2025 I-RIM Conference
October 17-19, Rome, Italy
ISBN: 9788894580570
10.5281/zenodo.17629636

Autonomous Forest Navigation and Mapping: Field Validation of a Mobile Robotic System

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***Abstract*—This work introduces a mobile robotic platform developed for autonomous navigation in wooded environments and for automatic estimation of the location of individual trees and their trunk diameters. The proposed system combines LiDAR measurements and camera images within a framework that leverages SLAM together with deep learning for trunks recognition. The proposed navigation and mapping approach is tested in a wooded area near Udine (Italy), using a skid-steered mobile robot. Experimental results demonstrate that the robot is capable of navigating effectively avoiding obstacles while generating forest maps enriched with tree trait information.**

***Index Terms*—mobile robotics, 3D mapping, forest monitoring**

I. Introduction

Precise mapping and monitoring of forest ecosystems play a crucial role in sustainable forest management. Conventional forest inventory approaches primarily rely on manual measurements of tree attributes, including location, height, and Diameter at Breast Height (DBH) [1], [2]. Nowadays, mobile robotic systems, equipped with onboard sensors, offer an effective alternative for forest inventory by autonomously conducting repeated surveys and ensuring consistent data collection [3]. A notable example is the teleoperated all-terrain vehicle presented in [4], which uses a Light Detection and Ranging (LiDAR) sensor to generate 3D maps as point clouds that are then exploited for DBH estimation. The robot in [5] employs a self-supervised learning approach for predicting traversable paths in forests. Furthermore, in [6] an example of quadrupedal robot capable of estimating tree traits from point clouds acquired during autonomous missions is described.

In this work, we present a skid-steered mobile robotic platform designed for autonomous navigation, 3D mapping of forest environments, and automatic estimation of tree parameters. The proposed system relies on a Simultaneous Localization and Mapping (SLAM) algorithm for autonomous navigation and environment reconstruction [7]. Furthermore, by extending the framework proposed in [8], this work implements an approach based on the combination of image and LiDAR data for estimating tree locations and DBH. An overview of the proposed framework is reported in Fig. 1. The approach is tested with an AgileX Scout 2.0 mobile platform. Experimental findings demonstrate that the robot can autonomously traverse forest environments, adapting its path to avoid tree trunks and other obstacles. The proposed mapping approach is also capable of identifying tree locations and estimating trunk diameters.

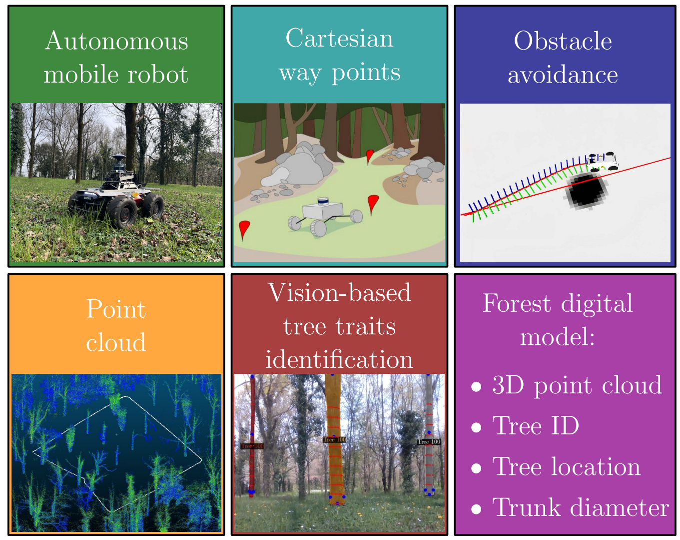

Fig. 1. Proposed approach for autonomous navigation and mapping in forest.

II. Proposed approach

Localization and mapping are performed using the LIO-SAM algorithm [9], which provides the odometry while incrementally building a 3D point cloud of the forest, integrating multiple inputs (LiDAR, IMU, GNSS, and wheel odometry). Moreover, GNSS data and a loop closure strategy are employed to correct long-term drift [7]. The autonomous navigation framework requires the user to specify waypoint coordinates that drive the robot through the forest. Global paths between waypoints are initially planned as straight lines, under the assumption that tree trunks can be locally handled by the obstacle avoidance system. For local planning, the Timed-Elastic-Band (TEB) method optimizes these trajectories online, reducing execution time while ensuring safe clearance from obstacles by using point cloud data. The TEB planner continuously updates 2D cost maps online using the most recent LiDAR scans.

