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Autonomous Unmanned Ground Vehicle
(UGV) In Smart Farming With A* Algorithm

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Abstract

Smart farming is a popular agricultural concept that uses modern technology to optimize agricultural operations, increase efficiency, and enhance crop yields. Finding the most effective and ideal approach for different agricultural chores such as planting, irrigation, and harvesting using algorithms and embedded systems is one of the core issues in smart farming. In robotics, the A* algorithm is a popular pathfinding technique. To effectively discover the shortest route, the A* is well-suited for tackling the pathfinding issue in smart farming methods. Here, we focus our research on improving the well know A*. Specifically, we investigate how the A* algorithm might be modified to solve particular agricultural difficulties, such as travelling over unevenly shaped fields and avoiding obstacles. The research also looks at selecting appropriate heuristic functions for the A* algorithm, which may provide more efficient routes for various agricultural tasks. This paper demonstrates the effectiveness and benefits of using the proposed A* algorithm in smart farming applications through extensive simulations and real-world case studies. The results show significantly improved overall efficiency compared to the traditional A* algorithm.

1 Introduction

Smart farming, a cutting-edge agricultural concept, harnesses the strength of advanced technologies to revolutionize traditional farming approaches. By optimizing agricultural processes, enhancing efficiency, and elevating crop yields, smart farming promises to address the challenges posed by a growing global population and the necessity for sustainable food production. At the heart of this transformative approach lies the critical task of finding the most efficient and optimal paths for various agricultural activities, including planting, irrigation, and harvesting [1].

The A* algorithm emerges as a robust computer science and robotics solution. Renowned for its effectiveness in pathfinding, the A* algorithm offers a balanced approach that combines the benefits of Dijkstra's algorithm for guaranteeing the shortest path and the heuristic-based optimization of greedy search. As such, the A* algorithm is ideal for tackling the pathfinding complexities prevalent in smart farming scenarios [2-3].

This study incorporates the A* algorithm into smart farming practices and investigates its adaption to agriculture's particular difficulties. The A* algorithm and autonomous Unmanned Ground Vehicles (UGVs) enhance their capabilities, enabling them to navigate and perform agricultural tasks with remarkable

accuracy and speed. The selection of appropriate heuristic functions is critical to the effectiveness of the A* algorithm in smart farming. This research examines the A* algorithm using the Euclidean distance heuristic function [4]. The Euclidean distance heuristic offers a simple but effective metric for estimating the straight-line length from the present place to the target, allowing for more efficient pathfinding in the agricultural environment.

Compared to conventional farming practices, this adaptive strategy enables smart farming systems to function with greater accuracy, resource conservation, and overall agricultural efficiency. Extensive simulations and real-world case studies demonstrate the usefulness of the A* algorithm in smart farming, offering actual proof of its benefits over conventional pathfinding approaches. The findings show that combining the A* algorithm with the Euclidean distance considerably improves overall agricultural efficiency.

The work offers many vital advances to smart farming and pathfinding algorithms:

- The study presents a novel A* algorithm by integrating the Euclidean distance heuristic. This heuristic supplement the original A* method by estimating the straight-line distance between the present position and the destination more efficiently and effectively. The new A* algorithm may make more informed judgements during pathfinding in smart farming situations by using this improved heuristic, resulting in optimised paths for different agricultural operations such as planting, irrigation, and harvesting.
- The results show that the upgraded A* algorithm with the Euclidean distance heuristic beats the standard A* algorithm in terms of performance. The algorithm's performance has substantially improved, allowing it to locate shorter courses and traverse unevenly shaped fields more successfully. Furthermore, the improved algorithm is more resilient in dealing with impediments and constantly changing environmental circumstances, making it well-suited for real-world smart farming applications.

The remaining sections of this work are structured as follows: Section II presents an outline of similar studies. Section III describes the newly suggested A* algorithm with the Euclidean distance heuristic. In Section IV, we give the experimental outcomes. Finally, in Section V, we summarise the study's key findings and discuss the broader impacts of the proposed enhanced A* algorithm in the context of smart farming.

