Towards Platform-Agnostic Geospatial Awareness: Fusing Satellite Priors with LiDAR Laser Point cloud for Seamless Indoor-Outdoor Navigation

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***Abstract*—Autonomous navigation is highly dependent on the accuracy and precision of its perception system, with odometry drift and GNSS signal degradation remaining major challenges. We propose a preliminary platform-agnostic navigation framework that provides geospatial localization at odometry frequencies, regardless of GNSS availability, treating outdoor and indoor navigation as a unified environment. To achieve this, we leverage georeferenced satellite and aerial imagery alongside Umeyama alignment to compute a local-to-global transformation. This prior feeds into a traditional Iterative Closest Point (ICP) registration, allowing any mobile robot or vehicle to correct its local position and allows the re-initializitation of the FAST-LIO2 state into global coordinates. The system was validated using a Unitree Go2 EDU as a mobile platform, following a trajectory of manually selected coordinates that incorporates indoor-outdoor transitions and altitude variations due to access ramps.**

***Index Terms*—Autonomous Navigation, Geospatial Awareness, LiDAR-Inertial Odometry, GNSS-Denied Localization, Sensor Fusion, Indoor-Outdoor Mapping, Mobile Robots.**

I. Introduction

A major challenge in absolute spatial localization is maintaining a consistent position estimate during indoor-outdoor transitions. This difficulty primarily arises from the loss of Global Navigation Satellite Systems (GNSS) signals in denied environments, coupled with the inherent latency required to recalculate a 3D position when transitioning back outdoors. Consequently, mobile platforms are often forced to alternate between disparate navigation systems, leading to variable and unstable transition periods.

To address this, we present a fully deployed system that transfers geospatial metadata directly to point clouds generated by the mobile platform. This approach ensures continuous, centimeter-level geodetic positioning regardless of the environment (indoor or outdoor) and is robust to varying lighting conditions. By supplying unified, stable coordinates to a mission manager and position controller, our system enables truly seamless autonomous navigation, effectively eliminating the traditional boundaries between indoor and outdoor domains.

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II. System Architecture

The proposed framework follows an atomized design, where each individual module contributes to the overall pipeline to achieve seamless global localization. This is accomplished by fusing geo-referenced satellite priors with local LiDAR-inertial odometry using ***Fast_LIO2*** [1], a system specifically designed for resource-constrained environments. The architecture is composed of three main stages: virtual geo-referenced point cloud map generation, prior-based point cloud geo-alignment, and local odometry and point cloud registration (global odometry initialization).

A. Geo-aligned point cloud generation from geo-referenced dataset

The first module extracts building contours from public regional datasets to build a lightweight, absolute global prior point cloud. We accomplish this by combining semantic data from two distinct sources: high-resolution satellite imagery (PNOA_MA_OF_ETRS89) [2] in the EPSG:25830 coordinate system, and aerial LiDAR relief segmentation (MapaLidar _0616) [3], originally in EPSG:4326.

To make both datasets spatially consistent, we align their coordinate reference systems using their embedded GeoTIFF metadata. Specifically, we use the PROJ [4] library to perform the spatial re-projection. Once aligned, an initial coordinate given either by GNSS or manual input—defines a Region of Interest (ROI) to crop both images. Because the aerial LiDAR encodes terrain relief as color ranges, a simple color filter isolates the building areas. After that, standard computer vision algorithms extract the contours to output a "Binary Geo-referenced Contour" image. Finally, we extrude these 2D contours and their spatial metadata into a sparse virtual point cloud, which acts as our destination point cloud.

Once the destination cloud was setted, a base point cloud must be generated which be used as prior point cloud for robot real time initialization. Some of the LIO (*e.g. Fast LIO2* [1])techniques returns an accumulated point cloud. This massive point cloud would be used as a prior dataset to reach to the global frame.

