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Potential field method to navigate several mobile robots

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Abstract Navigation of mobile robots remains one of the most challenging functions to carry out. Potential Field Method (PFM) is rapidly gaining popularity in navigation and obstacle avoidance applications for mobile robots because of its elegance. Here a modified potential field method for robots navigation has been described. The developed potential field function takes care of both obstacles and targets. The final aim of the robots is to reach some pre-defined targets. The new potential function can configure a free space, which is free from any local minima irrespective of number of repulsive nodes (obstacles) in the configured space. There is a unique global minimum for an attractive node (target) whose region of attraction extends over the whole free space. Simulation results show that the proposed potential field method is suitable for navigation of several mobile robots in complex and unknown environments.

Keywords Mobile robots · Potential field method · Obstacle avoidance · Target seeking · Navigation

1 Introduction

Automatic path planning is an important aspect of the development of autonomous robots. Path planning is about motions of a robot in order to go from some initial configuration to a final configuration and in doing so without colliding with physical objects present in its workspace. By embedding real-time path planners in robot controller considerable amount of computational burden can be overcome. A robot moving in accordance with Newton's laws in a potential field will never hit the obstacle. The potential field approach uses a scalar function called the potential function. It has a minimum value, when the robot is at the goal configuration and has a high value on obstacles. Anywhere else, the function slopes down towards the goal configuration, so that the robot can reach the target by following the negative gradient of the potential field. The high value of the potential field prevents the robot going near the obstacles.

Potential field methods, introduced by Khatib [1], are widely used for real time collision free path planning. In this technique the robot gets stuck at local minima before attaining the goal configuration. Borenstein et al. [2] have developed a real-time obstacle avoidance approach for mobile robots. The navigation algorithm takes into account of dynamic behavior of a mobile robot and solves the local minimum trap problem. The repulsive force is much larger than the attractive force being considered by them. In other words, the target position is not a global minimum of the total potential field. Therefore the robot cannot reach its goal due to the obstacle nearby. Garibotto et al. [3] have proposed a potential field approach for local path planning of a mobile robot in telerobotics context, that is, with the presence of a human operator in the control loop at a supervisory level.

Kim et al. [4] developed a new function in artificial potential field by using harmonic functions that eliminate local minima for obstacle avoidance problem of a mobile robot in a known environment. Rimon et al. [5] have presented a new methodology for exact robot motion planning and control unifying kinematic path planning problem and the lower level feedback controller design. They validate their results in simulation mode. Ratering et al. [6] have proposed hybrid potential field method to navigate a robot in situations

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in which the environment is known. They have tested their techniques in real as well as simulated mode. Gulder et al. [7] have discussed a suitable control for tracking the gradient of an artificial potential field. However such functions are usually plagued by local minimas. Al-Sultan et al. [8] have introduced a new potential function for path planning that has the remarkable feature of no local minima.

Yun et al. [9] have analysed a wall following action using potential field based on motion planning method. They have demonstrated the usefulness of their method in simulation and experimental mode. Chuang et al. [10] have presented analytical tractable potential field model of free space. They have used Newtonian potential function for collision avoidance between object and obstacle. McFetridge et al. [11] have used artificial potential field (APF) method for obstacle avoidance. Their APF is variable, which is used to determine the importance of each obstacle on the robot's path. Sekhawat et al. [12] have developed a technique based on holonomic potential field taking into account the nonholonomic constraints of the system. Liu et al. [13] have presented a navigation algorithm, which integrates virtual obstacle concept with a potential-field-based method to maneuver cylindrical mobile robots in unknown environments. Their study focuses on the real-time feature of the navigation algorithm for fast moving mobile robots. They mainly consider the potential-field method in conjunction with virtual obstacle concept as the basis of their navigation algorithm. They have shown their results in simulation and experiment modes.

Wang et al. [14] have presented a new artificial potential field method for path planning of non-spherical single-body robot. The optimal path problem is calculated as per the heat flow with minimal thermal resistance. Park et al. [15, 16] have presented the mobile robot path planning technique that integrates the artificial potential field approach with simulated annealing. Song et al. [17] have described a framework for controlling and coordinating a group of robots for cooperative manipulation tasks Xi-yong et al. [18] have presented a robot navigation algorithm with global path generation capability. Their algorithm prevents the robot from running into local minima. Simulation results show that the algorithm proposed by the author is very effective in complex obstacle environments.