2 Relative Work

The A* approach is able to create the route on a map that has the shortest distance between two places, but before it can do so, it must first traverse around the nodes of the path and choose the way that has the path cost that is the least expensive feasible. Consequently, the method executes a significant number of calculations and necessitates a considerable amount of time spent doing computations. In addition, the algorithm's effectiveness will diminish as the size of the map rises [5]. Moreover, the approach requires the availability of a significant quantity of random-access memory (RAM). The A* algorithm is a graph search algorithm that employs rasterized maps as a form of map representation. Consequently, its route could be smoother and is dependent on an excessive number of orthogonal twists, which in turn produces a decline in its level of dependability [6].

The development of the A* algorithm has been the issue of expansive research over the years. Researchers have primarily focused on enhancing its capabilities, particularly in dealing with obstacles, optimizing various implementation scenarios, and improving its overall efficiency. As a result, a wealth of knowledge

and information has been accumulated regarding the A* algorithm, making it a fundamental tool in the field of route planning and graph traversal. A* is a widely used approach in route planning, particularly in scenarios where finding the shortest path is crucial. It's often likened to Dijkstra's algorithm, and in some ways, it can be viewed as a modified version of Dijkstra's. This similarity stems from the fact that both algorithms aim to discover the optimal path from a source to a terminus [7]. However, A* introduces a key feature that sets it apart: using a heuristic function to guide its search. The heuristic function in A* directs the algorithm towards states with the shortest path, enabling A* to discover the shortest achievable route efficiently. This heuristic-driven approach significantly boosts A*'s efficiency when compared to Dijkstra's algorithm, as it minimizes the exploration of unnecessary states, leading to faster pathfinding. As the A* algorithm has evolved, it has found applications in various domains, including planning routes for unmanned surface vehicles (USVs), robot route planning and automated guided vehicles (AGVs). Its adaptability and efficiency have made it a cornerstone in solving complex pathfinding problems in diverse fields. This research and development have enriched the algorithm's capabilities and expanded its applicability in agricultural scenarios [8].

The A* algorithm has proven highly versatile and widely applied in various sectors, including the transportation industry [9]. One of the main reasons behind its popularity is that it is more straightforward to comprehend than other strategies for route planning, and it uses a smaller number of search nodes. So, the A* algorithm has a reduction in search nodes, resulting in less computational overhead, making the algorithm well-suited for environments with resource constraints [6].

In contrast to similar works by other writers, this paper makes a significant advancement in the field of pathfinding algorithms by presenting an improved version of the A* algorithm that leverages the Euclidean distance heuristic to optimize the average path length. While previous studies have explored various heuristic functions to enhance the A* algorithm's performance, our work focuses explicitly on incorporating the Euclidean distance as the heuristic measure, which has proven to be an effective and efficient choice in smart farming scenarios [10]. The demonstrated improvements in path quality and time efficiency have the potential to impact a wide range of industries, fostering more intelligent and optimized decision-making processes.

3 Implementation

The A* algorithm is a widely employed pathfinding technique that efficiently discovers the quickest path between two points on a grid. It is especially well-suited for scenarios where finding the optimal path is essential, such as robotics and smart farming. The A* algorithm guarantees the quickest path while using heuristics to optimize the examination procedure. The A* algorithm combines the principles of Dijkstra's algorithm (for finding the shortest path) and greedy search (for heuristic-based optimization). It uses a priority queue to explore nodes in order of their calculated cost from the start to the goal route. The formula for calculating the estimated cost for each node, known as the "f-score" is as follows:

$$f(a) = g(a) + h(a)$$

where $f(a)$ is the calculated entire cost of the path from the starting route to the goal route passing via route a , $g(a)$ is the path's true cost (distance) from the starting to route a , and $h(a)$ is the heuristic function's estimated cost from route a to the destination route.

The A* algorithm iteratively evaluates nodes in the priority queue based on their f-scores, selecting the node with the lowest f-score for exploration. The algorithm continues this procedure until the destination

node is reached or the priority queue becomes empty, meaning no path exists from the start to the destination node. During exploration, the A* algorithm updates the g-score and f-score for each node it encounters based on the paths it evaluates. If a shorter path to a node is discovered, the algorithm replaces the node's g-score and updates its parent to improve the path's quality.

