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Public Security Patrol Based on 3D Path Planning

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Abstract. Social condition, accompanied by booming economy and technology, has become increasingly complex, gradually increasing pressure on public security. Therefore, enhancing public security patrol performance has become important means for ensuring the security of lives and property of people. This study aimed to select a combination of public security patrol and three-dimensional (3D) path planning as the breakthrough point to explore the operating current condition and existing problems of the combination. 3D path planning under a simulation environment was implemented using bidirectional A*, rapidly exploring random tree (RRT) Extend, and RRT-Connect algorithms. Finally, the prospects of the combination of police patrol and 3D path planning were discussed to provide a new thought for the future development of police patrol.

Keywords. A* algorithm; 3D path planning; police patrol; rapidly exploring random tree extend, RRT Extend

1. Research background

The urbanization process, accompanied by a booming economy and rapid population growth, has gradually been accelerated, imposing increasing pressure on public security in densely populated areas and urbanized communities. The appearance of novel criminal activities and the constant updating of technological means have made the maintenance of social public security more difficult. Both hidden and concealed characteristics of criminal behaviors have also led to new challenges to police patrol work. Therefore, under the current public security situation, maintaining social stability and public security is of paramount significance.

This study selected three-dimensional (3D) path planning as the breakthrough point for enhancing police patrol performance to explore the operating situation, actual effect, and existing problems in the combination of police patrol and 3D path planning. Moreover, considering urban terrains commonly existing in actual police patrol practices, the corresponding simulation environment was established. A 3D path planning under the simulation environment was performed based on bidirectional A*, rapidly exploring random tree (RRT) Extend, and RRT-Connect algorithms. Further, both advantages and disadvantages of various algorithms were compared. Finally, the possible problems and

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challenges, future improvement directions, and patrol system structure in the combination of public patrol and 3D path planning were discussed from a wide perspective.

This manuscript is organized as follows. In Section 2, the related studies on patrol and 3D path planning have been described in detail. Section 3 focuses on the technological implementation of 3D path planning, in which the related principle and implementation model of 3D path planning as well as the implementation effect of 3D path planning are expounded. Finally, in Section 4, the prospect of combining public security patrol and 3D path planning is analyzed, and the preset research results are concluded and discussed.

2. Research status worldwide

Existing studies rarely combined public security patrol and 3D path planning. This study first reviewed the previous studies in the following two dimensions.

The studies on public security patrol mainly concentrated on the following domains.

(1) Patrolling mode. Adams *et al.* enumerated various factors affecting the deployment of public security patrol. They proposed that these factors should be quantified with danger declaration to calculate the disposition results of a patrol police force[1]. Bottema and A. Johannes proposed the mode of intelligence-led policy driven by patrol and performed value assessment. Considering the plan of the intelligence officer in the Fenghuang Police Office as the experimental unit, they made an in-depth investigation of the detailed communication process and the related effects[2].

(2) Patrolling strategy. Peak and Glensor pointed out that public security patrol should be combined and complemented with community patrol[3]. Braga *et al.* indicated that public security patrol should emphasize high-risk criminal sites rather than decentralize the police force around the city[4].

(3) Patrolling methods. Menton *et al.* compared the Patrolling methods using bicycles and cars in five different cities and pointed out that bicycles were more highly accepted by the public[5]. Saint-Guillain Michael, Paquay Celia, and Limbourg Sabine investigated the dependence of random request time with random vehicle routing problems and related applications in online public security patrol management[6].

(4) Patrolmen attributes. Elin Granholm Valmari, Mehdi Ghazinour, Ulla Nygren, and Kajsa Gilenstam examined the environment where patrolmen lived to determine the obstacles and resources that affected the living modes[7]. Frédérique Lehouillier, Marc-Olivier Dugas, and Martin Lavallière investigated the relationship between bicycle patrolling and the physical attributes of police officers, and concluded that bicycle patrolling might contribute to maintaining effective patrolling duties for police officers[8].

At present, public security patrolling has been widely reported, covering the following aspects: conclusion of the current public security patrol model, problem research, strategy analysis, mode innovation, and introduction of high-tech equipment for improving quality and efficiency. Despite comprehensive studies on 3D path planning and the enhancement in both theory and actual applications, achieving an adequate combination between 3D path planning and public security patrol still lacks in-depth research.

Therefore, referring to previous research contents, viewpoints, and methods, this study combined the currently mature 3D path planning technique for exploring the public security patrol method. The proposed public security patrol paid much attention to theoretical exploration, algorithm optimization, efficiency, accuracy, and universality.

3. Technological implementation of 3D path planning

3.1 Algorithm implementation

The BUILD_RRT method constructs the RRT tree with random sampling and extension. The EXTEND method extends the point on the tree; specifically, a new point is generated and connected to the nearest point, which can be added to the tree if the new point is found to be effective.

The NEAREST_NEIGHBOR method finds the point on the tree closest to the given point q. First, point V on the tree is converted into the numpy array. If the length of V equals 1, the algorithm can directly return to the point; otherwise, the algorithm calls the *repmat* function and copies the point q as a matrix with the same number of rows of V. Next, the Euclidean distance between the point and each point in V is calculated, and the algorithm returns to the point with the minimum distance as the nearest neighbor point.

