Path Planning Using Artificial Potential Field Method And A-star Fusion Algorithm

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***Abstract*—Aiming at the deficiencies in A-star algorithm and artificial potential field method, this paper proposes a fusion algorithm based on artificial potential field method and A-star algorithm. Although the A-star algorithm can obtain a relatively short path, it cannot handle dynamic obstacles, the artificial potential field method can handle dynamic obstacles but the generated path is much longer than the A-star algorithm. Artificial potential field method and A-star fusion algorithm is proposed to avoid dynamic obstacles and find a shorter path simultaneously. Then we evaluated our proposed method by comparing it with the A-star algorithm, artificial potential field method and two other reference methods. The simulation results show that our proposed method can generate a shorter path and effectively avoid dynamic obstacles.**

Keywords—A-star algorithm, Artificial potential field method, Fusion algorithm, Shorter path

Ⅰ. INTRODUCTION

Path planning plays an important role in the field of robotics, including UAV, unmanned boats, unmanned vehicles. The goal of path planning is to find a path with the shortest distance and shortest time given a starting point and an ending point on a established map. In recent years, a lot of research has been conducted on path planning. There are many mature paths planning methods, for examples, A-star algorithm [1,5], rapid random tree (RRT) [2], artificial potential field method [3], artificial moment method [4].

Considering the A-star algorithm can obtain a relatively short path, it cannot handle dynamic obstacles, and the artificial potential field method can handle dynamic obstacles but the generated path is much longer than the A-star algorithm. Thus, the artificial potential field method and A-star fusion algorithm is introduced to settle above issues.

The idea of the artificial potential field method is that the obstacle gives the robot a repulsive force and the target points give it gravity at the same time. By continuously calculating the direction of the resultant force, the position of the next point coordinates is calculated. The most important part is here, the points of path generated by the A-star algorithm will be used, and a circle of a specified radius is drawn at the current point. If there exists points in the circle which belong to the path generated from A-star algorithm, the gravity at this time becomes the gravity of these points and the target point of the robot. And in this way, the planned route will be closed to the path of the A-star algorithm. The generated path will be better because the path it generates is close to the trajectory of the A-star algorithm. And dynamic obstacles are avoided effectively because the fusion algorithm inherits the characteristics of the artificial potential field method to avoid moving obstacles to high real time.

The rest of this paper is structured as follows. We review related works in Section II. Section III illustrates our proposed the artificial potential field method and A-star fusion algorithm, including its framework and implementation details. In Section Ⅳ, we evaluate the performance of the proposed the artificial potential field method and A-star fusion algorithm, and make comparisons with related methods. Finally, we discuss the conclusions of our work.

II. RELATED WORKS

In recent years, the problem that the path generated by the traditional A-star algorithm is not optimal, and the problem of dynamic obstacles that cannot avoid obstacles, has attracted the attention to many scholars. [6] proposed a hybrid algorithm. The algorithm first uses the A-star algorithm for planning to obtain the initial path, and then sequentially uses each inflection point

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of the initial path as a sub-target point, and uses the improved artificial potential field method of local path planning to obtain the final path. [7] uses a global path planning A-star algorithm to obtain an initial path. On a sub-base, a local path is obtained by the artificial potential field method of local path planning. The two parts are combined together to obtain an optimal path. [8] uses the artificial potential field method to guide the global path planning, and the gravitational field is used to control the flight direction of the UAV. [9] first uses the smooth A-star algorithm for global path planning in a static obstacle environment; then when the robot encounters a dynamic obstacle, the A-star artificial potential field method is used for local dynamic path planning. [10] first uses the artificial potential field method to plan the path. If it falls into the local minimum, it uses the A-star algorithm to control its movement towards the virtual target point to escape the local minimum, and then converts back to the artificial potential field method to continue the search until reaching the target point.

Considering that some of the above improvement methods is not optimal, this paper proposes a new and improved fusion algorithm, the generated path length is shorter than the above, and it can also satisfies the requirements of high real-time.

III. ARTIFICIAL POTENTIAL FIELD METHOD AND A-STAR FUSION ALGORITHM

In this section, we will introduce the basic principle of fusion algorithm. The fusion algorithm is improved on the basis of A-star algorithm and artificial potential field algorithm. The principle of the fusion algorithm is as seen in Fig. 1.

