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Modified Potential Function for Obstacle Avoidance in an Unknown Environment

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Abstract: Path planning or navigation is one of the most important applications for robot control system. It involves computing a collision free path between start point and end point. In this study artificial potential field method is modified. First the new potential functions are defined and then motion planning algorithm based on the new potential field method is presented. Finally computer simulation is used to demonstrate the effectiveness of the motion planning scheme based on the new potential field method. This method is used to solve the drawbacks such as local minimaand oscillation problem.

Key words: Artificial potential field, navigation, obstacle avoidance, robot path planning, computer

INTRODUCTION

Path planning for autonomous mobile robots is necessary to automatically decide and execute robot motion without collision in order to perform certain task in a given environment. Although, many algorithms exit, the features that distinguish these algorithms are whether the environment is known or unknown and whether it is static or dynamic.

The environment in which all information about obstacles ispriory known is known environment. The path planning of the mobile is done from the given information. Some of the algorithms used in known environment for path planning of mobile robots include. Sub goal network (Sud *et al*., 2008), Algorithm using artificial intelligence, artificial potential field method (Khatib,1986), path planning by approximate cell de composition (Cai and Ferrai, 2009), real time re planning using D* algorithm (Stenz, 1995), navigation of mobile robot using triangular cell based map (Oh *et al*., 2004) and motion planning using unified approach and generalized voronoi diagrams (Tarjan, 1981 and Takahashi and Schilling,1989).

In unknown environment, robot does not have any knowledge about information or only partial information is known. In that case robot has to get the necessary information from the available sensors or use the partially available information to plan the path. Number of researches has been under gone for robot navigation in an unknown environment for instance, genetic algorithm, (Elshamli, 2004; Sedighi *et al*., 2004) simulated annealing (Blackowiak and Rajan, 1995) and ant colony algorithm (Dorigo and Gambardella, 1997; Garcia *et al*., 2009; Zhua *et al*., 2011).

This study presents a new efficient approach for autonomous mobile robot motion control and avoids collisions while reaching the desired point. The basic idea behind potential field method is to fill the robot's workspace with an artificial potential field in which the robot is attracted to its target position and is repelled away from the obstacles. In the artificial potential field method the potential force has attractive force and repulsive force. The combination of these two forces will generate a total force with magnitude and direction and the mobile robot should move in that direction to avoid collision and reach the desired path. The scalar function in artificial potential field method is a potential function. The function value is minimum when the robot is at target and the value is maximum on obstacles (Pimenta *et al*., 2005).

In Khatib first introduced artificial potential field method (Khatib, 1986). The artificial potential field is the sum of attractive potential field and repulsive potential field. The artificial potential field method uses a scalar function called potential function. When slopes down towards the target point so that the robot can reach the target by following the negative gradient of the total potential field. Although, APF has good and fast response it suffers from some draw backs in implementing it for real time applications. Under some situations the robot gets trapped into local minima problem and

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oscillations. Sgorbissa and Zaccaria (2012) discuss a hybrid approach in which the robot navigates in a partially unknown environment usingprior knowledge of environment with local perceptions. Dead lock condition is avoided but this method is relying on local perceptions and navigation strategies. To solve the dead lock problem robot regression and potential field filling is proposed by Qi *et al.* (2008) and Shi *et al.* (2010). In Hong *et al.* (2011) quantum particle swarm optimization is employed to modify the parameters of APF. Other kinds of improved artificial potential fields are investigated in (Donnart and Meyer, 1996; Sheng *et al.*, 2010; Bing *et al.*, 2011; Yang *et al.*, 2011).

In a new potential field method for motion planning of mobile robots in a dynamic environment where the target and obstacles are moving is proposed (Ge and Cui, 2002). The attractive potential field is defined as a function of the relative positive and velocity of the target with respect to the robot. The repulsive potential is also defined as the relative position and velocity of the robot with respect to the obstacles. Accordingly the virtual force is defined as the negative gradient of the potential with respect to position and velocity rather than position only.

All the above mentioned APF method and its improved methods still suffer from many draw backs such as high time complexity in high dimensions. Those methods do not completely solve local minima and oscillation which makes them inefficient in practice.

