ROBOSAT Deliverable

D5.1 In-lab and field measurement setups

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Abstract

This deliverable presents the in-lab and field-measurement setups established across the ROBOSAT consortium to support the collection of high-quality GNSS, multi-sensor, and environmental datasets for robotic navigation research. At Tampere University (TAU), both static and dynamic data acquisition campaigns were designed using the MGSE©-REC-SC front-end, with measurements set-ups prepared for collections under diverse signal propagation environments including open-sky, forested, urban, and mixed indoor–outdoor conditions. Complementary to these efforts, ETH deployed its advanced multi-sensor ANYmal platform equipped with tightly time-synchronized cameras, LiDARs, IMUs, and an RTK-GNSS module to produce high-precision ground-truth trajectories over more than 10 km of traversed paths. Additional in-lab capabilities at Universitat de València (UV) will provide heterogeneous RF-based positioning systems, event-based cameras, and anechoic chamber facilities for controlled experimentation. Finally, CITST has initiated plans for large-scale field measurements in natural non-urban environments, including the integration of GNSS, imaging, and elevation data via portable user-mounted systems. Together, these setups lay the foundation for a comprehensive multi-modal dataset essential for evaluating and enhancing GNSS performance and developing environmentally aware navigation methods within the ROBOSAT project.

Keywords: *GNSS; in-lab measurements; field measurements; hardware; software*

1. In-lab and planned field-measurement setup at TAU

1.1. Static Laboratory Setup

Initial static measurements will be conducted using the MGSE©-REC-SC front-end in a controlled rooftop environment at Tampere University. The primary antenna for laboratory captures will be the NovAtel rooftop antenna, which is permanently installed on the rooftop of the building with a cable connection routed to the laboratory, providing a stable open-sky view suitable for clean reference signal collection. The navXperience 3G+C mobile antenna will also be used in static conditions for comparison purposes, though its performance in this configuration is expected to be limited given the absence of a clear sky view from indoors. The two antenna configurations will be compared in terms of acquired signal quality, C/N_0 levels, and acquisition performance as processed through the FGI software-defined GNSS receiver in MATLAB.

1.2. Dynamic Field Measurement Campaigns

Dynamic signal capture campaigns will be conducted outdoors using the MGSE©-REC-SC carried as a portable unit powered via USB connection to a laptop, with the navXperience 3G+C mobile antenna used for all field measurements. Four distinct measurement scenarios are planned, each targeting a different signal propagation environment relevant to GNSS performance characterisation. The first scenario involves open-sky conditions in an unobstructed outdoor area, providing a baseline reference for signal quality, acquisition performance, and positioning accuracy under ideal reception conditions. This dataset will serve as the benchmark against which the remaining scenarios are evaluated.

The second scenario targets signal degradation due to natural obstruction, with measurements collected along forested hiking trails in the Tampere area. The dense tree canopy introduces signal attenuation and intermittent blocking, allowing characterization of the front-end's behavior under foliage-induced signal fading. The route will additionally include passages underneath bridges along the trail network, where complete signal blockage is expected for a short duration, providing data on signal re-acquisition performance following total outage.

The third scenario focuses on urban multipath effects, with measurements collected in the Tampere city center environment. Signal reflections from building facades, combined with partial sky obstruction from surrounding structures, will introduce multipath-corrupted signals that are of particular interest for studying the impact of the propagation environment on raw I/Q data quality and downstream positioning performance.

The fourth and most precisely instrumented scenario involves a mixed indoor-outdoor measurement campaign on the Tampere University campus. The route will transition repeatedly between open-sky outdoor conditions and indoor environments, capturing the signal degradation and loss associated with entering buildings as well as the re-acquisition behaviour upon returning outdoors.

Precise timestamps will be recorded throughout the campaign to annotate the collected I/Q data with the exact moments of environmental transitions. For example, the time of entering a university building, the time of exiting, and the time of entering a second building will all be logged to the nearest second. These event timestamps, alongside similar annotations for the bridge passages and dense forest segments in the other scenarios, will enable accurate correlation between the known propagation environment and the observed signal characteristics in the recorded data, supporting a rigorous analysis of GNSS signal behaviour across the full range of tested conditions.

