International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 13 Issue 11 ǁ November 2025 ǁ PP. 142-145

Enhanced A* Algorithm for Path Planning in Facility Agricultural Robots: Optimization and Validation

Chunyan Zhang[1]

Abstract. *Traditional A* algorithms struggle with balancing search efficiency and path accuracy in agricultural environments, producing polygonal paths with redundant turns. This study proposes an improved A* fusion algorithm with multi-dimensional optimization: a dynamic corner correction strategy based on path coherence to reduce unnecessary steering, and an adaptive Bézier curve fitting method that classifies turning points for smoother, more continuous paths. Tests in two grid environments with different obstacle densities show the improved algorithm outperforms traditional A*: average runtime is cut by 22.12%, path length by 9.50%, and turning points by 49.28%. It is well-suited for real-time path planning in agricultural mobile robots, offering a theoretical and engineering framework for dynamic path planning in agricultural robotics.*
Keywords: *A* algorithm, Path planning, Agricultural robot, Bezier curve*

Date of Submission: 04-11-2025 Date of acceptance: 14-11-2025

I. Introduction

In the field of autonomous navigation for agricultural robots, Global Navigation Satellite System (GNSS)-based solutions have been widely implemented in open-field environments [1]. However, in greenhouse settings, numerous obstacles and structures frequently obstruct satellite signals, leading to significant signal degradation. Consequently, robots operating in protected agricultural environments cannot rely exclusively on GNSS for autonomous navigation [2]. This limitation underscores the critical need for safe, efficient, and reliable path planning in facility agriculture robotics.

Several researchers have proposed enhancements to the conventional A* algorithm. For instance, Cao Liling et al. [3] introduced a redundant node deletion strategy to mitigate issues related to excessive turning points—which adversely affect feeding vehicle operation and increase energy consumption—by eliminating unnecessary nodes and simplifying path geometry. To address the constrained search efficiency of A* in complex environments, Feng Zepeng et al. [4] preprocessed static obstacles to extract visible transit nodes, applying triangular boundary search in open areas and a three-neighborhood search mechanism in obstructed zones, supported by a bidirectional alternating search strategy. Kang Kaishen et al. [5] expanded the standard 8-neighborhood search in A* to a 12-neighborhood approach, classifying generated paths into four cost categories and selecting the minimal-cost route as optimal for mobile robot navigation. Tong et al. [6] combined A* with an enhanced artificial potential field (APF) method, incorporating a distance adjustment factor to refine the repulsive potential field and resolve issues related to unreachable targets.

Although these improvements offer certain advantages over the classical A* algorithm, the distinctive characteristics of agricultural settings—such as unique spatial layouts and obstacle distributions compared to industrial environments—pose persistent challenges. Key limitations remain, including the fixed heuristic weight, which often leads to a trade-off between search efficiency and path accuracy in complex agricultural scenarios. This results in paths with redundant turns and polygonal segments that, while continuous, fail to comply with the kinematic constraints of agricultural robots. Furthermore, inefficient backtracking in narrow channels or dead ends, coupled with sharp turns in the trajectory, increases collision risks and violates motion smoothness requirements.

To systematically address these issues, this paper proposes an enhanced A* algorithm that integrates Bézier curve optimization. The proposed method includes a dynamic turning correction mechanism based on path coherence criteria to minimize unnecessary steering and an adaptive Bézier curve fitting strategy that classifies turning points to ensure path smoothness and continuity.

1 Improved A* Algorithm

The traditional A* algorithm adopts a greedy strategy, selecting the node with the lowest cost for expansion, which often generates a large number of right-angle or acute-angle turning points, especially near obstacle boundaries. In the decision-making process of the algorithm, it only focuses on minimizing the immediate cost of the current node, without considering the overall coherence of the path. This narrow focus often leads to conflicts between local cost optimization and global path smoothness.

Moreover, since the algorithm does not evaluate the rationality of the node expansion direction, the movement direction between adjacent nodes often changes frequently and suddenly. When multiple nodes have such directional mutations in sequence, redundant nodes will accumulate, resulting in a "sawtooth" path. As shown in Figure 1, this phenomenon not only increases the complexity of robot motion control, but also increases energy consumption.

