.2 UAV

The UAV currently in use to carry the UWiBaSS is an octocopter. The 'Kraken' Octocopter has a maximum takeoff weight of 20 kg. With an empty weight of 8.5 kg, batteries and payload of 11.5 kg can be lifted. Each of the 8 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 lidar, mounted on one of the 8 arms accurately measures the distance to the ground. It is set up with a 'Here+' GPS system allowing 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 radio link.

3. Methods

3.1 Campaign setup & deployment

Our radar system can be either flown manually or autonomously. In the latter case, the UAV automatically follows a pre-defined track, with set speed and height above ground. Currently, the system only allows for VLOS campaigns as the UAV has no camera mounted and lacks obstacle detection sensors in the front.

The UWiBaSS can be fully operated with three switches (board computer on/off; radar on/off/logging) that are mounted on its outside. Survey data is downloaded after the mission with a WLAN cable and processed for a first quick look.

From arriving at a campaign site to deployment, it takes approximately 15-20 min. Preparation work includes mounting propellers and battery on the UAV, antennas on the UWiBaSS and setup of the ground control station as well as radio communication with the airport tower.

3.2 Postprocessing of radar data

An inherent property of antennas is that the incident field reflected from a target will be integrated at the receiving end of the antenna. Hence, the field of view of the antennas will be averaged when the transmitted signal returns to the receiving antennas. This means that a single measurement illuminates a 3D volume of snow, approximately 0.35 m wide and as deep as the snowpack, when the radar is 1 m above the snow surface, but only returns a 1D average of the returned energy.

The radar data is first correlated with the transmitted signal to produce the impulse response of the medium within the radar range. Additionally, some processing to compensate for non-linear antenna effects is performed. The radar traces are then 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, we now represent the pixels in terms of power. This can help to analyze the data as some noise is removed from the image. A histogram equalization and thresholding procedure is also added to distribute the pixel intensities evenly while suppressing low level pixels to reduce noise.

4. Results

We collected radar data from two campaigns. The first was a roughly 50 m transect in wet snow along a road (Figure 2). The second deployment was a slow overflight over a buried person and a metalplate at different depths (Figure 4). The goal of these two different campaigns was to assess the UWiBaSS' capabilities of resolving snow stratigraphy and detecting a person and an object. Both challenges have real-world applications and are thus of critical interest.

4.1 50 m transect

Figure 2: Setup of the 50 m transect with snowpit locations indicated every 15 m. Photo by Tore Humstad.

We found challenging snow conditions in the transect, which required some postprocessing of the radar data. The snowpack consisted of wet snow in the upper 70 cm with an estimated liquid water content of 3-8 %, whereas the lower 50 cm had a liquid water content of 0-3 %. Pronounced layering was mostly missing the upper half of the snowpack, whereas two prominent melt-freeze crusts were found towards the bottom of the snowpack (Figure 2). Densities ranged between 444 and 571 kg/m^3, likely a function of the liquid water content and the large grain sizes.

The radar image shows a clear first reflection that indicates the wet snow surface, roughly 40-50 cm below the UWiBaSS (Figure 2). A significantly weaker reflection from the ground surface is visible at a depth of 160 cm, which corresponds to a snow depth of 120 cm taking into account the permittivity of wet snow. Four clear reflections within the snowpack indicate the transition from a soft layer to a hard layer to a softer layer at roughly 75 and 50 cm in the in-situ stratigraphy, as well as the two prominent ice layers.