Navigation of multiple mobile robots in presence of static and moving obstacles using potential field method is presented in this work. In this paper we propose a new potential field method for motion planning of mobile robots in a highly cluttered environment. The attractive potential function is defined as a function of relative position of the target with respect to robots. The repulsive potential function is also defined as the relative position of robots in respect of the obstacles. The new repulsive function is so considered that the total potential has a global minimum at the target position. Simulation results using 'ROBPATH' (Appendix A) are presented to demonstrate the performance of the proposed approach.

2 Potential field method

The motion-planning problem for multiple mobile robots in a dynamic environment is to control the robots motion from an initial position to final targets, while avoiding obstacles. Two assumptions are made to simplify the analysis:

Assumption 1. The robots are of mass point.
Assumption 2. The robots moves in a two dimensional workspace. It's position in the workspace is denoted by $q = [x, y]$ is known.

2.1 Attractive potential function

The attractive potential function used [1] is,

$$U_{\text{att}}(q) = \frac{1}{2}\delta\rho^m(q, q_{\text{Target}}) \tag{1}$$

where δ is a positive scaling factor

$\rho(q, q_{\text{Target}}) = \| q_{\text{Target}} - q \|$ is the distance between the robot q and the target q_{Target} and $m = 2$.

The attractive potential force is given by the negative gradient of the attractive potential field.

$$F_{\text{att}}(x) = -\nabla U_{\text{att}}(x) = \delta(x_{\text{Target}} - x) \tag{2}$$

where the operator $\nabla = \frac{\partial}{\partial x}\hat{\imath} + \frac{\partial}{\partial y}\hat{\jmath} + \frac{\partial}{\partial z}\hat{k}$

2.2 Repulsive potential function

The repulsive potential function used [1] is,

$$U_{\text{rep}}(\text{obs}_i) = \begin{cases} \frac{1}{2}\alpha_i \left(\frac{1}{\rho(q, q_{\text{obs}_i})} - \frac{1}{\rho_0} \right)^2 & \text{if } \rho\big(q, q_{\text{obs}_i}\big) \le \rho_0 \\ 0 & \text{if } \rho\big(q, q_{\text{obs}_i}\big) > \rho_0 \end{cases} \tag{3}$$

$$F_{\text{rep}}(\text{obs}_i) = -\nabla U_{\text{rep}}(\text{obs}_i)$$

where $i = 1$ to n, n is number of obstacles, 'α_i' is the positive scaling factor,

$\rho_0 =$ Positive constant denoting influences of the obstacle on the robot and $\rho(q, q_{\mathrm{obs}_i})$ is the minimum distance from the robot 'q' to the obstacle.

In the environment (Fig. 1) three obstacles surround the target and robot. The repulsive potential forces due to obstacle 1, 2 and 3 are:

For obstacle 1, $F_{\mathrm{rep}}(\mathrm{obs}_1) =$

$$\begin{cases} \alpha_1\left(\frac{1}{\rho(q_x, q_{\mathrm{obs}_{1x}})} - \frac{1}{\rho_0}\right)\frac{1}{\rho^2(q_x, q_{\mathrm{obs}_{1x}})}\frac{\partial}{\partial x}\rho(q_x, q_{\mathrm{obs}_{1x}})\hat{i} \\ + \alpha_1\left(\frac{1}{\rho(q_y, q_{\mathrm{obs}_{1y}})} - \frac{1}{\rho_0}\right)\frac{1}{\rho^2(q_y, q_{\mathrm{obs}_{1y}})}\frac{\partial}{\partial y}\rho(q_y, q_{\mathrm{obs}_{1y}})\hat{j} \\ + \alpha_1\left(\frac{1}{\rho(q_z, q_{\mathrm{obs}_{1z}})} - \frac{1}{\rho_0}\right)\frac{1}{\rho^2(q_z, q_{\mathrm{obs}_{1z}})}\frac{\partial}{\partial z}\rho(q_z, q_{\mathrm{obs}_{1z}})\hat{k} & \text{if } \rho(q, q_{\mathrm{obs}_1}) \le \rho_0 \\ 0 & \text{if } \rho(q, q_{\mathrm{obs}_1}) > \rho_0 \end{cases} \tag{4}$$

