A Measurement System for Distributed UWB-based Ranging and Localization in Snow Avalanches

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ABSTRACT

We present a systems approach for tracking of mobile systems in an avalanche scenario using an ultra-wideband (UWB)-based ranging and localization system. UWB-based positioning is particularly challenging in outdoor scenarios covering large distances in complex topography. In the long-term, we are interested in tracking the motion of snow avalanches; particularly their inner dynamics are still unknown since they remain hidden for most observation approaches. Our system model considers multiple anchors distributed with inter-node distances in the order of a few hundred meters. Mobile nodes, which move with the avalanche in the field, are tracked via UWB time-of-flight measurements and further supported by inertial measurement units. Our system further integrates LoRa and IEEE 802.11 mesh for configuration and management, with UWB for measurement and reporting. First measurement results in the field show good accuracy and confirm the design choice.

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1 INTRODUCTION

Radio ranging and localization in dynamic outdoor environments is usually done using some global navigation satellite system (GNSS). While the technology is mature and has been very successful in many application domains, its main weaknesses are the comparably high energy consumption and the low accuracy in highly dynamic environments with complex topography [5]. We are interested in one of such challenging environments, namely tracking the motion of snow avalanches in mountain areas [1].

Ultra-wideband (UWB)-based ranging has in general been well explored [2, 4, 6]. However, there are still many open questions related to outdoor environments covering larger distances; particularly with complex terrain and snow and ice conditions. Recently, some of the most popular UWB-based systems have been compared in indoor and outdoor scenarios [3]. At the same time, first measurements in snow (snow covered systems or communication through snow) [1, 7] confirmed the feasibility of UWB in our scenario.

In this paper, we introduce our system architecture and present first validation experiments in the field. Fig. 1 depicts the conceptual system design. Anchors are deployed at the edge of the measurement area. The anchors use an IEEE 802.11 mesh in combination with LoRa for configuration and coordination of measurements. The objective is to provide ranging and eventually localization and tracking of nodes

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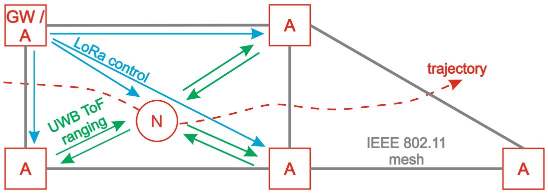


Figure 1: System design. Anchors (A) span an observation area. They are interconnected using an 802.11 mesh network. Gateways (GW) connect the system to our backend. Nodes (N) to be tracked use UWB for measurements and LoRa for configuration.

moving in the measurement area. An UWB-based system is used for time-of-flight (ToF) measurements and the transport of these results via the anchors to a gateway node. The node is using the same UWB chip. The cover is realized in form of 3D-printed housings, which are later placed in avalanche release areas and flow with the general mass movement. In the context of this paper, we experimented with the setup by manually moving the node within the measurement area.

Our main contributions can be summarized as follows:

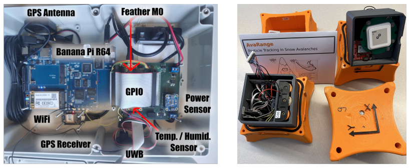
- We developed a complete UWB-based radio ranging system for usage in snow fields in mountain areas;
- we realized a prototype of the overall system; and
- we present results from initial validation experiments confirming the envisioned measurement functionality.

2 SYSTEM DESIGN

The overall system concept is depicted in Fig. 1. We distinguish three different device types. The mobile *node* represents the system to be tracked. Multiple *anchor* nodes are distributed along the tracking area. Both devices are equipped with UWB-based ranging devices. One or multiple of the anchors are acting as a *gateway* device, which are used to coordinate measurements and to collect and forward experiment results to backend server systems.

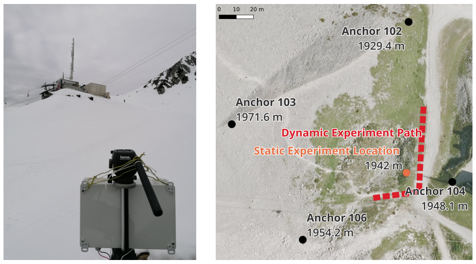
For exchanging data, monitoring and controlling the system, and the ranging itself, we use a variety of communication technologies. UWB is used for the actual ranging procedure, i.e., the ToF measurements. LoRa is used for sending commands to the node and transmitting sensor data at regular intervals. Anchors use an IEEE 802.11 WiFi mesh network used for setting ranging configurations and transmitting ranging data to the backend server. Local GNSS receivers provide ground truth positions of the anchors.

A schematic overview of the anchor is depicted in Fig. 2a. The main component is a BananaPi R64 running OpenWRT Linux for local processing. A custom PCB is used to connect a Feather M0, a variety of sensors (e.g., temperature), and a DW1000 UWB chip for ToF radio ranging. The feather is responsible for collecting and transmitting sensor data such as temperature, humidity, and power consumption. It also controls the power supply to the system, i.e., it is able to power-up / power-down the main system to save energy.