MATERIALS AND METHODS

Basic principles of artificial potential field method

Artificial potential field: Assume that the robot is of point mass in an artificial potential field. In artificial potential field method, a mobile robot is considered to be subjected to an artificial potential force. The artificial potential force has two forces. Attractive force, Repulsive force. The goal generates attractive force and attracts the robot to the goal. All obstacles in the environment generate repulsive force to the robot that is inversely proportional to the distance from the robot to the obstacles and is pointing away from obstacles. The combination of these two forces will generate a total force with magnitude and direction. The robot moves toward this direction to reach the goal without collision. Therefore the artificial potential field is defined as the resultant of attractive field and repulsive field.Thus the APF is defined as:

$$U(q) = U_{att}(q) + U_{rep}(q) \tag{1}$$

The position of mobile robot in the workspace is:

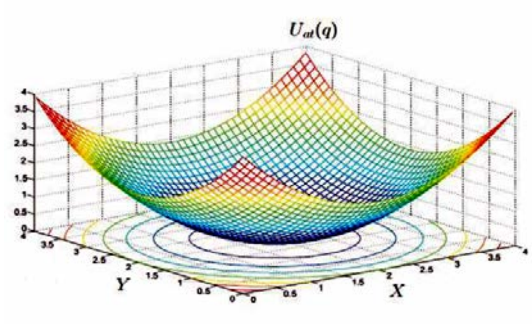

Fig. 1: Attractive potential field

$$q = (x, y)^T \tag{2}$$

The position of obstacle is:

$$q_{obs} = (x_{obs}, Y_{obs}) \tag{3}$$

The position of goal is:

$$q_{goal} = (x_{goal}, y_{goal}) \tag{4}$$

Attractive potential field: Figure 1 shows the attractive potential that grows quadratic ally with the distance to the goal. The attractive potential field is generated to attract the robot to reach the goal the artificial field created by the goal is given by:

$$U_{att}(q) = \frac{1}{2}k(q - q_g)^2 \tag{5}$$

$$U_{att}(q) = \frac{1}{2}k\rho_{goal}^2(q) \tag{6}$$

The k is positive co-efficient for artificial potential field.The location vector of target is:

$$q_{goal} = (x_{goal}, Y_{goal})^T \tag{7}$$

The Euclidean distance from location of robot to the position of target is:

$$P_{goal}(q) = \left\| q - q_{goal} \right\| \tag{8}$$

The attractive force on robot is calculated as the negative gradient of attractive potential field and takes the following form:

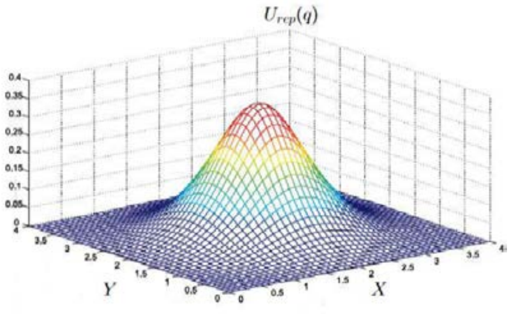

Fig. 2: Repulsive potential field

$$F_{att}(q) = -\nabla U_{att}(q) \tag{9}$$

$$F_{att}(q) = -\nabla \frac{1}{2} k \rho^2_{goal}(q) \tag{10}$$

$$F_{att}(q) = -k(q - q_{goal}) \tag{11}$$

The $F_{att}(q)$ is a vector directed toward q_{goal}. The components of $F_{att}(q)$ can be written as:

$$F_{att-x}(q) = -k(x - x_{goal}) \tag{12a}$$

$$F_{att-y}(q) = -k(y - y_{goal}) \tag{12b}$$

Repulsive potential field: Figure 2 shows repulsive force inversely proportional to the distance from the obstacle:

$$U_{rep}(q) = \begin{cases} 0, \quad \rho(q) \geq \rho_0 \\ \frac{1}{2}\eta\left(\frac{1}{\rho(q)} - \frac{1}{\rho_0}\right), \rho(q) \leq \rho_0 \end{cases} \tag{13}$$