For obstacle 2, $F_{\mathrm{rep}}(\mathrm{obs}_2) =$

$$\begin{cases} \alpha_2\left(\frac{1}{\rho(q_x, q_{\mathrm{obs}_{2x}})} - \frac{1}{\rho_0}\right)\frac{1}{\rho^2(q_x, q_{\mathrm{obs}_{2x}})}\frac{\partial}{\partial x}\rho(q_x, q_{\mathrm{obs}_{2x}})\hat{i} \\ + \alpha_2\left(\frac{1}{\rho(q_y, q_{\mathrm{obs}_{2y}})} - \frac{1}{\rho_0}\right)\frac{1}{\rho^2(q_y, q_{\mathrm{obs}_{2y}})}\frac{\partial}{\partial y}\rho(q_y, q_{\mathrm{obs}_{2y}})\hat{j} \\ + \alpha_2\left(\frac{1}{\rho(q_z, q_{\mathrm{obs}_{2z}})} - \frac{1}{\rho_0}\right)\frac{1}{\rho^2(q_z, q_{\mathrm{obs}_{2z}})}\frac{\partial}{\partial z}\rho(q_z, q_{\mathrm{obs}_{2z}})\hat{k} & \text{if } \rho(q, q_{\mathrm{obs}_2}) \le \rho_0 \\ 0 & \text{if } \rho(q, q_{\mathrm{obs}_2}) > \rho_0 \end{cases} \tag{5}$$

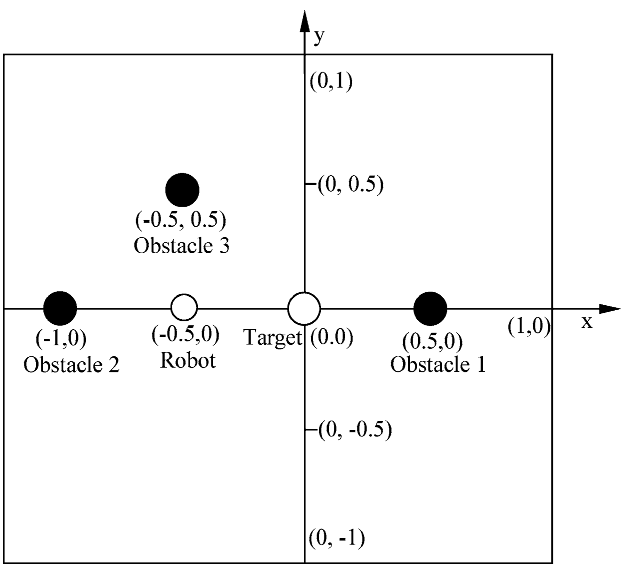


Fig. 1 Location of target, robot and obstacles

For obstacle 3, $F_{\mathrm{rep}}(\mathrm{obs}_3) =$

$$\begin{cases} \alpha_3\left(\frac{1}{\rho(q_x, q_{\mathrm{obs}_{3x}})} - \frac{1}{\rho_0}\right)\frac{1}{\rho^2(q_x, q_{\mathrm{obs}_{3x}})}\frac{\partial}{\partial x}\rho(q_x, q_{\mathrm{obs}_{3x}})\hat{i} \\ + \alpha_3\left(\frac{1}{\rho(q_y, q_{\mathrm{obs}_{3y}})} - \frac{1}{\rho_0}\right)\frac{1}{\rho^2(q_y, q_{\mathrm{obs}_{3y}})}\frac{\partial}{\partial y}\rho(q_y, q_{\mathrm{obs}_{3y}})\hat{j} \\ + \alpha_3\left(\frac{1}{\rho(q_x, q_{\mathrm{obs}_{3x}})} - \frac{1}{\rho_0}\right)\frac{1}{\rho^2(q_x, q_{\mathrm{obs}_{3x}})}\frac{\partial}{\partial z}\rho(q_x, q_{\mathrm{obs}_{3x}})\hat{k} & \text{if } \rho(q, q_{\mathrm{obs}_3}) \le \rho_0 \\ 0 & \text{if } \rho(q, q_{\mathrm{obs}_3}) > \rho_0 \end{cases} \tag{6}$$

Total potential influences on the robot $\{U_{\mathrm{Total}}\} =$
Attractive potential due to target $\{U_{\mathrm{att}}\}+$
Repulsive potential due to 'n' number of obstacles $\{\sum_{i=1}^{n} U_{\mathrm{rep}}(\mathrm{obs}_i)\}$

$$U_{\mathrm{Total}} = U_{\mathrm{att}} + \sum_{i=1}^{n} U_{\mathrm{rep}}(\mathrm{obs}_i) \tag{7}$$

Similarly the total force applied on the robot is the sum of attractive potential force and repulsive potential forces.

$$F_{\mathrm{Total}} = F_{\mathrm{att}} + \sum_{i=1}^{n} F_{\mathrm{rep}}(\mathrm{obs}_i) \tag{8}$$

When the above-induced forces are applied on a robot where three obstacles are present in the environment along with target, it was observed that the robot would trap in local minimum.

