TOWARDS AN OPEN HARDWARE IOT PLATFORM FOR ADVANCED MEASUREMENT OF SNOWPACK PROPERTIES AND AVALANCHE INSIGHTS

Albert Loichinger*[1] Felix Nyffenegger[1], Anselm Koehler[2], Jan Thomas Fischer[2]

[1] University of Applied Science Eastern Switzerland, IPEK Rapperswil, Switzerland
[2] Department for Natural Hazards, Austrian Research Centre for Forests, Innsbruck, Austria

ABSTRACT: Inflow sensor concepts such as particle tracking, offer a promising potential to further investigate avalanche dynamics. Beyond the scientific merit of such data, discussion with stakeholders like infrastructure operators and other public or private relevant entities underscores the potential for practical applications of insights into local snowpack properties. For instance, patrollers require more detailed and refined data to improve decision-making for avalanche control strategies, including determining the optimal timing for avalanche control operations.

In collaboration with avalanche research and sensor development, the next generation of sensor nodes emerged with the goal to generate meaningful data and advanced insights into the snowpack and avalanche behavior. The aim is to create an open and expandable low-cost platform to support diverse applications within both academic research and professional avalanche mitigation. The platform will consist of mechanical, electrical and software modules, which can be combined to specific applications for both, stationary observation of the snowpack as well as detailed tracking of artificial avalanche particles.

The initial phase of implementation aims to further evaluate and refine avalanche discrete element flow simulations with data collected by widely distributed IoT devices in the relevant avalanche track. These devices will be placed into the snowpack during winter to observe minor movements and collect climate data over several month with low-power consumption. Yet, the nodes are capable to wake up and switch to high frequency recording in the event of an avalanche. During observation, data is sent several times per day via narrow band IoT (NB IoT) to a cloud platform for analysis and visualization. Advanced sensors are to be developed in order to gain detailed information which are base for defined simulation models. Here are the liquid water contend, mechanical shear behavior and others in focus.

Preliminary findings indicate promising communication performance using NB IoT and GNSS in comparable conditions. Goal is to include measured data into simulation models. During winter 24/25 extended test in avalanche test-sites are planned.

KEYWORDS: Instrumentation, monitoring, sensors, particle tracking, IoT

1. INTRODUCTION

Based on discussion with application groups like the mountain railroad (e.g. Rhaetian railroad and local road authorities), equipment suppliers there is a need for detailed information out of the snowpack in relevant positions. The work of Innsbruck BFW in particle tracking needs to be continued towards an open IoT platform. Additional functionality is to be included to gather advanced data from the individual position. As the developed devices will be on a low cost basis using available electronics systems, they can be placed in positions where they may get lost or destroyed with a heavy avalanche. An extended battery life time will allow to place them in the beginning of the winter season and receive data for several months. Various applications will include advanced sensors to measure data like the liquid water content, detonation shock wave and other parameters. These data will also allow deeper insights into the traveling avalanche besides position and therefore be basis for simulation studies. The platform has been established and tested in late winter 23/24.

2. STATE OF THE ART

Predecessors to these in-flow sensors include the early experiments by Vilajosana et al. (2011) and the first full-scale avalanche measurements by Winkler et al. (2018), where a ball equipped with a global navigation satellite system (GNSS) and inertial measurement unit (IMU) was deployed in an avalanche in 2013. However, this early prototype remained underdeveloped, primarily due to the limitations of hardware originally designed for drone operations, which resulted in unreliable tracking of the sensor's location within the avalanche. Not only the electronics posed

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* *Corresponding author address:*
Albert Loichinger IPEK OST
Oberseestrasse 10, 8640 Rapperswil Switzerland
Albert.Loichinger@ost.ch
T +41 79 391 3851

limitations, but also the round shape facilitated decoupling of the sensor ball from the flow due to rolling.

Building on this foundation, the second generation of AvaNodes introduced several key improvements. Enhanced battery life allowed for longer measurement periods, while upgrades to the GNSS module provided more accurate geospatial data, including Doppler velocities. The AvaNode in their first and second generation focus on more reliable tracking with GNSS, as the experiments indeed proved satellite based location tracking to be working inside the snowcover or avalanche (Neuhauser et al., 2023). The measurements base of a consumer grade GNSS module CAM-M8Q produced by ublox, and especially the recording of three-dimensional Doppler velocities are of high-resolution. Location reconstruction via IMU tracking inside an avalanche is today challenging, and error grow considerably with flow duration and length. However, a sensor fusion of GNSS tracking with IMU for the intermediate time steps can provide further localization details (Neurauter et al., 2023).