(a) Anchor. **(b) Node.**

Figure 2: Main hardware components.



(a) Anchor at experiment site. **(b) Locations of anchors and experiments.**

Figure 3: Experiment site at Nordkette; a mountain area in the Alps north of Innsbruck, Austria.

The node is depicted in Fig. 2b. For radio ranging, it also uses the same DW1000 UWB chip connected to an Arduino Feather M0. The DW1000 timestamping supports a precision of about 15 ps, which is essential for accurate ToF ranging. In addition, the node also includes a GNSS, an IMU, and retrieval systems.

3 VALIDATION EXPERIMENT

We performed a set of initial measurements in a rather accessible terrain to evaluate the functionality of the system, to obtain information on maximum measurement distances, and to get initial insights on the measurement accuracy. The experiment site is a typical avalanche zone at Nordkette, a mountain area in the Alps north of Innsbruck, Austria. Fig. 3 shows the locations of the installed anchors as well as the positions of the measurements.

3.1 Accuracy of UWB Rangings

In a first set of experiments, we studied the UWB ranging accuracy of two stationary positioned nodes (cf. Fig. 3b). We measured the distance between all anchors reachable via UWB to the nodes and identified two main factors influencing accuracy: orientation of node to anchor and signal strength. Fig. 4 shows a histogram of the ranging accuracy to one selected anchor. Two different nodes were placed at the stationary location, with Node 3 facing upwards and Node 12 facing downwards. We can see that this strongly affects the ranging distribution, with Node 12 having more than double

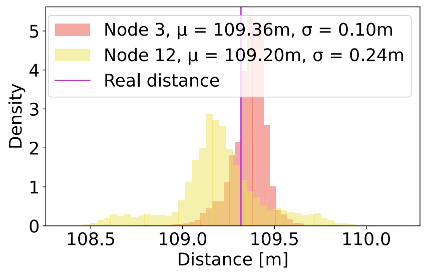


Figure 4: Ranging accuracy of stationary nodes in different orientation to anchor 103.

the standard deviation of Node 3. Also, Node 12 has some large distance errors of up to 80 cm, which are not present for Node 3. In Fig. 5, we show the impact of the signal quality measured in form of RSSI on the ranging accuracy. As can be seen, the signal is also strongly attenuated by snow layers between anchor and node.

3.2 Tracking in Mobile Experiment

In a second experiment, we explored the feasibility of tracking a mobile node. Instead of an avalanche, we had an experienced skier taking the node and skiing downhill, as exactly as possible following the track indicated in Fig. 3b. In order to validate the measurement results, we also carried a separate high-precision GNSS tracker alongside the node. As can be seen in Fig. 6, the accuracy of both systems is quite similar. One very important, and visually quite obvious, difference is the sampling rate. The UWB-system can support a much higher sampling rate than the GNSS sensor. This will eventually impact the avalanche studies, as for dynamic measurements, the sampling frequency plays an enormous role to obtain most accurate information about the avalanche dynamics. Due to technical problems during this experiment, only rangings to three anchors were possible, leading to the large elevation differences in Fig. 6. We see that the 2D path matches the GNSS quite closely. So the 3D case can likely be improved by adding further anchors in this scenario.

4 CONCLUSION

In this paper, we introduce a measurement system that allows to obtain fine grained UWB measurements in large-scale outdoor environments. We make use of an IEEE 802.11 mesh network interconnecting fixed anchors. Anchors and nodes use both LoRa and UWB for configuration and measurements. For the prototype, we selected the DW1000 UWB system, which allows to measure distances of up to 500 m. In a first set of experiments, we validated the system in the target area, i.e., a mountain region in the Alps. From the results, we can see that our system is highly accurate in 2D with the majority of errors being less than 20 cm. The error in 3D is currently higher but this can likely be dealt with using more anchors. Most importantly, our UWB-based system can operate on a much higher sampling rate than high-precision GNSS systems, thus, allowing better and more fine-grained insights into the dynamics of avalanches. In the upcoming winter, we plan a first set of experiments in artificially released avalanches.

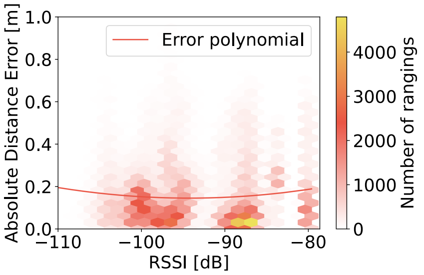
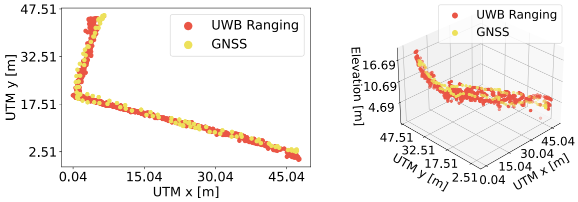


Figure 5: Effect of RSSI on ranging accuracy.



(a) Mobile tracking in 2D **(b) Mobile tracking in 3D**

Figure 6: Comparison of our UWB ranging to GNSS.

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