HIGH-RELIABILITY NAVIGATION FOR MULTI-FUNCTIONAL ROBOTS USING RFID TRIGGERS AND 3D SLAM IN A PROTECTED HORTICULTURE

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Abstract

Protected horticulture in Japan is facing a serious labor shortage, yet existing robots have not achieved sufficient return on investment, and their adoption remains limited. To support the deployment of multi-functional robots, we developed a high-reliability autonomous navigation system that integrates RFID-based event-triggered state transitions with LiDAR-based simultaneous localization and mapping (SLAM).The developed mobile platform was built on an omnidirectional robot equipped with four mecanum wheels, a 3D-LiDAR, an IMU, and a UHF-RFID reader. Real-time computation was performed on a Jetson Orin Nano, while a Teensy 4.0 microcontroller handled low-level motor control. The software stack was implemented on ROS 2 Humble; SMACH managed state transitions, and MongoDB stored tag information. When an RFID tag was detected, a custom node retrieved the tag coordinates and the current robot pose, generated a straight-line path, and sent it to a C++ pure-pursuit action server for execution.To select a suitable SLAM algorithm for greenhouse environments, FAST-LIO and LIO-SAM were compared. The results showed that LIO-SAM provided the most stable pose estimation under multiple evaluation conditions, including straight-line motion, travel speed, and solar radiation, and it was therefore adopted as the system's back-end SLAM.For greenhouse validation, ten missions were conducted in which the robot traversed two consecutive crop rows. The navigation success rate reached 90% (9/10 missions), with a mean positional error of 9 cm during motion.

Keywords: Autonomous navigation, data-driven agriculture, ROS (Robot Operating System) 2, RFID-based landmark identification, data-driven crop mapping

INTRODUCTION

In Japan, agricultural robots are highly expected due to a severe labor shortage, and in protected horticulture, robots with autonomous mobility are indispensable for efficient operations. However, as crops grow, greenhouse environments change dynamically, making it difficult for conventional navigation methods based on static maps to ensure stable travel. In this study, we developed an autonomous navigation system that combines RFID-triggered

state transitions with pure-pursuit path tracking, and its accuracy was evaluated.

MATERIALS AND METHODS

Fig.1 shows the robot used in this study. A Jetson Orin Nano was employed as the control computer, a 3D LiDAR (Livox Mid360) was used for environmental perception, and an IMU was used for attitude estimation. Fig.2 illustrates the system configuration. State transitions were managed with SMACH, a Python-based state machine library, and the path tracking algorithm adopted was Pure Pursuit, which iteratively calculates the curvature toward a target point located a certain distance ahead of the current position. Furthermore, an RFID trigger was used to access information stored in the database and switch state transitions. Through greenhouse navigation tests, the performance of the proposed system was evaluated.

RESULTS & DISCUSSION

The evaluation tests were conducted with the proposed system under a straight-line traveling condition using the Pure Pursuit algorithm, the RMSE in both lateral and longitudinal directions remained within 15 cm over an 18 m section, and the navigation was high accuracy. Furthermore, ten missions were carried out in which the robot consecutively traversed two crop rows. As a result, the navigation success rate reached 90% (9/10 missions), with a mean positional error of 9 cm during motion. These results reflect the robustness of adopting LIO-SAM as the back-end SLAM in greenhouse environments and indicate the effectiveness of combining RFID triggers with path tracking control in the proposed system.

CONCLUSIONS

In this study, we developed a high-reliability autonomous navigation system for greenhouse environments by combining RFID-triggered state transitions, LiDAR-based SLAM, and pure-pursuit path tracking. The evaluation tests showed a navigation success rate of 90% and a mean positional error of 9 cm, demonstrating stable performance even under dynamically changing greenhouse conditions as crops grew. These results confirmed the effectiveness of integrating RFID-based landmark recognition with robust SLAM. As a future work, we aim to build an information platform for realizing multifunctional agricultural robots that integrate fruit detection with SLAM-based location information and harvest yield information.
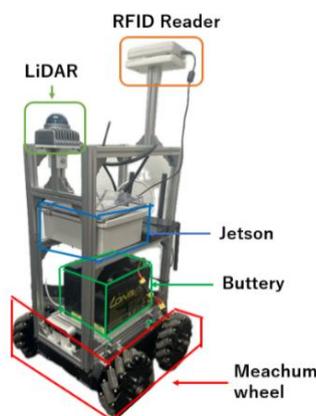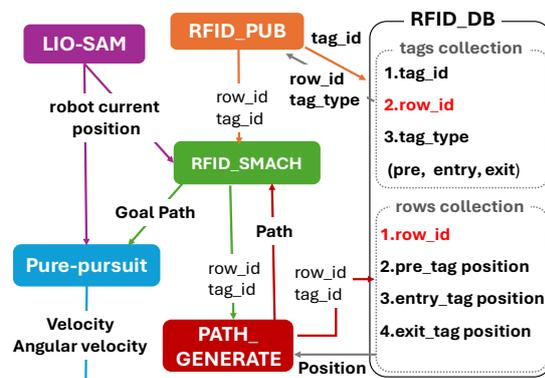
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Fig.1 The developed robot

Fig.2 System configuration