Road Military Transportation Path Planning Based on The A* Algorithm

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Abstract. Due to the unique nature of road military transportation, conventional algorithms for point-to-point path planning cannot meet the practical requirements. This paper proposes a new method for road military transportation path planning based on the A* algorithm. By incorporating a heuristic function into the A* algorithm to assess the feasibility of the path based on the specific requirements of road military transportation, the optimal path is determined. The feasibility of this method is demonstrated through algorithmic experiments, which contributes to the improvement of military transportation efficiency.

Keywords: Military transportation, Path planning, A* algorithm

1 Introduction

In times of war, road military transportation plays a crucial and significant role, including enabling rapid troop mobility, providing fire support, conducting intelligence and reconnaissance, facilitating communication and command control, medical evacuation, engineering and maintenance support, and logistical assistance. All these functions have a significant impact on the outcome of the war, making the operational efficiency of military transportation vital for achieving victory and ensuring the safety of soldiers. Scholar Wang [1] introduced path planning with constraints on turning radius, utilizing the MAKLINK graph for path description. By incorporating constraint equations for path nodes into the path calculation, an improved firefly algorithm was able to satisfy both the possibility of free vehicle movement in space and the vehicle's turning radius requirements. Scholar Fang [2] proposed an improved A* algorithm for path planning and designed an adaptive heuristic function to obtain the global optimal solution. The results showed that it reduced path search time and improved transportation efficiency. Scholar Zhao [3] addressed the computational burden of robot path recognition and proposed an improved local path algorithm, reducing the computational load and improving efficiency. Scholer Ju [4] proposed an improved version of the A* algorithm that utilizes the principle of the shortest straight line between two points. When encountering scenarios where multiple obstacles are closely adjacent, the algorithm merges the pre-existing paths that circumvent individual obstacles. This enables the algorithm to

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directly traverse across adjacent obstacles simultaneously, resulting in a reduction of the shortest path obtained by the traditional A* algorithm. The effectiveness of this approach has been demonstrated through simulation comparisons. Scholar Alyasin [5] employed the Dijkstra algorithm to find the shortest path for robots on a known road network. Meanwhile, scholar Udhan [6] extended the Dijkstra algorithm by dynamically modifying the path weights to influence the accuracy of the algorithm and obtain the shortest path in a dynamic environment. Scholer Zhao [7] propose a genetic algorithm-based path planning approach. Firstly, the Dijkstra algorithm is employed to find the shortest path in a static environment. As the robot progresses forward, an adaptive adjustment method is employed to enhance the orientation coefficient and pheromone levels. This adaptive adjustment allows the robot to effectively navigate around obstacles and ultimately obtain the optimal path. Scholer Chen [8] propose a merger of the A* algorithm and the Adaptive Ant Colony Algorithm to address the limitations of both approaches. The hybrid algorithm, referred to as the A*-based quadratic node search algorithm, begins by employing the A* algorithm to identify the shortest path. Building upon this path, unnecessary nodes are pruned by evaluating the relationship between the starting point and turning points. By integrating the Ant Colony Algorithm, we aim to overcome the drawbacks of the A* algorithm, namely longer path distances, and the time-consuming nature of the Ant Colony Algorithm. The ultimate objective is to achieve automatic global path planning that effectively avoids all obstacles.

The aforementioned studies have relatively narrow focuses. In current road military transportation, different types of military vehicles have varying requirements for paths. For example, transport vehicles have similar dimensions and weights to civilian vehicles and relatively low demands on roads. Tanks, armored vehicles, missile launchers, and rocket launchers, on the other hand, are heavier and have different body sizes compared to ordinary vehicles, requiring higher load-bearing capacity and width of roads or bridges. Road military transportation faces higher security risks compared to other transportation modes, as military vehicles on the road and the routes they travel can become targets for attacks and sabotage. Therefore, path planning in road military transportation should possess adaptability and adjustability.

Based on the specific requirements of road military transportation, this paper proposes an optimal path planning method for road military transportation using the A* algorithm and its heuristic function to eliminate invalid paths. The method aims to compute paths that meet the practical needs of road military transportation, thereby improving transportation efficiency.