1.3. Prior Setup: Android Ephemeris Data Extraction

A preliminary investigation was conducted into the direct extraction of GNSS ephemeris data from an Android smartphone, with the goal of integrating ephemeris information into a custom navigation solution alongside GIS data. Ephemeris data is essential for any such solution, as it provides the precise orbital parameters and satellite clock corrections needed to compute each satellite's position in space at the time of signal transmission. Without valid ephemeris, pseudorange measurements alone cannot yield a reliable position solution.

An Android application was developed to capture raw GNSS navigation messages and decode the embedded ephemeris parameters directly from the device. Testing was carried out on a Google Pixel 7 handset. While the application successfully registered some satellite signals and produced decoded output, the extracted data was largely unusable. The decoded ephemeris fields contained corrupt or physically implausible values, rendering the data unsuitable for use in a navigation solution.

Several causes were identified for this outcome. The Android SDK does not expose public constants for BeiDou navigation message types, as these are marked as internal, meaning BeiDou ephemeris could not be retrieved through the standard API. Similarly, Galileo ephemeris reception via the navigation message callback was found to be unreliable on the Pixel 7, despite the hardware visibly tracking Galileo satellites in the GnssStatus API output. Additionally, certain GNSS features within Android require an active location request to be fully initialised before navigation message callbacks are activated, which introduced further complications. It is possible that the issue is partly chipset-specific, and the outcome may differ on other Android devices, though this was not investigated further. Given these limitations, the ephemeris extraction approach was abandoned and the focus shifted to raw I/Q data collection using the MGSE©-REC-SC front-end as the primary data source for the project.

2. In-lab and field-measurement setup at ETH

Measurements at ETH were done using the sensor setup detailed in WP2 and also in [2]. The sensor box designed in this context contains a large range of sensors, from cameras to LiDARs to highly accurate IMUs. Everything is tightly time-synchronized and georeferenced using an RTK-GNSS device to enable later use of the data for the purposes of ROBOTSAT. A view of the sensors and their output is shown in Figure 1 The sensor box is also designed in a modular way that will allow later additions of new sensors, especially the IQ-grabber, which will be used by TAU in the context of the project.

An initial data collection was done, consisting of 49 separate missions that total >10 km and >5 h of data. Examples of trajectories from a satellite perspective are shown in Figure 2. This initial dataset will enable the partners in the consortium to work with ANYmal and to provide feedback on what their needs are going forward. Since the goal of the project is to evaluate and improve the performance of GNSS algorithms, a solid baseline and ground truth are required. As the GNSS module can not work as a reference for itself, a more accurate solution is required. For this purpose, we also use a Total Station, which is a highly accurate laser-based surveying tool that can provide sub-millimeter accuracy. The Total Station tracks a prism which is mounted on top of the robot to create a ground truth trajectory that can be later compared to the GNSS solution. While this trajectory is not itself geo-referenced, it is rigidly the best possible solution for the motion estimation of the robot. Later alignment can be done, as was explored in D2.1 and D3.1. More details on the ground truth and the recorded data are available in the afferent report [3].

3. In-lab setup at UV

The laboratory at Universitat de València (UV) is fully equipped with a set of heterogeneous positioning technologies, including Wi-Fi RSSI fingerprinting, Wi-Fi Fine Time Measurement (FTM) for measuring round-trip time, advanced antenna arrays for measuring BLE Angle of Arrival (AoA), and advanced UWB equipment for measuring Time of Arrival (ToA) as well as Angle of Arrival.

In addition to RF-based solutions, UV also has a neuromorphic camera capable of capturing events. A neuromorphic camera, also known as an event-based camera, silicon retina, or dynamic vision sensor, is an imaging sensor that responds to local changes in brightness. Event cameras do not capture images using a shutter as conventional (frame-based) cameras do. Instead, each pixel in an event camera operates independently and asynchronously, reporting changes in brightness as they occur and remaining silent otherwise. This results in much higher temporal resolution compared to conventional frame-based cameras.

