A Study of Path Planning for Mobile Robots in Orchards

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Abstract. As science and technology continue to advance,agricultural production gradually develops to mechanization, automation and intelligence direction.The future of intelligent orchard has become an inevitable development trend, and the development foundation of it includes the path planning problem of the orchard mobile robot.This paper mainly introduces and analyzes the different path planning methods under the three types of orchard mobile robot.Firstly, this paper presents the problems to be solved in the path planning of orchard mobile robot.Then, introduce and discuss three ways included in pathway planning:Environmental map construction method, unit decomposition method and A * algorithm, also introduce and analyze the advantages and disadvantages of each algorithm.Search for the relevant literature addressing the shortcomings of the algorithms.After that, based on the understanding and analysis of the algorithm, a path planning algorithm more suitable for the orchard environment was derived.This paper presents, demonstrates and analyses the current state of the art in orchard robot path planning research, and concludes with more optimal algorithms that can be utilised in orchard environments, which can promoting research and development of mobile robots for orchards.

Keywords: Orchard mobile robots;Path planning method;Path planning problem.

1 Introduction

China is the world's largest fruit-producing region and consumer market, China is also paying more attention to agricultural equipment.With the development of technology,Agricultural production gradually develops to mechanization, automation and intelligence direction.At the same time, as the young rural labour force continues to gather to the city, the aging of the fruit farmer's workforce is serious, the future of the inevitable development trend of intelligent orchards [1].Fruit picking is a seasonal task and a complex operation.Fruit picking by hand can be very labour intensive and inefficient [2].So it is extremely important to replace any work with machines, i.e. to promote the mechanisation and automation of the orchard [3,4].However, because of the complexity of orchard environments and structures, it is difficult for large machines to perform large-scale planting and harvesting in orchards.There are therefore three types of problems: the complexity of the orchard environment; the

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unstructured nature of the orchard environment; and the specificity of the users of the mobile orchard robots [5].The orchard mobile robot can identify and adapt to different environments, which can effectively cope the complex and unstructured orchard environment [6].In the midst of this, smart orchards can't be developed without precision agriculture [7].Automated navigation is an important element of precision agriculture, and the path planning reviewed in this paper is among the research areas it encompasses.In complex orchards, reasonable path planning can help to improve the automation of orchard production and provide accurate control information for orchard operation robots, as well as lay the foundation for subsequent picking work.

Mobile robot path planning technology, that is, the robot according to its own sensors on the environment perception, to plan a safe operation route.At the same time, complete the work task efficiently.Mobile robot path planning mainly solves three problems: First,enables the robot to move from an initial point to a target point; Second, with a certain algorithm, the robot can bypass obstacles and pass through some necessary points to complete the corresponding tasks; Third, on the premise of completing the above tasks, try to optimize the robot operation trajectory.One of the main components of research on intelligent mobile robots is robot path planning technology.It began in the 1970s, and so far, a large number of research results have been reported.The purpose of this review is to introduce three algorithms to find the relevant literature, analyze the advantages and disadvantages of the algorithm, and finally select the path planning algorithm more suitable for the orchard mobile robot.To accomplish the review's goal, this work primarily applies the comparative analysis and literature review methodologies.

2 Path Planning Algorithm

2.1 Visibility Graph Algorithms

In the process of robot path planning, the robot is usually viewed as a point, i.e., its bitmap space is considered. The robot becomes a movable point without considering attitude, volume and incomplete kinematic constraints.Equate the obstacle to a regular polygon, then connect the obstacle, start point and target point with a straight line.It is also important to ensure that the connected lines do not pass through obstacles, and a diagram connected in this way is called a visibility graph [8,9].As shown in Fig. 1.The advantage is that the algorithm is very simple, especially when the environment map describes the objects in polygons; the optimal solution in terms of path length can be obtained.The disadvantage is that the resulting path is too close to obstacles to be safe.

Improvement of Visibility graph algorithms by Weiwei Shao and Zhenglei Luo [8].They dilated the obstacles to solve the shortcomings of the original visualisation method, where the robot is too close to the obstacles.Subsequently, some unnecessary obstacles in the visual map method will be deleted.Through the principle of the shortest straight line between two points, the direction of path planning will be selected, thus reducing the complexity of path planning and computing time, and increasing the scope of application of the visual map method.The advantage is that the algorithm is simple and short time-consuming, but there are some shortcomings, the improved algorithm is suitable for static global path planning where the working environment is known.For dynamic obstacles, due to the real-time and positional uncertainty, it is not possible to complete the planning for dynamic obstacles, and it is not widely applicable to practical situations [8,10].A similar approach is the Voronoi diagram method, where the basic idea is to take the middle point between obstacles and maximise the distance between the robot and the obstacles.More secure than visibility graph algorithms, but longer paths, more suitable for short-range localisation sensors.

