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NIKE BLUETRACK: Improved Real-time Real-world Capabilities for Underground Tracking

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This paper is a follow-up to NIKE BLUETRACK: Blue Force Tracking in Underground Structures. In the last paper, the principles for tracking agents in underground structures were presented. However, two aspects were not described: data acquisition and real-time performance. This paper highlights the usage of the Robot Operating System to ensure real-time capabilities of the positioning system. Finally, the final performance tests and evaluations on agents in combat scenarios are presented.

Key Words: blue force tracking, indoor localization, UWB, foot-mounted IMU, ROS

1. Introduction

Blue force tracking in complex underground scenarios is still a challenging topic. Due to changing and specific environmental conditions and requirements, no holistic solutions have been found yet. However, some advances have been made in the recent future. In our last paper (Watzko et al., 2022) we presented a blue force tracking system in Global Navigation Satellite System (GNSS)-denied environments, e.g., tunnels, within the NIKE research and development program.

To overcome the problem of missing GNSS positions, an Ultra- wideband (UWB) network was established. Additionally, a dual foot-mounted Inertial Navigation System (INS) was developed to support the UWB measurements. By using recurrent neural networks to detect Zero Velocity Updates (ZUPTs), the drift component could be reduced to the extent that small UWB outages of several minutes could be bridged. Map information from the Fast Tunnel Modelling Tool (FTMT) (Hofer et al., 2021) was further introduced to improve the solution. Finally, a particle filter (PF) was used to integrate all measurements into a single positioning solution. Furthermore, a theoretical concept was developed to place the UWB anchor during the mission, thus creating a instantaneous custom network.

Until now, processing has been done in post on a stand-alone computer. The previous data collection campaigns were complicated and had no reference other than coarse visual knowledge of the route. This paper outlines the final changes to the system design, focusing on the Robot Operating System (ROS). With these adaptations, real-time capabilities can be achieved. Based upon this, the two final test campaigns are presented. The goal of the first campaign was an accuracy estimation, the goal of the second campaign was to test the real-world suitability and overall performance. Results are presented numerically as well as graphically, and problems encountered are discussed.

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2. Robot Operating System

Prior to explaining the Robot Operating System (ROS), a refreshment on the current filter design is given. The design is divided in two stages: a dual foot-mounted INS pre-processor and the main PF. Within the PF a state vector with a 3D position in the WGS84 coordinate system and a heading is estimated.

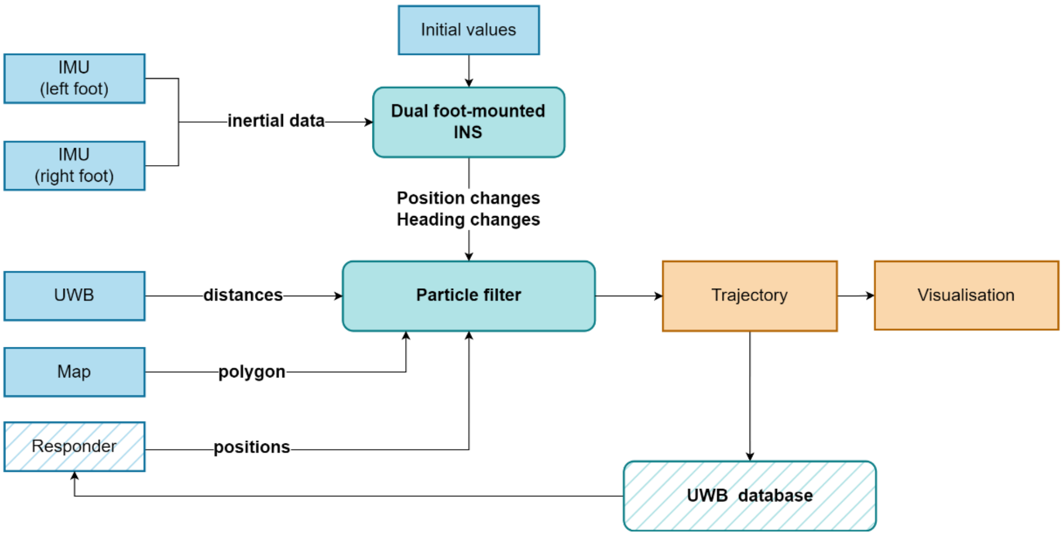

Figure 1: two-staged filter architecture

Figure 1 depicts the proposed filter architecture as a simple diagram. The two main stages are displayed in the centre with the corresponding input values. Initial values can be obtained from an outdoor UWB core network and the magnetometers. The UWB database is displayed hatched, since only a theoretical placeholder was implemented. In this prior version, the computational steps were performed linearly in time in a common program. For improved real-time performance and simplified programme structure, the system was ported to ROS.