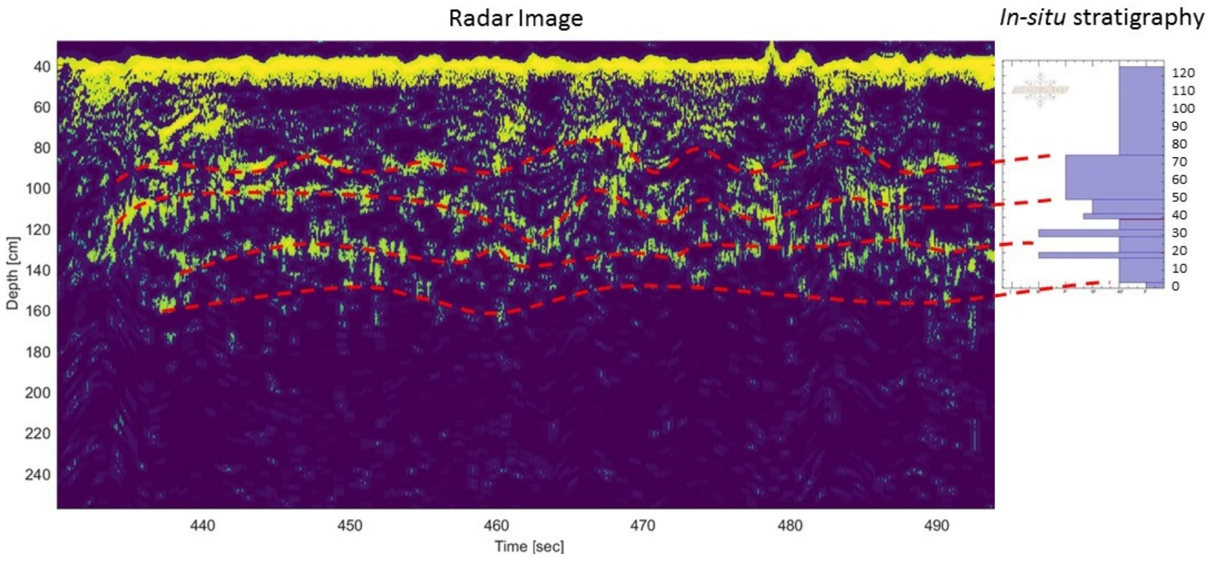

Figure 3: Left panel: Radar image showing intensity variations in backscattered energy (yellow means more energy) through snow depth (y-axis) and time (=distance on the x-axis). Right panel: In-situ stratigraphy from a snowpit dug in the transect. Blue columns show hand hardness of the different snow layers (horizontally elongated column indicates hard snow). The red dashed lines indicate our interpretation of the radar image.

4.2 Buried person & metal plate

In similar snow conditions to the 50 m transect, into the side of a snowbank, a metal plate and a person were buried. We flew the UWiBaSS four times over both targets, with the best result shown in Figure 5. Below the clearly visible snow surface, two hyperbolic reflections are visible, indicating the metal plate and the person buried in the snow.

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.

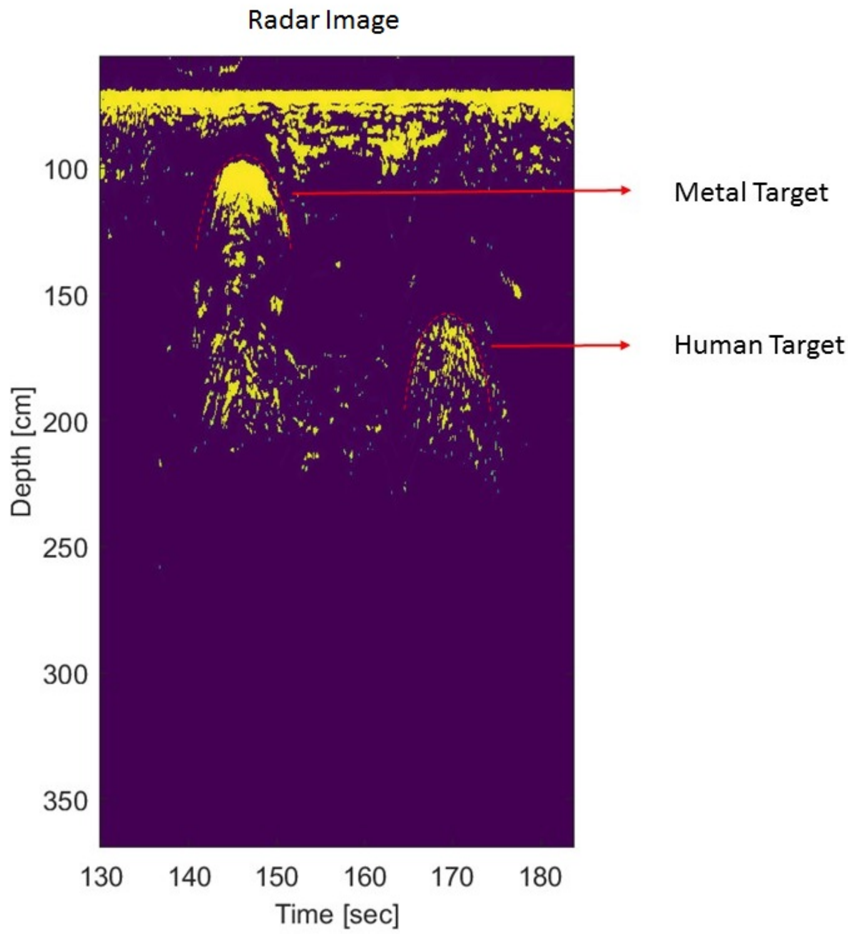

Figure 5: Radar image showing variations in backscattered energy (yellow means more energy) through snow depth (y-axis) and time (=distance on the x-axis). The red dashed lines indicate the target hyperbolas typical for strong point reflectors.

