Development of Modified Path Planning Algorithm Using Artificial Potential Field (APF) Based on PSO for Factors Optimization

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Development of Modified Path Planning Algorithm Using Artificial Potential Field (APF) Based on PSO for Factors Optimization

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Abstract

Solving the path planning problem considered as one of the most important aspects in the navigation of the robot, which should involve with any optimization method to get the best path. This paper presents a mixing approach of modified robot path planning, by applying first particle swarm optimization (PSO) to find the best values of Artificial Potential Field (APF) factors in order to make an iteratively enhancement till reaching the shortest path. This path will be smoothed by spline equation. The result clearly shows the high performance and strength of this mixed approach between the PSO method and APF.

Keywords: Artificial Potential Field; Particle Swarm Optimization (PSO); Path Planning.

1. Introduction

Motion planning is an important affair in robotics. In an environment which filled by obstacles, the purpose of path planning is to find an acceptable collision-free path to ensure the movement of the robot from the initial point to the final destination. Also is to locate a set of points for the robot to go away from the obstacles and prevent it from any possible collisions till reach the goal. The previous algorithms deal with path planning problems of robots by the navigation in a totally known environment filled with static obstacles [1-7].

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The artificial potential field (APF) technique is commonly applied for path planning to many types of robots. In the APF theory, the field of forces affect on the robot. The total force came by combination of to two types of forces: first type is the field of attractive force and second type is the repulsive field force. In this method, each obstacle can create a repulsive force to the robot which its magnitude is proportional inversely to the distance measured from the robot to the obstacles. If the distance greater than the influence area the force will not affect the robot otherwise if the robot in this area, then it will be repelled. The direction of all obstacles forces is pointing away from the robot. In the same time the target point has attractive force that has an effect in all the environment to attract the robot to the goal. The summation of these two force components will create a field with whole magnitude and direction in which the robot moves to the goal with avoiding any possible collision [8]. The potential function used in this method has two values, a minimum value, when the robot is very near or at the final destination and a highest value on each obstacle. The function tends down and converges the robot to the final destination [9]. Khatib's who gave the basic definition of the method in the configuration space where the minimum forces at the target point but the highest on the obstacles so the whole environment will represent as valleys which are the goals and hills which are obstacles. The goal point in the potential field is attract the robot while it is repelling by obstacles in the environment. The gradient has followed by the robot till reaching the target point and in the same time avoid any possible collisions with the obstacles [10]. A navigation method was proposed to find suitable path. The main idea behind this method is to combine the virtual obstacle with potential field to make the cylindrical mobile robot movement flexible in totally unknown environments.

The Simulation results of the experiments show acceptable performance and ability to find suitable solve to the commonly problem in Artificial Potential Field theory, especially the local minima problem. In the function of the classic artificial potential field approach, there is no optimization method was deal with [11]. An Evolutionary Artificial Potential Field (EAPF) for path planning introduced.

The artificial potential field theory in this method was combined with the genetic algorithm, to reach the best potential field functions. This proposed approach had the ability of pointing the robots that deal with dynamic obstacles. The functions of potential field for obstacles and target are also known which contain a changeable factors. The performance strength of this methodology is clear after taking in consideration the dynamic obstacles and dynamic goal [12].

2. Artificial potential field theory

In case of mass point let q referred to the robot position to move in a environment with two-dimension. The robot current position represented by q=[x y] while the position coordinate of obstacle denoted by q_{obs} =(x_{obs},y_{obs}), and the goal position is q_{goal} =(x_{goal}, y_{goal}),

2.1 Attractive Surface of Potential Field

The parabolic form is the very commonly style of potential field function. The attractive potential that grows up quadratic way proportional with the distance to the goal shown in (Figure 2).

