KEEPING WINTER ROADS OPEN: INTEGRATING SNOW AVALANCHE RISK ASSESSMENT DATA FROM UNCREWED AERIAL VEHICLES INTO ROADWAY AGENCIES' DECISION SUPPORT SYSTEMS

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ABSTRACT: Uncrewed aerial vehicles (UAVs) are increasingly used to monitor snow conditions. Routine operational use by roadway owning organisations for avalanche risk assessments require an understanding of UAV and sensor technology as well as of relevant organisational aspects. To investigate these areas, the Norwegian public-sector innovation project "Geohazard Survey from Air" (GEOSFAIR) is exploring remote decision support using UAVs. The effort has developed methodologies for effectively collecting and integrating UAV data into the decision support system for roadside avalanche risk assessments, helping keep critical roadways open and safe.

KEYWORDS: unmanned aircraft, sensors, roadside avalanche operations

1. INTRODUCTION

Uncrewed aerial vehicles (UAVs) can be used to monitor snow height and snow conditions in avalanche terrain. Routine operational flights of UAVs in various environments require an understanding of UAV and sensor technology as well as of relevant organisational aspects, such as pilot training and regulatory requirements. To investigate both the technological and the operational aspects of the use of UAVs, the Norwegian public-sector innovation project "Geohazard Survey from Air" (GEOSFAIR), is researching aspects of remote decision support using datasets gathered by UAVs. The project is developing methodologies for effectively collecting and integrating UAV data into operational systems used for roadside avalanche risk assessments. Outcomes of the project contribute towards supporting transportation authorities as they keep critical roadways open, safe, and reliable.

GEOSFAIR is led by the Norwegian Public Roads Administration (NPRA) in collaboration with two research partners, the Norwegian Geotechnical Institute (NGI) and SINTEF. The project runs from 2021 to 2024, with a total project budget of approximately USD $1.1 million.

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2. UAV TECHNOLOGY AND FIELD TESTS

In a series of field tests at NGI's avalanche research station Fonnbu, located in Strynefjellet mountains in Norway (Figure 1), and at exposed roadside sites, the project team used various commercial-off-the-shelf UAV technologies and methods with different technology-readiness-levels (TRLs) to monitor snowpack characteristics including surface morphology, snow height, snowpack layering and snow properties, and changes in surface and snowpack characteristics over time. Aircraft carrying a range of sensors and cameras were tested, including optical sensors (RGB, near-infrared, thermal infrared), laser scanners, and ground penetrating radar. The collected datasets provided results of varying usability to practitioners. A summary of field tests follows.

Figure 1: NGI's avalanche research station Fonnbu (photo: Sunniva Skuset, NGI).

2.1 *Thermal Infrared and Multispectral Images*

Images were collected using UAV-borne and hand-held thermal infrared imagers to measure snow surface temperatures. In a controlled avalanche release, thermal video footage enabled remote tracking of the release (see Figure 2, upper panel). In snow pit tests, measurements correlated well with conventional thermometers (see Figure 2, lower panel). Thermal cameras on UAVs can provide usable information in conditions with low visibility where conventional RGB cameras do not work well due to darkness or poor weather.

A UAV-borne, 5-channel multispectral camera (Figure 3) was tested to determine if this type of infrared imaging could infer grain size of snow surfaces. Collecting this information over time could be used to understand present and past surface processes. Both hand-held and UAV images were collected during the field tests, but the results were not optimal for discriminating snow types. The tests did, however, help develop a workflow for using multispectral images, which require considerable post-processing before they are usable. Additional tests of this technology will be conducted.