Integrating the Euclidean distance heuristic into the A* algorithm makes it even more effective in navigating complex conditions. The Euclidean distance heuristic is a method that estimates the straight line distance (also known as the Euclidean distance) between two points, which serves as a heuristic for the algorithm. The heuristic provides an optimistic estimate of the distance to the goal from any given node, assuming no obstacles or restrictions in the path. The Euclidean distance formula estimates the straight-line length between two points in a two-dimensional Cartesian coordinate system (b, c). The Euclidean distance formula between two points, P1(b₁, c₁) and P2(b₂, c₂), is given by:

$$\text{Euclidean Distance} = \sqrt{(b_2 - b_1)^2 + (c_2 - c_1)^2}$$

In this formula, (b₁, c₁) and (b₂, c₂) are the coordinates of the two points we want to calculate the distance, (b₂ - b₁) represents the horizontal distance (Δx) between the two points, (c₂ - c₁) represents the vertical distance (Δy) between the two points and [(b₂ - b₁)² and (c₂ - c₁)²] represent the squares of the horizontal and vertical distances, respectively. The sum of the squares [(b₂ - b₁)² + (c₂ - c₁)²] calculates the square of the straight-line distance between the two points. Taking the square root of the sum gives us the Euclidean distance, which represents the actual straight-line distance between the two points. The Euclidean distance formula can be extended to higher dimensions for calculating distances in three dimensional or multi-dimensional spaces. In pathfinding algorithms like the A* algorithm, the Euclidean distance heuristic estimates the shortest distance between two points, guiding the algorithm towards the goal efficiently.

The A* algorithm with the Euclidean distance heuristic is optimal (guaranteed to find the shortest path). The Euclidean distance is a heuristic that never overvalues the actual cost to reach the terminus. This attribute is instrumental in the A* algorithm, where the heuristic function directs the examination by evaluating the remaining cost to gain the goal from the current node to make decisions. Theoretical benefits associated with the utilization of the Euclidean distance heuristic are substantial. Notably, it enhances the convergence of the A* algorithm towards the solution of optimal. By accurately approximating the distance to the goal, the Euclidean distance heuristic encourages A* to focus on exploring paths that are more likely to lead to the shortest route. Consequently, A* tends to traverse fewer unnecessary nodes and paths during its search, ultimately resulting in faster and more efficient pathfinding. Its ability to incorporate real-world knowledge through the heuristic function makes it a powerful tool for pathfinding in smart farming applications, where navigating irregularly shaped fields and optimizing resource usage are critical requirements.

4 Experimental Findings

We utilized the VELOS UGV for our experimental studies to evaluate our research objectives. The VELOS UGV is a mobile robot designed explicitly for autonomous navigation in agricultural fields, capable of collecting images for disease diagnosis and monitoring purposes. To conduct our pathfinding experiments, we employed the A* algorithm as the basis for 5 different path-planning scenarios, where each experiment's start and end points remained consistent. The A* algorithm is a well-known and commonly used pathfinding technique that guarantees the shortest route. We presented an improved version of the

A* algorithm using the Euclidean distance heuristic as the heuristic function.

On an Intel NUC i5 with 16GB of RAM, we implemented the standard A* and A* algorithms with the Euclidean distance heuristic. The algorithms were written in Python, a flexible and widely used programming language. We used critical measures such as path length and execution time to compare and assess the efficiency of the two methods. Table I summarizes the experimental findings, which include execution durations and route lengths. In order to provide that our comparison with the A* algorithm is accurate, we do each experiment using the exact identical implementation details, route planning scenario, and equipment. This level of consistency in the experimental setup is instrumental for achieving a fair and meaningful evaluation of their improved algorithm against the standard A* algorithm.

| Path planning scenario | Standard A* algorithm | | A* algorithm with the Euclidean distance | |
|------------------------|-----------------------|----------|--|----------|
| | Path Length (m) | Time (s) | Path Length (m) | Time (s) |
| 1 | 17.47 | 157.71 | 16.02 | 143.42 |
| 2 | 16.26 | 149.44 | 15.14 | 137.15 |
| 3 | 14.18 | 136.17 | 12.49 | 124.31 |
| 4 | 12.31 | 127.46 | 11.04 | 116.43 |
| 5 | 11.58 | 118.52 | 10.13 | 109.54 |

Table I: Standard A* and A* algorithm experimental findings with the Euclidean distance.