The AvaNode system so far is distinctively shaped as a concave cube to minimize rolling and sliding on the snow surface, ensuring stable data collection during the flow. Designed with a replaceable housing to protect the hardware and reduce costs, the nodes are designed to be deployed safely by dropping them into the avalanche release area. The sensor components are mainly build upon low-cost electronics and designed as a prototype platform for further developments. Now, as tracking proved working, the AvaNode platform needs a redesign with the focus on additional sensors that capture important flow parameters beyond measuring basic motion parameters. Those parameter include for example snow temperatures, liquid-water content, pore-space pressure to name a few. Additionally, the previous systems lack of enduring battery capacity. They only can be employed in controlled avalanche experiments with a direct access to the release area where the sensors are implemented manually.

3. SYSTEM ARCHITECTURE

The complete system is organized into electronics, embedded software and an IoT cloud stack. In order to involve as many researchers and users as possible into data generation and further enhancement of the system, we decided to organize all components open source.

Form experience gained in other large scale environmental IoT projects (Nyffenegger et al., 2022) a well established open source IoT stack was chosen for this setup: InfluxDB as time series data store, Mosquite and Telegraph as MQTT interface and Graphana as visualization layer. All components are organized in docker containers to assure easy deployment and good scalability.

Since all currently known areas of interest are in reach of a mobile network we favored NB-IoT (Narrow Band IOT) over LoRa for low power communication, as no additional gateways and frequency configuration are required. However, the software architecture would allow easy replacement of NB-IoT with other technologies such as LoRa WAN.

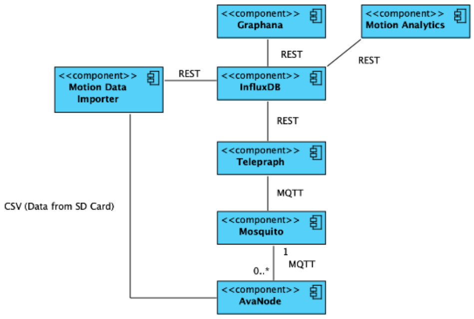


Figure 1: IOT architecture

The electronics at the current design iteration are built from standards prototype shields and breakouts. This allowed to test difference senors in the field.

The embedded software consists of thee main structural elements: A state machine to control the overall behavior of the device, a specialization of a generic sensor class for each sensor to implement it's specific behavior incl. filtering and dumping data to the SD flash store, and a communication class to prepare and send the payload. The software is intended to be used and enhanced by several research groups, therefore and object oriented and modular architecture is chosen.

The main procedure implemented by the state machine follows these steps illustrated in Figure 3. The avalanche state is triggered by the motion sensor, currently at an acceleration a > 0.6 x g.

The housing design will include a core keeping and protection the battery and electronics. The outer shape and included volume can be freely designed to avoid rolling on surface. Key to closely following the surrounding inside the traveling avalanche is the overall density and center of gravity of the node. This can be designed individually and aligned including additional masses into the node. The outer cones are designed to include sensors and user interface like switch and connectors. These can be opened easily for access and modular modification.

The full stack of hardware and software is available open-source on https://gitlab.ost.ch/alpineguard.

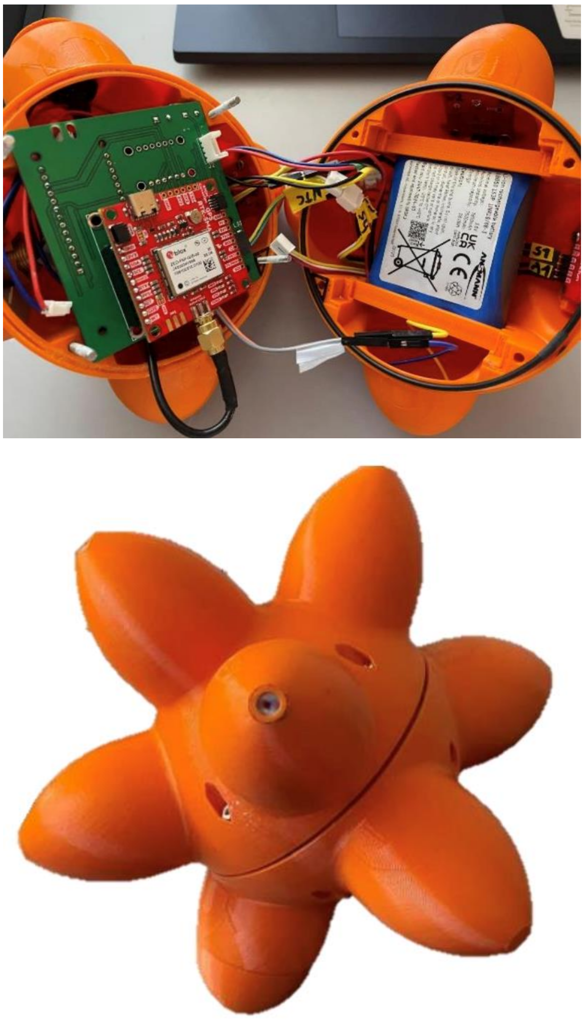
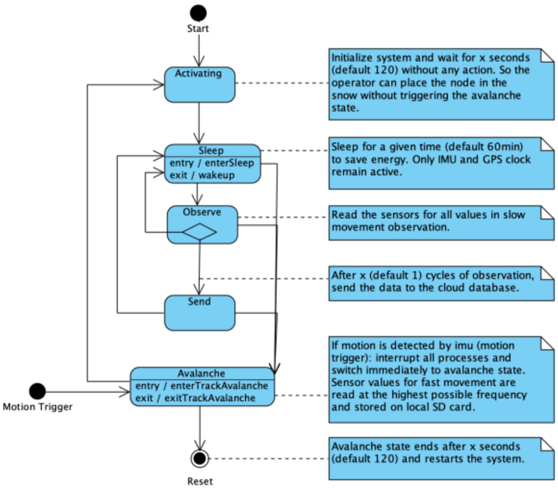


