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An investigated study on Potential Field methods for mobile robot path planning

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Abstract— **This paper deals with the path planning for autonomous mobile robot in cluttered and bounded environment. It focuses on a reactive path planning method which is the artificial Potential Field (PF). Its principle idea is to assimilate the robot to a particle subjected to an attractive force created by the target and repulsive force created by the obstacles. Several works have stemmed from this method to ameliorate the potential function performance such as the navigation function. The aim of this paper is to compare the traditional artificial PF with the navigation function and to investigate the performance of each method for well-chosen case studies. The performance criteria taken into consideration are: oscillations, obstacle avoidance, elapsed time, convergence to the goal and trajectory length. The advantages and shortcomings of each method are presented and discussed.**

Keywords—Path Planning; Autonomous robot; Potential Field method; navigation function; cluttered and bounded environment

I. INTRODUCTION

Path Planning is an important task for robot navigation. It aims to enable the robot to move from its starting point towards a destination point while avoiding obstacles encountered in his path [1-2]. Therefore, the basic function of the path planning is to compute a valid collision-free path when getting the robot to seek the goal. Several methods have been developed, typically classified into deliberative (local path planning) and reactive approaches (global path planning) [3].In the deliberative approach, information about the environment is already known using map, cells, grid etc. Firstly, this information are regrouped and stoked in the robot path planning program. Then, the path is constructed to join the initial point to the goal such us Visibility Graph [4], Voronoi Graph [5] and Cell Decomposition [6]. These methods are capable of finding the path in static environment if it exists. However, in dynamic environment, they can lose the effectiveness if an unpredicted obstacle appears suddenly in the path. This problem is a result of not including the obstacle information in the known map, so this requires a re-planning witch needs a high computational power and causes a slow response times. In the reactive approach, the robot's sensors and actuators generate directly the navigation behavior without using maps. Therefore, the robot has to sense the environment and then decides either to avoid obstacles or to generate path planning toward goal. Thus, this approach is real time obstacle avoidance since it takes into consideration contingency measures that may affect the safe navigation of the robot [7]. Artificial PF [8] is one of the successful reactive algorithms. It has been widely used for autonomous mobile robot path planning due to its elegant mathematical analysis. It is firstly proposed by Khatib in [8]. The main idea behind this approach is to assign an attractive potential field to the target to attract the robot, and a repelling potential field to the obstacles to repel it. The function in which these two potentials are combined represents the energy of the system. Being under the influence of the total force generated by the negative gradient of this energy, the robot moves to its destination while avoiding the obstacles on its way. Several works have stemmed from this approach. In [9], a virtual escape potential is introduced and activated once the robot is trapped in a local minimum. This method enhances the trajectory by raising the chances of reaching the goal, but does not eliminate the risk of being trapped in a local minimum situation. In [10] an adaptive PF approach is proposed for obstacle avoidance of unmanned aircrafts. For that, a rotating potential field around the obstacle is used. In [11], authors proposed an improved PF method in dynamic environment. This proposed method introduced velocity vector to PF which enables the robot to avoid obstacles while locate and track dynamic target. In [12], a combined strategy of the improved PF and navigation potential function is introduced to accelerate the convergence speed and optimize the path. In [13], a novel repulsive function of robot orientation and angular velocity is proposed to ameliorate the performance of avoiding obstacles. In [14] a deadlock free PF based path planning algorithm is presented. This method enables the robot to escape from deadlock and non-reachability problems of mobile robot navigation.

In this set-up, the traditional PF method [8] [17], and the navigation function [15-16] are to be investigated in a bounded environment with spherical obstacles, and a comparative study is done to evaluate the performance of each approach.

The outline of this paper is as follows: the traditional PF is defined in section II. The navigation function is given in section III. Simulation results and discussions are proposed in section IV. Finally, section V concludes this paper with some prospects.