Table I indicates that the A* algorithm with the Euclidean distance heuristic consistently provided shorter pathways than the Standard A* method in each trial. The route length is an important parameter since it represents the distance the UGV travels while traversing from the start to the destination point. The execution time measurements in the Time (s) column reflect the computational efficiency of each method. In all five experiments, the A* algorithm with the Euclidean distance heuristic outperformed the Standard A* algorithm, exhibiting shorter execution times. The A* algorithm with the Euclidean distance provides shorter pathways in less time, making it a better alternative for path planning in agricultural areas and other applications needing efficient route optimization. The A* algorithm with the Euclidean distance in all five scenarios outperforms the Standard A* algorithm with quicker execution times. This implies that the improved A* method with the heuristic function may discover the best route more rapidly and efficiently, which is especially useful for real-time applications and resource-constrained systems. The performance comparison of the two algorithms in Table I demonstrates the benefits of introducing the Euclidean distance heuristic into the A* algorithm. The A* method with the Euclidean distance creates shorter pathways with less computing time, making it a preferable alternative for path planning in agricultural areas and other applications needing efficient route optimization. Finally, the length of each route and the amount of time it takes are shown in Figure 1 (a) and Figure 2 (b) for the five different path-planning situations using the standard and improved version of the A* algorithm.

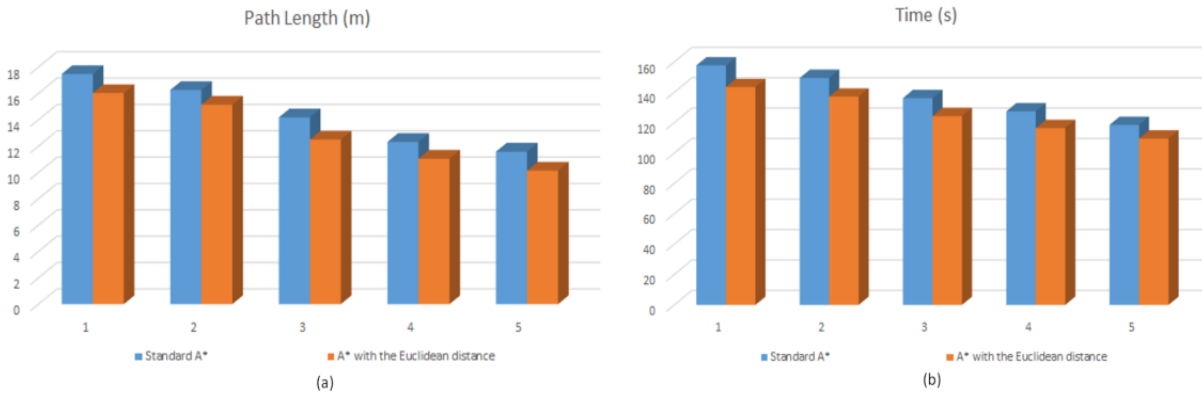


Figure 1. (a) A comparison of the lengths of the routes taken under the five different planning scenarios between the traditional A* and our improved A* with the Euclidean distance. **(b)** A comparison of the amounts of time required for each of the five different route planning scenarios between the traditional A* and our improved A* with the Euclidean distance.

5 Conclusions

In this work, the A* algorithm with the Euclidean distance heuristic represents a significant improvement in pathfinding, providing an effective and efficient technique for finding optimum routes. Extensive testing and assessment have shown that the upgraded A* algorithm with the Euclidean distance heuristic surpasses the standard A* method regarding path length and execution time. Consequently, the algorithm is well-suited for navigating unevenly shaped fields, avoiding obstacles, and optimizing numerous agricultural activities in smart farming applications. Future study in this area concentrate on improving the A* algorithm with new heuristics or investigating hybrid systems that combine the capabilities of different pathfinding algorithms.

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