In the example described in Fig. 1 the robot position $q = [x, 0]$, target position $q_{\mathrm{target}} = [0, 0]$, obstacle 1 $q_{\mathrm{obs}_1} = [0.5, 0]$ on the right-hand side of the target, obstacle 2 $q_{\mathrm{obs}_2} = [-1, 0]$ on the left-hand side of the target and obstacle 3 $q_{\mathrm{obs}_3} = [-0.5, 0.5]$ present in the environment. Here target and robot are within the influence of obstacles.

Total potential function

$$\begin{aligned} U_{\mathrm{Total}} &= U_{\mathrm{att}} + \sum_{i=1}^{n} U_{\mathrm{rep}}(\mathrm{obs}_i) \\ &= \frac{1}{2}\delta x^2 + \sum_{i=1}^{3}\frac{1}{2}\alpha_i\left(\frac{1}{\rho(q, q_{\mathrm{obs}_i})} - \frac{1}{\rho_0}\right)^2 \end{aligned} \tag{9A}$$

$$F_{\mathrm{Total}} = F_{\mathrm{att}} + \sum_{i=1}^{n} F_{\mathrm{rep}}(\mathrm{obs}_i)$$

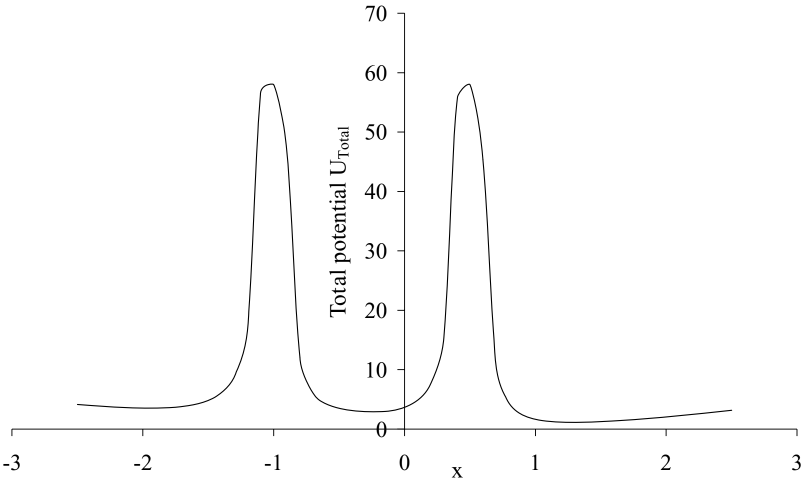


Fig. 2 Total potential function

$$= \begin{bmatrix} \left\{ \alpha_1 \left(\frac{1}{\rho\left(q_x, q_{\mathrm{obs}_{1x}}\right)} - \frac{1}{\rho_0} \right) \frac{1}{\rho^2\left(q_x, q_{\mathrm{obs}_{1x}}\right)} \frac{\partial}{\partial x} \rho\left(q_x, q_{\mathrm{obs}_{1x}}\right) \hat{i} + (0)\,\hat{j} + (0)\,\hat{k} \right\} \\ + \left\{ \alpha_2 \left(\frac{1}{\rho\left(q_x, q_{\mathrm{obs}_{2x}}\right)} - \frac{1}{\rho_0} \right) \frac{1}{\rho^2\left(q_x, q_{\mathrm{obs}_{2x}}\right)} \frac{\partial}{\partial y} \rho\left(q_x, q_{\mathrm{obs}_{2x}}\right) \hat{i}\,(0)\,\hat{j} + (0)\,\hat{k} \right\} \\ + \left\{ (0)\,i + \left(\alpha_3 \left(\frac{1}{\rho\left(q_y, q_{\mathrm{obs}_{3y}}\right)} - \frac{1}{\rho_0} \right) \frac{1}{\rho^2\left(q_y, q_{\mathrm{obs}_{1y}}\right)} \frac{\partial}{\partial z} \rho\left(q_y, q_{\mathrm{obs}_{1y}}\right) \right) \hat{j} + (0)\,\hat{k} \right\} \end{bmatrix} \tag{9B}$$

Figure 2 shows the variation of total potential field with respect to robot position along x-axis when $\alpha_1 = \alpha_2 = \alpha_3 = \delta = 1$ and $\rho_0 = 2$.

