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RESEARCH PAPER

Least-time Path Algorithm Based on Missile Guidance

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Abstract: A dynamic and real-time single-vehicle path algorithm considering system optimization is proposed by the method of simulating missile guidance. Targeted at minimizing the run-time of a single vehicle, the algorithm plans a path for the vehicle to avoid traffic congestion and help optimize the overall traffic state. This algorithm begins with preliminary path planning to find the points from which ideal paths that help balance the vehicle traffic flow can be generated. Then the algorithm plans for the ideal paths before the actual path is derived from the ideal ones. Throughout the driving process, the algorithm dynamically and cyclically plans the path in real-time, and dynamically revises the plan of the path covering the sections ahead based on the traffic state. Simulation showed that the proposed algorithm effectively enables vehicles to avoid congestion and save travel time, and helps balance the vehicle traffic flow and optimize the traffic state.

Key Words: traffic engineering; path algorithm; simulating missile guidance; system optimization; ideal path

1 Introduction

Classical path algorithms, such as the Dijkstra algorithm[1,2] and A* algorithm[3,4] were initially aimed at generating the shortest path. Then some researchers applied least-time algorithms to accommodate for the dynamic characteristics of traffic systems. Typical algorithms for time-dependent vehicle path planning problems include the restricted dynamic programming heuristic algorithm[5], genetic algorithm[6], ant colony optimization[7], and simulated annealing[8].

The above-mentioned algorithms mainly targeted at optimizing the path of a single vehicle as expected by the driver, who, as a user, whose top priority is the shortest path or the least travel time[9]. Meanwhile, the intent of traffic manager is the optimal traffic system in which the distribution of traffic flow is balanced and the overall delay is minimal. If these algorithms are simultaneously used by multiple vehicles in a same road network, they would be unfavorable for the optimization of traffic system and traffic jam occurs[10]. The path algorithms proposed in reference [11] consider time window constraint, and some of them take into account the optimization of traffic systems. However, if there are too many vehicles, excessively huge calculation is required and inter-objective conflicts may occur, which potentially prevents the system from reaching an optimal solution. In addition, a traditional dynamic single-vehicle path algorithm need to predict the state of traffic flow in a road network[12] before it can dynamically produce a path for the vehicle. Therefore, the planning accuracy relies on how the state is predicted in real-time. High precision of the predicted state inevitably requires a large number of calculations in the prediction and planning. This is why such algorithms are unsuitable for multiple vehicles' path determination in a large-scale traffic network.

To this end, a dynamic and real-time single-vehicle path algorithm considering system optimization is proposed. The proposed algorithm, which has already been applied to simulate missile guidance[13], is able to consider the requirements of both the driver and the traffic manager[14]. It meets the driver's objective that he/she should be guided to avoid congested road sections and save travel time. To attain an ideal path, the proposed algorithm examines dynamic change to the congestion across a traffic network and finds the points of the ideal paths that help balancing the vehicle traffic flow. Then the algorithm considers a trade-off between the ideal path and the path that meets the objective of a single vehicle, to generate the final path to be executed. The algorithm cyclically plans the path while the vehicle travels. In other words, it dynamically revises the path in remain sections based on the real-time information of traffic state

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provided by an information platform[14].

2 Dynamic path algorithm simulating missile guidance

The algorithm enables a single vehicle to avoid congested road sections and minimize its travel time; it also generates the paths which favor traffic flow balance and system optimization.

2.1 Principle and procedure of the algorithm

According to reference [15], the problem of precise missile guidance is how to strike (1) as close as possible to the target and (2) from a specific direction. It is because that an ideal route for the missile is usually the path with minimal travel time. However, a missile cannot always fly along an ideal flying route due to the effect of gravity. To overcome the effect of gravity or other spatial states, the route of the missile in the air may be too long or require much more travel time. The influence from gravity is the fundamental cause of the conflict in missile guidance. Therefore, the route generated by missile guidance is a trade-off between the ideal route and the route under certain spatial state.

Vehicle path planning holds some similar features with missile guidance such as: (1) the final objective—to arrive at a destination using minimal travel time; (2) they all need to overcome the resistance from some influential factors like the influence from traffic state to vehicles, particularly in traffic congestions. Due to the effect of the traffic state, the path-planning may cause traffic congestion if all the vehicles only try to meet their individual objectives but ignore the efficiency of the entire traffic system. However, if the system optimization becomes the first concern, i.e., to balance the traffic state, the planned paths may introduce too much detour or require too much travel time. Therefore, missile guidance is a good way to settle the conflicts between the two objectives.

Vehicle path planning is distinct from the missile guidance in that: (1) traffic state of a traffic system varies over time and place, but for missile guidance, the gravity is constant for any spatial environment; (2) the former problem is restricted by the structure of road network, traffic speed limitation, and the scope of path planning, while the latter one is free from such restrictions in spatial environment.

To address these two differences, the state of a traffic system, which corresponding to the gravity item in missile guidance, should be expressed in real-time. And then the ideal paths for a single vehicle which is beneficial for system optimization should be planned with missile guidance simulation. At last, the actual structure of road network, speed limit, and scope of path planning are considered in order to generate an actual path that is a trade-off between the single-vehicle path-planning and the system optimization.

The fundamental principles are illustrated as follows:

First, we need to determine the ideal paths for the single vehicle. An ideal path is the theoretically best one that enables the vehicle to avoid congested road sections and minimize travel time without considering the restrictions in a real traffic network.

Fig. 1 elaborates such principle of the algorithm. Assuming that heavy traffic flow occurs at crossings a, b, e, and f, as well as the sections connected to them; light flow occurs at crossings c, d, and g, and any other sections. The ideal path from origin A to destination B is a curve that can avoid heavy-traffic crossings and sections between the two points. If we suppose that all crossings are connected to each, and path $AdcB$ is observed to be the best one appropriating the ideal path and meets the objective of avoiding congested road sections.

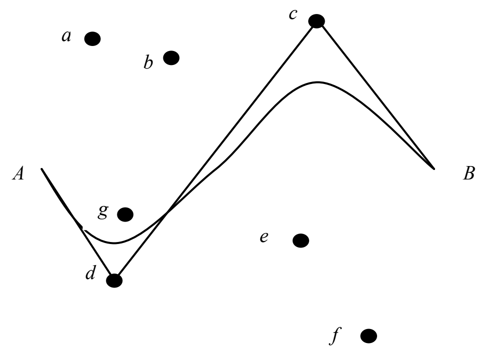

Fig. 1 Principle of the algorithm

The path algorithm is operated as follows:

Step 1: The preliminary path planning is actually an operation to identify the points of ideal paths generated (namely, the "IPG points"). It evaluates real-time traffic flow and congestions in traffic system and marked out the smooth points that can achieve the goal of system optimization with balanced traffic flow.

Step 2: Using the motion equation to test whether the IPG points meet the requirements of path planning and match the actual traffic status. Then connect all the satisfactory IPG points to form an ideal path.

Step 3: Taking the ideal path as the center and searching by a fixed step along the Y-axis to find an actual path that meets the objective of path planning.

Step 4: Throughout the driving process, we define the start point of the road section as the vehicle origin and the terminal of the road as the destination, and then dynamically evaluate paths according to the real-time traffic state. The planning is conducted one more time when the vehicle arrives at the next road section. Such cyclic planning will be carried on until the vehicle reaches its destination and forms a real-time dynamic algorithm.

2.2 Algorithm and steps of preliminary path planning

The preliminary path planning requires IPG points to avoid congested road sections and get as close as to smooth sections.