5. Discussion

Both hardware and software of the UWiBaSS and the UAV worked perfectly during the campaigns. Our pilot Ándre Kjellstrup safely maneuvered the system within cm over the snow surface in manual mode, ensuring optimal radar penetration and range resolution. However, the first results from post-processing of the radar data in the field yielded no results, which we first assigned to the incapability of the radar waves in the 0.95 - 6 GHz band to penetrate wet snow. During post-processing we found the problem to be erroneous parameter settings in the processing software. After fixing this issue, we achieved the results presented above.

5.1 Capabilities and incapabilities of the UWiBaSS

The UWiBaSS is optimized to resolve detailed snow stratigraphy as well as to detect objects, like cars and persons in dry snow. The focus on dry snow stratigraphy comes from the vision to deploy the system in avalanche starting zones, determining the depth and spatial distribution of weak snow layers that can collapse under stress from overloading and release a dry slab avalanche. In order to achieve this ambition high vertical resolution has been traded against high penetration depth in wet snow which can be obtained using lower radar frequencies.

Weak snow layers are in the order of 1 cm thick; thus their detection is very difficult. Nevertheless, we have shown in the results above, that distinct layer differences are detectable. Weak snow layers are in almost all cases always 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 %. Some post-processing techniques are currently required to enhance the information content not readily visible. Moreover, as a buried person was also clearly detectable, the range of snow conditions in which the UWiBaSS can be deployed is large, making it a system that can be applied throughout the entire winter. A limiting factor for the detection of the buried person was, that in four overflights, only one time the person was visible in the radar data. Likely, in that successful case we flew the UAV very slowly at a very low height above the snow surface. With a field of view of approximately 0.35 m in diameter when flying 1 m over the snow surface, a very tight grid needs to be flown in order to cover an avalanche debris with a missing person or car.

5.2 Capabilities and incapabilities of the UAV

The ‘Kraken’ octocopter has been designed to test the UwiBaSS under controlled circumstances. It has not been optimized for operational use with regard to flight time or particular operational scenarios where real-time sensor navigation, data processing and visualization is needed. However, we have developed tools for operational use of UAV’s (nlive and cryocore) that are currently used for other applications such as iceberg tracking. ‘Kraken’ could be set up with these operational tools in order to handle more complex missions.

5.3 Next steps

We are currently working on a second radar with a larger ambiguous range in the air of 42 m. This will allow to raise the field of view from about 0.35 m to 7.14 m in diameter, thereby opening up the grid, however, leaving the range resolution constant at 5 cm. By flying higher and thus safer above the ground, missions further away from the pilot, than demonstrated during the campaigns are feasible, even without further upgrades of the UAV from its current status.

6. Conclusion

We have demonstrated our UAV-mounted ultra-wideband GPR called UWiBaSS during two campaigns on Andøya. The system was designed to resolve snow stratigraphy and detect objects in dry snow. We successfully detected prominent snow layering in wet snow conditions as well as the detection of a metal plate and a person buried at different depths beneath the snow surface. We furthermore demonstrated a deployment of our system within roughly 15-20 min as well as capabilities of flying our UAV with the UWiBaSS manually within 40-50 cm above the snow surface.

For a fully operational system, the next steps are the development of a GPR that can be flown higher above the ground, an UAV with better capabilities of flying autonomously also BVLOS and a real-time processing of the radar data during the mission. Nevertheless, a radar expert would be required to interpret the radar data in real-time in the current configuration. Automatic detection of buried persons or cars could possibly be remedied using an artificial intelligence approach for on-board machine interpretation of the radar signals. Such detections could then be followed by automatically flagging of the objects and geotags targets in the radar data.

In conclusion, we are interested in further developing the radar, in scientific and technical exchange with other developers and in further test campaigns and potential real-world application with The Norwegian Road Administration.

Acknowledgments

We would like to acknowledge Andøya Space Centre for hosting the demonstration and for their excellent hospitality.