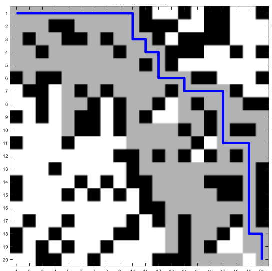


Fig. 1 The traditional A* "zigzag" path shape

1.1 Corner Correction Mechanism

To address the issues mentioned above, the improved algorithm incorporates a corner correction mechanism based on the path coherence criterion. The core concept involves predicting the rationality of movement directions at nodes and eliminating redundant turning nodes, thereby ensuring that directional changes in the path comply with the kinematic constraints of the mobile robot. For each expanded node n, record the movement direction Dir($p(n) \rightarrow n$), from its parent node $p(n)$ to n, The set of directions is defined as follows:

$$Dir \in \{U, D, L, R\} \quad (1)$$

Through the direction vector:

$$V\left(p(n) \rightarrow n\right) = \left(x_n - x\_p(n), y_n - y\_p(n)\right) \quad (2)$$

Determine the specific direction to provide basic information for prediction. Based on the path coherence criterion, predict the optimal movement direction of the next-hop node n' of node n:

$$Dir^*(n \rightarrow n') = Dir\left(p(n) \rightarrow n\right) \quad (3)$$

If there is an obstacle in this direction, select the suboptimal direction according to the priority order of "vertical direction → diagonal direction". After the prediction is completed, the consecutive nodes in the same direction in the path are merged and optimized. Let the path segment be $n_1 \rightarrow n_2 \rightarrow n_3 \rightarrow \ldots \rightarrow n_k$ .if the following condition holds true:

$$Dir(n_1 \rightarrow n_2) = Dir(n_2 \rightarrow n_3) = \ldots = Dir\left(n_{\{k-1\}} \rightarrow n_k\right) \quad (4)$$

Under the condition that obstacle avoidance constraints are satisfied, the path segment can be simplified as follows $n_1 \rightarrow n_k$.

Using three grid maps with obstacle densities of 10%, 20% and 30% respectively, and under the same starting conditions, compared with the traditional A* algorithm, the turning point density of the proposed corner correction algorithm is reduced by 54.5%, 44.4% and 53.8% respectively in the three map configurations, as shown in Figures 2 and 3.

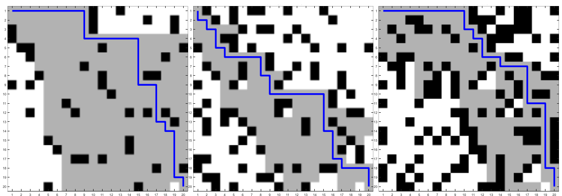


Fig. 2 Optimize the path shape without dynamic inflection points in three types of raster maps

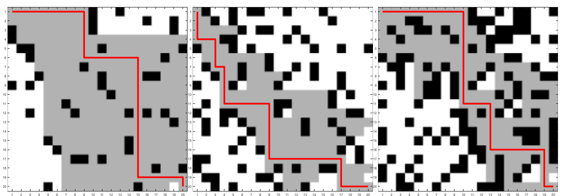


Fig. 3 The optimized path forms of dynamic inflection points under three types of raster maps

1.2 Bézier Curve Optimization

When there are n+1 control points, the corresponding n-th degree Bézier curve[9] is expressed as:

$$P(t)=\sum_{i=1}^{n}P_iB_{i,n}(t),t\in[0,1] \quad (5)$$

$$B_{i,n}(t)=C_n^i t^i(1-t)^{n-i}=\frac{n!}{i!(n-i)!}t^i(1-t)^{n-i} \quad (6)$$

$$i=0,1,2,\ldots,n$$

For a two-segment polyline formed by a start point P_0 ,a turning point P_1 ,and an end point P_2 (representing a turning unit in the original path), quadratic Bézier curves are employed to achieve smooth transitions. During the optimization of the original path, a quadratic Bézier curve is constructed for the path segment $P_0 \to P_1 \to P_2$ as follows:

$$B(t) = (1-t)^2 P_0 + 2(1-t)tP_1' + t^2P_2,\ t \in [0,1] \quad (7)$$

When consecutive adjacent turning points (defined as a "turning point group," such as P_1 , P_2 , P_3),exist in the original path, a single quadratic Bézier curve cannot achieve overall smoothness. In such cases, a cubic Bézier curve is adopted. For the continuous corner path segment $P_0 \to P_1 \to P_2 \to P_3$,a cubic Bézier curve is constructed as follows:

$$B(t) = (1-t)^3 P_0 + 3(1-t)^2 tP_1' + 3(1-t)t^1P_2' + t^3P_3,\ t \in [0,1] \quad (8)$$

Schematic diagrams of the quadratic (second-order) and cubic (third-order) Bézier curves are shown in the figure 4 and 5 below.

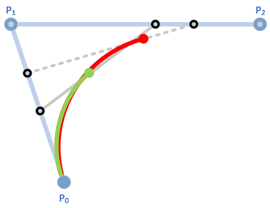


Fig. 4 the second-order Bezier curve

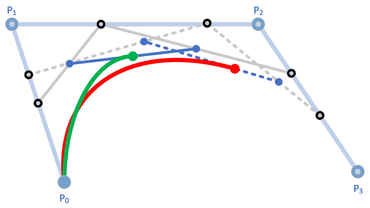
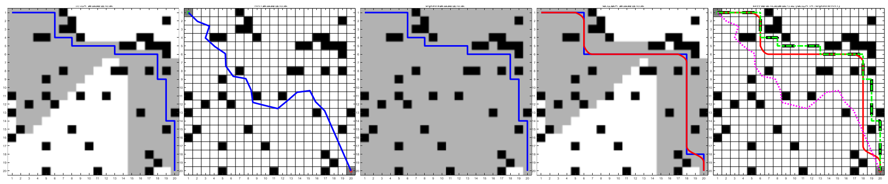


Fig. 5 the third-order Bezier curve

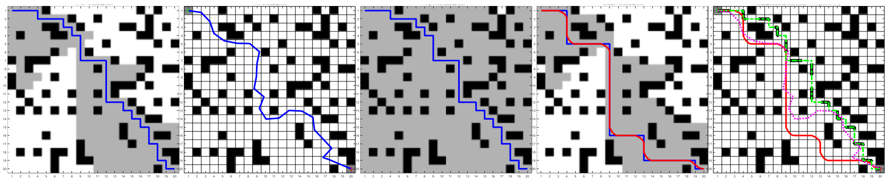
II. Simulation and Validation

To validate the effectiveness of the proposed algorithm, this study constructed two grid map scenarios with uniform specifications (20×20), where the scene complexity and obstacle proportion follow a progressively increasing trend. Across these three distinct grid maps, consistent starting coordinates (1,1) and target coordinates (20,20) were set, with obstacle fill rate serving as the criterion for scene classification: a 10% fill rate corresponds to a simple scenario, while 20% represents a moderate scenario. In the experiments, a performance comparison was conducted among Dijkstra's algorithm, the RRT algorithm, the traditional A* algorithm, and the improved A* fusion algorithm. The grid color scheme is defined as follows: white grids indicate traversable space, black grids represent obstacles, gray grids denote explored nodes, and blue represents the planned path. All simulation experiments were performed under the following environment parameters: a 64-bit Windows 11 operating system, an Intel Core i7-12650H processor, 32 GB of RAM, and MATLAB R2018a as the simulation platform. The corresponding experimental results are shown in Figures 6 and 7, respectively.



(a) (b) (c) (d) (e)

Fig. 6 Simulation results of path planning for different algorithms in simple environments: (a) Dijkstra's algorithm, (b) RRT algorithm, (c) A* algorithm, (d) improved A* fusion algorithm, (e) Path comparison diagrams of the four algorithms



(a) (b) (c) (d) (e)

Fig. 7 Simulation results of path planning for different algorithms in general environments: (a) Dijkstra algorithm, (B) RRT algorithm, (c) A* algorithm, (d) improved A* fusion algorithm, (e) Path comparison diagrams of the four algorithms

The improved A* algorithm has better performance in path planning. Compared with the traditional A* algorithm, it has shorter running time, shorter path length and fewer turning points. Specifically, the average running time of the improved A* algorithm is reduced by 22.12% compared with the traditional A* algorithm, the path length is shortened by 9.50%, and the number of turning points is reduced by 49.28%.