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II. TRADITIONAL POTENTIEL FIELD

In this section we introduce the approach of traditional artificial PF which is firstly proposed by Khatib in [8]. The main idea is to assume that the robot is immersed in a total potential field generated by superposing two effects into one resultant force. These effects represent an attractive force created by the target and a repulsive force created by the obstacle. This combination of two forces is dedicated to control the motion of the robot in a safer path while avoiding obstacles.

A. Attractive potential function

The attractive field between the robot and its target is constructed to pull robot to the goal area. The attractive field $U_{att}(q)$ should increases as the robot rolls away from the goal (equation 1).

$$U_{att}(q) = \frac{1}{2} K_{att} \left\| q_{goal} - q \right\|^2 \qquad (1)$$

Where :

K_{att} is a positive parameter, $q_{goal} = (x_{goal}, y_{goal})^t$ is the position of the target,, q = $(x, y)^t$ is the position of the robot and $\left\| q_{goal} - q \right\|$ is the Euclidean distance between the robot and the target

Therefore, the force created by the goal is defined as :

$$F_{att}(q) = -\nabla U_{att}(q) = -\frac{\partial U_{att}(q)}{\partial q} \qquad (2)$$

$F_{att}(q)$ is a vector pointed toward q_{goal} with magnitude linearly related to the distance from q to q_{goal}

B. Repulsive potential function

The repulsive field between robot and obstacles is constructed to repel the robot from the bothering obstacles. However, when the robot is far from obstacles, robot's motion must be unaffected. The repulsive function [8] has the following equation (3)

$$U_{repi}(q) = \begin{cases} \frac{1}{2} K_{rep} (\frac{1}{d_i(q)} - \frac{1}{d_0})^2 & \text{if } d_i(q) \le d_0 \\ 0 & \text{if } d_i(q) > d_0 \end{cases} \qquad (3)$$

Where :

$U_{repi}(q)$ is the repulsive potential field of each individual obstacle i, K_{rep} is a positive parameter, d_0 is the influence distance of the obstacle, $d_i(q)$ is the distance from the robot to the closest point in each individual obstacle .

The force is the negative gradient of repulsive potential function as follows :

$$F_{repi}(q) = -\nabla U_{repi}(q) \qquad (4)$$

$$F_{repi}(q) = \begin{cases} K_{rep} (\frac{1}{d_i(q)} - \frac{1}{d_0})(\frac{1}{d_i^2(q)}) \nabla d_i(q) & \text{if } d_i(q) \le d_0 \\ 0 & \text{if } d_i(q) > d_0 \end{cases} \qquad (5)$$

Or,

$$\nabla d_i(q) = \frac{q - q_c}{\left\| q - q_c \right\|}$$

Where $q_c = (x_c, y_c)^t$ is the position of the closest point in the obstacle. If the environnement contains n obstacles, than the total repulsive potential field is:

$$U_{rep}(q) = \sum_{i=1}^{n} U_{repi}(q) \qquad (6)$$

The total potential function is obtained by superposing the attractive and the repulsive force:

$$U(q) = U_{att}(q) + \sum_{i=1}^{n} U_{repi}(q) \qquad (7)$$

Thus, the result potential force is:

$$F(q) = -\nabla U(q) = F_{att}(q) + \sum_{i=1}^{n} F_{repi}(q) \qquad (8)$$

The traditional artificial PF method can be used in real-time obstacle avoidance and trajectory control. However, it has fatal problems: When the robot is far away from the target, the attractive force will become very great. It makes the robot moving too close to the obstacles. Therefore, the robot has the risk of collision with obstacles. Moreover, when the position of the target is very close to obstacles, robot is not able to reach the target. This phenomenon is called Goals Non-Reachable with Obstacle nearby (GNRON). Also, when the attractive and the repulsive forces are equal but on the opposite direction, the potential force of robot is zero, then the robot will be trapped in local minima and strong oscillations appears. These disadvantages will be proved by simulation results in section VI.