Furthermore, UV has a dedicated anechoic chamber for experimentation (see Figure 3). It measures 5 m × 8 m × 5 m

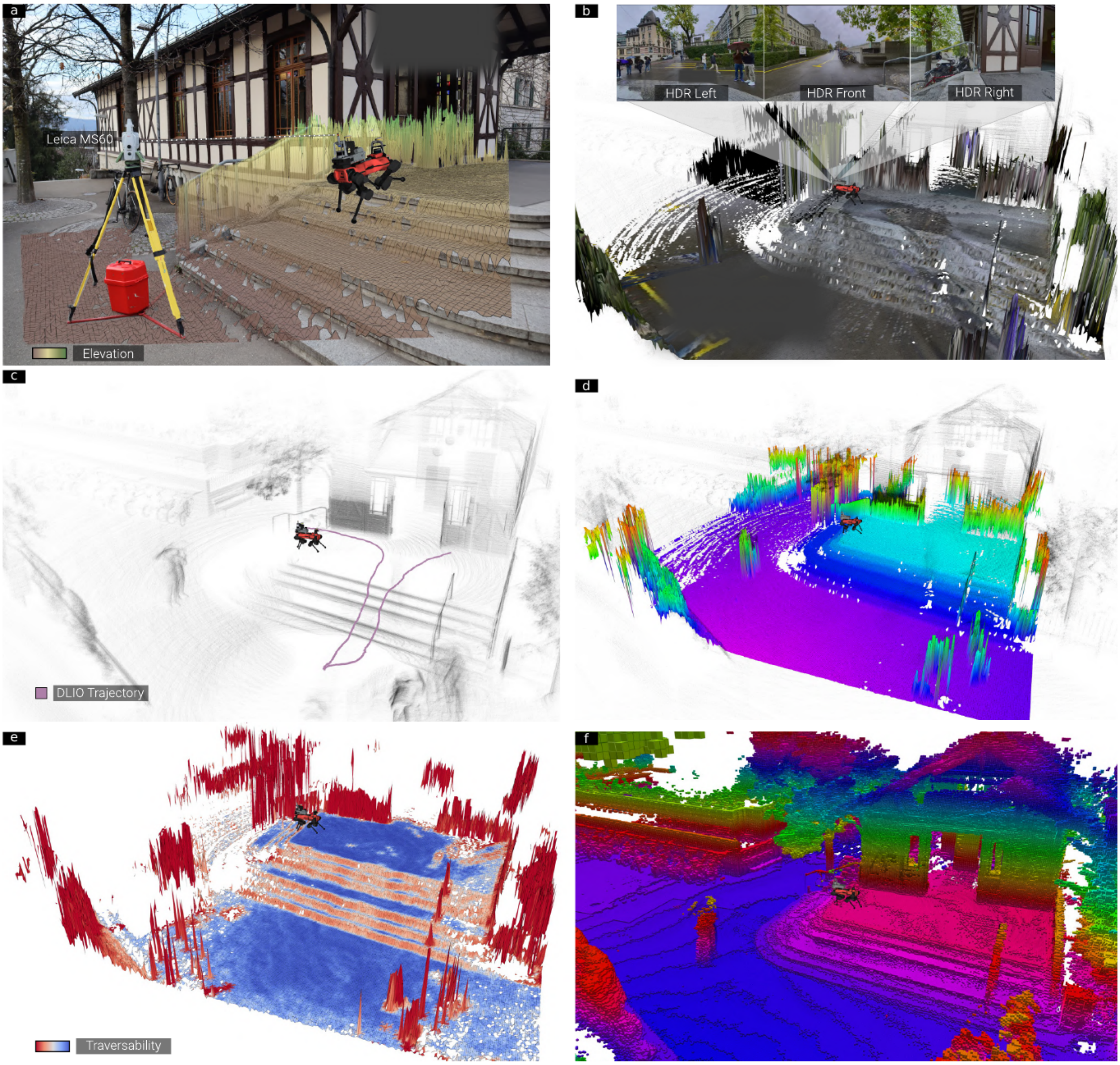

Figure 1. Example Deployments: (a) Total Station setup used for the ground truth pose generation. (b) Accurate intrinsic and extrinsic camera calibration enables precise projection of RGB data onto the colorized elevation map. (c) Accumulated point cloud and trajectory visualization based on the registration by an odometry module. (d) The 2.5D elevation mapping shows the smoothness of the local geometry perception. (e) Traversability analysis derived from the elevation map. (f) 3D Volumetric map generated using the Wavemap [1] module.

and allows project partners to measure antennas and wireless sensor devices in the frequency range from 300 MHz to 110 GHz. The chamber supports both spherical far-field and planar near-field measurements.