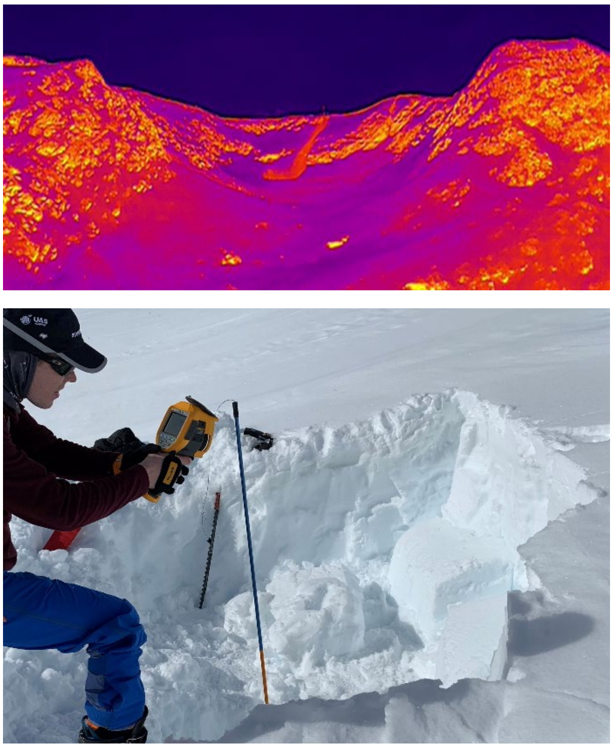

Figure 2: (Upper panel): UAV-borne thermal imaging during avalanche release (avalanche visible in upper centre of image). (Lower panel): Testing of a hand-held thermal imager in a snow pit; instrument used to validate UAV-borne thermal images.

Figure 3: Multispectral camera mounted on UAV.

2.2 *Photogrammetry (Optical Images)*

Conventional RGB images are easy to collect and use, since most UAVs are equipped with optical cameras. Images of avalanche areas can provide usable information to avalanche experts. When mapping terrain using photogrammetry, obtained by applying Structure-from-Motion (SfM) processing to UAV-collected digital images, results provided accurate information about snow heights and about the nature of the snow surface. Survey images collected with real-time kinematic (RTK) positioning and calibrated using advanced photogrammetric processing software, enabled consistent results, even without the use of ground control points. The measured vertical average deviation across terrain models was typically on the order of ±5-10 cm but was often dependent on the steepness of the terrain.

Operationally, collecting photogrammetric survey data can have limitations due to digital noise, non-matched images caused by lack of recognizable surface features, and limited performance in flat light or dark conditions. High quality photogrammetry results also require that the UAV is flown over the area of interest using effective terrain-following flight paths with suitable image overlap and flight altitude. While photogrammetry-derived map products provided good results for qualitative interpretation, the required lighting conditions and processing time limited the usefulness of this technology for operational purposes.

2.3 *LiDAR (Light Detection and Ranging)*

Low-cost LiDAR sensors, designed to be carried on UAVs, have recently entered the market. LiDAR measurements were used to map snow-covered terrain heights and information about features of the snow surfaces in the test areas. The snow surface was mapped in a series of 22 repetitive campaigns to support site specific avalanche warning. The data were used to produce shaded relief maps, snow height and change detection maps as well as snow surface inclination maps. The elevation maps generated from the LiDAR data were sufficiently accurate

(±10-15 cm) and could be collected in low-light conditions and in winter weather (active precipitation).

Figure 4: UAV-borne LiDAR scanner preparing for take-off.

2.4 Ground Penetrating Radar

The field test findings suggested that ground penetrating radar (GPR) can provide quantitative measures concerning snow height, snow properties and snowpack layering. This information can be correlated with data from snow pits, photogrammetry, LiDAR, keeping in mind that spatial resolutions are different. The GPR system was tested with a shielded 1GHz antenna (Figure 5), which needs to be flown close to the snow surface to ensure data quality. To map avalanche relevant snowpack layers (e.g., ice layers, facets, buried surface hoar layers), it was found that higher antenna frequency (1.5-2 GHz) systems should be used to allow for sufficient resolution to map shallow thin layers. However, higher antenna frequencies lead to reduced penetration depth. Different flight height and flight speeds were tested to optimize the survey and data quality. Recording data at an altitude of 2-3 m above ground resulted in the best compromise between data quality and flight safety. Provided careful flight planning, data can be safely recorded with a flight speed of 2-3 m/s, allowing the aircraft to cover survey profiles with length >1 km on one set of batteries.