ROS is an open-source framework for building complex robotic systems. ROS provides a simple and efficient way to communicate between different parts of a program. This communication takes place by means of so-called ROS nodes. ROS nodes are connected to the ROS master, which coordinates all the ROS nodes. ROS messages are used to send information from one node to another. A node publishes messages on a topic to which other nodes can subscribe.

The different software components of the NIKE BLUETRACK system are loosely coupled using the ROS communication infrastructure (Figure 2). Firstly, the INS node program block, which receives inertial data from the XSense IMU via a Bluetooth Application Programming Profile (API), transforms the accelerations and angular rates into stepwise position changes. The Bluetooth API is written in *Python 3.7* using the Python package *Bleak* as Generic Attribute Profile (GATT) client software. The developed API allows the sensors to synchronise and receive inertial data in real-time at a maximum rate of 60 Hz. On the *ins_chatter* topic, among others, the processed position changes and heading changes are published. Another block receives UWB distances via a serial interface using ROS. The UWB distances are obtained using the internal asymmetric double-sided two-way ranging (ADS-TWR) algorithm of the Qorvo DWM1001 devices. The published *uwb_chatter* topic includes the unprocessed string containing the UWB anchor IDs and distances. The data is extracted and processed at a later stage.

The received distances (UWB node), the INS state (INS node) as well as external information (Server API node), such as estimated anchor positions and map information, are also forwarded to the main program component - the particle filter (PF node) - via the ROS interface. The ROS communication is designed so that the published data can trigger actions. Whenever a new INS step is processed and published, the PF node is executed.

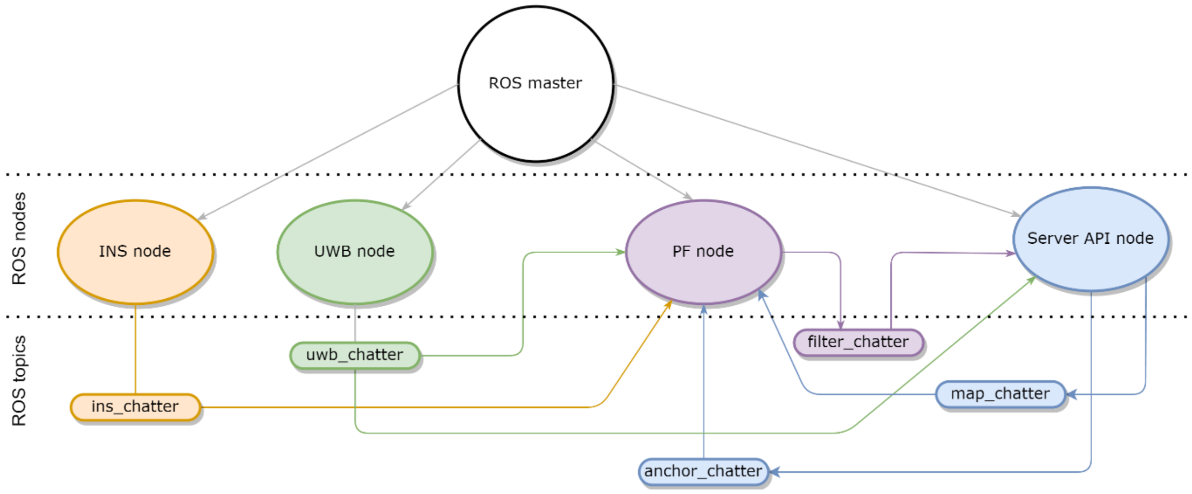

Figure 2: Defined ROS nodes and topics

The content of the message (i.e., relative changes) is used to propagate the particles by adding the position changes in direction of the updated heading of each particle. Then the latest message from the *uwb_chatter* topic is retrieved. Utilising the UWB distances, each particle weight is updated. In detail, a Gaussian Multivariate Mixture (GMM) model is used. The model can represent a combination of Gaussian distributions (to represent multimodal distributions) with multiple variables (number of ranges). Next, the *map_chatter* topic is read and used to exclude particles outside of the walkable area. In conclusion, the PF node estimates a single best state (position and heading) by calculating a weighted mean out of all particles. Together with the velocity values from the INS and a covariance estimation, a message is published on the *filter_chatter* topic. The Sensor API node, in turn, receives the message, whenever a new solution is available. The Server API node itself shares the estimated state via WiFi with the Subsurface Operations Mission Tool (SOMT) for visualisation (cf. IL, 2020). Depending on the unit carrying the system, a symbol is added for distinguishing agents in the SOMT. In a full-featured release, the Server API node would also publish updated UWB anchor positions on the *anchor_chatter* topic.