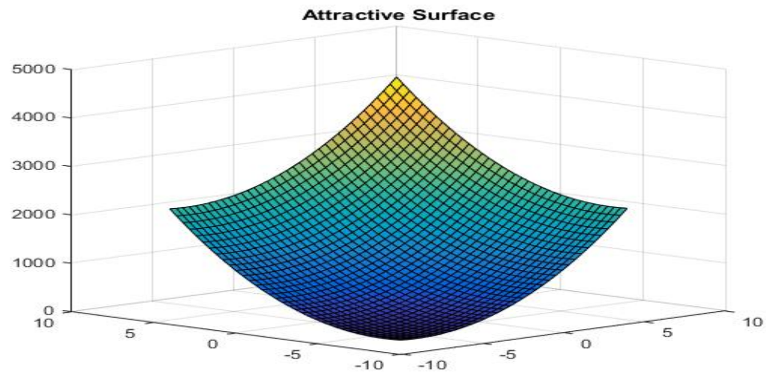


Figure 1: Attractive Surface

$$U_{att}(q) = \frac{1}{2}\ K_a\ \ d^2\ (q, q_{goal}) \qquad (1)$$

where K_a is the relative factor of the attractive potential surface , $d\ (q, q_{goal})$ is the Euclidean distance from the robot to the desired point (goal) q_{goal}. The attractive force is measured as the negative gradient of the attractive potential field:

$$F_{att}(q) = -\nabla U_{att}(q) = -\ K_a\ \ d(q, q_{goal}) \qquad (2)$$

2.2 Repulsive Potential Field

The repulsive force has a relative relationship between the distances of the obstacles to the position of robot. The repulsive potential surface was introduced by the repulsive forces of all the obstacles. The equations (3-4) represent the repulsive potential function and figure (2) shows the repulsive surface.

$$U_{rep}(q) = \sum_i U_{repi}(q) \qquad (3)$$

Where $U_{repi}(q)$ referred to the repulsive potential field created by obstacle *i*, where *i* is number of obstacles.

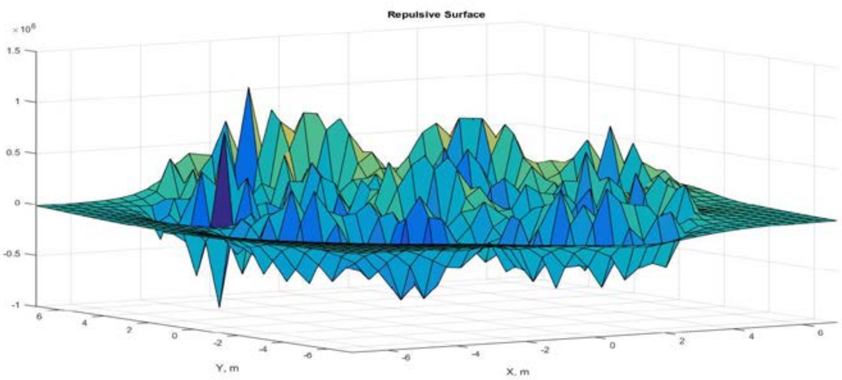


Figure 2: Repulsive Surface

$$U_{rep}(q) = \begin{cases} \frac{1}{2} K_{rep}\left(\frac{1}{d\,(q,q_{obs})} - \frac{1}{d_0}\right)^2 d\,(q,q_{goal})^n & if\ d\,(q,q_{obs}) < d_0 \\ 0 & if\ d\,(q,q_{obs}) > d_0 \end{cases} \quad (4)$$

Where q is the robot current position, n is a real integer number, the position of obstacle is q_{obs} and d_0 is the positive number referred to the distance of effective obstacle, the distance between the robot and the obstacles is $d\ (q, q_{obs})$ and the factor of the repulsive potential surface is K_{rep} which is an adaptable constant. The total repulsive force is negative slope as shown in equation (5) [13]:

$$F_{rep}(q) = -\nabla U_{rep}(q) = \begin{cases} K_{rep}\left(\frac{1}{d\,(q,q_{obs})} - \frac{1}{d_0}\right) \frac{(q,q_{obs})}{d^3(q,q_{obs})} & if\ d\,(q,q_{obs}) < d_0 \\ 0 & if\ d\,(q,q_{obs}) > d_0 \end{cases} \quad (5)$$