4. Planned field-measurement setup at CITST

The datasets to be collected in Romania should correlate positioning and imaging information of natural non-urban, environments (non-urban). The focus is not only on satellite data but on collecting a set of data which are similar to the once which are collected by mobile robotic platforms (e.g., the ANYmal robot at ETH) while moving through unstructured terrains covered by various types of vegetation, rocks, snow, etc. This implies collection using various cameras (RGB, RGB-D, wide-angle camera WA-RGB, etc.), LIDARs, barometers, and devices or applications to collect raw GNSS data. A first step towards building a data collection was to look into exiting datasets. GPS coordinates are available for various mountain trails [1] (Figure 4) but these data do not contain any other additional data, e.g., images along the trails. For example, only few images are available along the trails provided by muntii nostri [2] (Figure 5).

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[1] https://alpinet.org/main/poteci/gps.php?idxtracks=40&lng=ro&zonaid=19

[2] https://alpinet.org/main/poteci/gps.php?idxtracks=40&lng=ro&zonaid=19&utm_source=chatgpt.com#tab-tracks

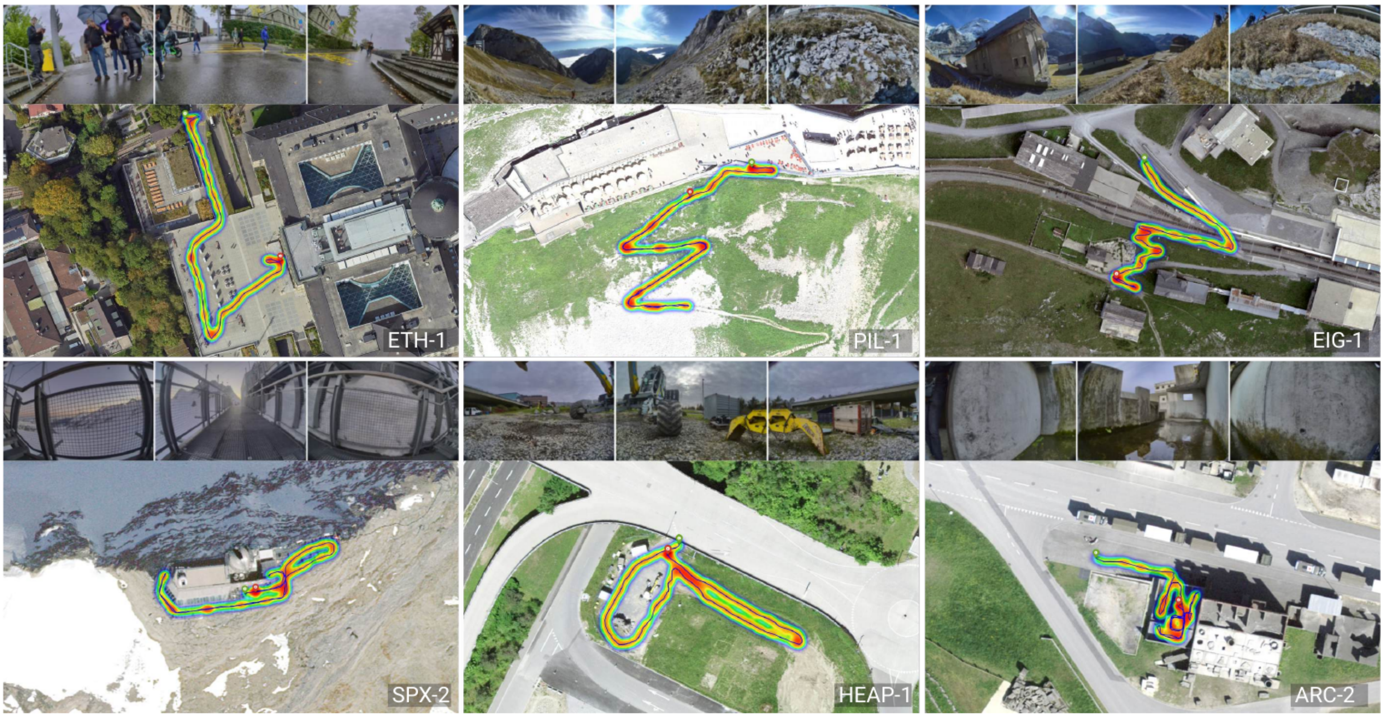

Figure 2. Dataset preview. Aerial imagery alongside on-board RGB views from a subset of the cameras for six missions of ANYmal traversing different environments. The path color indicates the frequency with which the robot is at that location.