III. NAVIGATION FUNCTION

The navigation function represents also another kind of a potential function [15-16]. It is introduced to solve some problems caused by the traditional PF. The gradients here are defined via distance functions. The navigation potential functions can be constructed as follows:

$$\gamma(q) = \frac{d^2(q, q_{goal})}{(d^{2k}(q, q_{goal}) + \beta(q))^{\frac{1}{k}}} \qquad (9)$$

Where: $$\begin{cases} \beta(q) = \prod_{i=0}^{n} \beta_i(q) \\ \beta_i(q) = \begin{cases} -d^2(q, q_{obsi}) + r_i^2 & if \ i = 0 \\ d^2(q, q_{obsi}) - r_i^2 & if \ i > 0 \end{cases} \end{cases}$$

r_i is the radius of the obstacle, q_{obs0} is the center and r_0 is the radius of the work space and k is a positive parameter.

The gradient of the navigation potential function is:

$$\nabla\gamma(q) = \frac{2(q-q_{obs})[d(q,q_{goal})^{2k}+\beta(q)]^{\frac{1}{k}}}{[d(q,q_{goal})^{2k}+\beta(q)]^{\frac{2}{k}}} - \frac{d^{2}(q,q_{goal})\frac{1}{k}[d(q,q_{goal})^{2k}+\beta(q)]\frac{1-k}{k}s(q)}{[d(q,q_{goal})^{2k}+\beta(q)]^{\frac{2}{k}}} \quad (10)$$

Where:

$$\begin{cases} s(q) = 2kd(q,q_{goal})^{2k-2}(q-q_{goal}) + \nabla\beta(q) \\ \nabla\beta(q) = \sum_{i=0}^{n}\nabla\beta_i(q)\prod_{j=0,\, j\neq i}^{n}\beta_j(q) \\ \nabla_i\beta(q) = \begin{cases} -2(q-q_{obs}) & if\ i=0 \\ 2(q-q_{obs}) & if\ i>0 \end{cases} \end{cases}$$

The parameter k makes the navigation function has the form of a bowl near to the goal. To have a successful free-path planning from a starting point to the goal position, the value of the parameter k must be well chosen. Fig 1 shows the effect of changing the parameter k for the case of having four obstacles in front of the robot and a goal position beyond the obstacles. It is clear that after a certain value of k (k =6), the navigation potential doesn't be effected.

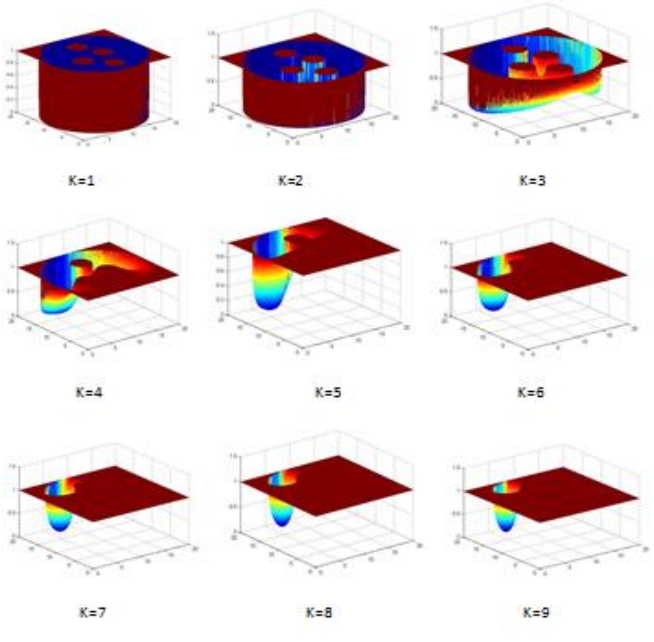


Fig1: Navigation potential functions with different value of k

Although the navigation function could solve the problem of local minimum and oscillation in most of the cases, it has some major problems: It requires an intensive calculation. Also, the performance in the term of real time is bad and the Local minimum problem in some situation is not solved. Moreover, there is no rule to choose the proper value of k .