2 Method Introduction

There are several algorithms used for optimal path planning, including A* algorithm, Dijkstra's algorithm, Bellman-Ford algorithm, Floyd-Warshall algorithm, Bidirectional Search algorithm, and other genetic algorithms. Dijkstra's algorithm is a classic algorithm used to solve the single-source shortest path problem. Its basic idea is to progressively determine the shortest path from the starting node to other nodes. At each step, it selects the node with the shortest distance in the current path and updates the shortest paths of its neighboring nodes. Once the shortest path to the destination is found, the algorithm stops. The Bellman-Ford algorithm is employed to solve the single-source shortest path problem and supports graphs with negative-weight edges. It iteratively relaxes the edges to gradually update the shortest path lengths of nodes until convergence. The Floyd-Warshall algorithm is utilized to solve the all-pairs shortest path problem, which involves finding the shortest paths between any two nodes. This algorithm employs dynamic programming to progressively update the shortest path lengths between pairs of nodes. The Bidirectional Search algorithm is used to solve the single-source shortest path problem. It simultaneously searches from both the start node and the target node to narrow down the search space and improve efficiency. The A* algorithm is a heuristic search algorithm that guides the search process by evaluating a cost function for each node. The algorithm selects the node with the lowest cost for exploration and updates the path and cost information based on the connectivity and cost function between nodes. The key to the algorithm lies in selecting an appropriate heuristic function to estimate the cost from a node to the target node, guiding the search process and showcasing its advantages.

Regarding the characteristics of road military transportation, the proposed path planning method in this paper primarily considers three aspects: road width, bridge load capacity, and path adaptability.

2.1 Road Width

During road military transportation, there are specific tasks and transport requirements that involve the use of oversized military vehicles. For example, the Bridge Layer Vehicle is used to quickly deploy temporary bridges to allow military forces and vehicles to cross rivers and other obstacles. These vehicles typically have large platforms and long arms to support and carry heavy bridge components. There are also electronic warfare vehicles used for electronic warfare and communication interference, as well as command and control vehicles for providing communication capabilities in the theater of operations. These vehicles often have wider bodies and extended structures to accommodate a large number of electronic devices and antennas. Furthermore, there are transport vehicles used for transporting large equipment, engineering machinery, or other military assets. These vehicles have spacious cargo compartments or platforms to accommodate the size and weight of specialized equipment. When it comes to path planning for oversized military vehicles, attention should be given to road width to ensure passage.

In the proposed path planning method in this paper, road weights are reassigned based on width, as shown in Equation (1). During path planning, the vehicle width is first determined, and then the road weight W_E is evaluated. Roads narrower than the vehicle width are assigned an infinite weight to avoid passing through them.

$$W_E = \delta / W_i \tag{1}$$

Where W_E represents the recalculated road weight, δ is a selection function, and to ensure reasonable weight assignment, δ is set to a multiple of 3.5, specifically 31.5. W_i denotes the road width. Considering the characteristics of Chinese roads, assuming a single lane width of 3.5 meters and an ideal condition of a one-way four-lane road, the maximum value for W_i is 14 meters.

2.2 Bridge Load Capacity

Military vehicles have a wide range of weights. Armored vehicles, artillery tractors, and others can vary from a few tons to tens of tons. For example, the British FV510 Warrior weighs approximately 17.5 tons, the American M1A2 Abrams main battle tank weighs around 63 tons, the American M1070 Heavy Equipment Transporter weighs about 30 tons, and the Russian KAMAZ-6350 heavy artillery tractor weighs approximately 23 tons. Missile launchers and rocket launchers generally weigh in the tens of tons, such as the Russian 9A52-4 "Tornado" multiple rocket system weighing around 45 tons and the TOPOL-M intercontinental ballistic missile system launcher weighing around 50 tons. For overweight vehicles, it is important to consider the load capacity of the roads, especially when passing over bridges. The maximum limit parameters of bridges should be met to ensure bridge safety and the smooth operation of transportation plans. The load capacity of a bridge is determined by factors such as bridge structure, material strength, bridge piers and support structures, and vehicle weight. This study focuses on whether the vehicle weight satisfies the load capacity of the bridges.