3. Accuracy Test Measurements

The developed system was tested for real-time capability and accuracy in underground facilities at Zentrum am Berg (ZaB) in Eisenerz. Tests were conducted in the six-meter-wide eastern railway tunnel (ERT).

Figure 3: Test subject with sensors mounted on helmet and shoes (left). ERT with Leica MultiStation used as reference in front (right)

UWB anchors were placed on existing tunnel survey prisms, allowing the absolute position of the twelve anchors to be retrieved. A core network of four anchors was established at the surrounding of the start point. The tunnel model was loaded onto the device in advance. A pedestrian test subject wore two foot-mounted IMUs and an UWB tag on a helmet (Figure 3: left). As Mobile Processing Unit (MPU) a Raspberry Pi 4 Model B (≥4 GB RAM) was chosen. Reference tracking was done using a Leica Nova MS60 MultiStation (Figure 3: right). Line of sight restrictions due to the presence of a train limited the functionality.

Table 1 describes the seven tested routes. Different scenarios were performed to gain knowledge on the behaviour. The data were stored in ROS bagfiles for post processing.

Table 1: Description of accuracy tests

Test	Description	Distance [m]
Test 1	walking along the right train platform, turn at train	≈170
Test 2	walking along right train platform, passing the train	≈300
Test 3	installation of one UWB anchor	≈305
Test 4	walking near core network, first connectivity test with SOMT	≈155
Test 5[1]	walking inside the train	≈230
Test 6	simulation of dynamic built-up of anchors	≈860
Test 7	different motion types	≈325

For evaluation, 20 iterations of each route were calculated and compared to the trajectory of the reference, which can be assumed to be at least 10-times more accurate. The average root-mean-squared error (ARMSE) in the horizontal and vertical are displayed in Table 2.

Table 2: Estimated positioning error expressed in terms of ARMSE determined by 20 repetitions

Test	Horizontal Position Error (m)	Vertical Position Error (m)
Test 1	0.724 ± 0.05	1.46 ± 0.14
Test 2	1.163 ± 0.25	1.13 ± 0.17
Test 3	0.933 ± 0.24	1.19 ± 0.12
Test 4	0.750 ± 0.14	1.23 ± 0.13
Test 5[1]	− ± −	− ± −
Test 6	1.499 ± 0.40	1.32 ± 0.13
Test 7	0.646 ± 0.04	1.53 ± 0.17

[1] No reference available due to missing visual contact.

The range of the horizontal ARMSE spans from 0.65 m to 1.5 m, while the vertical ARMSE ranges between 1.13 m and 1.53 m. The vertical ARMSE can be explained by the geometry of the UWB anchor and the poorer performance of the IMU in the up-coordinate. The horizontal ARMSE is influenced by the local environment. Good line-of-sight-conditions (near core network) yield the highest levels of accuracy, while an accuracy loss is present in the vicinity of the train due to multipath effects of the UWB signal.

In test 6, a simulation of the dynamic anchor setup was performed. Initially, four anchors located at the back of the tunnel (000B, 01ED, 0224, 02BF) were activated, while the remaining anchors were subsequently turned on at their predefined positions. As the anchor coordinates were known, this test focused primarily on assessing the changing geometry and availability of UWB. Figure 4 displays the filter solution and the reference trajectory. The operator followed the walkway, moving along the walls and crossing the railway tracks to install anchors on both sides. The initial section of the trajectory, up to anchor points 242F and 45C6, exhibited noise due to suboptimal geometry at start. Moreover, the presence of metallic objects in the tunnel affected the accuracy of the initial magnetometer heading for this route. By using UWB measurements, the drift in the trajectory was gradually corrected over time, resulting in a smoother trajectory. It is worth noting, that the presence of multipath effects caused by the metallic train led to an outward displacement of the solution at anchor point 46DF. This real–life example shows how the INS can bridge the positioning filter over a short period of time to deploy new anchors.