IV. SIMULATION RESULTS

The traditional artificial PF and the navigation function are tested according to four different cases. The environment used for all cases is bounded by a sphere located at [10, 10] with a radius of 10. The environment contains also obstacles having spherical forms. We have chosen the required parameters for the two functions. For the traditional artificial PF: $K_{att}=0.5$, $K_{\mathrm{Re}\,p}=1$, $d_0=1$ and for the navigation function, the parameters are as follows: $k=1$ for the first case, $k=3$ for the third case and $k=2$ for the rest.

A. *Case : One-obstacle direct-free path*

In this case, the environment contains a unique obstacle located at [10, 10] with radius 2. The robot is initially placed at [8, 6] and the target has the coordinate of [15, 16].

1. *Traditional Potential function:*

In this simple case, the algorithm of path planning based on the traditional PF has succeeded in finding a direct-free path from the initial position to the end position without collision with the obstacle (Fig 2). As for Fig 3, it shows that repulsive forces change smoothly without sudden changes. The convergence time for the robot to reach the target is 0.248849 sec and the length of the path found is 12.8132 m.

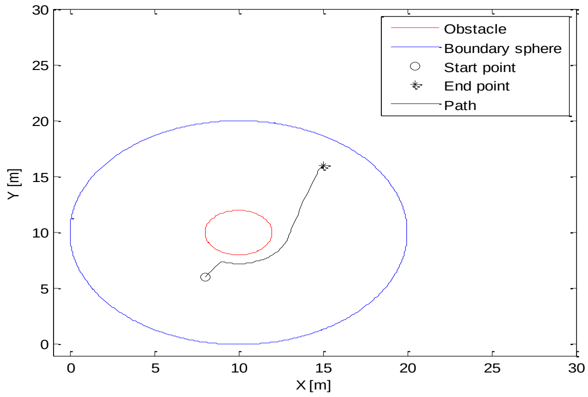


Fig 2: Robot trajectory in [O, X,Y] reference with the traditional PF

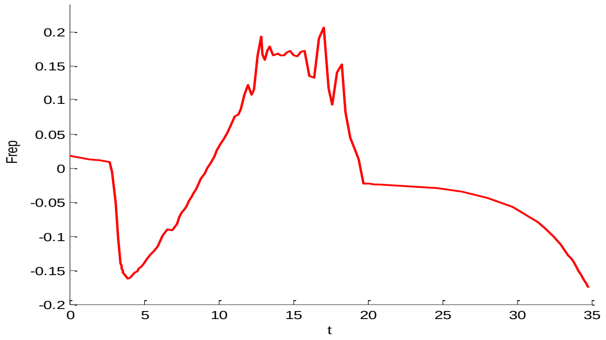


Fig 3: repulsive force with traditional PF

2. *Navigation function*

The navigation function enables the robot to reach its target without collision with the obstacle (Fig 4). The repulsive force which, repels the robot from the obstacle, changes smoothly without sudden change (Fig 5). The convergence time is 0.019787sec and the length of the path found is 20.5935 m.

