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## ESTIMATING RICE CANOPY HEIGHT USING A GROUND-BASED SLAM LiDAR SYSTEM

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### Abstract

This study evaluates the application of a ground-based LiDAR system, integrated with a Simultaneous Localization and Mapping (SLAM) algorithm, to estimate rice crop canopy height (CH). Using the Velodyne VLP-16 LiDAR sensor, point cloud data were collected and processed to map the rice field. The experimental area covered approximately 600 m<sup>2</sup> during the crop's vegetative stage. LiDAR-derived canopy height (LCH) was extracted using percentile-based metrics and compared with manual measurements obtained at georeferenced points. Statistical evaluation using root-mean-square error (RMSE) and coefficient of determination (R<sup>2</sup>) revealed that the 90th, 95th, and 99th percentiles showed strong agreement with manual measurements (RMSE: 4.84 – 14.32 cm; R<sup>2</sup>: 0.61 – 0.70), with the 95th percentile offering the most accurate results. These findings demonstrate that a ground-based SLAM LiDAR system provides a reliable and efficient solution for crop canopy assessment in realistic field environments.

**Keywords:** canopy height, ground-based LiDAR, SLAM, rice, point cloud

### INTRODUCTION

Canopy height – the vertical distance from the ground to the upper leaf surface – is a vital agronomic parameter for evaluating crop condition and yield potential (Confalonieri et al., 2011). In contrast to plant height (measured from ground to the leaf tip), canopy height offers a more practical metric for farmers due to its relevance in assessing field-scale growth patterns. However, manual CH monitoring is time-consuming and prone to human error. LiDAR technology provides a non-destructive, scalable alternative (Tilly et al., 2014), especially when integrated with SLAM algorithms. Although SLAM-based LiDAR has been widely used for autonomous navigation and mapping, its application in agricultural contexts, specifically for canopy monitoring, remains underexplored. Leveraging the Velodyne VLP-16 LiDAR sensor, this study aims to evaluate the effectiveness of a SLAM-integrated, ground-based LiDAR system for measuring rice canopy height in realistic field conditions.

### MATERIALS AND METHODS

A Velodyne VLP-16 LiDAR sensor, integrated with a Microstrain 3DM GX5-35 inertial sensor, was backpack-mounted and elevated approximately 2 m above ground to scan a 15 × 40 m rice field in Awaji, Japan. The point cloud was generated using the LIO-SAM SLAM algorithm, which integrates LiDAR and IMU data for accurate real-time mapping. Point cloud data were collected at two time points: two weeks post-transplanting (for defining ground level) and three weeks later (for canopy height assessment). Twenty-five georeferenced sampling points were

manually measured to obtain ground-truth canopy height – defined as the vertical distance from the ground to the upper leaf surface – using a steel measuring tape. Each point was associated with a  $1 \times 1$  m buffer zone. The point clouds were processed using CloudCompare for alignment, cleaning, and registration via Iterative Closest Point (ICP), Statistical Outlier Removal (SOR), and manual segmentation. LCH values were computed using 90th, 95th, 99th percentiles, and maximum height. Accuracy was evaluated using RMSE, residuals, and  $R^2$ .

## RESULTS & DISCUSSION

Figure 1a shows the normalized point cloud of the rice field, capturing spatial variation in canopy height. LCH values were computed for each  $1 \times 1$  m georeferenced buffer zone, based on 25 manually measured validation points. The 90th, 95th, and 99th percentiles all showed good agreement with manual CH data, with RMSE ranging from 4.84 to 14.32 cm and  $R^2$  from 0.61 to 0.70. The 95th percentile performed best, achieving an RMSE of 4.84 cm and  $R^2$  of 0.66, as illustrated in the scatterplot in Fig. 1b. Residual analysis revealed that the 99th percentile tended to overestimate CH, while the 90th percentile slightly underestimated it. This variation highlights how different percentiles capture the upper canopy differently. Note that validation points were located along the field edge due to access constraints. Overall, the 95th percentile provided the most balanced and reliable estimate of CH across the field, supporting its suitability for practical, non-destructive canopy monitoring.

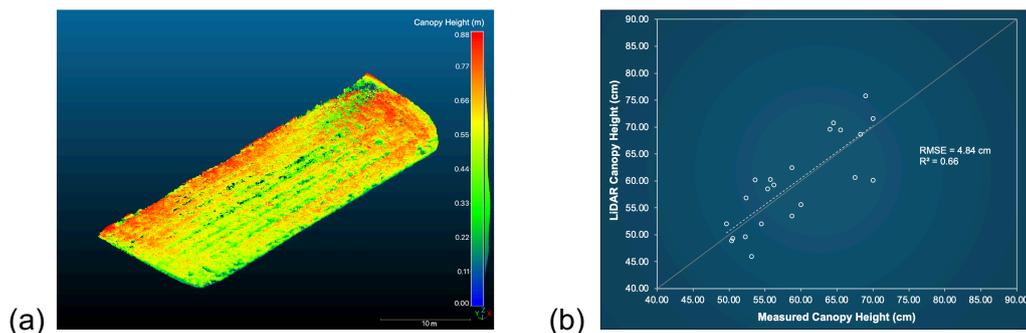


Fig. 1. (a) Normalized rice field point cloud with canopy height variation. (b) Scatterplot comparing LiDAR CH (95th percentile) and manual CH measurements.

## CONCLUSIONS

The ground-based SLAM LiDAR system demonstrated strong potential for real-time estimation of rice canopy height. The 95th percentile metric provided accurate, non-destructive CH measurements. This approach offers a scalable and efficient solution for assessing canopy structure in complex agricultural environments, supporting precision farming practices. Further improvements in dataset size, temporal frequency, and advanced point cloud processing methods could enhance system accuracy, consistent with findings from Walter et al. (2019).

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