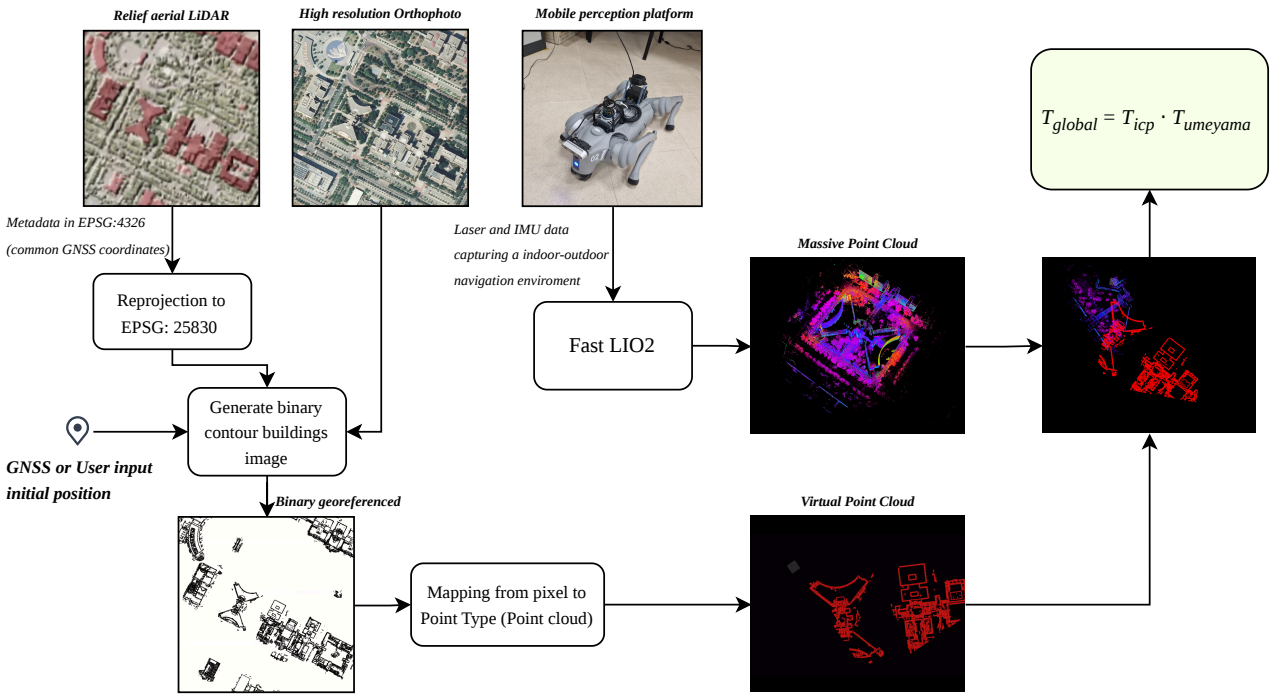

Fig. 1. Overall system architecture illustrating: virtual map generation, Global alignment of prior point cloud.

B. Prior Point Cloud Geo-Alignment and Live localization

The global localization pipeline is designed to provide real-time geodetic awareness with minimal computational processing, we address this goal by decoupling the map alignment from the live state estimation. This is achieved in two distinct phases.

First, we calculate the rigid transformation $T \in SE(3)$ to project the local base point cloud previously generated via active exploration with FAST-LIO2 [1] into the global frame. To find this transformation, we strategically select corresponding points between both point clouds. We then apply the Umeyama algorithm [5], implemented via the Eigen library [6], to solve the orthogonal Procrustes problem for a coarse initial alignment. Finally, we perform a fine registration step using the Iterative Closest Point (ICP) algorithm [7] provided by the Point Cloud Library (PCL) [8].

The second phase addresses live point cloud localization. This stage uses the real-time cloud generated by the FAST-LIO2 algorithm [1] during active navigation. By keeping the accumulated point cloud temporally small, we ensure a computationally lightweight execution of the ICP algorithm [7]. This step aligns the live local cloud with our previously generated prior base map. As a result, we can project the robot's spatial data into the global frame by traversing the complete transformation tree: first from the live local frame to the base map, and then from the base map to the absolute global coordinate system.

III. Experiments and Results

We tested our global localization framework on a Unitree Go2 EDU quadruped robot, which is equipped with a *Livox MID360* LiDAR with a built-in IMU. The experimental evaluation focused on validating the global initialization and assessing the system's robustness during a continuous indoor-outdoor mission.

A. Global Initialization and Projection

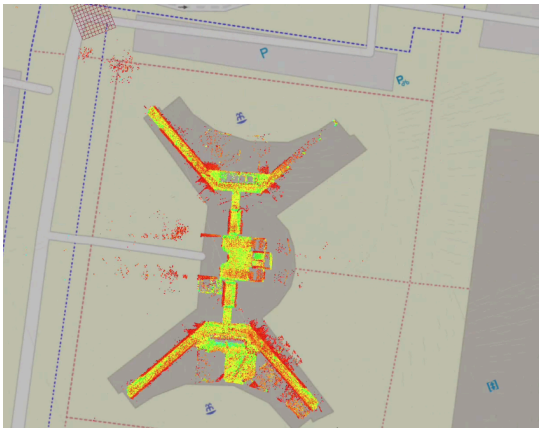

Fig. 2. Global localization validation. The locally generated point cloud is successfully projected and overlaid onto the absolute OpenStreetMap (OSM) layer, matching the building geometries.

First, we teleoperated the robot indoors to build the local base map. We then ran our alignment pipeline to match this local cloud with the virtual prior map generated from the public datasets. The initial estimation successfully superimposed both point clouds. To verify the accuracy visually, we projected the locally generated cloud onto the global reference frame and overlaid it on an OpenStreetMap (OSM) layer. The building geometries aligned almost perfectly. This result confirms that our approach grants the robot absolute GNSS-level positioning while operating entirely indoors, without relying on satellite signals.

B. Autonomous Indoor-Outdoor Navigation

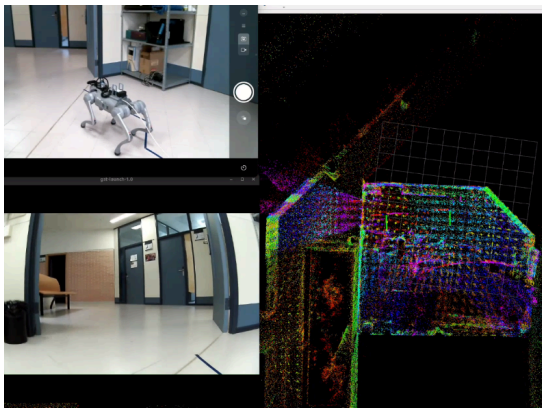

Fig. 3. Indoor navigation phase. The live point cloud (purple) is aligned with the prior base map (green).