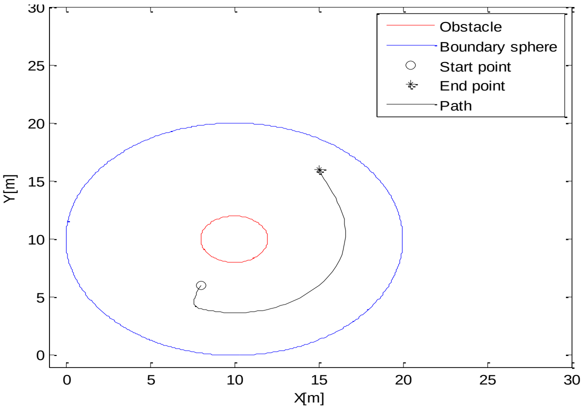


Fig 4: Robot trajectory in [O,X,Y] reference with the navigation function

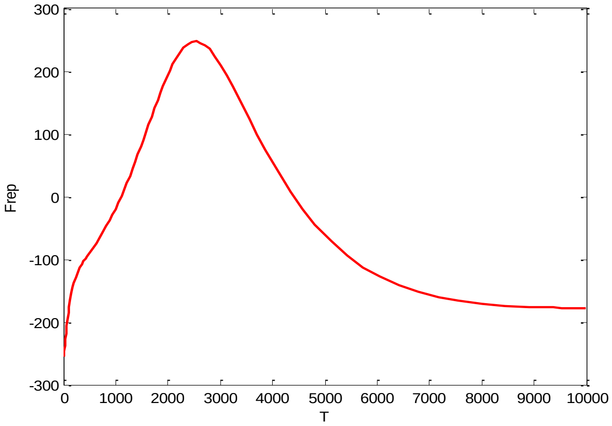


Fig 5: Repulsive force with the navigation function

B. *Case : two-obstacles direct-free path*

Now, we chose an interesting case where the environment contains two obstacles nearby. The first obstacle is located at [7, 10] and the second at [13, 12] with radius respectively 2 and 3. The robot is initially placed at [8, 2] and the coordinate of the target is [7, 18].

1. *Traditional Potential Field*

In this case, the algorithm of path planning using the traditional PF has given a free-direct path from the initial position to the target without collision with obstacles (Fig 6). However while avoiding both of the two obstacles, many oscillations appear at t= [20, 25] (Fig 7). The convergence time is 0.253439 sec and the length of the path found is 16.6339 m.

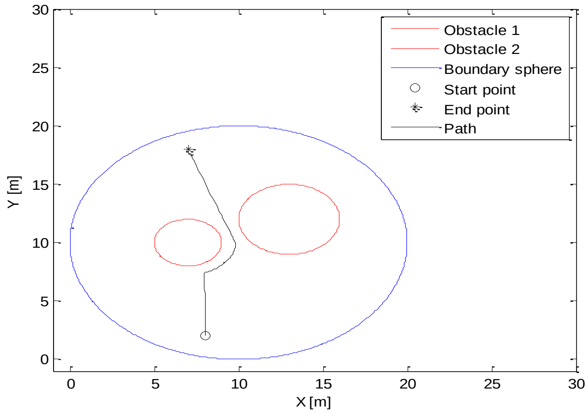


Fig 6: Robot trajectory in [O,X,Y] reference with the traditional PF

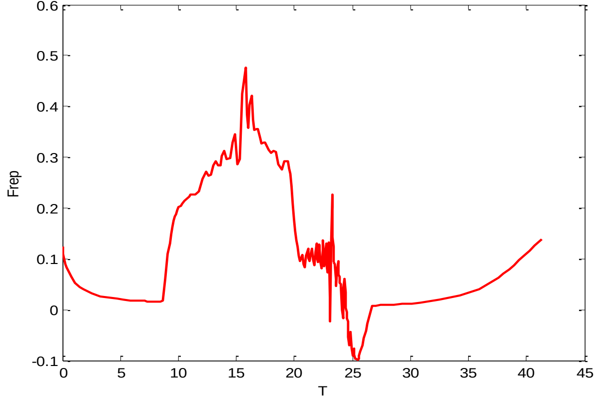


Figure 7: repulsive force with the traditional PF

2. *Navigation function*

By choosing a proper k, the navigation function enables the robot to reach its target without collision with obstacles nearby (Fig 8). The repulsive force which, repels the robot from the obstacle, changes smoothly without sudden change (Figure 9). The convergence time is 0.084496sec and the length of the path found is 28.1302m.