It can be seen from the graph (Fig. 2) that the robot will be trapped at the minimum (i.e., at $x = -0.2$). Therefore it is clear that the target is not the minimum of the total potential function. The total force at $x = -0.2$ is zero. Thus the robot can not reach the target, though there is no obstacle on its way. To overcome this problem, new repulsive potential functions are proposed which considered the relative distance between the robot and the target into account.

2.3 New repulsive potential function

From the above discussion we conclude that, the global minimum of the total potential field is not at the target position. This problem occurs as the robot approaches the target, the repulsive potential force increases due to presence of obstacle near the target. It is observed that if the repulsive potential force approaches zero, the robot approaches the target. To attain the global minimum at the target for the environment where three obstacles, one robot and one target present, we developed new repulsive potential functions that take the relative distance between the robot and the target are given in Eqs. (10)–(12).

$$U_{\mathrm{rep}}(\mathrm{obs}_1) = \begin{cases} \frac{1}{2}\alpha_1 \left(\frac{1}{\rho\left(q, q_{\mathrm{obs}_1}\right) - \rho_0} \right)^2 \rho^n\left(q, q_{\mathrm{target}}\right) & \text{if } \rho\left(q, q_{\mathrm{obs}_1}\right) \le \rho_0 \\ 0 & \text{if } \rho\left(q, q_{\mathrm{obs}_1}\right) > \rho_0 \end{cases} \tag{10}$$

$$U_{\mathrm{rep}}(\mathrm{obs}_2) = \begin{cases} \frac{1}{2}\alpha_2 \left(\frac{1}{\rho\left(q, q_{\mathrm{obs}_2}\right) - \rho_0} \right)^2 \rho^n\left(q, q_{\mathrm{target}}\right) & \text{if } \rho\left(q, q_{\mathrm{obs}_2}\right) \le \rho_0 \\ 0 & \text{if } \rho\left(q, q_{\mathrm{obs}_2}\right) > \rho_0 \end{cases} \tag{11}$$

$$U_{\mathrm{rep}}(\mathrm{obs}_3) = \begin{cases} \frac{1}{2}\alpha_3 \left(\frac{1}{\rho\left(q, q_{\mathrm{obs}_3}\right) - \rho_0} \right)^2 \rho^n\left(q, q_{\mathrm{target}}\right) & \text{if } \rho\left(q, q_{\mathrm{obs}_3}\right) \le \rho_0 \\ 0 & \text{if } \rho\left(q, q_{\mathrm{obs}_3}\right) > \rho_0 \end{cases}$$

where $\rho(q, q_{\mathrm{obs}_1}), \rho(q, q_{\mathrm{obs}_2}), \rho(q, q_{\mathrm{obs}_3})$ are the minimum distances between robot q and obstacles 1, 2 and 3.

$\rho\left(q, q_{\mathrm{Target}}\right)$is the distance between the robot and the target.

These equations along with factor $\rho^n(q, q_{\mathrm{Target}})$ drag the robot towards the nearest target, thus ensuring the robot to be at the global minimum.

The total potential $\{U_{\mathrm{Total}}\}$ can be obtained using Eq. (7).

For $n = 2$ and $\delta = \alpha_1 = \alpha_2 = \alpha_3 = 1$ we found (Figs. 3 and 4) there is only one minimum exist which is at the target. The calculation of heading angle is shown in Appendix A.

2.4 Petri Net modelling to avoid collision among the robots

C.A. Petri [11] first developed Petri Net model. The detail principle of the Petri Net Model to avoid robot collision is described below.