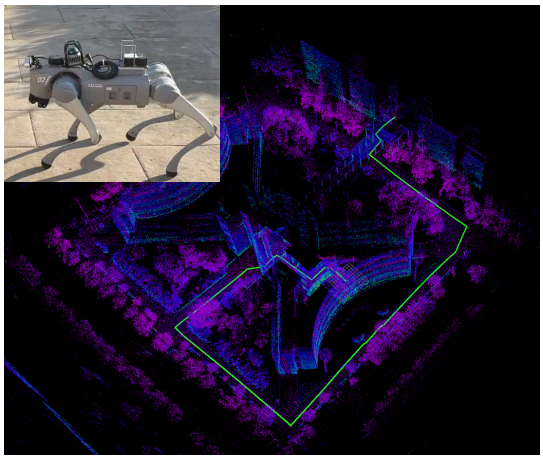

Fig. 4. Odometry evaluation during the autonomous indoor-outdoor mission. Base point cloud represented in blue-purple colors and the path is marked in green tones.

Next, we evaluated the live navigation capabilities. Using a Proportional-Integral-Derivative (PID) position controller, we commanded the quadruped to follow a predefined geometric path. This trajectory forced a complete indoor-outdoor-indoor transition and included altitude variations due to access ramps.

The system handled the environmental transitions smoothly. It maintained continuous location without suffering any discrete pose jumps, which are common when switching between standard indoor SLAM and outdoor GNSS systems. To measure the accumulated drift, we analyzed the closed-loop trajectory. As shown in our odometry plots, the state estimation in the X, Y, and Z axes returned extremely close to zero once the robot arrived back at the launch point. This minimal drift proves the robustness of anchoring the local odometry to our absolute prior map.

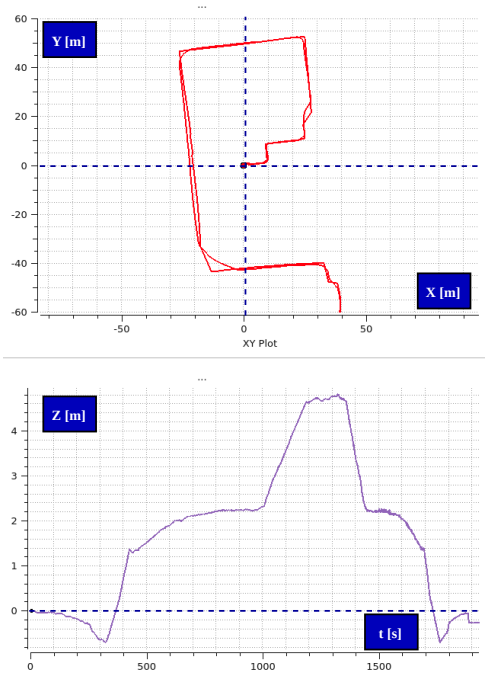

Fig. 5. State estimation and odometry evaluation plots. The graphs demonstrate minimal accumulated drift in the X, Y, and Z axes after completing the closed-loop indoor-outdoor trajectory.

IV. Conclusions and Future Work

A. Conclusions

This paper presented a robust, platform-agnostic global localization framework designed to ensure continuous geodetic awareness during autonomous indoor-outdoor missions. By anchoring local LiDAR-Inertial Odometry (LIO) to an absolute prior map generated from public geospatial datasets, we successfully eliminated the dependency on a GNSS system. Experimental validation on a quadruped robot demonstrated seamless transitions between enclosed and open environments. The proposed architecture effectively addressed the stochastic behavior of coordinate frame alignment issues and discrete

pose jumps typically associated with alternating navigation systems. As displayed in the *figure 5* by the closed-loop trajectory evaluation, the system maintained high positional stability with minimal accumulated drift, safeguarding the physical integrity and mission continuity of the mobile platform.

B. Future Work

Future research will focus on extending this architecture into a fully multi-domain navigation framework. We plan to deploy the system on Unmanned Surface Vehicles (USVs) to evaluate its robustness in maritime port environments, as well as integrate Visual-Inertial Odometry (VIO) to support Unmanned Aerial Vehicles (UAVs) in highly constrained indoor spaces. Furthermore, we will conduct comprehensive quantitative evaluations to benchmark the system's performance against an RTK-GNSS baseline, extracting precise Absolute Trajectory Error (ATE) and Root Mean Square Error (RMSE) metrics. Finally, we intend to develop lightweight watchdog systems capable of detecting estimation failures and resetting the odometry pipeline to mitigate accumulated drift. Alongside this, we will explore the automation of structural point selection (e.g., buildings or infrastructure) to dynamically solve the kidnapped robot problem via Umeyama/Procrustes [5] alignment without manual intervention.

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