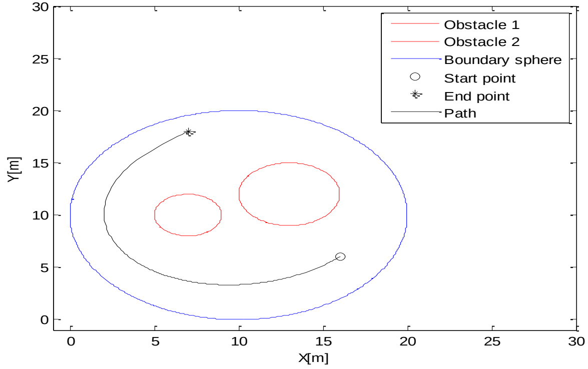


Fig 8: Robot trajectory in [O,X,Y] reference with the navigation function

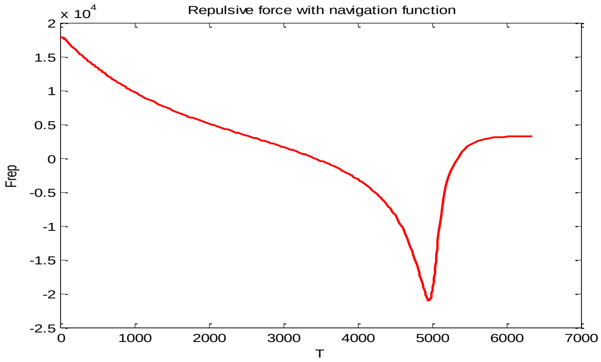


Fig 9: repulsive force with the navigation function

C. Case: three-obstacle direct-free path

This case presents another interesting situation where the environment contains three obstacles and the last obstacle is near the goal. The obstacles are located at [8, 8], [14, 8], [10, 15]. The robot is initially located at [8, 2] and the goal is at [10, 18].

1. Traditional Potential function

When using the traditional artificial PF, the robot avoids the two first obstacles with strong oscillation and then it trapped in local minimum (Fig 10 and Fig 11). This problem appears because the robot position at this point, the center of the obstacle and the target are aligned.

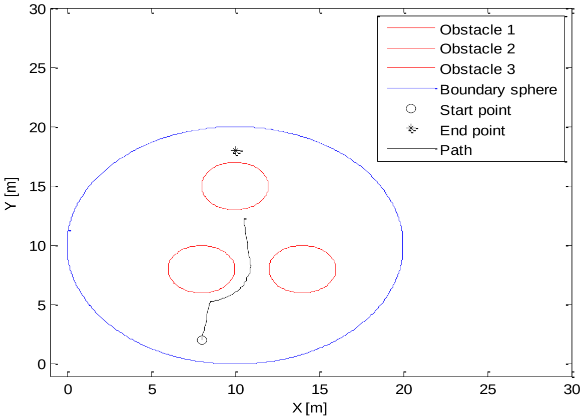


Fig 10: Robot trajectory in [O,X,Y] reference with the traditional PF

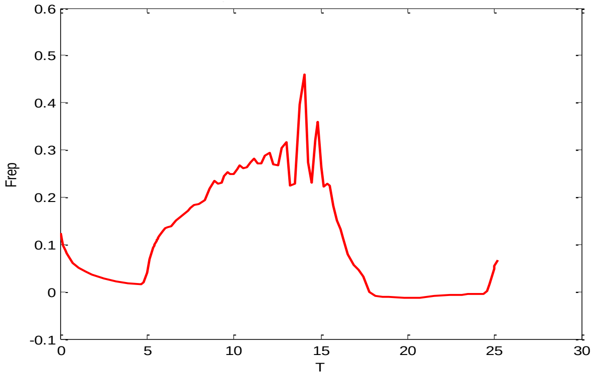


Figure 11: Repulsive force with the traditional PF

2. Navigation function

When using the navigation function in this case, the robot avoids all the obstacles and reaches the target (Fig 12). The path found is smooth without oscillations (Fig13) In this case, the convergence time using the traditional APF is 0.528094seconds and the length path is 28.6948.