The η is positive scaling factor. There is no impact for robot when the distance between robot and obstacle is greater than ρ_0. The repulsive force on robot is calculated as the negative gradient of repulsive potential field. The repulsive force is:

$$F_{rep}(q) = -\nabla U_{rep} q = \begin{cases} 0, \quad \rho(q) \geq \rho o \\ \eta\left(\frac{1}{\rho(q)}\right) - \left(\frac{1}{\rho_0}\right)\left(\frac{1}{\rho^2(q)}\right)\nabla\rho(q), \quad p(q) \leq \rho_0 \end{cases} \tag{14}$$

$$F_{rep}(q) = -\nabla U_{rep}(q) = \begin{cases} 0, \quad \rho(q) \geq \rho o \\ \eta\left(\frac{1}{\rho(q)}\right) - \left(\frac{1}{\rho_0}\right)\left(\frac{1}{\rho^2(q)}\right)\frac{q - q_{obs}}{\|q - q_{obs}\|}, \\ \rho(q) \leq \rho_0 \end{cases} \tag{15}$$

The $F_{rep.x}$ and $F_{rep.y}$ are the Cartesian components of the repulsive force F_{rep}. The components can be written as:

$$F_{rep}, x(q) = \begin{cases} 0, \rho(q) \geq \rho_0 \\ \eta\left(\frac{1}{\rho(q)}\right) - \left(\frac{1}{\rho_0}\right)\left(\frac{1}{\rho^2(q)}\right)\frac{x - x_{obs}}{\|q - q_{obs}\|}, \\ p(q) \leq \rho_0 \end{cases} \tag{16}$$

$$F_{rep}, x(q) = \begin{cases} 0, \rho(q) \geq \rho_0 \\ \eta\left(\frac{1}{\rho(q)}\right) - \left(\frac{1}{\rho_0}\right)\left(\frac{1}{\rho^2(q)}\right)\frac{y - y_{obs}}{\|q - q_{obs}\|}, \\ \rho(q) \leq p_0 \end{cases} \tag{17}$$

The total repulsive potential field is the sum of all obstacle‘ repulsive potential field. Total artificial potential is:

$$U(q) = U_{att}(q) + \sum_{i=1}^{n} U_{rep}(q) \tag{18}$$

Artificial force function: The total artificial force that is applied to the mobile robot is calculated by the negative gradient of APF which is the steepest descent direction for guiding robot to target point:

$$F(q) = -\nabla U(q) \tag{19}$$

$$F(q) = -\nabla U_{att}(q) - \nabla U_{rep}(q) \tag{20}$$

$$F(q) = F_{att}(q) + \sum_{i=1}^{n} F_{rep}(q) \tag{21}$$

Inherent limitations of artificial potential field method for robot path planning: The potential force of robot will become zero when the attractive force and repulsive force is equal and collinear but on the opposite direction. This will lead to local minima and oscillations similarly the robot cannot reach the goalwhen it is located near to obstacles.

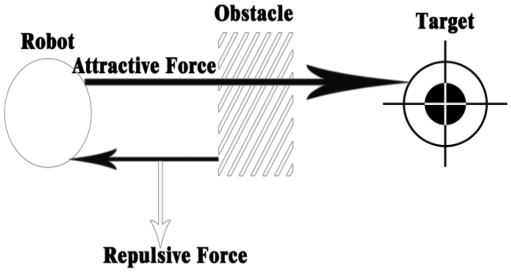

Fig. 3: The Robot is far away from target

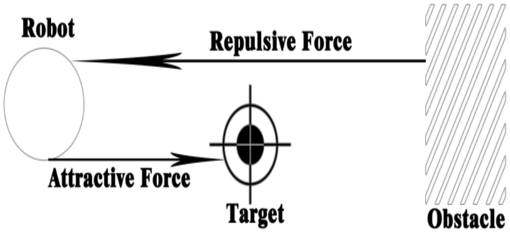

Fig. 4: The Robot Non reachable Target

Realization of modified artificial potential method: When Robot is Far Away From Target the value of attractive field depends on $p_{goal}(q)$, distance between robot and target. So when target is located very far away from robot (Fig. 3), the attractive force will become very large. Then due to error in path planning the robot may easily collide with obstacles. The attractive field and attractive force may be modified to avoid collision. The modified attractive field and modified attractive force are:

$$U_{att}(q) = \begin{cases} \frac{1}{2}k\rho_{goal}^{2}(q), \rho_{goal}(q) \le d \\ dk\rho_{goal}(q), \rho_{goal}(q) \ge d \end{cases} \quad (22)$$

$$F_{att}(q) = \begin{cases} -k(q - q_{goal}), \|q - q_{goal}\| \le d \\ \frac{-dk(q - q_{goal})}{\|q - q_{goal}\|}\|q - q_{goal}\| \ge d \end{cases} \quad (23)$$