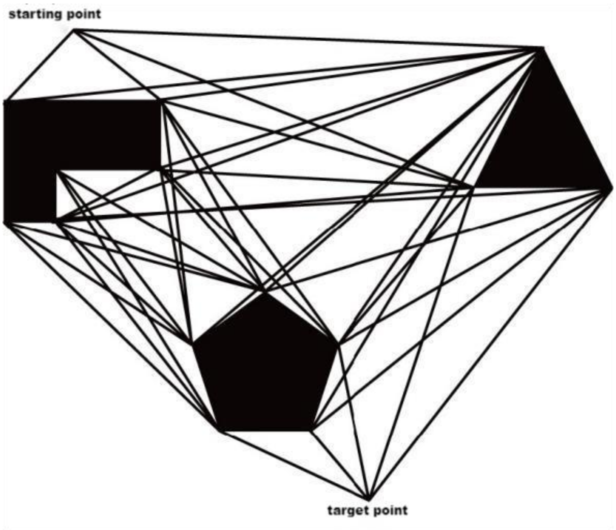

Fig. 1. Visibility graph algorithms [8].

2.2 Cellular Decomposition Method

Cellular decomposition method refers to the decomposition of the entire region of the obstacle in the bitmap space into a number of unobstructed sub-regions, each of which serves as a cell.A connected graph is formed using cells as vertices and neighbourhoods between cells as edges, and then an algorithm is used to find paths that can connect the start and end points.Fig. 2 can be used as a reference.

Commonly used Cellular decomposition are Trapeziodal decomposition method and Boustrophedon decomposition method.The Trapeziodal decomposition method is to sweep a straight line across the target area, and when the line encounters the vertices of a polygonal obstacle, three scenarios are generated, based on which the environment is divided into several trapezoidal sub-areas [11].The Boustrophedon decomposition, on the other hand, is based on the Trapeziodal decomposition, which merges and reduces the subregions it produces, thereby reducing duplicate coverage and improving efficiency, but there is still the problem of duplicate coverage at the boundaries of neighbouring subregions [11].The advantage of this approach is that the robot does not need to consider the exact position in each free area cell, but only how to move from one cell to a neighbouring free cell.However, the disadvantage is that the method is limited to the case where the obstacles are polygons and the computational efficiency is extremely dependent on the complexity of the objects in the environment.

Shen Li proposed a full-coverage path planning method using a new raster map-based cell decomposition approach.The method is simple, practical, with high coverage and the method does not require any shape of the obstacle [9].Since the A* algorithm is used to plan the paths and calculate the distances between the current position and the nodes and vertices in the sub-region, the disadvantage of long computation time is also exposed for complex environments with many sub-regions.

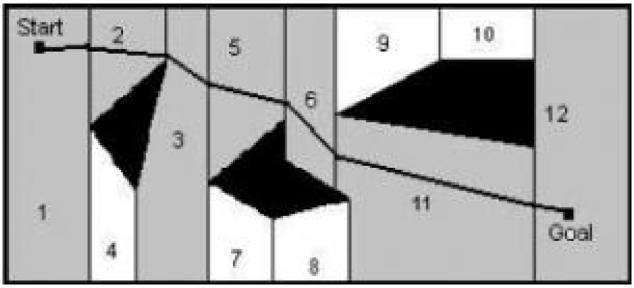

Fig. 2. Trapeziodal decomposition method [12].

2.3 Heuristic Search Algorithms: the A* Algorithm

One of the oldest and most popular search algorithms is the Dijkstra algorithm.It uses a breadth-first search strategy, expanding outwards from the initial node until it reaches the target node.The most popular heuristic search algorithm for state space at the moment is the A* algorithm, which was derived from the Dijkstra algorithm.In addition to state space based problem solving, the A* method is frequently used for mobile robot path planning [13].

The core of the A* algorithm is to find the optimal paths in the connectivity graph based on a heuristic evaluation function, which is the following formula 1:

$$f(x)=g(x)+h(x) \tag{1}$$

The estimated shortest path from the start node to the destination node via the current node is represented by the f(x).The real path length from the start node to the current node is indicated by g(x).Heuristic function h(x) is an estimate of the shortest path from the current node to the target node.and and heuristic functions generally use the Euclidean distance between two points [13].