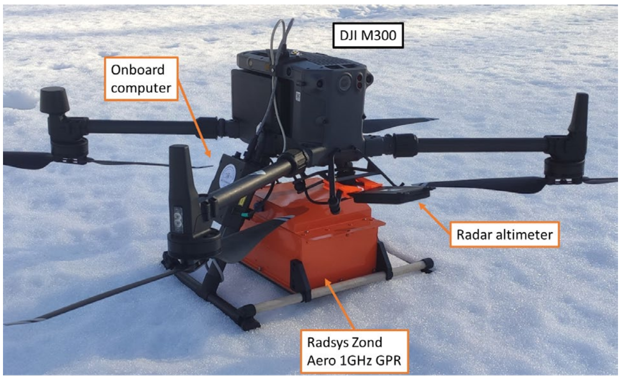

Figure 5: Major components of the UAV-mounted GPR system.

2.5 Other Technologies

Testing other instruments and methodologies with relatively lower TRLs, such as pyranometers (for albedo characterization), snow laser drills (snow stratigraphy), UAV-borne synthetic aperture radar (SAR), radio-frequency identification (RFID), green LiDAR (for sub-surface characterization) have been discussed, but not yet prioritized, as the operational aspects are at least as important for the project as the technology development itself.

3. OPERATIONALIZING UAV MISSIONS

The GEOSFAIR team is developing procedures and workflows for automatic near real-time processing of the large amounts of avalanche related sensor data collected by UAVs. The work addresses the operational concerns that are critical for the successful and routine uptake of UAV technology by roadway agency staff, such as training and certification of pilots, operating in poor flying conditions, maintenance of UAVs and associated equipment such as batteries, and last, but not least, institutional commitments to allocate the necessary resources.

To support the collection of avalanche risk data on a routine operational basis, the team has created autonomous UAV flight plans for surveys over steep mountainous terrain, using mission planning software combined with publicly available elevation data for Norway. This supports precise flights over rugged avalanche terrain and is achieved by developed workflows for georeferencing images as well as photogrammetry processing procedures which create automated 3D elevation models to guide UAV flight paths. The research team will also be testing a mobile application that enables scheduled, remote UAV operations.

The most operational routine tested so far in the project, was to perform LiDAR scanning of the snowed-in slopes above highway RV15 close to NGI's research station and to make these measurements available to avalanche forecasters. Measurements were carried out during mornings, between 09.00 and 11.00, upon which the incoming data was processed and presented to the forecasters through an online portal (see Figure 6).

The forecasters could then analyse the data after 12.00 noon. This updated snow information could be included in the site-specific avalanche warning for the road, published at 14.00. This was done in 22 repetitive campaigns from January to March 2023.

The project team also developed software to allow for analysis of sensor data that can be run over a client-server architecture. This enables automatic data analysis by roadway administration staff on images obtained from the UAV.