The combination of the two surfaces of attractive potential U_{att} and a repulsive potential U_{rep} result the total potential field. Which is represented by the equation (6).

$$U(q) = U_{att}(q) + U_{rep}(q) \quad (6)$$

All forces that applied to the robot is came by the negative gradient and use the steepest descent method to lead the robot direction to final destination.

$$F(q) = -\nabla U(q) = -\nabla U_{att}(q) - \nabla U_{rep} \quad (7)$$

Where the gradient vector of U is ΔU, the influence force that act on the robot is expressed as the summation of two components first one is the attractive vector and the second is the repulsive vectors force, F_{att} and F_{rep}, respectively. [14]

$$F(q) = F_{att}(q) + F_{rep}(q) \quad (8)$$

3. Particle swarm optimization method (pso)

The basic ideas of particle swarms, was to find computational intelligence by employing simple analogues of social interaction, rather than purely individual cognitive abilities. Searching for corn by bird swarm were the first samples of their simulation. The method after 5 years was developed till become more powerful. The number of particles was added to the research space to some cases and each one solves the problem function at own current location. The movement of each particle should measure its position in the search field, this done by summation of some information of the previous position and new position which may considered as the best locations with one or more members of the flocks. and with some random perturbations. After the total particles have been gone, the next iteration will take a place.

At the end flock totally, like a swarm of birds collectively foraging for food, it should search near the optimal place which represent the fitness function [15]. PSO play important role in path planning research. A Multi-robot cooperation was proposed to find the performance for some hard tasks can be developed by the collaboration between the robots in totally unknown environment. A group of robots search cooperatively to reach the goal points. The PSO fitness function is the potential function, in this research employs the PSO method to discover the unknown area, but even the appropriate cooperation not lead the robots to find the optimal path [16], Rainer Palm presence the safe navigation of multiple non-holonomic mobile robots in shared areas. Artificial potential fields used to avoid obstacle for mobile robots. and the attitude of mobile robots is optimized by particle swarm optimization (PSO).[17]

4. Proposed method: apf factors optimization based on pso

The first modification is on the force and its directions ,In The normal Artificial Potential Field the environment will be grid of points, every point in this grid has force that came from two sources the attractive force from the target point and repulsive force from the obstacle (if the points in the range of the influence) , and every point has two type of force one towards X axis and the other towards Y axis, some of researcher play with these forces to inforce the robot to find one lonely path with this equations :

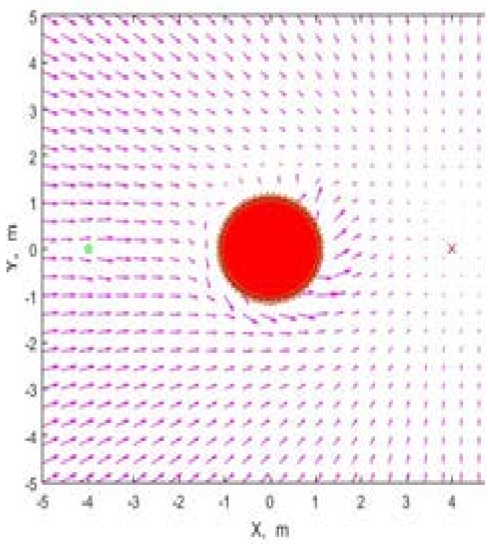
$$F_{x\_total} = F_{x\_att} + F_{x\_rep} + F_{y\_rep} \quad (9)$$

$$F_{y\_total} = F_{y\_att} + F_{y\_rep} - F_{x\_rep} \quad (10)$$

$$F_{x\_total} = F_{x\_att} + F_{x\_rep} - F_{y\_rep} \quad (11)$$

$$F_{y\_total} = F_{y\_att} + F_{y\_rep} + F_{x\_rep} \quad (12)$$

The equations (9,10) result (Figure 3) and equations (11,12) result (Figure 4) which shows that the forces in one direction around the obstacle as shown :