The following Fig. 3 presents the principle steps of this algorithm:

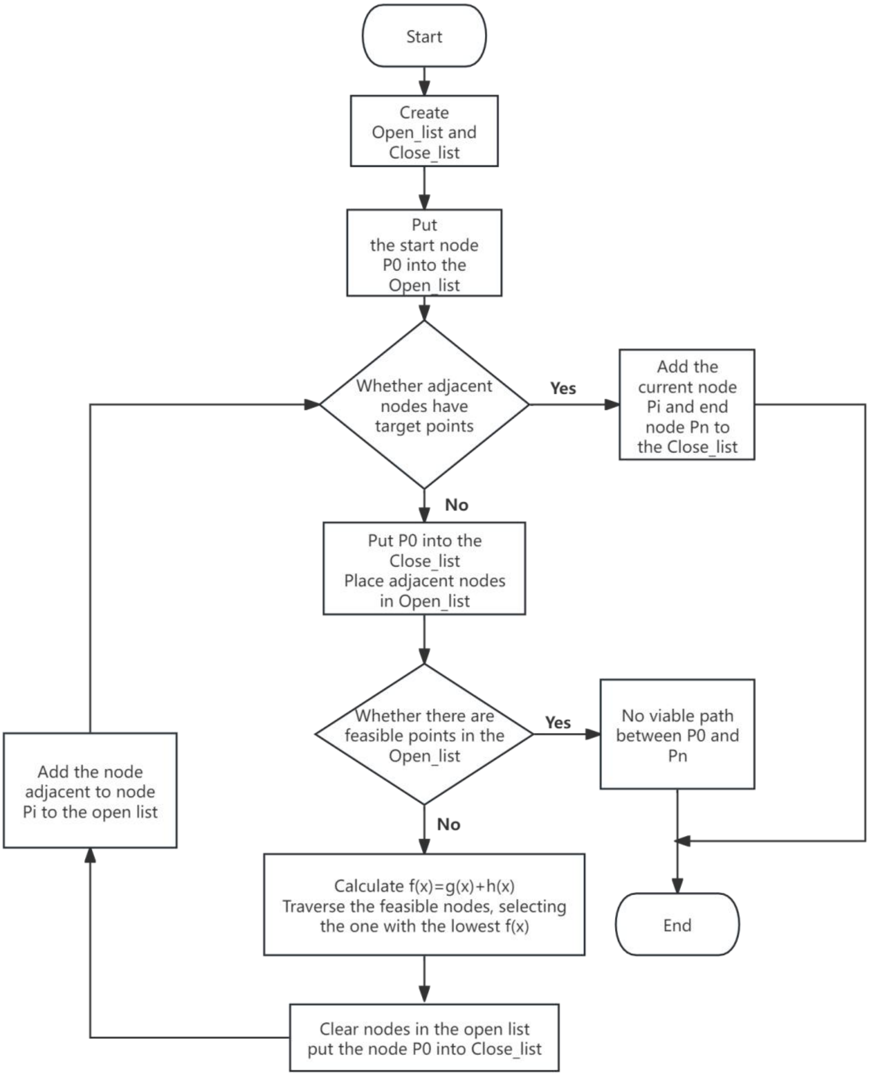

Fig. 3. A* Algorithm Flowchart [12].

The Dijkstra method, an ergodic search that is straightforward, simple to use, and always finds the shortest path, is the traditional shortest path search algorithm.However, as the quantity of nodes in the network become larger, the algorithm searches a large number of nodes and is very inefficient.Fig. 4 represents the comparison of the search area range between Dijkstra algorithm and A* algorithm.

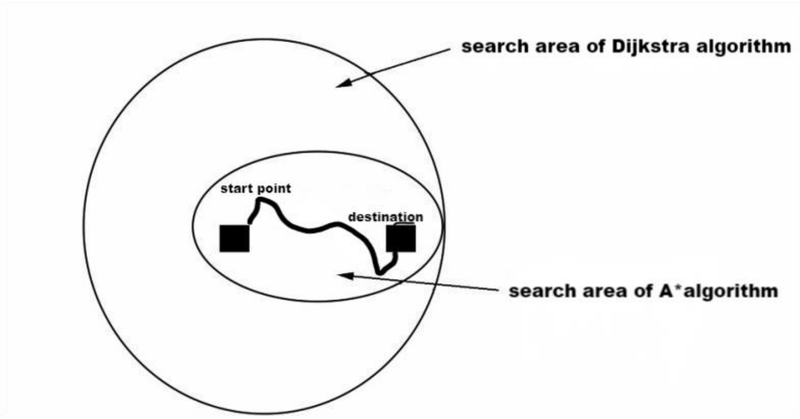

Fig. 4. Comparison of Dijkstra algorithm and A* algorithm search regions [14].

Peng Gao et al. proposed an improvement of the A* algorithm by introducing heuristic function weight coefficients to reduce the greediness of the A* algorithm itself to avoid obtaining a suboptimal solution of the path, and using the DWA local planning method to realise obstacle avoidance in dynamic environments [15].Hui Shi et al. are considering two elements in the valuation function in terms of distance and direction,They solved the problem of non-uniformity of units by normalising them [14].Keyu Shen et al, for the A* algorithm in path planning, there are too many traversal nodes, turning angle is large problem, proposed a can adapt to the scene map of the improved A* algorithm [16].

