Wireless Nodes for RF-Based Measurement of Liquid Water Content in Snow

Towards New Sensing Solutions for Avalanche Prediction

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Introduction: Predicting wet-snow avalanches remains one of the greatest challenges in avalanche forecasting. A key indicator of snowpack instability is the liquid water content (LWC) of snow. Wet-snow avalanche risk is known to increase significantly once the LWC exceeds 3%. Existing measurement methods often require additional information such as snow density, complicating remote long-term monitoring in alpine environments.

Approach / Technology: Previous research developed an RF-based measurement principle capable of measuring LWC largely independently of snow density under laboratory conditions. Building upon this concept, this thesis presents the development of an autonomous sensor node for long-term deployment in alpine environments. The battery-powered system embedded in a waterproof enclosure is shown in Fig. 3, highlighting the STM32 MCU (1), modem (2), GNSS antenna (3), NB-IoT antenna system (4), RF generator (5), LWC sensing board (6), and the RF power detector (7). Particular attention was given to minimizing power consumption, ensuring reliable operation under harsh winter conditions, and maintaining wireless connectivity despite deep snow cover throughout the winter season.

Result: Field evaluations conducted on Mount Titlis demonstrated stable and repeatable sensor operation under realistic alpine conditions. Fig. 1 shows the deployed sensor nodes prior to burial. The system reliably distinguished between different snow states and produced consistent and accurate measurements. Somewhat increased uncertainty was observed at higher LWC levels. In addition to LWC and temperature measurements, an integrated accelerometer enables monitoring of sensor orientation and snowpack movement. Wireless communication remained reliable even when the node was buried beneath more than 1.5 m of snow. GNSS supports deployment mapping and device recovery. The web platform shown in Fig. 2 provides monitoring, data visualization, and remote configuration capabilities for deployed sensor nodes. Together, these results demonstrate the feasibility of autonomous, density-independent LWC monitoring for large-scale snowpack monitoring in alpine environments.

Figure 1: The LWC Sensor Nodes Before Tests on Mount Titlis.
Own presentment

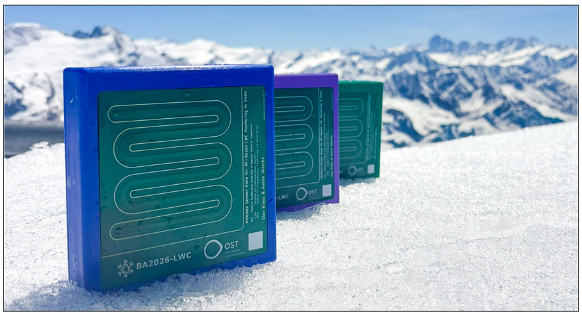


Figure 2: Dashboard for Remote Monitoring and Configuration.
Own presentment

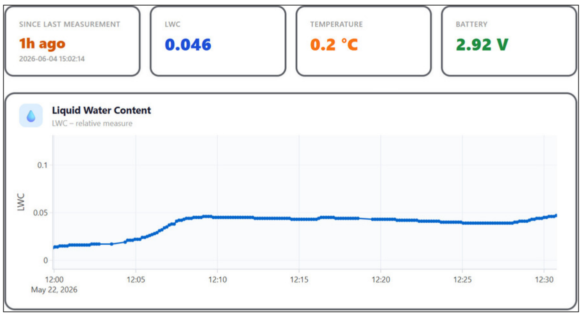
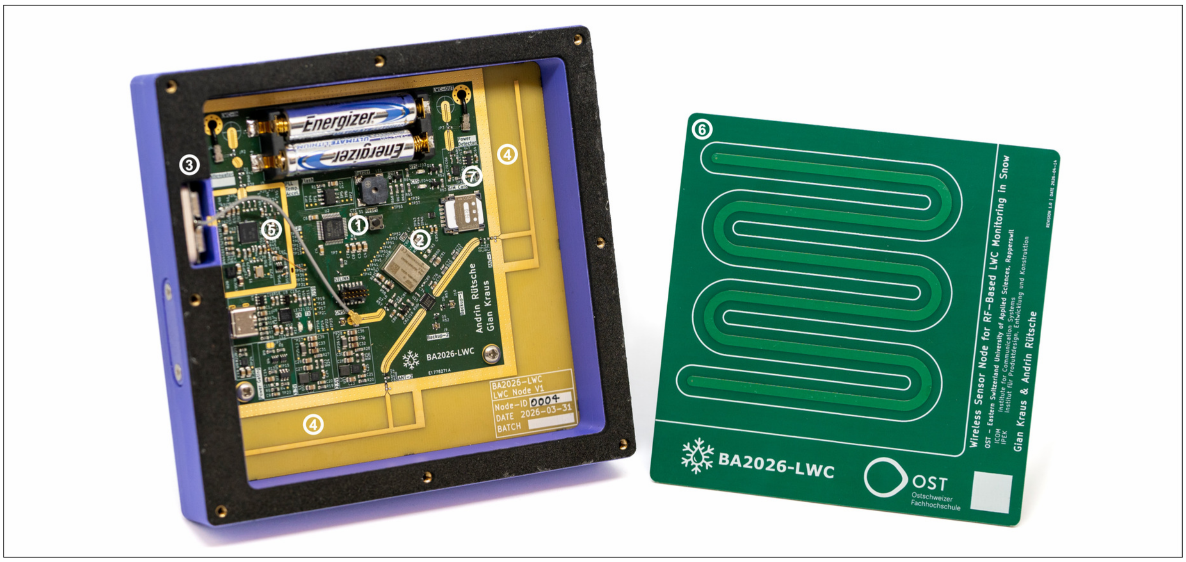


Figure 3: Internal View of the Developed Sensor Node.
Own presentment



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