The proposed algorithm not only achieves global path optimization but also generates smoother trajectories with shorter paths and reduced computational time, facilitating more efficient and reliable path execution for reaching target positions.

III. Discussion and conclusion

To address the core limitations of the traditional A* algorithm in autonomous system path planning—including constrained search efficiency, insufficient path smoothness, and difficulties in guaranteeing global optimality—this paper proposes an enhanced A* algorithm that integrates dynamic corner correction and Bézier curve-based path smoothing. Through theoretical modeling, analytical verification, and multi-scenario simulation experiments, the performance advantages and engineering applicability of the proposed algorithm are systematically evaluated.

Experimental results demonstrate that the improved algorithm achieves coordinated optimization of search efficiency, path quality, and obstacle avoidance safety across grid environments with varying complexity and obstacle distributions. Its performance advantages become increasingly prominent as environmental complexity escalates.

The proposed approach is particularly suitable for real-time path planning in autonomous systems such as agricultural mobile robots, providing an extensible theoretical framework and engineering implementation paradigm for dynamic environmental path planning research in agricultural robotics.

References

[1].C. -T. Vu, H. -C. Chen and Y. -C. Liu, "Toward Autonomous Navigation for Agriculture Robots in Orchard Farming," 2024 IEEE International Conference on Recent Advances in Systems Science and Engineering (RASSE), Taichung, Taiwan, 2024, pp. 1-8, doi: 10.1109/RASSE64357.2024.10773736.

[2].M. S. U. Khan, T. Ahmed and H. Chen, "A Review of SLAM Techniques for Agricultural Robotics: Challenges, Architectures, and Future Directions," 2025 IEEE 15th International Conference on CYBER Technology in Automation, Control, and Intelligent Systems (CYBER), Shanghai, China, 2025, pp. 598-603, doi: 10.1109/CYBER67662.2025.11168347.

[3].CAO Liling， YUE Jingming， CAO Shouqi An Improved A* Algorithm for Energy Saving Path Planning of Automatic Ｒeplenishment Vehicles in Farms [J]. Machine Design and Ｒesearch,2025,41(03):349-354.DOI:10.13952/j.cnki.jofmdr.2025.0232.

[4].FENG Zepeng, LI Zonggang, XIA Guangqing, CHEN Yinjuan. Research on Improving A* and APF Algorithms for Mobile Robot Path Planning, Computer Engineering and Applications 2025-07-03 https://doi.org/10.3778/j.issn.1002-8331.2501-0092.

[5].KANG Kaishen, HUANG Hailong. Research on path planning in complex environment based on improved A* algorithm［J］. Journal of Mechanical Transmission, 2025, 49(7)：22-30.

[6].Xiaolong Tong, Shanen Yu, Guangyu Liu, A hybrid formation path planning based on A* and multi-target improved artificial potential field algorithm in the 2D random environments, Advanced Engineering Informatics,Volume 54,2022,101755, ISSN 1474-0346，https://doi.org/10.1016/j.aei.2022.101755.

[7].Y. Li, Y. Geng and Y. Ji, "A Survey of the Present Landscape and Prospective Trajectories in Rescue Robots," 2024 International Symposium on Intelligent Robotics and Systems (ISoIRS), Changsha, China, 2024, pp. 54-59, doi: 10.1109/ISoIRS63136.2024.00018.

[8].Wang, F.; Sun, W.; Yan, P.; Wei, H.; Lu, H. Research on Path Planning for Robots with Improved A* Algorithm under Bidirectional JPS Strategy. *Appl. Sci.* 2024,14,5622. https://doi.org/10.3390/app14135622

[9].Zafer Duraklı, Vasif Nabiyev,A new approach based on Bezier curves to solve path planning problems for mobile robots,Journal of Computational Science,Volume 58,2022,101540,ISSN 1877-7503,https://doi.org/10.1016/j.jocs.2021.101540.