Less adaptable in arbitrary maps are the classic A* method and the enhanced A* algorithm seen in the literature, and there are problems of traversing a large number of nodes, a large total turning angle, insufficiently smooth planning paths, and long path-finding time in path planning.The advantages of the algorithm are rapid response to the environment, direct search path, high probability of finding the optimal solution, reduced redundancy time, and the ability to handle dynamically changing environments.

3 Discussion

For Visibility graph algorithms, despite the simplicity of their algorithms, they are limited to the shape of environmental obstacles.In dealing with the orchard path planning problem, the complex environment and non-structural nature of orchards, the characteristics of fruit tree growth, spacing, topography and other factors are complex and variable.When dealing with complex polygonal obstacles,visibility graph algorithms increases the number of connecting lines as the number of obstacles increases, leading to a significant increase in the complexity of path planning.This complexity makes it difficult to apply visibility graph algorithms effectively in an unstructured environment such as an orchard.In addition to this, orchard mobile robots need to take into account the physical size and shape of the robot when performing their tasks.However, in the planning of the visibility graph algorithms, the robot is usually simplified to a mass point, which leads to the possibility that the robot may collide with the edges of the obstacles while moving along the path planned by the visibility graph algorithms.This safety hazard makes the visibility graph algorithms not applicable to path planning for mobile robots in orchards.

For the Cellular decomposition method, it is also necessary to take into account the complexity of the orchard environment, with fruit trees of different locations, shapes and sizes, resulting in a complex and variable environmental layout.The Cellular decomposition method requires the entire environment to be divided into a number of unobstructed, non-overlapping regions, which may be difficult to achieve in orchard environments,where the space between fruit trees is usually irregular and closely connected.Besides, the orchard environment is dynamic; fruit trees grow, ripe fruit falls, and even new plants or obstacles may appear.Due to this dynamism and variability, the units divided by the Cellular decomposition method may soon become obsolete and require re-division. This undoubtedly increases the difficulty and complexity of path planning.At the same time the Cellular decomposition method requires detailed delineation and modelling of the environment, which may require significant computational resources and time. In large-scale and complex environments such as orchards, the computational complexity of the Cellular decomposition method may increase significantly, thus affecting the real-time and efficiency of path planning.Therefore the Cellular decomposition method is not applicable to the orchard mobile robot path planning problem.

For the heuristic search algorithms: A* algorithm.For the problems encountered in both of the first two methods, the variable environment in the orchard, the distribution of fruit trees, terrain and other factors may affect the robot's path planning.The A* algorithm is able to handle a variety of complex scenarios and obstacle distributions.The A* algorithm gradually expands the search range until the target node is found by constructing and maintaining open and closed lists. This gradual expansion allows the A* algorithm to be flexible in dealing with complex environments in orchards.The algorithm uses heuristic search to effectively identify the optimum path in complicated environments by combining the benefits of the greedy best-first search algorithm and the Dijkstra algorithm.In a fruit garden.In an orchard, due to the presence of a large number of fruit trees and other obstacles, there is a need for an algorithm that can quickly and accurately plan the robot's movement path, and the A* algorithm meets this need by evaluating the heuristic estimation function of each node and selecting the optimal expansion node to quickly find the shortest path from the start to the end point.In addition to this the A* algorithm has a completeness guarantee that it will always find an optimal path as long as there exists a path from the starting point to the end point.So A* algorithm can be used as a path planning algorithm for mobile robots in orchards.

4 Conclusion

The path planning issue of a mobile robot in an orchard is discussed in this work,mainly introduces the principles of its three different path planning methods,and puts forward the advantages and disadvantages of each method,and briefly introduces the improvement of the corresponding methods Literature.Finally,the feasibility of the three approaches is considered and analysed through the complexity, non-structural, dynamic change, safety and efficiency aspects that need to be considered for orchard path planning.It is finally concluded that both Visibility graph algorithms and Cellular decomposition method have various defects that prevent them from being used in path planning for mobile robots in orchards.While the A* algorithm can perfectly solve and deal with the problems that cannot be solved by the first two methods, and can be used as a path planning method for mobile robots in orchards.

Given the ongoing advancements in science and technology, the technology of path planning and the environment will be more complex and changeable,which demands that the path planning algorithm be able to react to changes in the complicated environment fast.Perhaps this is not a problem that can be solved by just one algorithm, and in the future exploration of mobile robot path planning, in addition to the development of new algorithms, there are also improvements to the original algorithms to improve their robustness.Meanwhile, in the future path planning and orchard picking robots might be combined.Algorithms should meet the robot design and adjust to different environments to meet the needs of the orchard planting industry, reduce resource consumption, improve economic efficiency, reduce labour costs and improve productivity.

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