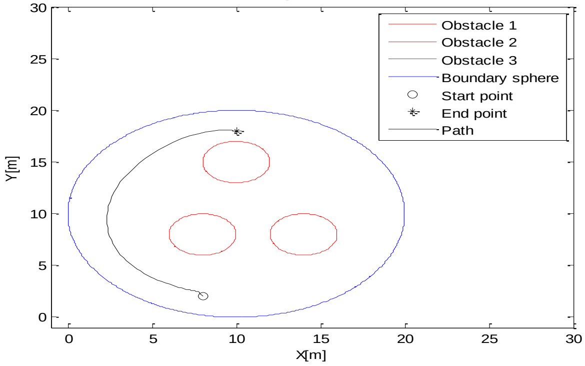


Fig12: Robot trajectory in [O,X,Y] reference with the navigation function

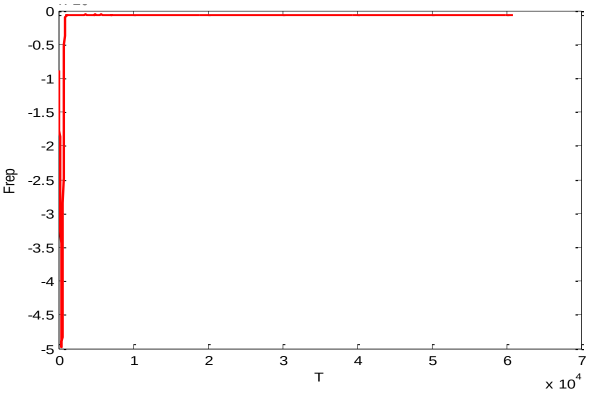
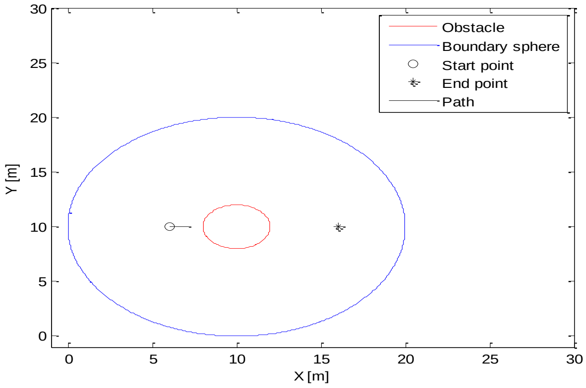


Fig 13: Repulsive force with navigation function

D. Case : Particular case

Now, the environment is built with a unique obstacle located on the direct line from the robot to the goal. In this case, the two potential functions fail to reach the target, and the robot is trapped in local minimum situation (Fig 14 and Fig 15).



Fie 14: Robot trajectory in [O,X,Y] reference with the traditional PF

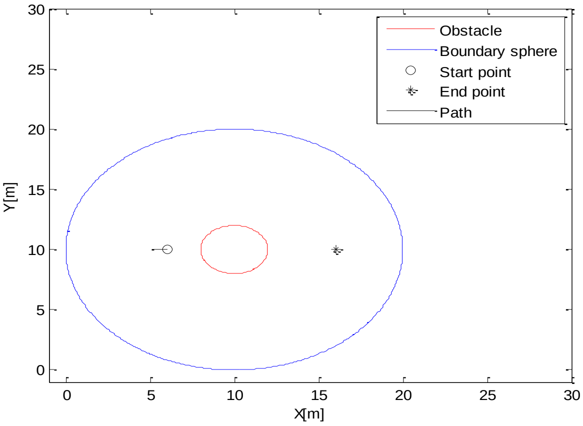


Figure 3: Robot trajectory in [O,X,Y] reference with the navigation function

E. Discussion

From all the previous simulations, we can notice that:

Navigation function succeeded in reaching the target and avoiding obstacles in all cases except in the last case where the robot, the obstacle and the target are aligned. In this case the robot trapped in local minimum. For the traditional PF ,it succeeded in reaching the target in the simple case and the second case where obstacles are nearby with oscillation. However in the third case when the obstacle is near the goal, the APF succeeded in avoiding only the two first obstacles and failed in reaching the target. For the last case the robot trapped in local minimumand can not reach the goal.

V. CONCLUSION

In this paper we have detailed and implemented two potential methods for path planning. Simulation results show the advantages and limits of each function. As it is seen, we can say that the navigation function is the most efficient for path planning in term of reaching target, avoiding obstacles and smooth path near obstacles. But it couldn't solve the problem of local minimum and the length of the path traveled is a little bit huge. In future works we aim to solve the problem of local minimum and optimize the path of the robot.

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