Figure 2: Electronics and housing of current design iteration.



Initialize system and wait for x seconds (default 120) without any action. So the operator can place the node in the snow without triggering the avalanche state.

Sleep for a given time (default 60min) to save energy. Only IMU and GPS clock remain active.

Read the sensors for all values in slow movement observation.

After x (default 1) cycles of observation, send the data to the cloud database.

If motion is detected by imu (motion trigger): interrupt all processes and switch immediately to avalanche state. Sensor values for fast movement are read at the highest possible frequency and stored on local SD card.

Avalanche state ends after x seconds (default 120) and restarts the system.

Figure 3: State Machine Diagram

4. PRELIMINARY RESULTS

In spring 2024 between March and June a first series of field tests was executed. The main goal of these experiments was to test the chosen components and the software logic in the field. No real avalanche could be recorded during these tests. However, the generated data give some indication of what can be expected from such measurement and what current limitations exist.

Figure 4 shows the node state of the sensor, as well as its orientation in Euler angles in an 1hr resolution. In the middle of the graph (afternoon of 27th) the sensor starts to tilt by the roll and yaw angle. At some point, a strong movement was detected. Two peaks in the state chart show that the node changed into avalanche mode. However, in this situation no avalanche was observed in reality. Instead, the sensor node melted free from snow and started to roll down some meters in the steep terrain. Later there is some slow movement of the sensor visible, probably due to the melting snow cover.

Figure 4: Experiment in Waagtal, Hochybrig: Sensor X77, initially placed approx. 30 to 40cm below snow cover.

Fast movement of the node is illustrated in Figure 5, resulting from an experiment on Julierpass. The node was dropped into the hillside which activated “avalanche state” before it rolled downhill. GPS-track (blue) and the path of integrated acceleration (red) do not correlate but show some similarity. The offset of the starting point originates form the GPS position recorded at the time stamp of the first acceleration data.

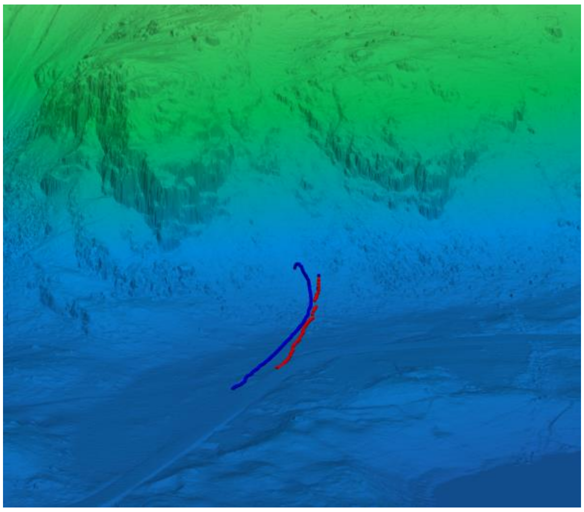


Figure 5: Track of node rolling down near Julierpass: blue GPS-track, red calculated from acceleration and orientation.

During the last experiment on Weissfluh Joch in the skiing resort of Davos, one of the nodes was equipped with two temperature measurement. Figure 6 shows the temperature on top (yellow) and at the bottom (green) of the sensor at approximately 30cm below surface.