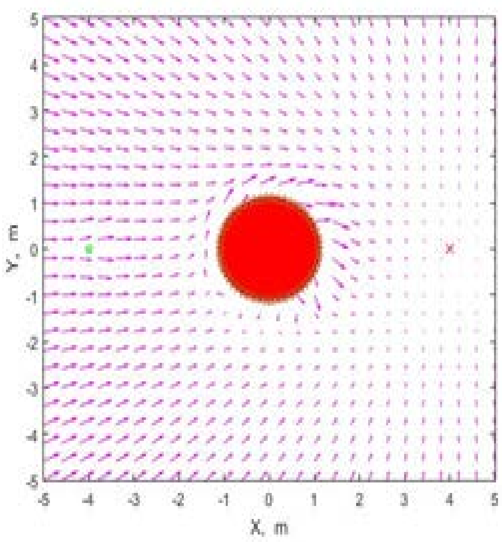


Figure 3 **Figure 4**

In this work proposed to remove the third term in equations (9-12) and add a term which found by try and error and it is suitable to these cases, the term was added to each equation to make the total force in X, Y axis goes towards goal and in the same time insure the path will be free collision as shown in equations (13,14) and figure (5)

$$F_{x\_total} = F_{x\_att} + F_{x\_rep} - 0.75 \quad (13)$$

$$F_{y\_total} = F_{y\_att} + F_{y\_rep} + 0.5 \quad (14)$$

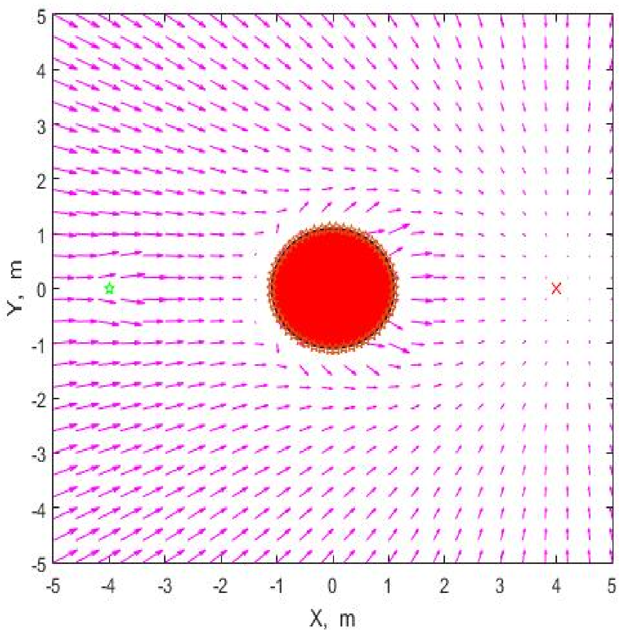


Figure 5

The second modification on the factors of APF, the attractive and repulsive factors (K_a,K_r) play an important role in the proposed potential field method. If the attractive value is very large, then only the effectiveness of the attractive force will take in account. On the other hand, if its value is small, then the attractive force will be ignored. However, there is no methodical technique to determine it. Therefore, the PSO is used to serve for this purpose, the repulsive factor has an effect in specific area, which is, represent the influence around the obstacle so it is important to be optimized, the mathematical expression of PSO is as the follow:

Lets suppose S represent the search domain, *n* referred to the particle number, the position of all particles represented by this vector $X_i = (x_{i1}, x_{i2}, \dots x_{iD})$, the global best position till now is $P_i = (p_{i1}, p_{i2}, \dots p_{iD})$,the best position in the all flock's represent as $P_g = (p_{g1}, p_{g2}, \dots p_{gD})$, the rate of changing the position by i_{th} particle is the vector $V_i = (v_{i1}, v_{i2}, \dots v_{iD})$. the particles update their positions according to the equation (15-16) [18]:

$$v_{id}(k+1) = w \times v_{id}(k) + c_1 \times rand(\,) \times (P_{id}(k) - x_{id}(k)) + c_2 \times rand(\,) \times (P_{gd}(k) - x_{id}(k)) \quad (15)$$

$$x_{id}(k+1)= x_{id}(k) + v_{id}(k+1) \qquad (16)$$

Where $c1$, $c2$ are positive constant factors called acceleration factores and w is called the inertia weight which represent the value given according to the equation (11):

$$w \leq 1 \qquad (17)$$

The cost function of PSO algorithm is the path length and defined as :

$$L= \sum_i ((pf_{path_{x(i+1)}} - pf_{path_{x(i)}}) + (pf_{path_{y(i+1)}} - pf_{path_{y(i)}}))^{0.5} \qquad (18)$$

Where $(pf_{path\,x}, pf_{path\,y})$ is the X,Y axis coordinate of the path .

