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UWB-IMU System Application and Analysis in Cucumber Greenhouses

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Abstract

Accurate and stable positioning is essential for autonomous navigation and environmental monitoring in greenhouse environments. Simultaneous Localization and Mapping (SLAM) is one of the methods to determine the location. This method generally requires a computer and measurement devices such as LiDAR and cameras, making it relatively costly and demanding in terms of deployment conditions. In contrast, ultra-wideband (UWB) is attracting attention as a high-resolution, short-range localization and ranging technology, offering simpler system architecture and lower cost.

This study aims to develop and analyze an indoor localization system that integrates UWB and an inertial measurement unit (IMU) for application in cucumber greenhouse environments. The complexity of greenhouse structures such as metal frames and dense plant coverage often leads to signal obstruction and multipath effects, reducing the accuracy of the localization. To address this, the proposed system combines UWB's high-precision ranging capability with the directional and acceleration sensing using the IMU. Two sensor fusion algorithms, the Kalman filter and the unscented Kalman filter are implemented and analyzed for their localization accuracy and stability. The accuracy verification experiments were conducted in a real cucumber greenhouse under various movement paths and occlusion scenarios. The results showed that the UWB-IMU fusion system outperformed standalone UWB in terms of stability and responsiveness, especially in occluded or signal-degraded environments. This technology demonstrated a strong potential for integration into autonomous robots or environmental monitoring platforms in smart agriculture, improving both operational efficiency and precision crop management.

Keywords: Ultra-wideband (UWB), inertial measurement unit (IMU), sensor fusion, greenhouse localization, smart agriculture

INTRODUCTION

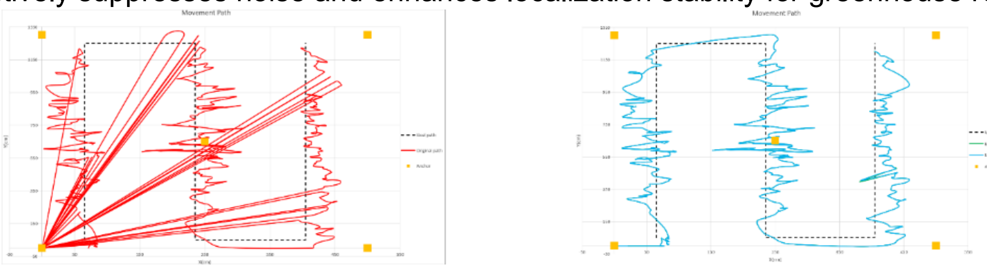
In cucumber greenhouse production, the demand for automation and precision operations is steadily increasing. However, the enclosed structure, narrow aisles, and dense crop canopy not only restrict manual efficiency but also introduce challenges such as signal reflection and attenuation from metal frames and foliage. These conditions often lead to instability in traditional localization methods, including standalone UWB or vision-based systems. To address this issue, this study develops an indoor localization system that integrates ultra-wideband (UWB) ranging with inertial measurement unit (IMU) sensing. By applying Kalman filtering and Unscented Kalman filtering for sensor fusion, the proposed approach aims to improve localization accuracy and stability under occlusion and interference conditions in greenhouse environments.

MATERIALS AND METHODS

The localization system comprised UWB modules (D-DWM-PG3.9), an IMU sensor (BNO055), and a Raspberry Pi for real-time data acquisition and processing. Experiments were conducted in a cucumber greenhouse of approximately 968 × 726 cm, where metal frames and dense foliage often caused signal obstruction and multipath effects. Five anchors were deployed at the four corners and the center, each mounted at a height of 1.8 m. Trajectory tests were carried out along the greenhouse aisles, with data collected at 2 Hz. The measurements were preprocessed to reduce abnormal disturbances, followed by sensor fusion using the Kalman Filter (KF) and Unscented Kalman Filter (UKF). Localization performance was evaluated by comparing the results with the reference path and calculating mean error and RMSE as key metrics.

RESULTS & DISCUSSION

Figure 1 shows that raw UWB data contained severe noise and jumps, while sensor fusion with KF/UKF produced smoother trajectories. Table 1 indicates the mean error decreased from 22.83 to 21.50 cm and RMSE from 29.19 to ~26.6 cm (~9% improvement). KF and UKF showed similar performance, confirming that fusion effectively suppresses noise and enhances localization stability for greenhouse robots.



(a). Raw UWB trajectory (b). Filtered trajectory (KF/UKF)

Fig.1 Comparison of localization trajectories

Table 1. Localization error comparison among different methods.

Metric	Raw UWB	KF Fusion	UKF Fusion
Mean Error (cm)	22.83	21.50	21.50
RMSE (cm)	29.19	26.56	26.60

CONCLUSIONS

This study demonstrated that fusing UWB with IMU using KF/UKF reduced noise and jumps, improving localization stability in greenhouse environments. The mean error decreased to 21.5 cm and RMSE to ~26.6 cm, confirming the benefit of sensor fusion. Future work will optimize filter parameters, enhance outlier suppression, and integrate the system with autonomous robots for real greenhouse operations.

REFERENCES

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