During path planning, the A* algorithm is utilized, and a heuristic function is set to determine the bridge's passability based on the weight of the mission vehicle. When N<HZ, the bridge is passable, and the path is valid. When N>=HB, the bridge is impassable, and the path is invalid. Here, N represents the vehicle weight, HZ represents the maximum allowable weight of the bridge. The heuristic function code is shown in Figure 1.

```
# Import existing graphml file
graph = nx.read_graphml('graph.graphml')

# Define two specific edges as bridges
specific_edges = [('L','R'),('V','P')]

# Manually enter vehicle weight
input_value = float(input("Please enter the weight of the vehicle N:"))

# Heuristic function to determine the validity of a specific edge
def heuristic(graph,edges,input_value):
    for edge in edges:
        edge_property = graph[edge[0]][edge[1]]['weight']
        if input_value > edge_property:
            return False
    return True

# Use a heuristic function to determine the validity of a specific edge
valid_edges = heuristic(graph,specific_edges, input_value)
```

Fig. 1. Heuristic Function.

2.3 Path Adaptability

Due to the high risk of attacks in road military transportation, it is advisable to select routes with a higher number of intersections during path planning. Including multiple intersections in the route serves several purposes: Firstly, it conceals intentions, making it difficult for the enemy to determine the specific objectives of the transport convoy and the importance of the transportation mission. Secondly, it disperses targets, making it harder for the enemy to focus on a single point. Finally, it provides alternative routes for military transportation, ensuring flexibility. Routes with more intersections allow for easier direction changes and quick switching to alternative routes when necessary, ensuring the security and continuity of military transportation.

During path planning using the A* algorithm, multiple optimal paths from the origin to the destination can be found. The final path is then determined based on the number of intersections encountered along each path.

The proposed method operates as follows: Firstly, the width and weight of the mission vehicle are inputted based on requirements. Then, the road weights are recalculated according to the input data. Path planning is performed using the A* algorithm, and the path with the highest number of intersections is selected from the multiple optimal paths. The operational flowchart is depicted in Figure 2.

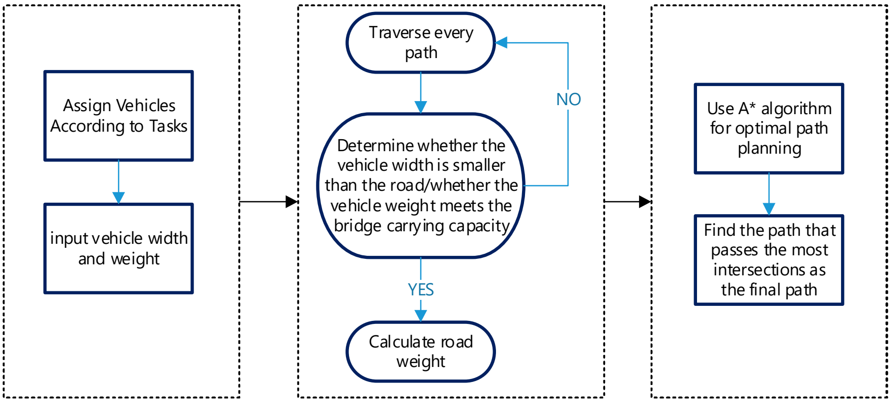


Fig. 2. The Flowchart of Operation.

3 Experiment ang Result

The path simulation experiment is conducted using the Python programming language environment. The data structure used is a topological graph representing a simulated city road network, as shown in Figure 3(a). Each edge represents a road, and the numbers indicate the width of each road in meters. The letters represent intersection nodes in the city, while L-R and V-P denote bridges. During program execution, specific military vehicle dimensions and weight information, as well as the starting and ending points, are inputted based on mission requirements. The program then calculates the optimal path suitable for the given vehicle using the defined computational process.

In the simulation, let's assume the mission starts at point A and ends at point X. The military vehicle has a width of 4 meters and a weight of 30 tons. The L-R bridge has a load capacity of 25 tons, while the V-P bridge has a load capacity of 50 tons.