The details of the determination of the attractive and repulsive factors can be summarized as follows

1- Define PSO Parameters, APF factors(K_a, K_{rep}) and their ranges.
2- Generate randomly factors within the proposed ranges.
3- Apply APF algorithm based on randomly generated factors as soon as APF construct and find possible path with the cost function calculation.
4- Update the local and best global factors of PSO algorithm according to acceptable path.
5- Repeat steps 2, 3, 4 for the selected number of particles.
6- Update the velocity and position equations for the next factors of APF

$$v_i(k+1) = w \times v_i(k) + c_1 \times rand()\times(P_{iatt}(k) - x_{iatt}(k)) + c_2 \times rand()\times(P_{gatt}(k) - x_{iattL}(k)) \qquad (19)$$

$$x_i(k+1) = x_i(k) + v_i(k+1) \qquad (20)$$

$$v_i(k+1) = w \times v_i(k) + c_1 \times rand()\times(P_{irep}(k) - x_{irep}(k)) + c_2 \times rand()\times(P_{grep}(k) - x_{irepL}(k)) \qquad (21)$$

$$x_i(k+1) = x_i(k) + v_i(k+1) \qquad (22)$$

Where the $P_{ia}$is the best position for the i_{th} particle for the attractive factors, x_{ia} is the current position, $x_{iaL}$is the local best position and the letters (att) refer to attractive factors, it is the similar definition to the equations (21-22) where the letters (rep) refer to repulsive factor.

7- Apply APF based on the updated values of the attractive and repulsive factors and calculate the cost function.
8- Update the local and global values to find the best global value for the factors.
9- Repeat the steps 6, 7, 8 for the updated factors according to number of population and number of iterations.
10- After find the Global values of each factor as the best value the corresponding generated path as best constructed path.

The flowchart explain the whole process :