Tree recognition is performed on images using PercepTreeV1 [8], a Mask R-CNN–based architecture with three output heads: class and bounding box, segmentation mask, and keypoints. Five keypoints are predicted for each tree,

Fig. 2. Sensorized AgileX Scout 2.0 mobile robot.

among which the left and right trunk edges and the trunk center are used for DBH estimation and trunk localization. To complement these 2D detections, LiDAR scans are used to recover 3D information. Using the extrinsic calibration between the camera and LiDAR sensor, points within the camera field of view are projected onto the images, as in [9]. Time synchronization ensures alignment of frames acquired at different rates, while segmentation masks filter out non-trunk points. Nearest-neighbor searches are then applied to associate projected LiDAR points with the trunk center and edge keypoints, from which DBH is computed in meters. Tree positions, initially expressed in the robot frame, are transformed into the global map frame using the most recent pose estimated by the SLAM algorithm. Since each tree is detected multiple times across frames, DBSCAN clustering is applied to group predictions belonging to the same tree. This density-based method, robust to outliers, identifies clusters of sufficiently dense points while discarding isolated ones. Finally, unique tree locations and DBH values are obtained by taking the median of measurements within each cluster.

III. Experimental Results

The proposed approach for autonomous navigation and forest mapping is tested on the skid-steered AgileX Scout 2.0 mobile robot (Fig. 2). The onboard sensor suite includes a Velodyne VLP-16 LiDAR sensor, an Xsens MTi-630 9-axis IMU, an Ardusimple simpleRTK2B Budget kit as the GNSS system, and a RealSense D435 RGB-D camera. Experimental tests are performed in a wooded area of Cormor Park (Udine, Friuli-Venezia Giulia, Italy) under full sunlight conditions. The test involves the execution of a square path with side of 15 m.

The experimental results in terms of robot path and estimated tree traits are reported in Fig. 3. The mobile robot demonstrates to be able to navigate in the wooded area, detect trees, and modify online the planned path to avoid obstacles.

IV. Conclusions

A mobile robot for navigation and mapping in forest has been presented. Although challenges remain (e.g., missed tree detections caused by foliage density, trunk occlusions, and

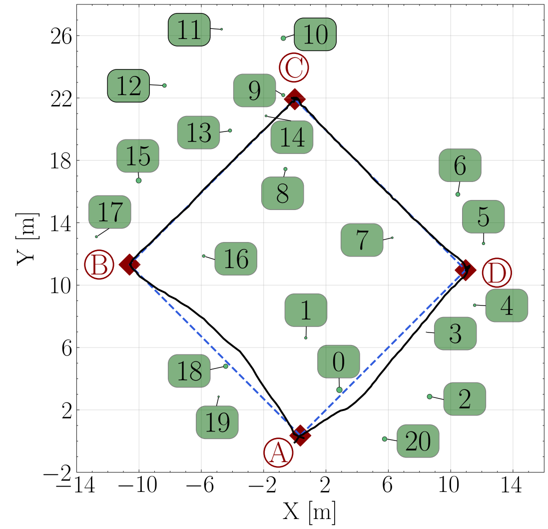

Fig. 3. Example of 2D plot of the planned and executed path of the robot, estimated tree locations, DBHs, and IDs. The red letters indicate the user-specified waypoints, the dashed line and the solid line represent the planned path and the path executed by the robot, respectively. The trees locations and DBHs are depicted with green circles, each associated with a unique tree ID.

limited visibility of remote trees), the results confirm the feasibility of the navigation and mapping framework for forest inventory. Future work will investigate AI-based path planning for terrain traversability, higher-resolution LiDAR sensors, the robustness of the perception pipeline with respect to bushes, more demanding forest conditions, as well as crowded areas.

Acknowledgements

This study was carried out within the PRIN 2022 project "An Artificial Intelligence approach for Forestry Robotics in Environment Survey and Inspection (AI4FOREST)" funded by the European Union Next-Generation EU (National Recovery and Resilience Plan (PNRR), Mission 4, Component 2, Investment 1.1, PRIN 2022, Code 2022LP4ASR, CUP G53D23002880001), and within the Agritech National Research Center (National Recovery and Resilience Plan (PNRR), Mission 4 Component 2, Investiment 1.4, D.D. 1032 17/06/2022, CN00000022, CUP G23C22001100007).

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