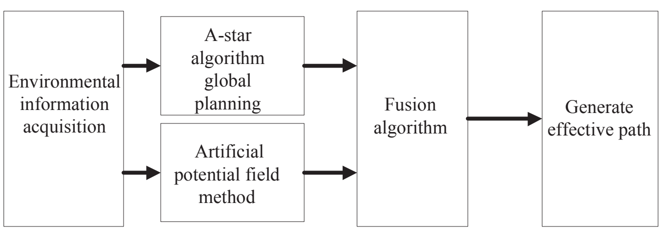

Figure 1. Structure diagram of the artificial potential field method and A-star fusion algorithm

We first obtain environmental information, and then determine the starting point and end points. We will use the A-star algorithm to generate a global path and save, on this basis, we use the fusion algorithm to start generating feasible paths until we reach the destination. This is the core idea of our proposed fusion algorithm.

Considering that the fusion algorithm is improved on the basis of the A-star algorithm and the artificial potential field method, so this section first introduces the basic principles of the A-star algorithm are introduced, and then elaborate on the basic principles of the artificial potential field method. Finally, we will introduce the basic principles of our proposed fusion algorithm.

A. Global planner : A-star algorithm

The A-star algorithm is a typical heuristic algorithm. Given a global map and starting and ending points, it can generate a more reasonable path. The cost function of the A-star algorithm is defined as followings:

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

Among them n is the current inspection point; $f(n)$ is the sum of the valuation function; $g(n)$ is the actual path substitution value from the starting point to the inspection point; $h(n)$ is the estimated substitution value from the inspection point to the end point.

$h(n)$ is calculated using the Euclidean distance between the inspection point and the end point:

$$h(n) = \sqrt{\left(x_n - x_{goal}\right)^2 + \left(y_n - y_{goal}\right)^2} \tag{2}$$

among them (x_n, y_n) are the coordinates of the inspection point; (x_{goal}, y_{goal}) is the coordinates of the end point.

The specific implementation steps of the traditional A-star algorithm are given below.

Algorithm 1 A-star algorithm

algorithm $A\_star(start, map, goal)$
$close \leftarrow NULL$
$open \leftarrow start$
$G[start] \leftarrow g[start] = 0, H[start] \leftarrow h[start]$
$F[start] \leftarrow H[start]$
while $open \neq \varnothing$ **do**
  $current\_Node \leftarrow$ *Node with the minimum F value in open*
  $open \leftarrow open \setminus \{current\_Node\}$
  $close \leftarrow close \cup \{current\_Node\}$
  if $current\_Node = goal$ **then**
    return *best_path*
  endif
  $neighbor\_Nodes \leftarrow$ *All neighbor Nodes of current_Node*
  for $N \in neighbor\_Nodes$ **do**
    if $N \in close$ **then**
      do nothing
    else if $N \in open$ **then**
      $G[N\_new\_calculated], H, F \leftarrow$ *calculated N's G,H,F*
      if $G[N \in open] > G[N\_new\_calculated]$ **then**
        N's parent $\leftarrow current\_Node$