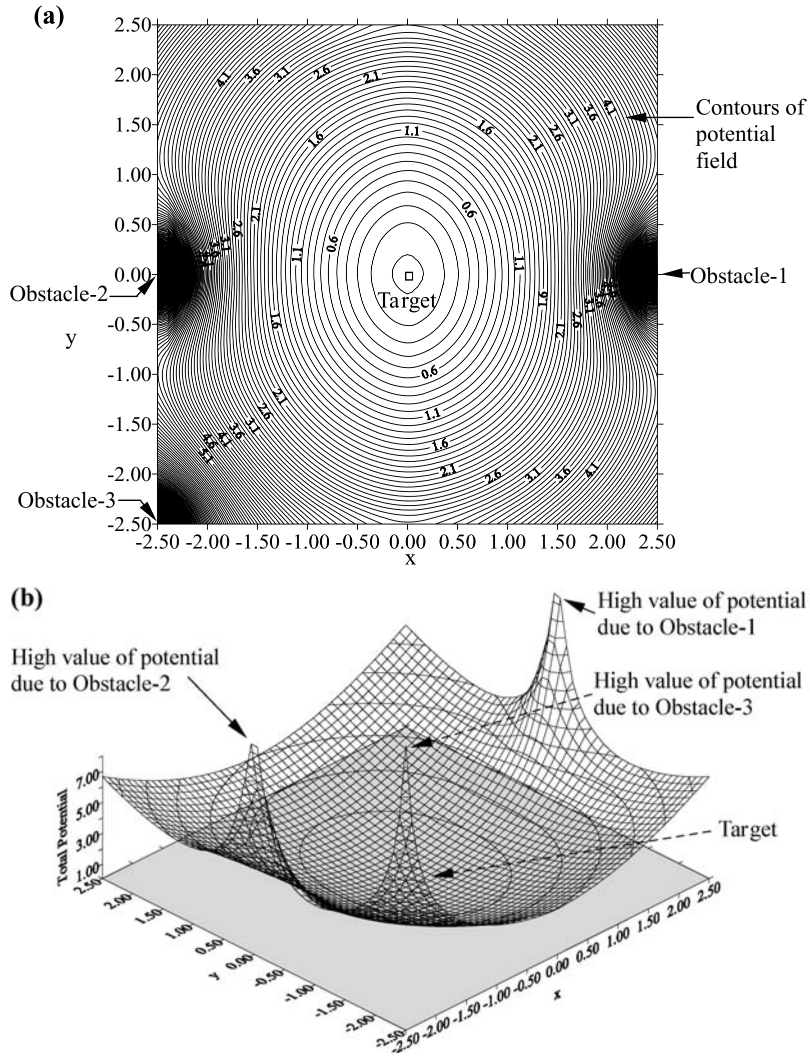


Fig. 3 (a) Contour plot for total potential field when the target is located at (0, 0) along with three obstacles. (b) Surface plot for total potential field when the target is located at (0, 0) along with three obstacles

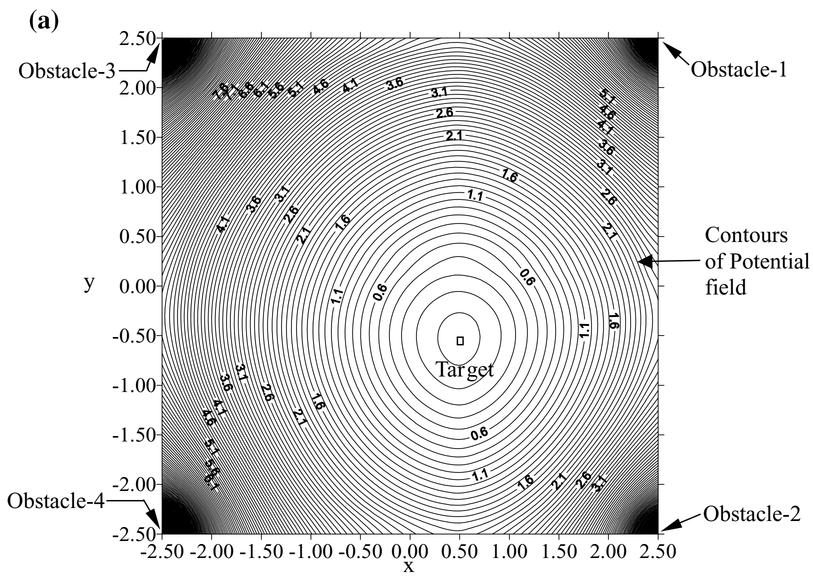


Fig. 4 (a) Orthographic projection for total potential field when the target is located at (0.5, −0.5) along with four obstacles located at four corners. (b) Axon metric representation for total potential field when the target is located at (0.5, −0.5) along with four obstacles located at four corners (*Continued on next page*)