Where:

d = Positive coefficient for attractive field

Robot non reachable target: When the distance between robot and target is less than $d_{obstacle}$ and the distance between target and the robot is d_{goal} then the robot experiences only attractive field and attractive force (Fig. 4). This method is named as repulsive force disappearance method. The modified potential field and potential force are:

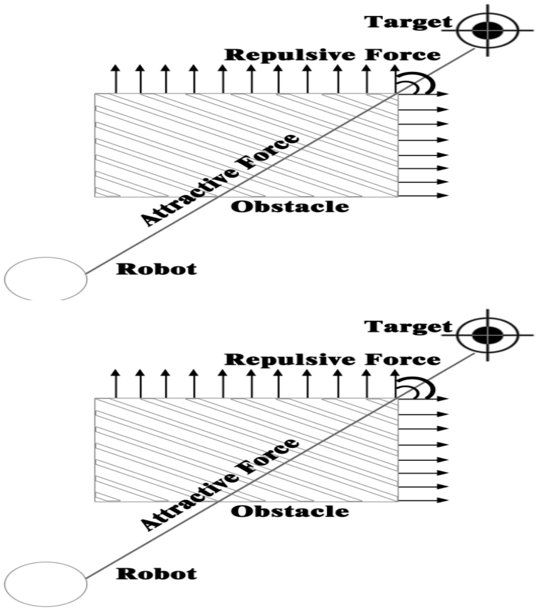

Fig. 5: Polygonal obstacle

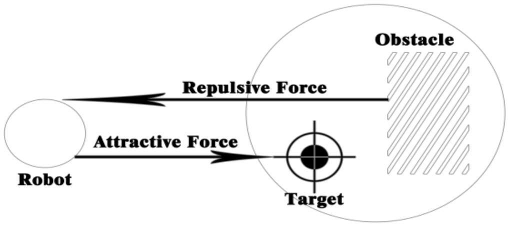

Fig. 6: Goals non reachable with obstacle nearby problem

$$U(q) = \begin{cases} U_{att}(q) + U_{rep}(q), U_{att}(q), \text{ other} \\ \rho(q) \le d_{obstacles} \text{ and} \rho_{goal} \le \end{cases} \quad (24)$$

$$F(q) = \begin{cases} F_{att}(q) + F_{rep}(q), F_{att}(q), \text{ other} \\ \|q_g - q_{obs}\| \le d_{obstacles} \text{ and} \\ \|q - q_{goal}\| \le d_{goal} \end{cases} \quad (25)$$

Polygonal obstacle: In the existing artificial potential field method the repulsive field about vertex of polygonal obstacle (Fig. 5) is not defined. In this method the repulsive field about vertex of polygonal obstacles is defined and the direction is the tangential line of semicircle.

Goals non reachable with obstacle nearby problem: In this case the target is located within the effective region of an obstacle (Fig. 6) so the repulsive force will push the robot

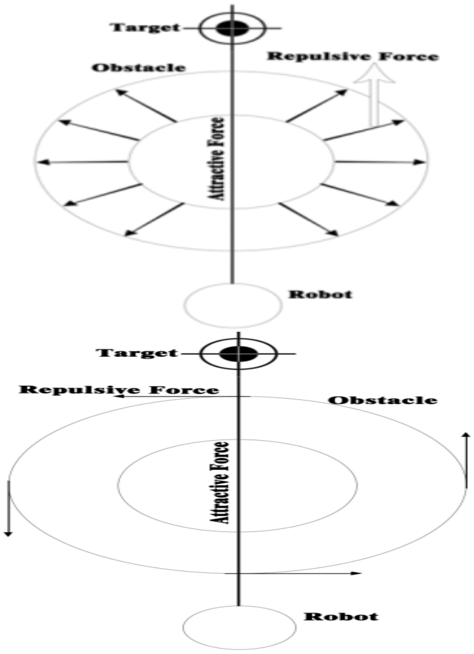

Fig. 7: Circle obstacle

away from the target and the robot cannot reach the goal.The repulsive force to the robot is inversely proportional to the distance from the robot to the obstacles and is pointing away from the obstacles

