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Research on Multi-Terrain Path Planning of Agricultural Robots Based on Multi-Algorithm Fusion

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Abstract: *With the acceleration of the intelligentization process of protected agriculture, agricultural robots have been increasingly widely used in operations such as spraying, picking, and inspection. However, the complex and variable operating environment—including large terrain differences, narrow spaces, and frequent occurrence of dynamic obstacles—poses severe challenges to the autonomous navigation ability of robots. Traditional path planning algorithms are insufficient in multi-terrain adaptability, path smoothness, and dynamic obstacle avoidance capability. To address these issues, this paper proposes a multi-terrain path planning method for agricultural robots based on multi-algorithm fusion, combining the improved A* algorithm, Dynamic Window Approach (DWA), and Bézier curve optimization (LM-BSZ) to achieve efficient and safe navigation in multi-terrain environments of protected agriculture. The system is built with a hardware and software architecture based on the ROS platform, using Jetson Nano as the main control unit, integrating sensors such as lidar, cameras, and encoders to construct a general-purpose robot platform suitable for hard ground (eel breeding base) and soft ground (pakchoi planting base). Through MATLAB simulation, Gazebo physical environment verification, and real-scene field testing, the results show that the proposed method plans paths closer to the center line of crop rows, reduces turning points by about 40%, shortens the dynamic obstacle avoidance response time by 18%, and exhibits good stability and adaptability on different terrains. This research provides a feasible technical path for the autonomous navigation of agricultural robots in complex protected environments, with strong practical value and promotion prospects.*
Keywords: *Agricultural Robot; Path Planning; Multi-Algorithm Fusion; ROS Platform; Dynamic Obstacle Avoidance*

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This research constructs a hardware and software platform for agricultural robots based on ROS (Robot Operating System) to realize autonomous navigation and operations in multi-terrain environments. The specific design is as follows:

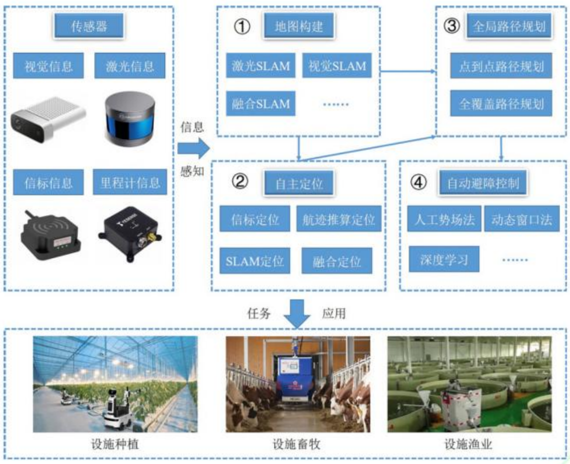

Figure 1 Key technologies and applications of navigation for facility agricultural robots

1. System Architecture Design

Hardware Configuration: The upper computer adopts NVIDIA Jetson Nano, which is responsible for SLAM mapping, positioning, path planning, and decision-making control; the chassis adopts a differential drive structure, equipped with encoders to feed back speed information; the perception module consists of a 2D lidar (for obstacle detection) and an RGB camera (for auxiliary recognition); communication is realized through Wi-Fi, and Rviz is used for visual monitoring.

Experimental Scenarios: Two typical protected agricultural environments are selected, namely hard ground (cement passages in an eel breeding base, with flat ground, fixed fences, and temporary personnel movement) and soft ground (a pakchoi planting greenhouse, with soft soil, crisscrossed gullies, and densely arranged crops).

2. Design and Improvement of Core Algorithms

I. Improved A* Algorithm (Global Path Planning)

The traditional A* algorithm uses "actual cost from the start point to the current point + heuristic estimated cost" as the evaluation function, which has insufficient adaptability to multi-terrains.

An operation efficiency function is introduced, and weights are assigned according to the difficulty of passing through different terrains (the weight of soft soil is greater than that of hard ground) to optimize the calculation of actual cost.

The heuristic function is improved by adding the term "reciprocal of the diagonal distance from the current feasible point to the nearest obstacle", prompting the robot to prioritize paths that are far from obstacles and centered between rows, thus ensuring operational safety and coverage.