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            endif
        else
            N's parent ← current_Node
        endif
    endfor
endwhile
```

B. Local planner:artificial potential field method

The idea of the artificial potential field method is to assume that there are virtual gravitational fields and repulsive fields around, the target points to give gravity of the robot, and the obstacle gives the robot repulsion. The gravitational force applied by the target point is proportional to the distance from the robot to the end point, and the repulsive force of the obstacle is inversely proportional to the distance from the obstacle to the robot. The combined direction of the two forces is the direction in which the robot moves and causes the robot to avoid obstacles to create an effective path.

The gravitational potential field functions defined as follows:

$$U_{att}(X) = \frac{1}{2} K_{att} \left(X - X_g \right)^2 \tag{3}$$

The repulsive potential field function is defined as follows:

$$U_{rep} = \begin{cases} \frac{1}{2} K_{rep} (\frac{1}{X - X_o} - \frac{1}{\rho_o})^2, X - X_o \le \rho_o \\ 0, X - X_o > \rho_o \end{cases} \tag{4}$$

where X is the current position of the robot; X_g is the position of the target point and X_o represents the position of the obstacle; K_{att} is the constant of the gravitational potential field; K_{rep} is the constant of the repulsive potential field; ρ_o is the maximum distance value that the obstacle poses a threat to the robot.

It is easy to obtain the expressions of gravitation and repulsion according to the negative gradient of the above gravitational potential field function and repulsive potential field function.

The expression of the target's gravity on the robot is as follows:

$$F_{att}(X) = -K_{att} \left| X - X_g \right| \tag{5}$$

The expression of the repulsion of the obstacle to the robot is as follows:

$$F_{rep} = \begin{cases} K_{rep} (\frac{1}{X - X_o} - \frac{1}{\rho_o}) \frac{1}{(X - X_o)^2}, X - X_o \le \rho_o \\ 0, X - X_o > \rho_o \end{cases} \tag{6}$$

The artificial potential field method has a good ability to avoid dynamic obstacles, and the calculation is fast and real-time. However, the A-star algorithm cannot avoid dynamic obstacles, so consider combining the two algorithms in next section.

C. Path planning with fusion algorithm

The idea of the artificial potential field method is that the obstacle gives the robot a repulsive force and the target points give it gravity. By continuously calculating the direction of the resultant force, the position of the next point is calculated. First consider a simple situation, as shown in Fig.2. Where R is the position of the current robot; G is the position of the target point; O is the position of the obstacle; Draw a circle of radius r with R as the center; P is the point included in the path generated by the A-star algorithm; F is the direction of the calculated resultant force.

Firstly calculate and save the route points according to the A-star algorithm. The equation using R as the center of the circle and r as the radius and the coordinates of R are $(x_{current}, y_{current})$.

$$\left(x - x_{current} \right)^2 + \left(y - y_{current} \right)^2 = r^2 \tag{7}$$

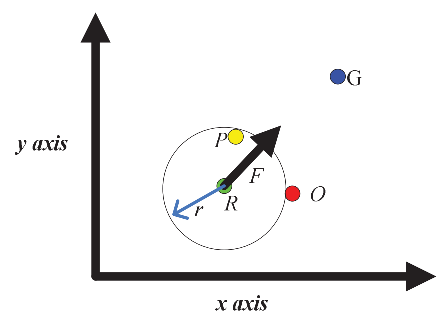


Figure 2. Simulation of fusion algorithm

Use the circle equation (7) to detect whether the path point generated by the above A-star algorithm is within the circle. And also satisfies the following conditions (Here P (x_p, y_p) as an example):

$$x_p - x_{current} > 0 \tag{8}$$

This constraint will ensure that the robot will always move towards the end point. If this constraint is not met, the point will be discarded.

It can be clearly concluded from Fig. 1 that P is a point that satisfies the condition. At this time, gravity is the sum of the gravity applied by the target point and point P of the robot:

$$F_{att} = F_P + F_G \tag{9}$$

where F_P is the gravitational force of P to the robot, and F_G is the gravitational force of the target point to the robot, both of which can be obtained by (5).