The total force at target point is not global minimum and so the robot cannot reach the goal. Hence, the repulsive potential field is modified by considering the distance between the robot and goal in the repulsive force function to provide global minimum at goal point.

$$U_{rep}(q) = \left\{ \frac{1}{2}\eta\left(\frac{1}{\rho(q)} - \frac{1}{\rho_0}\right)\rho^{n}_{goal}(q), \right. \quad (26)$$

$$\rho(q) < \rho_0,\ 0, \rho(q) > \rho_0$$

Where is a real number greater than 0. When the mobile robot is nearer the goal, the attractive potential field is reducing and the repulsive field is also reducing accordingly. When the robot reaches the goal point then the attractive force and repulsive force is zero. The composition of repulsive force can be written as:

$$F_{rep}(q) = -\nabla U_{rep}(q) = \begin{cases} F_{rep1} + F_{rep2}, p(q) < p_o \\ 0, \qquad p(q) < p_o \end{cases} \quad (27)$$

The F_{rep1} and the F_{rep2} are the decomposition of F_{rep}. The direction F_{rep1} represents the mobile from the point which is closest to the robot. The F_{rep2} represents the goal from the mobile robot:

$$F_{rep1}(q) = \frac{\eta\left(\frac{1}{\rho(q)} - \frac{1}{po}\right)\left(\rho^{n}_{goal}(q)\right)}{\rho^{2}(q)} \quad (28a)$$

$$F_{rep2}(q) = \eta\frac{n}{2}\left(\frac{1}{\rho(q)} - \frac{1}{\rho_0}\right)\left(\rho^{n-1}_{goal}(q)\right) \quad (28b)$$

Circle obstacle: The direction of repulsive field of circle obstacle (Fig. 7) is also modified.

RESULTS AND DISCUSSION

Simulation environment: Comprehensive simulation studies are carried out to validate the effectiveness and efficiency of the potential conformation. The simulation is carried out using MATLAB. The environment is a square of size 30×30 m. The coefficient k for calculating attractive potential field is 0.3. When robot is far away target, we set positive coefficient d as 3.The positive scaling factor of repulsive field $\eta$is 2. The largest impact distance for mobile robots from obstacles p_0 is 0.5. The $d_{obstacle}$ is distance between obstacles and target is 0.4 and the d_{goal} is distance between target and robot is 0.6 to solve the goal non-reachable problem.

Trajectory of robot to reach goal: The simulated environment is shown in Fig. 8, 10 and 12. The trajectory of robot is shown in Fig. 9, 11 and 13. The path generated by the proposed approach has various favorable features such as freedom from local minima compared with the existing artificial potential field method. The existing APF method will be inaccessible to target because of large obstacles near the target point. But, the proposed APF method can be very good at avoiding the obstacles to reach the target point. These experiments have amply demonstrated the modified potential field method advantages in reducing the shortcomings of existing method for robot path planning.

Simulation results: Fig. 14-16 shows the simulation result of the three environment. Compared to the proposed and existing methods the navigation time is reduced in proposed method. This improvement is mainly due to the reduction in the number of iterations performed. The navigation time is reduced by reducing the possibility of collision with close obstacles. Table 1 and 2 shows the performance of proposed method with respect to the existing method.