The RANDOM_CONFIG method is used for generating random configurations, that is, randomly sampling a point in the environment.

The NEW_CONFIG method is used for checking the effectiveness of the new configuration. By calling the *isCollide* function, whether the path from q_near to q_new collides with the obstacle in the environment is judged. If no collision occurs, the new configuration is effective and the algorithm returns to True; otherwise, the algorithm returns to False.

The CONNECT method is used for connecting the given point q on the RRT tree. The EXTEND method is recursively called until the point cannot be further extended, and the algorithm returns to the result S so as to represent the extended state, including Reached (reaching the goal point), Advanced (successfully extending the point), or Trapped (failing in extending the point).

The RRT_CONNECT_PLANNER method is the main function of the RRT-Connect algorithm. Using the RRT_CONNECT_PLANNER, two RRT trees, namely, Tree_A and Tree_B, are first created and initialized as the starting point and the goal point, respectively. Next, in each iteration, a point is randomly sampled and extended in Tree_A. If the point can be successfully extended (i.e., the algorithm does not return to the state Trapped), the new point q_new is obtained and used for connecting the points on Tree_B. If the goal point is reached in the connection (i.e., the algorithm returns to the state Reached), the algorithm successfully finds the path. After finding the path, the related information is stored for visualization and the algorithm returns to the implemented state.

The SWAP method is used for changing two tree objects. Using the RRT-Connect algorithm, exchanging Tree_A and Tree_B aims to alternatively use two trees for simultaneously achieving extension and connection.

The PATH method is used for generating the path from the starting point to the goal point. The father point of each point is traced back from the q_new until the starting point or the goal point is reached. The points along the path are saved in the format of a tuple, and the paths between the Tree_A and the Tree_B are connected and returned.

The visualization method is used for visualizing the RRT tree and paths. Based on the specified index values and the judgment result of whether the path has already been found (self.done), the algorithm judges whether the path is visualized. During the visualization process, 3D graphics, including spheres, obstacles, and sides of trees and paths, are plotted using the *Matlablib* library. The starting point and the goal point are marked in green and red, respectively. The perspectives of graphics are also set. Finally, the visualized results can be displayed with the *show* function in *matplotlib.*

Figure 1 shows the execution results using the compiled codes, in which the red line connecting the starting point and the terminal point denotes the obtained path planning result.

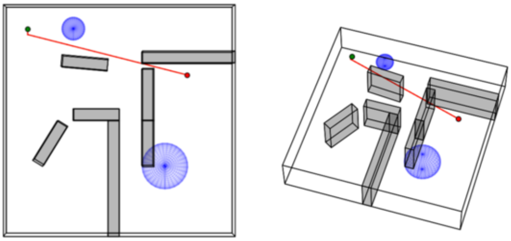

Figure 1. Execution result using the RRT-Connect algorithm.

3.2 Chapter summary

Overall, the bidirectional A*, RRT Extend, and RRT-Connect algorithms have their own advantages and disadvantages. In terms of the search mode, the bidirectional A* algorithm can extend along two directions and search the encounter point to construct the optimal path. The RRT Extend algorithm randomly samples the new point from the current point, extends to the goal point to construct the path tree, with a nondirectional search process, explores the environment, and approaches the goal point by constantly extending the tree. The RRT-Connect algorithm constructs two RRT trees simultaneously from the starting and goal points, and attempts to connect these two trees for path search.

In terms of search direction, the bidirectional A* algorithm starts the search simultaneously from the starting point and the goal point, extends toward the surrounding state along each direction, and stops the search when encountering a certain point from two directions, finally forming the final path. The RRT Extend algorithm generally begins the search from the starting point and extends to the goal point until a path is found or the maximum number of iterations is reached. The RRT-Connect algorithm uses two RRT trees for search (to be specific, one extension from the starting point and the other extension from the goal point) until the connection is reached or the path is found.

In terms of the search strategy, the bidirectional A* algorithm follows the strategy of heuristic search, searches along two directions with the A* algorithm, evaluates the priority of the point with the heuristic function, and selects the point with the optimal evaluated value, intending to find the optimal path fast. The RRT Extend algorithm and RRT-Connect algorithm adopt random sampling and extension strategy, randomly sample a new point in the environment and extend it to the nearest point to expand the path tree, explore the environment with randomness, and guide the search direction by selecting the probability of the goal point.

Three algorithms are applicable to different public security patrol environments and requirements. In the case of global path planning under a thoroughly understood patrol environment, the bidirectional A* algorithm shows the highest efficiency. In cases of complex patrol space and significant dynamic environment changes, the RRT Extend algorithm shows favorable performance. When using the police UAV for patrol, the RRT-Connect algorithm exhibits favorable applicability to complex environments and high-dimensional state space. In conclusion, the bidirectional A*, RRT Extend, and RRT-Connect algorithms show their own advantages and shortcomings in various aspects. Selecting an appropriate algorithm according to detailed application requirements and environmental characteristics is suggested.

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