The calculation of the repulsion force is the same as the traditional artificial potential field method, and the repulsion force of the surrounding obstacles to the robot is calculated according to (6). Finally, it can go from the current point to the next point according to the direction F of generating the resultant force.

There may be more than one P point that meets the actual conditions. The more general fusion algorithm is given below.

Algorithm 2 The artificial potential field method and A-star fusion algorithm

algorithm $fusion\_algorithm(start, goal, map, obstacle)$
 $Astar\_path \leftarrow A\_star(start, map, goal)$
 $current\_point \leftarrow start$
 while $current\_point \neq goal$ **do**
  for each $Astar\_point \in Astar\_path$ **do**
   $p\_point \leftarrow is\_inside\_circle(current\_point, Astar\_point, r_1)$
  endfor
  for each $p \in p\_point$ **do**
   $F_{att} \leftarrow F_{att} + calculated\_gravity(current\_point, p)$
  endfor
  for $obs \in obstacle$ **do**
   $obs\_point \leftarrow is\_inside\_circle(current\_point, obs, r_2)$
  endfor
  for $o \in obs\_point$ ***do***
   $F_{rep} \leftarrow F_{rep} + calculated\_repulsion(current\_point, o)$
  endfor
  $F \leftarrow F_{rep} + F_{att}$
  next_point ← *determined by the combined force F and step size*
 endwhile
function *is_inside_circle*(*current_point,Astar_point,r*)
  if abs(*current_point - Astar_point*)<*r* **do**
   return *Astar_point*
  endif
end
function *calculated_gravity*(X_1,X_2)
  return $-K_{att}$ (**abs**(X_1-X_2))
end
function *calculated_repulsion*(X,X_o)
 if ***abs***(X-X_o)> ρ_0 **do**
   return 0
 else
   return $K_{rep}(\frac{1}{X-X_O} - \frac{1}{\rho_0})\frac{1}{(X-X_O)^2}$
 endif
end

Therefore, according to the above algorithm, we can get the proposed fusion algorithm is the following idea.

Step 1: First use Algorithm 1 (A-star algorithm) to generate an optimal path point and save it.

Step 2: Repeat the following steps until the target point is detected:

(a) Use the current point $R(i)(i=1,2...)$ as the center to make a circle with radius r, and check whether the path point generated by Step 1 is inside the circle. If yes, suppose there are m points that satisfy the condition, which can be written as $P(j)(j=1,2,...,m)$; otherwise, the gravity only needs to calculate the gravity that the target point gives the robot.

(b) Calculate gravity $F(i) = F_G + \sum_{j=1}^{m} F_j$ according to the point in (a), where F_G is the gravitational force generated by G of the end point, $\sum_{j=1}^{m} F_j$ is the gravitational force produced by P_j that satisfies the constraints.

(c) The calculation of the repulsion force is the same as the traditional artificial potential field method, and the repulsion force of the surrounding obstacles to the robot is calculated according to (6).

(d) Calculate the combined force of (b) and (c). And calculate the position of the next point according to the direction of the obtained combined force, which is recorded as $path(i)$.

Step 3: The final generated path is as followings:

$path = [path(1), path(2), ..., G]$.

Ⅳ.Simulation And Analysis

We will evaluate the feasibility and validation of our proposed path planning method. We first setup the experiment environment. Then we conduct experiments to evaluate the performance of our proposed method.

A. Mapping and Parameters setting

We drew a map with a length and width of 15 meters. The coordinates of the starting point we set are $[1,1]$, and the coordinates of the ending point are set to $[11,11]$. 50 obstacles are randomly added to the map. The constant of the gravitational potential field is $K_{att} = 40$, the constant of the repulsive potential field is $K_{rep} = 5$; the maximum distance value of obstacles that threaten the robot $\rho_o = 2$ meters.

B. Experiment environment setting up

The configuration of evaluation platform is follows:

CPU: Intel（TM） core i7 8750H CPU@2.20GHz, 8G RAM, Windows 10 64bit. Evaluation environment: Matlab R2018b.

C. Evaluation Metric

In order to evaluate the performance of the the artificial potential field method and A-star fusion algorithm, we define two evaluation standards as follows:

$$R_{length} = \frac{length_{fusion} - length_{reference}}{length_{reference}} \tag{10}$$

$$R_{time} = \frac{time_{fusion} - time_{reference}}{time_{reference}} \tag{11}$$

where R_{length} represents the index of the improvement on the fusion algorithm proposed in this paper and the reference method in terms of the path length. And R_{time} represents the index of the improvement on the fusion algorithm proposed in this paper and the reference method in terms of the calculating time. $length_{reference}$ is the path length generated by the reference method, and $length_{fusion}$ is the path length generated by the fusion algorithm proposed in this paper, $time_{reference}$ is the calculation time required for the path generated based on the reference method, $time_{fusion}$ is the calculation time required for the path generated based on the fusion algorithm proposed in this paper.

In order to better express the evaluation criteria we have established, we give an example to illustrate the sign of R. For example, $R_{length} > 0$ means that the path length generated by the fusion algorithm in this paper is $(100 \times R_{length})\%$ higher than that of the reference method. On the contrary, $R_{length} < 0$ means that the path length generated by the fusion algorithm in this paper is $(100 \times R_{length})\%$ lower than the path length generated by the reference method.

D. Reference methods

We use A-star algorithm, artificial potential field method and two other fusion algorithms [6, 7] as reference methods.

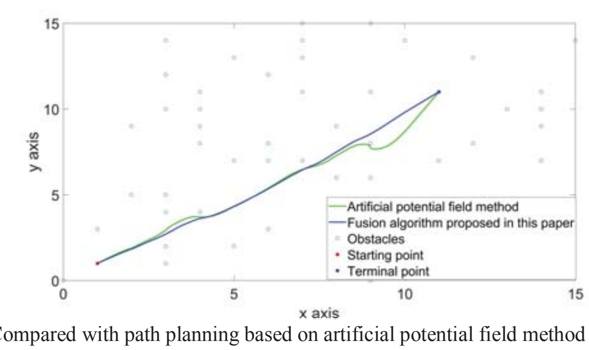
The method of reference [6] is to first use the A-star algorithm for planning to obtain the initial path, and then use each inflection point of the initial path as a sub-target point, and apply the improved artificial potential field method of local path planning to obtain the final path.

The method proposed by reference [7] is to use the global path planning A-star algorithm to obtain an initial path. On a sub-base, the local path planning artificial potential field method is used to obtain a local path and avoid obstacles. Together, we end up with an optimal path.

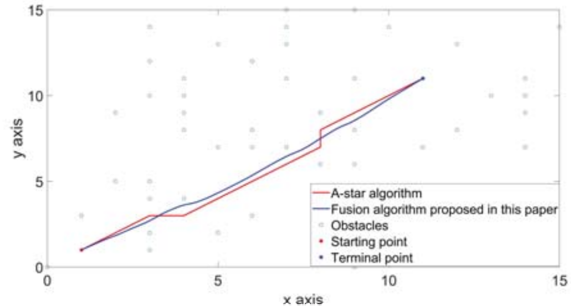
To compare their performance fairly, we do implement the reference methods completely.

E. The planning performance evaluation

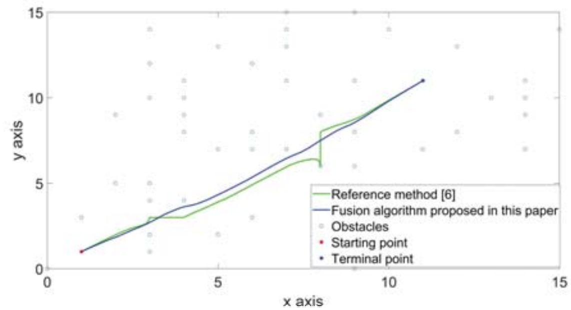
We utilize the methods of reference [6, 7], the A-star algorithm and the artificial potential field method to make path planning. First we calculate the length and calculation time of the path generated by each path planning algorithm. Then we will compare the path length they generated and the time required for path planning respectively. We give the path generated by each path planning method of Fig.3. We show the results of the comparison in terms of the path length of Table I. The results of comparison in terms of calculating time are presented in Table II.



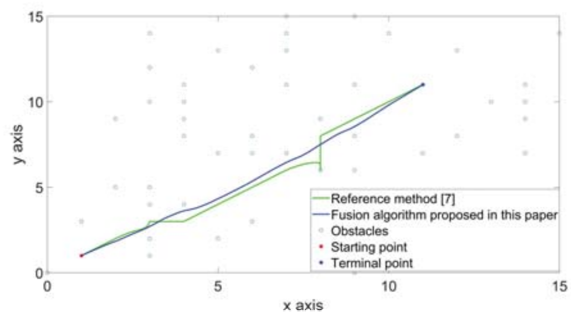
(a) Compared with path planning based on artificial potential field method



(b) Compared with path planning based on A-star algorithm



(c) Compared with path planning based on reference method [6]



(d) Compared with path planning based on reference method [7]

Figure 3. The path generated by the fusion algorithm in this paper is compared with other reference methods.

TABLE I. THE PLANNING LENGTH COMPARISON OF DIFFERENT METHODS

	A-star	Artificial potential field method	Reference method[6]	Reference method[7]	Fusion algorithm
Path length	14.7279(m)	15.0897 (m)	15.8056(m)	15.8767(m)	14.2182(m)
R_{length}	-3.46%	-5.78%	-10.04%	-10.45%	-

TABLE II. THE RESULTS OF COMPARISON IN TERMS OF PROCESSING TIME

	A-star	Artificial potential field method	Reference method[6]	Reference method[7]	Fusion algorithm
Processing time	2.1280(s)	0.7380(s)	2.6650(s)	2.3910(s)	3.3180(s)
R_{time}	55.92%	349.60%	24.50%	38.77%	-