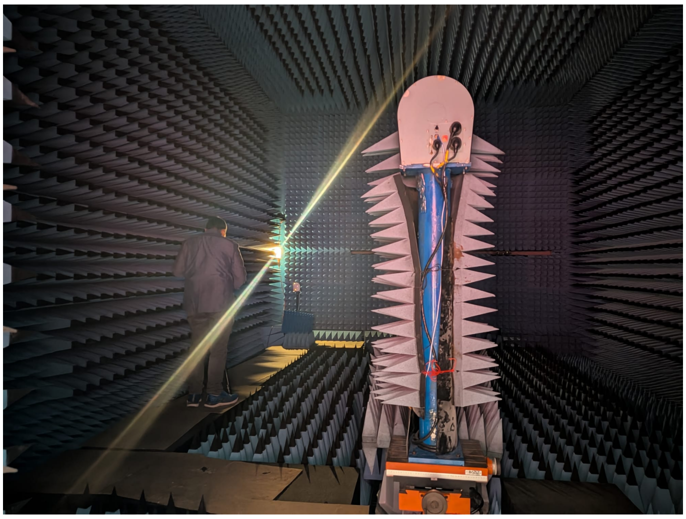

Figure 3. Anechoic Chamber at UV premises

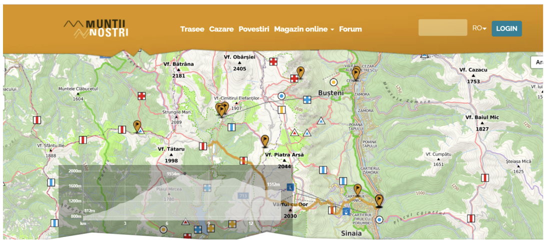

Figure 4. Various mountain trails. Flagged points provide images for a specific place and its GPS coordinates

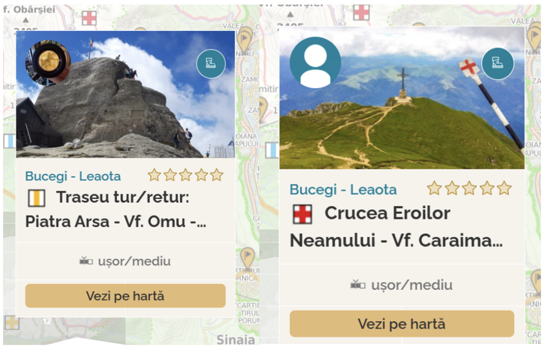

Figure 5. Sample pictures along available trails

Additionally, there are various applications which allow planning and recording of a hike. For example, PeakVisor [3] is a comprehensive mountain identification and navigation app that uses augmented reality and 3D maps to identify peaks, plan hikes, and track outdoor adventures. It also allows trip planning and visualization. However, we were not able to identify any suitable datasets which contain similar data as the ones acquired by ANYmal. Consequently, CITST is working on integrating the hardware and software components for field data collection. Two alternatives are currently being investigated:

1. Synchronous collection of: GNSS data using an Android app, elevation information, images with or without depth. A head-helmet and chest harness will be used to attach the hardware to the user collecting the data. The user will follow different trails, preferably several times during different outdoor conditions (light, weather, etc.). Alignment of the data will be done based on the recording time