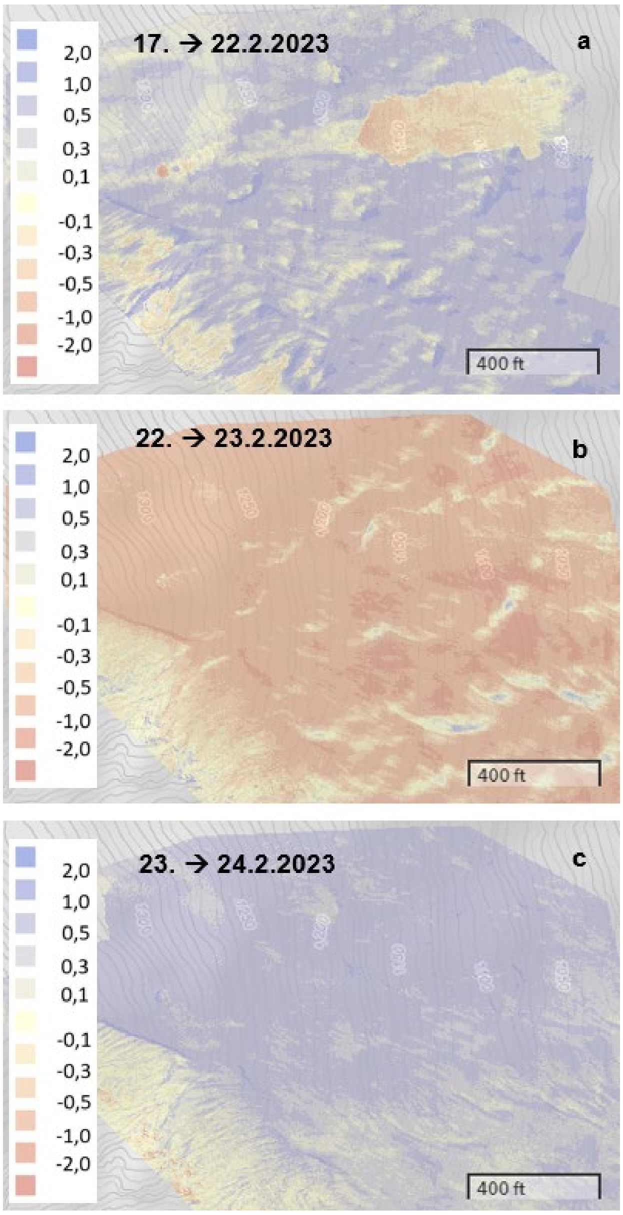

Figure 6: Example of a change detection map where blue colours represent increased snow height [m] (i.e. snow fall or wind slab formation) since last measurement, while red colours represents decreased snow height (i.e., erosion, melting or avalanches); (a) wind deposited snow and a recent controlled avalanche is documented on 21.2.2023, (b) followed by wind erosion, and (c) another round of new snow accumulation.

A comparison between forecasts made by two group of forecasters – those with or without access to these data – indicates that access to UAV data reduced both the expected avalanche likelihood and size (Haddad et al., 2023 – this issue).

4. NEXT STEPS

As part of this project, the research team will explore the use of UAVs for remote data collection including autonomous flights from fixed, unattended roadside garages that store UAVs. With the garages, an avalanche professional at the NPRA, for example after a new snow fall, can remotely launch the UAV and evaluate conditions. After a flight, the aircraft will return to the garage to be recharged for the next flight – all without direct human operation.

For the final part of the GEOSFAIR project, we are determining how to effectively integrate the use of UAVs into the road administration's decision support process. The resulting guidance on the use of UAVs and the data collected by this technology needs to be easily understandable and applicable for routine operations by NPRA staff, especially to those who are less experienced in the use of UAVs. The tools developed in the project are designed with the idea that they can be adopted in practice by maintenance and avalanche staff in a range of roadway-owning organisations. Ultimately, the outcomes should support better and more timely information about avalanche risk and more effective decisions about when to close and reopen roadways that are under the threat of an avalanche. The project will also apply the findings from this project to other natural hazards, such as landslides and rockfalls that impact roadways.

5. CONCLUSIONS

The goal of the GEOSFAIR project is to develop and test UAV-based data collection methods that can be used routinely by a roadway owning organisations' maintenance and avalanche staff to support rapid and effective decision making about avalanche risk and decide whether to close or open/reopen roadways. Our research has determined that UAVs, flying with appropriate sensors and supported by flight planning and data processing software, can effectively address this goal.

ACKNOWLEDGEMENT

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