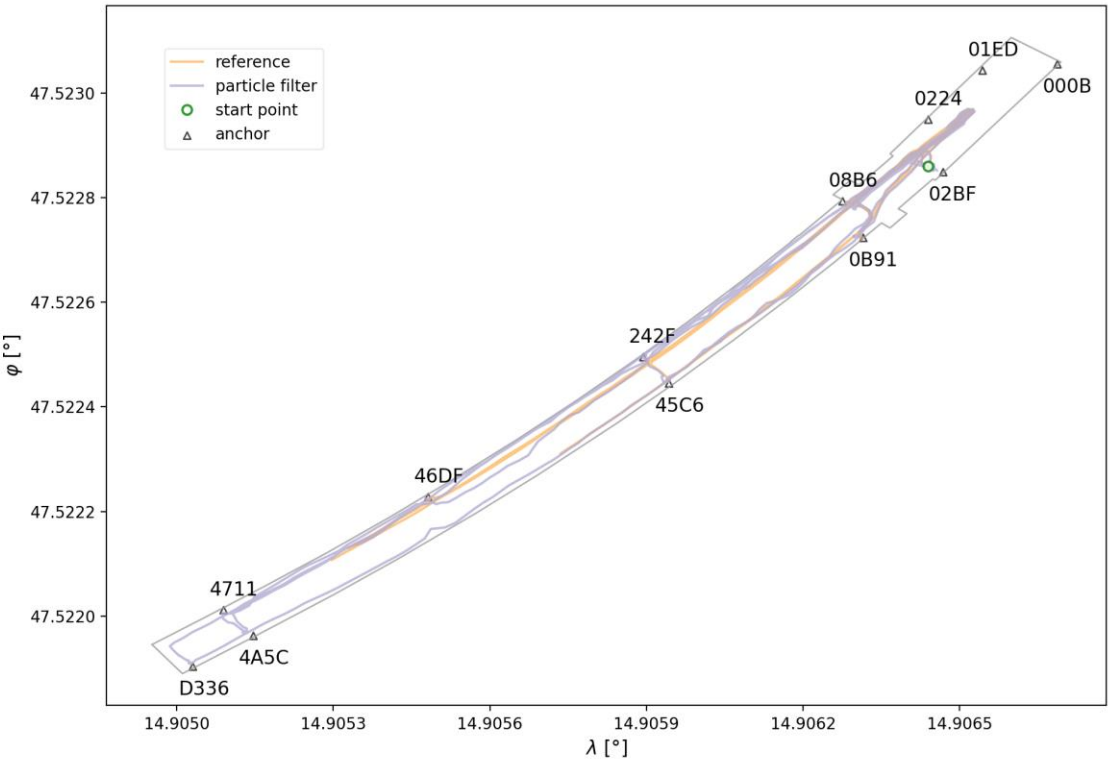

Figure 4: Filter solutions of Test 6 compared to the reference

4. IRON NIKE

Additional tests in a real-world scenario were carried out as part of the IRON NIKE event in 2022. Our IRON NIKE test campaign was held in the ten metres wide northern street tunnel (STN). Three armed forces were equipped with our NIKE BLUETRACK system and completed a hypothetical disaster scenario. In comparison to earlier tests, the UWB tag was mounted on the shoulder. As part of the campaign, they undertook different types of motion and hid behind parked vehicles. All three took slightly different paths up to 400 m deep into the tunnel before returning. No reference is available due to obstructions in the tunnel. 16 operational UWB anchor were pre-installed, with four of them outside of the tunnel in a safe area. The results of the real-time processed trajectories of all operators are shown in Figure 5. The fuzzy paths due to tactical movement and obstruction is clearly visible. Operator 3 even walked through a traverse tunnel where no UWB distance measurements were available. Since also anchor 0B1F and 0C0B failed, the INS successfully bridged the outage for around 40 m. Unfortunately, the initialisation for operator 2 failed, resulting in only INS measurements. Therefore, only a smooth erroneous path is shown. Compared to the post-processing results, there are marginal differences in the rear tunnel part with less UWB measurements. The positions were successfully transmitted and displayed in the SOMT. The whole system was not perceived as a nuisance by the operators.

5. Challenges

IRON NIKE showed the limitations and deficits of the system in very challenging scenarios. UWB is reflected from metallic surfaces, which can hardly be modelled. Due to the internal selection process of the Qorvo firmware, not all anchors were employed as intended. Furthermore, the Qorvo firmware only uses maximum four anchors per epoch. The large temperature gradient between outdoors and undergrounds caused the IMUs to drift more than in the accuracy tests.