From Fig.3 and Table I, we can see that the path generated by the proposed artificial potential field method and A-star fusion algorithm is shorter than other methods. More specifically, relative to A-star-based, artificial potential field method-based, reference [6]-based, and reference [7]-based method, the path length of our proposed method can be reduced at the scale of 3.46%, 5.78%, 10.04%, and 10.45%. This is because the method we proposed combines the excellent characteristics of the A-star algorithm and the artificial potential field method. When the fusion algorithm plans the path, it will be close to the path generated by the A-star algorithm, so the path length generated by the fusion algorithm must be shorter than the artificial potential field method.

Table II illustrates the processing efficiency of different methods. We evaluate the efficiency of the algorithm based on the processing time required to generate the path. It can be seen that our proposed method has a longer processing time than other methods. This is because it calculates several targets points more than references [6] and [7] when calculating gravity. However, we can find that the processing time required by the proposed fusion algorithm to generate a path is only 3.3180 seconds, allocate this time to the calculation time of each complement step, obviously the time will be shorter, which obviously meets the real-time requirements.

V. CONCLUSION

In order to solve the issue that the A-star algorithm cannot deal with dynamic obstacles and the path generated by the artificial potential field method is not optimal. We propose a fusion algorithm based on the artificial potential field method and A-star algorithm. Then we compare our proposed fusion algorithm with other related methods, the path generated by our proposed method is shorter than other methods, and also satisfies the requirements of handling dynamic obstacles and real-time. We perform simulation to evaluate the validation and feasibility of our proposed method. And the simulation results illustrate that the fusion algorithm proposed is effective and feasible. Moreover, the mobile robot platform we built by ourselves is not mature enough, so the next step is to consider making the above algorithm into a C++ project under Linux, and conduct actual experiments to evaluate the performance of our proposed algorithm.

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REFERENCES

[1] S. Sedighi, D. Nguyen and K. Kuhnert, "Guided Hybrid A-star Path Planning Algorithm for Valet Parking Applications," 2019 5th International Conference on Control, Automation and Robotics (ICCAR), Beijing, China, 2019, pp. 570-575, doi: 10.1109/ICCAR.2019.8813752.

[2] Shi Y, Yang J, Bu S, Zhu L. Intelligent vehicle path planning algorithm based on improved RRT [J]. Computing Technology and Automation, 2019, 38 (04): 81-86.

[3] Xu Y. Hybrid path planning of mobile robot combining particle swarm optimization and improved artificial potential field method [D]. Zhejiang University, 2013.

[4] Xu W. Artificial torque method for local path planning of mobile robots [D]. Dalian University of Technology, 2014.

[5] W. Seo, S. Ok, J. Ahn, S. Kang and B. Moon, "An Efficient Hardware Architecture of the A-star Algorithm for the Shortest Path Search Engine," 2009 Fifth International Joint Conference on INC, IMS and IDC, Seoul, 2009, pp. 1499-1502, doi: 10.1109/NCM.2009.371.

[6] Lin B. Research on path planning of handling robot based on improved A * algorithm and artificial potential field method [D]. Changan University, 2017.

[7] Xuan R. Research on intelligent car path planning based on improved A* algorithm and artificial potential field method [D]. Xidian University, 2019.

[8] Wang Y, Dai Z, Li T. UAV path planning based on A-star algorithm and artificial potential field method [J]. Journal of Yangzhou University (Natural Science Edition), 2019, 22 (03): 36-38 + 49.

[9] Ren Y, Fu L, Zhang Y, Mao J. Robot dynamic path planning based on smooth A * artificial potential field method [J]. Software Guide, 2018, 17 (01): 8-10.

[10] Sun J, Zhu Y, Lu J. Research on the path planning of manipulator arm based on artificial potential field method and A * algorithm [J]. Journal of Chengdu University of Information Technology, 2019, 34 (03): 263-266 .