Fig. 4 (*Continued*)

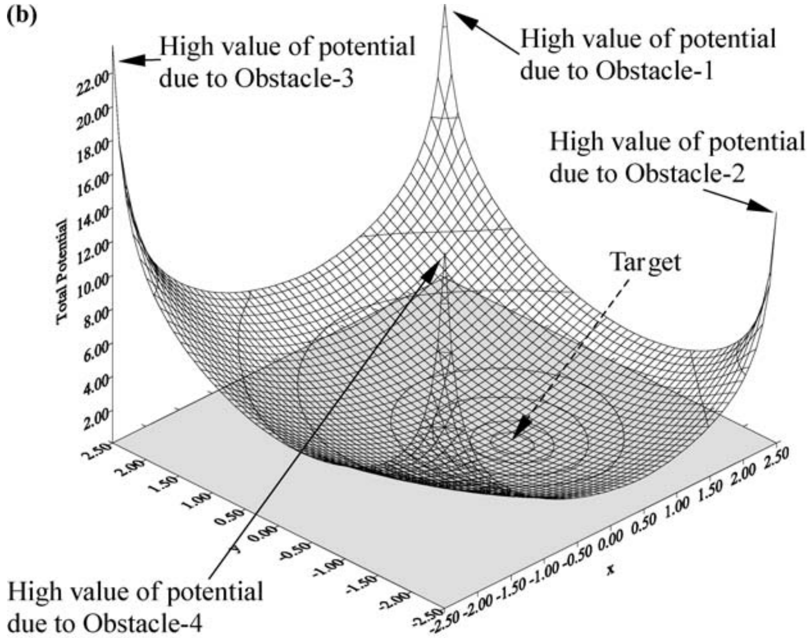
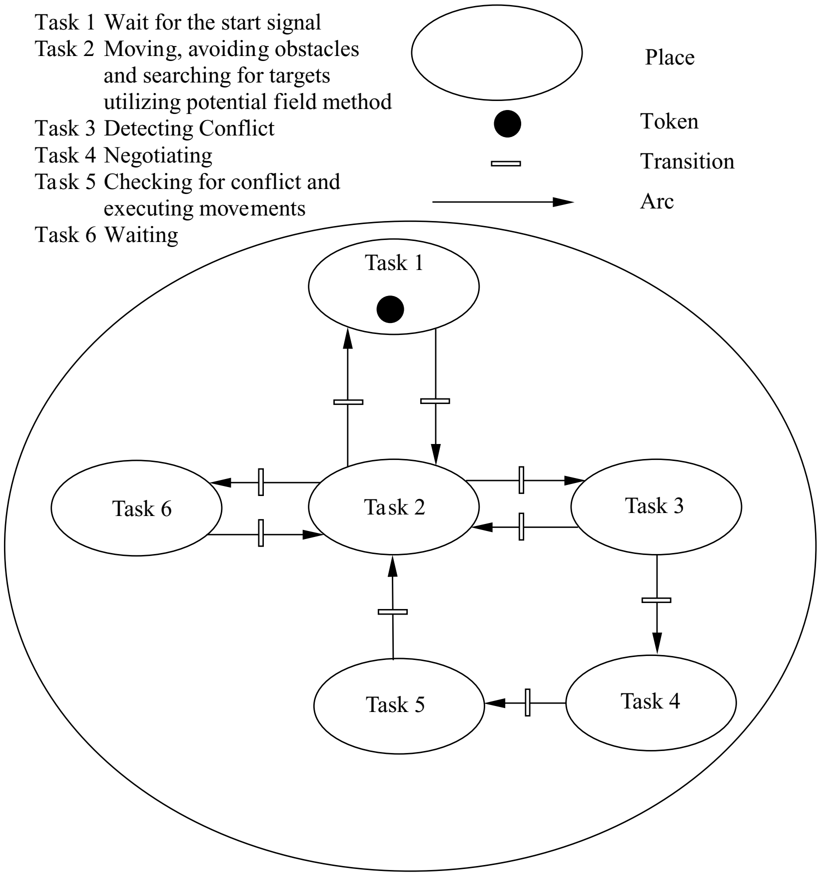


Fig. 5 Petri Net model for avoiding inter-robot collision



It is assumed that, initially, the robots are in a highly cluttered environment, without any prior knowledge of one another or of the targets and obstacles. This means the robot is in state "Task 1" ("Wait for the start signal"). In Fig. 5, the token is in place "Task 1".