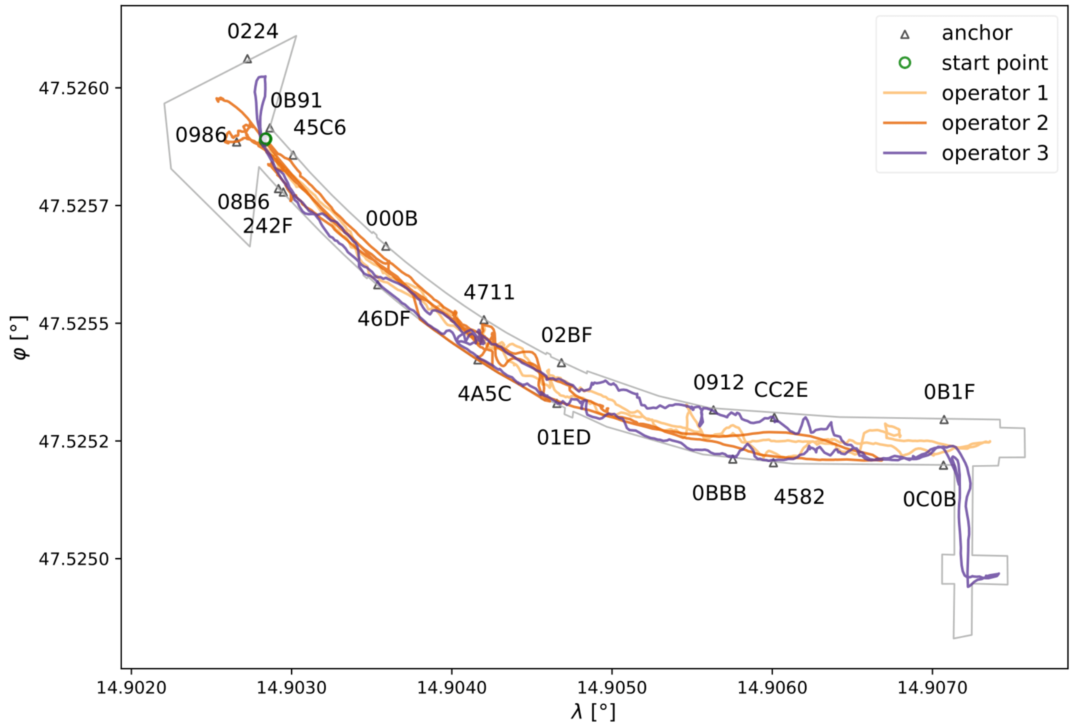

Figure 5: Tracking of operators at the demonstration event IRON NIKE

Additionally, an antenna array near the tunnel portal disturbed the magnetometer and therefore the initial heading. Interference between the WiFi and BLE module of the Raspberry PI hindered the synchronisation of the two IMUs. This error could be corrected within the software. Unsynchronised reception of the INS and UWB data further reduces the accuracy. Finally, the current plug connections do not withstand stress, which in one case caused the UWB to fail.

6. Outlook

Some adjustments could lead to improvement of the mentioned downsides: An UWB software, which enables more than four ranges would be a huge step forward. Inter-agent measurements would also enhance the solution in combat scenarios. For a final product the hardware needs to be adapted to avoid internal interference. Dynamic anchor placement still needs to be implemented and tested. The final test measurements showed that the NIKE BLUETRACK system can provide beneficial, accurate and robust real-time location information to the SOMT in challenging scenarios. The system handles different types of motion well and can bridge sections without placed UWB anchors. Further tests and improvements are already ongoing.

Publication bibliography

Watzko, Makus; Mascher, Karin; Koppert, Axel (2022): NIKE BLUETRACK: Blue Force Tracking in Underground Structures. #UOET22 Meeting Proceedings. Available online at https://www.milak.at/fileadmin/milak/InstOWB/UOET/Meeting_Proceedings/2022_WATZKO_etal_Blue_Force_Tracking_in_Underground_Structures.pdf, checked on 04/05/2023.

Hofer, Peter; Strauß, Clemens; Eder, Julian; Hager, Lukas; Wenighofer, Robert; Nöger, Michael (2021): Das Fast Tunnel Modelling Tool für Untertagebauwerke. In *Wichmann Verlag* (7). Available online at https://gispoint.de/fileadmin/user_upload/paper_gis_open/AGIT_2021/537707003.pdf, checked on 08/05/2023.

IL – Ingenieurbüro Laabmayr & Partner ZT GesmbH (2020): SOMT – SUBSURFACE OPERATION MISSION TOOL. Available online at https://www.laabmayr.at/tunnel-plus/rd/somt-subsurface-operation-mission-tool/, checked on 08/05/2023.