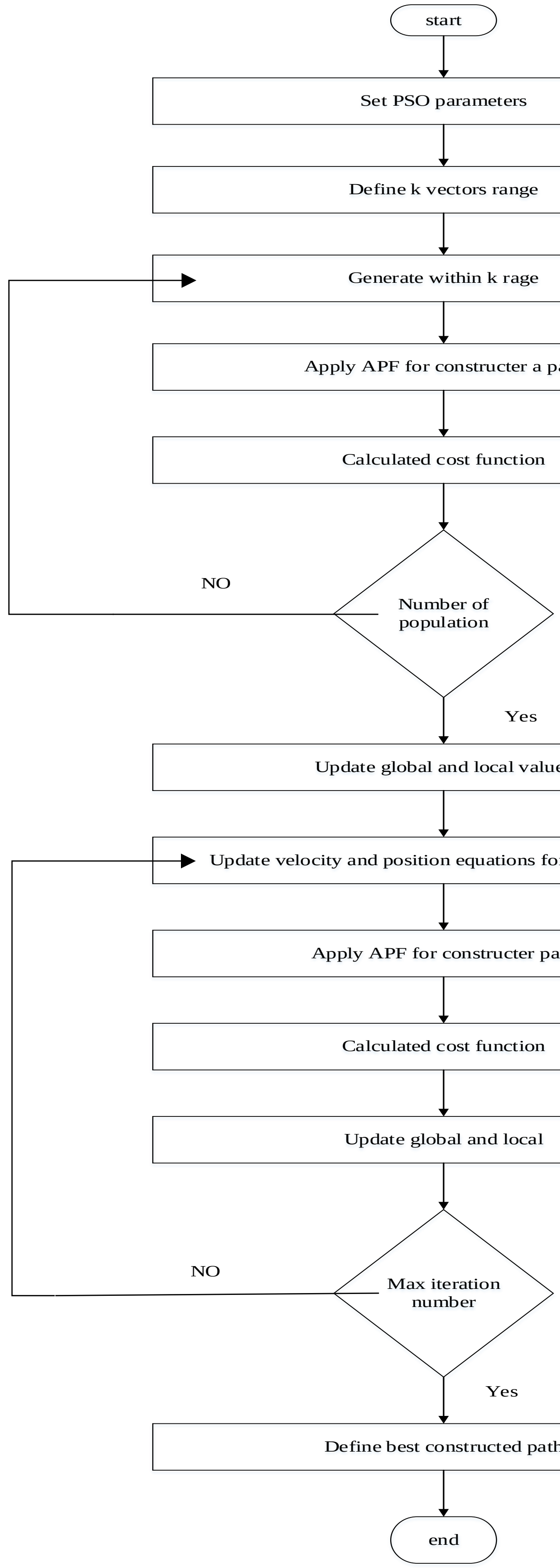


Figure 6

The final path that came from PSO (Global path) which have the shortest length will deal with spline equation , first the positions of via points will found by 'linspace' function they will be (6) points distributed along the path, the piecewise also created by the same function and they are (50) , these to vectors and the Global path are the input of spline to get the path shown in figures (7,9)

5. Simulation result

5.1 The First Proposed Environment

Figure (6) shows the first environment of robot navigation employing "Artificial Potential Field" as a path planning algorithm after optimization, and figure (7) shows the path after using spline method, in this proposed environment the robot goes from starting point (2,4) to goal (-1, -6) where seven stationery obstacles in the environment with 7 by 7 dimension:

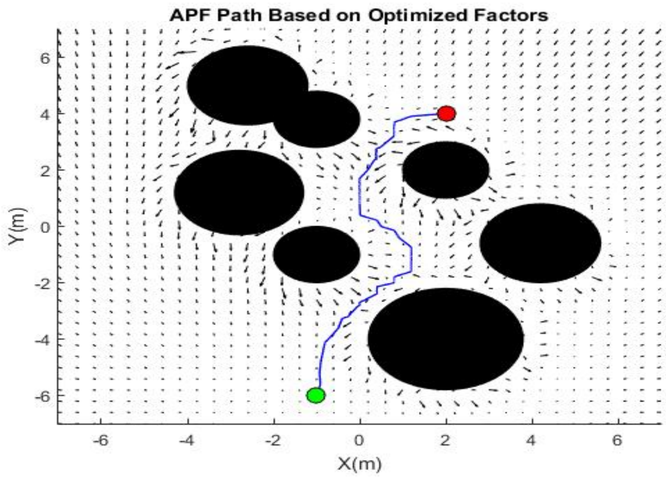


Figure 7

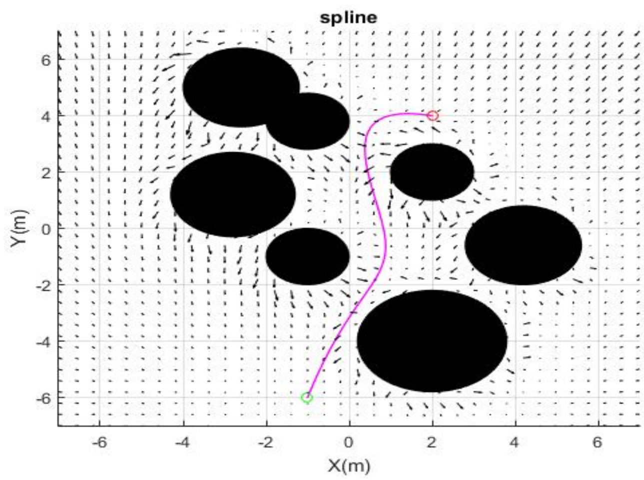


Figure 7

5.2 The Second Environment

Figure (8) represent the normal path of Artificial Potential Field but figure (9) is the smoothed path by spline method, this environment include seven static obstacles, the start point at (-6,6) and goal point is (6,-6), the dimension is 7 by 7