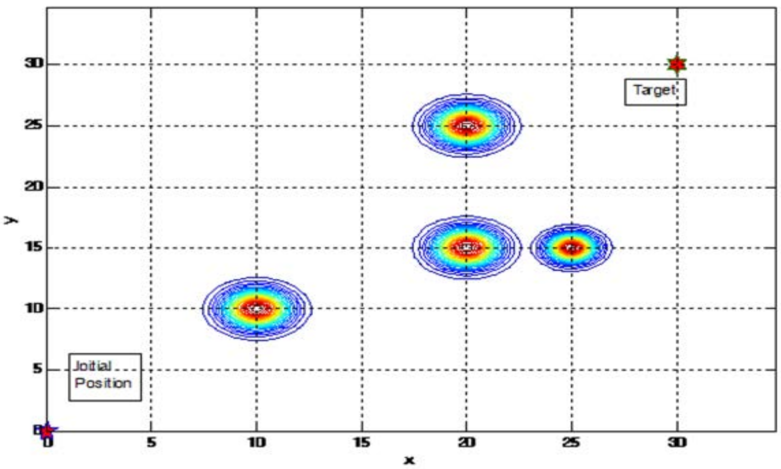

Fig. 8: Simulated environment 1

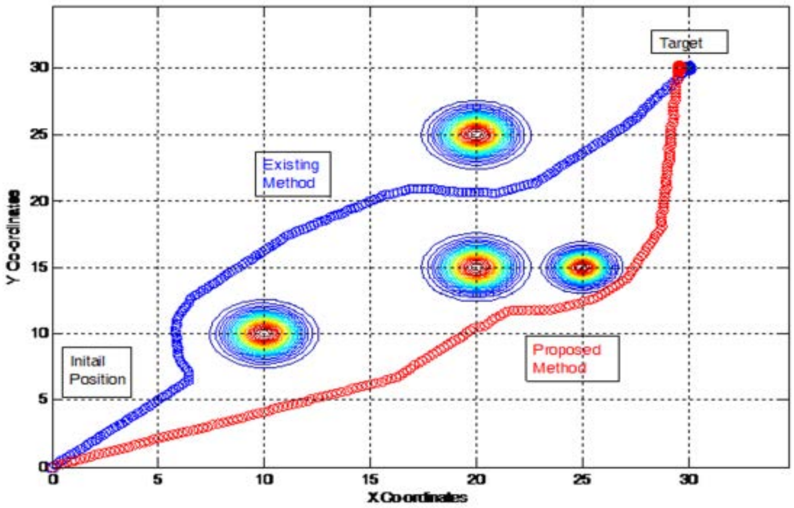

Fig. 9: Trajectory of robot in environment 1

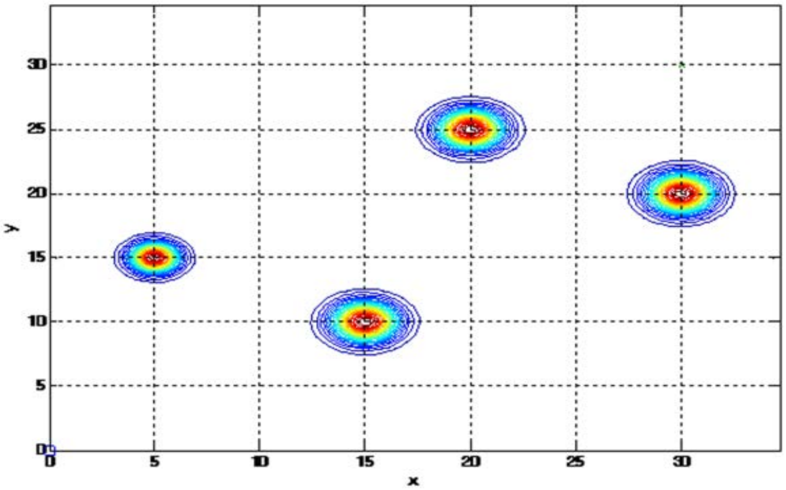

Fig. 10: Simulated environment 2

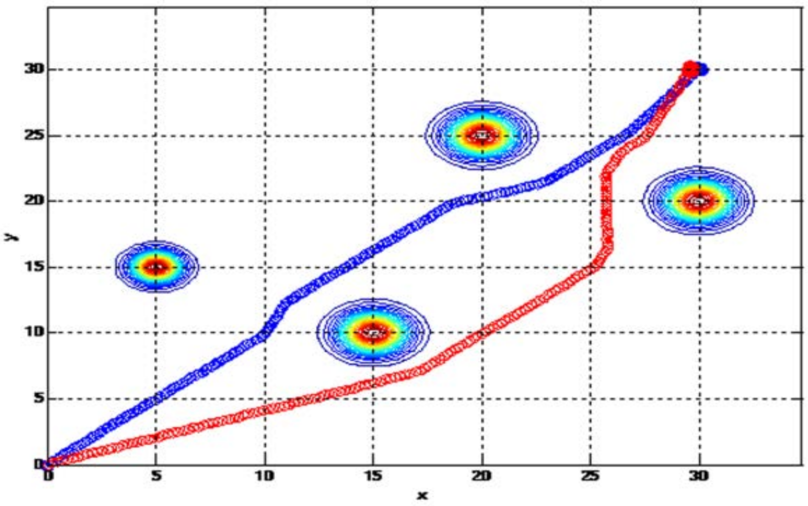

Fig. 11: Trajectory of robot in environment 2

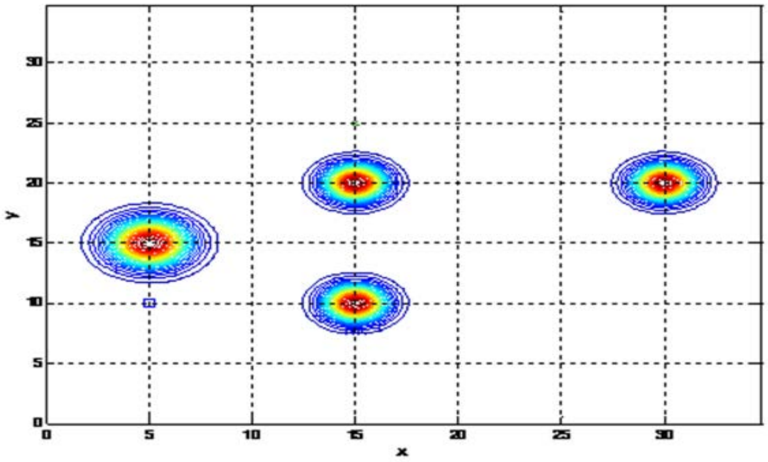

Fig. 12. Simulated environment 3

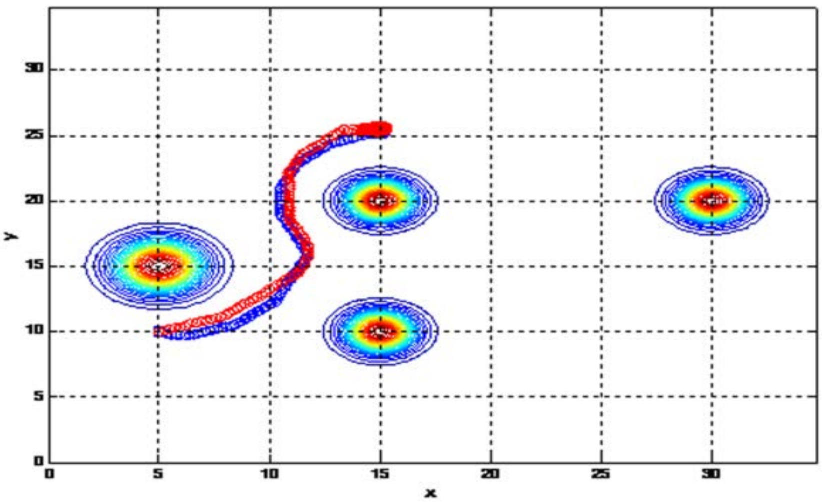

Fig. 13: Trajectory of robot in environment 3

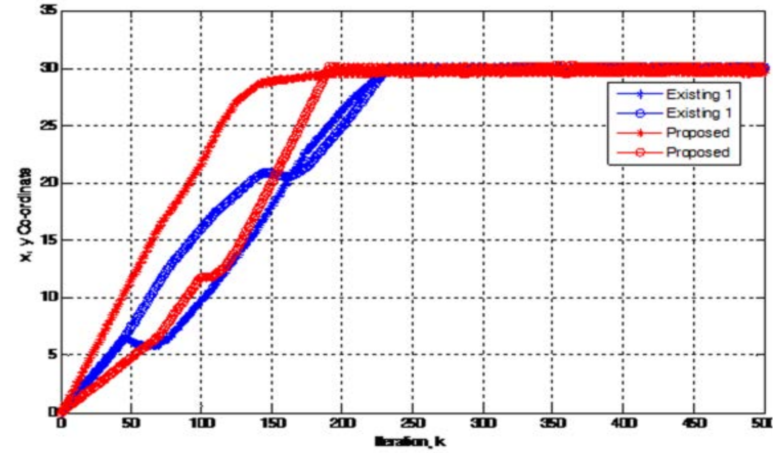

Fig. 14: Simulation result of environment 1

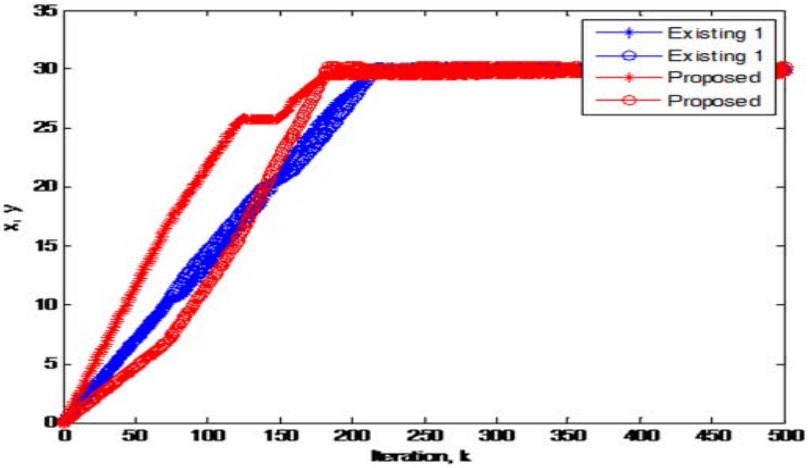