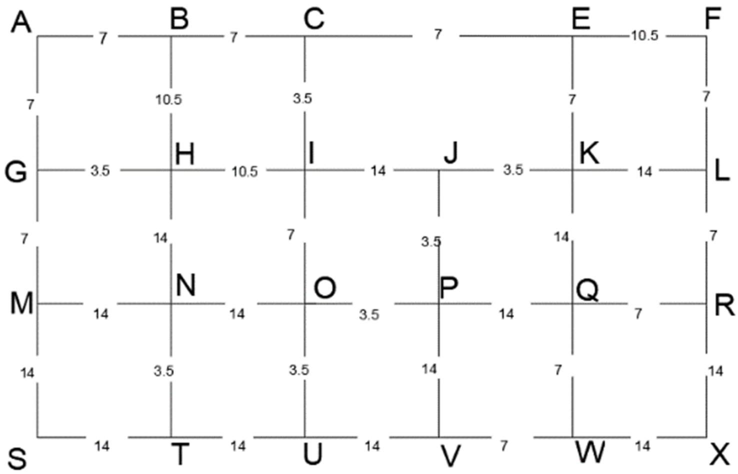
Using the proposed method for simulation, two optimal paths with the same weight are obtained, as shown in the highlighted section in Figure 3(b). The final path is selected by choosing the one that passes through the highest number of intersections, following the system's procedure.

For comparison, the results obtained using a regular algorithm are shown in Figure 3(c), with the highlighted portion representing the optimal path derived from it.

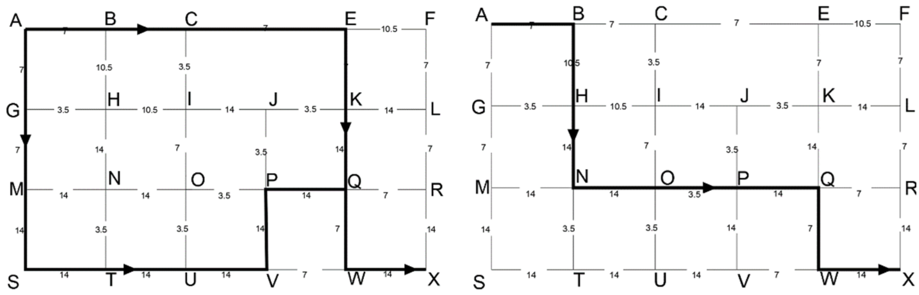
As shown in the figure, when using a regular algorithm to calculate the optimal path, it passes through the road segment O-P. However, the width of the road between O and P is 3.5 meters, which obviously does not meet the requirements for a special military vehicle with a width of 4 meters to pass through. Therefore, the path does not satisfy the demands of actual road military transportation, rendering it ineffective.

When employing the method proposed in this paper for path planning, the first step is to calculate the paths that do not meet the conditions based on the vehicle's length and weight (such as the road segment O-P and the bridge L-R). Then, the A* algorithm is utilized to find multiple optimal paths that comply with the criteria of road military transportation. Finally, the path with the highest number of intersections is selected. The resulting optimal path, while ensuring the shortest path for road military transportation, fulfills the requirements of military vehicle passage and path variability, making it an effective path.

Additionally, by varying the military vehicle width and the width of edges in the topological graph, it is observed that when the weights of the topological graph remain constant, the system's effectiveness becomes more pronounced as the military vehicle width increases. Conversely, when the vehicle width remains constant, the narrower the road, the more pronounced the system's effectiveness becomes.



(a)



(b) (c)

Fig. 3. (a) Road network topology map;(b) Results of the proposed method;(c) Results of regular algorithm.

4 Conclusion

Road military transportation plays a crucial role in determining the course of war during wartime scenarios. In such situations, precise route planning considering the variety of battlefield conditions is essential. Traditional algorithms fail to provide accurate results as they cannot account for specific circumstances. Therefore, this paper proposes a novel method for road military transportation route planning. By utilizing the characteristics of the A* algorithm and selecting an appropriate heuristic function based on the assigned vehicle dimensions and weight for a specific mission, this method improves search efficiency while eliminating road segments that are unsuitable for military vehicle passage. Multiple optimal paths are computed, and the final path is chosen from these paths based on the criterion of passing through the highest number of intersections. Experimental tests confirm that the proposed algorithm is more suitable for the practical requirements of road military transportation tasks compared to conventional algorithms. It contributes to enhancing the efficiency of road military transportation.

Due to the unique nature of road military transportation, additional factors need to be considered, including safety, interference resistance, and the characteristics of non-structured roads in the wilderness, among others. In future work, further research and analysis will be conducted to explore other aspects of military transportation, aiming to enhance efficiency in military transportation and improve the combat capabilities of military forces.

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