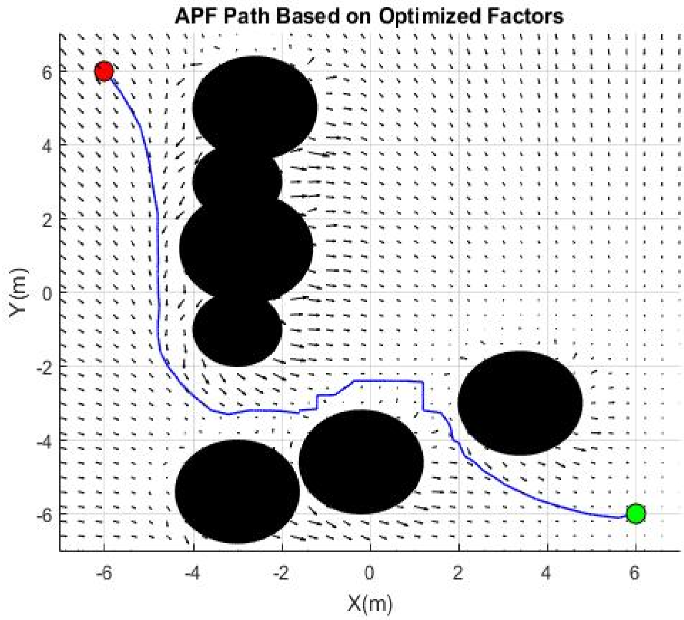


Figure 8

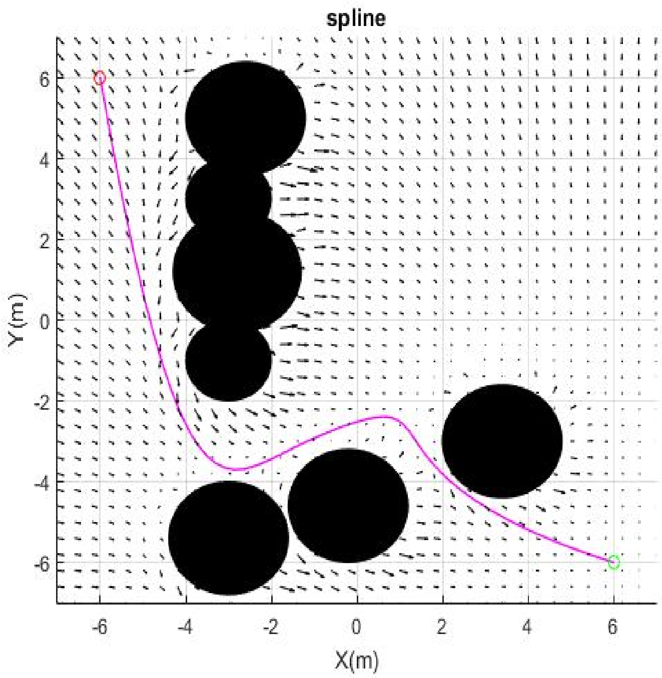


Figure 9

Table (1) explain the results of two environments in three cases

Table 1

Environment	1	2
Path length of APF(m)	15.9458	23.4030
Path length after optimization(m)	14.2544	22.4598
Path length after optimization and spline(m)	11.6636	20.0215
Suitable Range of attractive factor	(600-1100)	(1000-4000)
Suitable Range of repulsive factor	(5 – 20)	(20-40)
Number of populations	60	60
Number of Iterations	500	500

6. Conclusion

This paper presents an approach of modified path planning using APF and PSO. First by applying Particle Swarm Optimization method (PSO) to find best values of the Artificial Potential Field factors after each iteration of PSO the APF applied till reach the shortest path, this path will be smoothed by spline equation. The result clearly proves the advantage of using the mixed approach which is APF based on PSO for factors optimization. The length of the generated path after optimization processes was best and shortest path which traditional APF method could not find such a path.

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