Fig. 15: Simulation result of environment 2

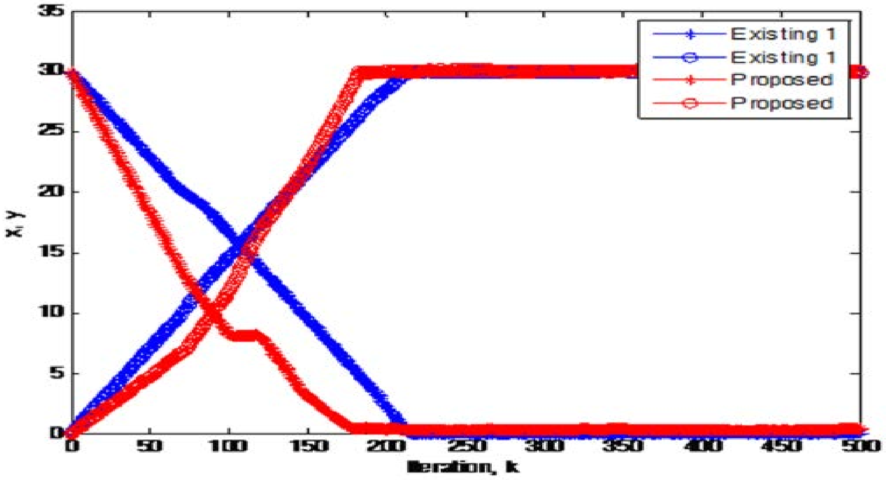

Fig. 16: Simulation result of environment 3

Table 1: Performanace of existing method

Variables	Environment 1	Environment 2	Environment 3
No. of iterations	200	190	180
Total navigation time (Seconds to reach goal)	400	380	360

Table 2: Performanace of proposed method

Variables	Environment 1	Environment 2	Environment 3
No of iterations	150	160	170
Total navigation time (Seconds to reach goal)	300	320	340

CONCLUSION

In this study a modified artificial potential method has been proposed for mobile robot path planning in a static environment where both the goal and the obstacles are fixed. The path generated by the proposed approach has various favorable features such as freedom from local minima, smoothness and collision avoidance. The simulation result shows the effectiveness of mobile robot motion planning schemes based on this modified Artificial Potential Field method. This method is mainly used to solve the local minima and oscillation problem without considering the optimal path. Finally best or better paths are the work need to be done in the future.

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