II. Improved DWA Algorithm (Local Path Planning)

The DWA algorithm samples trajectories in the velocity space and selects the optimal path based on the evaluation function, but the original algorithm is prone to falling into local optimality.

A sub-target point tracking term is added to the evaluation function, which represents the distance between the end of the current trajectory and the nearest sub-target point on the path planned by the A* algorithm, enhancing the ability to follow the global path.

Weight coefficients are adjusted through simulation experiments to obtain the optimal parameter combination for different terrains, improving the real-time performance of dynamic obstacle avoidance and the rationality of paths.

III. LM-BSZ Path Smoothing Optimization

To solve the problems of many turning points and sharp corners in the A* path, Bézier curves are used for secondary optimization.

In the row-changing and turning areas, cubic Bézier curves are used to connect adjacent path segments, ensuring continuous tangents at the connection points and reducing path oscillation.

In the dynamic obstacle avoidance area, quadratic Bézier curve interpolation is used to avoid the Runge phenomenon caused by high-order fitting and improve the continuity of path curvature.

Control points form a Bézier polygon based on path points and intermediate points to ensure a smooth transition.

3. Experiments and Results Analysis

Through MATLAB simulation, Gazebo physical environment verification, and real-scene field testing, the performance of the traditional A*+DWA algorithm and the proposed fusion algorithm in this paper is compared.

The core indicators are shown in the following table:

Performance Indicators	Traditional A*+DWA Algorithm	Proposed Fusion Algorithm	Improvement Effect
Average Path Length (m)	15.6	15.2	↓2.6% (Shorter path)
Number of Turning Points	12	7	↓41.7% (Fewer turns)
Maximum Curvature Change Rate (m^{-1})	0.83	0.51	↓38.6% (Smoother curvature)
Dynamic Obstacle Avoidance Success Rate	82%	96%	↑14% (More reliable obstacle avoidance)
Mean Deviation from Inter-row Center Line (cm)	18	9	↓50% (More centered path)

Field test results show that the robot can stably travel along the center line of crop rows in the pakchoi field with rapid obstacle avoidance response. In the eel breeding channel, it responds sensitively to suddenly appearing staff, adjusts the path smoothly, and no collisions occur.

3. Innovations and Conclusions

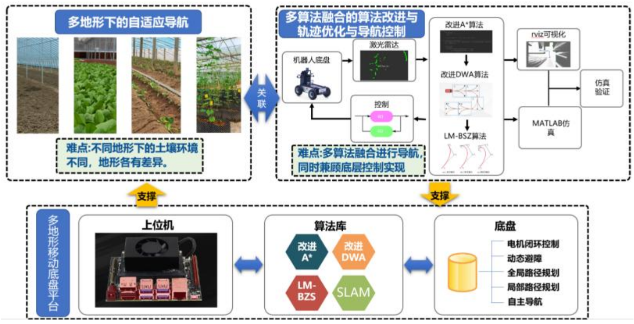

Figure 2 Research Content and Approach

4.1 Innovations

Propose an improved A* algorithm for multi-terrains, which realizes adaptive path generation by introducing an operation efficiency function and an obstacle perception term, improving the adaptability to agricultural scenarios.

Design a path optimization framework fused with LM-BSZ, which significantly improves path smoothness and curvature continuity on the premise of ensuring safety.

Construct a general-purpose agricultural robot experimental platform, and complete algorithm deployment and verification in real protected environments, with strong practical value.

4.2 Conclusions

The multi-algorithm fusion path planning method proposed in this paper can effectively improve the navigation performance of agricultural robots in complex and variable environments: in terms of path quality, the number of turning points is reduced and the curvature is smoother, meeting the movement needs of agricultural operations; in terms of obstacle avoidance capability, the success rate of dynamic obstacle avoidance is improved, enabling the robot to deal with various obstacles such as personnel and fences; in terms of terrain adaptability, it can operate stably on both hard and soft grounds with strong versatility.

Future work will further introduce visual semantic information to realize more intelligent environment understanding and task-oriented path planning.

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