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[3] https://peakvisor.com/

Type	Available options	Features
RGB camera	GoPro HERO12 or 13	5.3K video and high frame rate, head and chest mountable, GPS and data overlay can record speed, route, and movement context.
RGB-D camera	Intel RealSense D435	Depth range: 0.3–10 m, RGB resolution: 2 MP, stereo depth and IR projector.
WA-RGB camera	SVPRO 16MP Wide-Angle USB Camera, Arducam IMX291 Wide-Angle USB Camera	Resolution 2–16 MP, wide angle lens, USB powered.
Lidar	Garmin LIDAR-Lite v3	Range up to 40 m, very accurate distance measurements, good for outdoor experiments.
Elevation app	BasicAirData GPS Logger	Android app which allows export of recorded data as GPX, KML, or CSV. Works offline, records GPS position, altitude, speed, and time.
GNSS app	The GNSS Logger from Google	A lightweight app which records and stores GNSS raw measurements, together with reference tracks in NMEA format (latitude, longitude, altitude).

Table 1. Hardware and software components identified for the implementation of option 1

stamps.

2. Simultaneous collection of GNSS data and images/video using an Android phone with a dedicated application. The phone will be attached with a harness to the user collecting the data. Data collection will be implemented as in point 1. No alignment will be needed.

In both cases, we will optimize the frequency as well as the resolution of the collected data in order to save energy and keep the file size manageable.

Table 1 is presenting one of the options for the hardware and software components which are considered for the implementation of synchronous data collection (option 1). Some of their features are also presented. Other alternatives are also considered.

For the simultaneous data collection, we are considering to integrate to extend the MiMiR [4] in order to also record images and/or videos using the smartphone camera. The MiMiR is an open-source tool developed for recording raw GNSS measurements from Android smartphones by using the Android GNSS raw measurement API. It captures detailed satellite information and navigation data, including GNSS clock parameters, satellite identifiers, constellation type, carrier frequency, signal-to-noise ratio, and measurement time stamps. In addition to raw satellite measurements, the system logs standard position, velocity, and time information such as latitude, longitude, altitude, speed, and heading. The recorded data can be exported as CSV files. Field trips for testing and subsequent data collection are planned for May-August 2026 on various hiking trails in the Ilfov and Prahova counties and in the Bucegi mountains. These will be followed by winter.

5. Conclusions

The measurement setups developed across TAU, ETH, UV, and CITST form a coherent and complementary foundation for robust data acquisition within the ROBOSAT project. TAU's rooftop static configuration and diverse dynamic measurement scenarios will enable controlled assessment of GNSS signal behavior under a wide range of natural and urban conditions, while the systematic annotation of environmental transitions ensures strong correlation between propagation environments and recorded I/Q data. One of the existing limitations is the absence of an accurate ground truth; for static measurements, the ground truth position can be computed with high accuracy using PPP-RTK integration; for dynamic measurements, we are still investigating various options.

ETH's multi-sensor platform provides high-resolution, tightly synchronized robotic datasets supported by sub-millimeter ground-truth reference trajectories from a Total Station. These datasets are crucial for benchmarking GNSS algorithms, validating signal-processing improvements, and enabling the integration of GIS-aware methods explored in other work packages.

UV's advanced laboratory infrastructure further expands the consortium's ability to investigate multi-modal positioning technologies under controlled RF and sensor-precision experiments, including the use of wideband, UWB, BLE, Wi-Fi, and event-based sensing systems.

CITST's planned field campaigns will complement the existing robotic datasets by capturing GNSS, visual, depth, and elevation information in natural, unstructured environments that are difficult to replicate using a robotic platform.

The proposed wearable acquisition systems and optimization strategies for data frequency and storage support scalable collection across diverse terrain and weather conditions. Together, these coordinated efforts ensure that ROBOSAT will benefit from a rich and diverse collection of high-quality datasets, enabling rigorous evaluation of GNSS performance and supporting the development of next-generation environment-aware navigation algorithms.

References

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