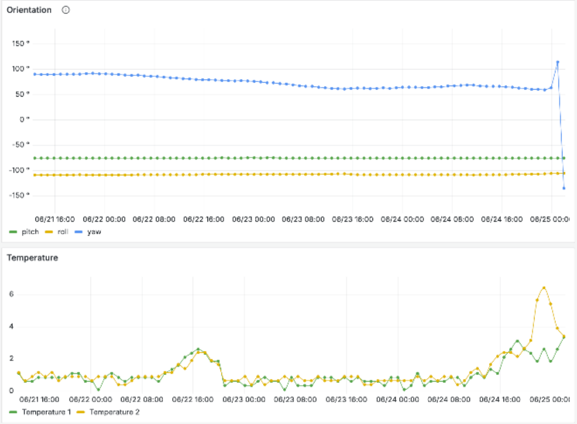


Figure 6: Experiments on Weissfluh Joch, Davos: Node X55, placed in 40° exposition in June

While temperatures in average vary between 0°C and 1°C, there is one peak around June 22 and a remarkable increase on June 25. Most likely it melted free during the day of June 25. Later the sensor was retrieved from surface of the snow cover. There was no movement discovered in this period. The drift of the yaw angle of about 30° indicates insufficient calibration of the magnetic sensor.

Figure 7 shows the accuracy of the GPS which may be expect not using RTK (real time kinematics). Even in this quite preliminary setup the signal varies +/- 6m without actual movement of the node.

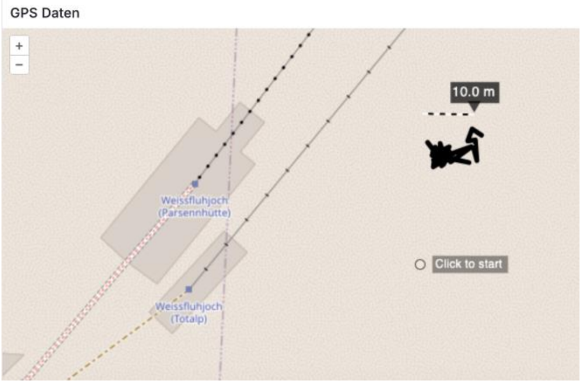


Figure 7: Experiments on Weissfluh Joch, Davos: Position of Node X29 between June 21 and June 26

5. DISCUSSION & CONCLUSION

The results presented above result from initial tests to evaluate the hardware and are not properly validated. Still they prove the feasibility of a multi-sensor node that can do both: slow and low-power observation and fast data acquisition during a triggered event. This pictures what kind of data can be derived from such devices. However there are few findings and limitations that need to considered for further development :

(i) It turned out that proper calibration directly in the field is essential. The calibration must be a mandatory step when starting up the node in future.

(ii) Accurate position measurement is crucial for both, slow and fast measurement. While during fast measurement GPS signal leads to coherent path, slow measurement, particularly if GPS is waked up from sleep mode, shows wide scattering. Implementation of GPS with RTK, or and alternative position measurement system will be essential for the slow moving translation of the node.

(iii) Power consumption at this stage is far to high. However, there is a lot of potential to improve and we are confident to build nodes that last online for at least 4 month.

(iv) Storage on an external SD card proved to be a bottleneck in data acquisition and a critical point of damage during the event of an avalanche.

(v) Communication with NB-IoT worked without any issues, even from under 1m snow cover.

(vi) Proper validation of data, particularly 3D movement of the node (translation, rotation) derived from 9DoF motion sensor will be an essential task to further prove the application of such sensor nodes.

Based on these findings, current effort is spent on an integrated design to have the core building blocks of the electronics (CPU, IMU, GPS, temperature sensor, data storage, and power-management) on a single integrated board. The board will still be a stackable prototype board that can be extended with other sensors or even actuators.

6. OUTLOOK

During the last winter the team has elaborate discussions with other partners in the avalanche and snow community. Several interviews were conducted to collect requirements and understand wanted application coverage. Therefore users can be clustered as following:

- Research: gain insights into snowpack with advanced sensors to calibrate simulation activities
- Equipment manufacturers (prevention, detonation, …) : allow measurement of missing information around their product influence, prediction based on refined measurement grid
- Authorities (road, rail, resort…) : Provide a broader basis with local refined information about key positions in their critical setup

As requirements are different for each user cluster, there will be several expansion stages where especially software is optimized for the respective functionality.

Also full freedom in design of the case is provided by the widely availability of FDM 3D printers. There will be a standard case with enough robustness to withstand an avalanche with minimal risk of destruction which can be modified to provide individual density and other parameters.

The use of a open source system would also allow to open the platform for anybody. Providing electronics, software, case definition, and connectivity to the integrated cloud service would enable contribution of many locations into our platform. Similar approaches have been performed in air quality measurements. That would deliver many detailed information not only about the overall snow layer, but give insights into local snow properties.

Therefore the authors agreed to start a project to establish a project within Germany, Austria and Switzerland to work on the design and testing of the system. Key advancements are to be developed in advanced sensors in long term stability, a toolset for fast and proper data analytics (e.g. acceleration to motion over terrain and communication and cloud integration.

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