Once the robots have received a command to start searching for the targets, they will try to locate targets while

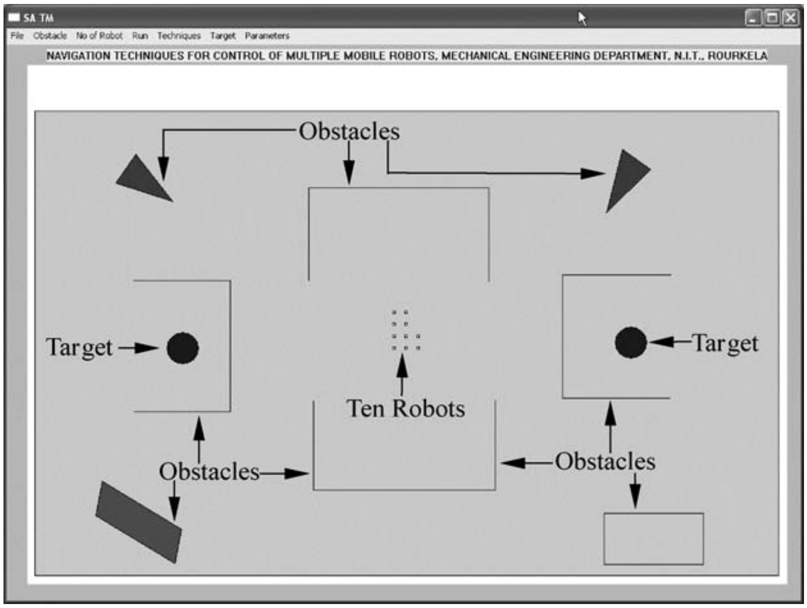


Fig. 6 Collision free movement using potential field method before starting of simulation

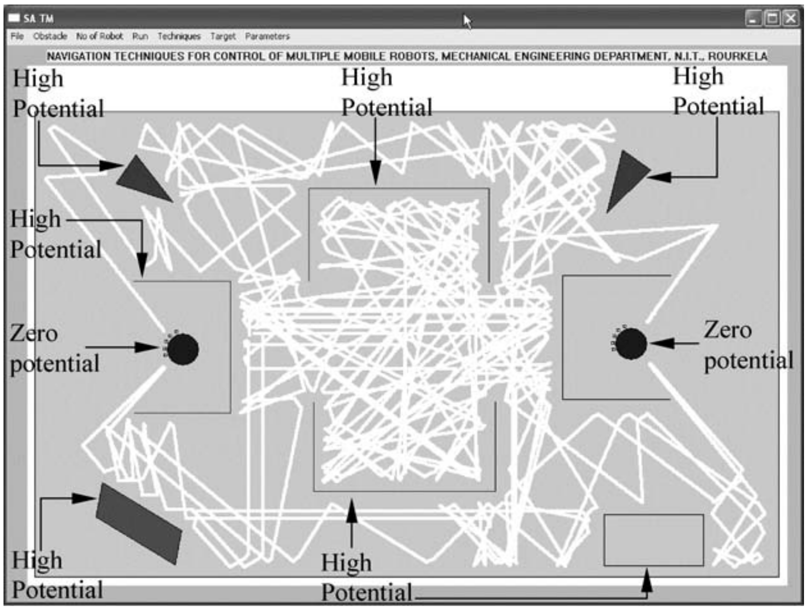


Fig. 7 Collision free movement using potential field method after all the robots reaches the targets

avoiding obstacles and one another. The robot is thus in state “task2” (“Moving, avoiding obstacles and searching for targets”).

During navigation, if the path of a robot is obstructed by another robot, a conflict situation is raised. (State “Task 3”, “Detecting Conflict”). Conflicting robots will negotiate with each other to decide which one has priority. The lower priority robot will be treated as a static obstacle and the higher priority robot as a proper mobile robot (state “Task 4”, “Negotiating”). As soon as the conflict situation is resolved, the robots will look for other conflicts and if there is no other conflict they will execute their movements (state “Task 5”, “Checking for conflict and executing movements”).

If a robot meets two other robots already in a conflict situation, its priority will be lowest and it will be treated as a static obstacle (state “Task 6”, “Waiting”) until the conflict is resolved. When this is done, the robot will re-enter state “Task 2”.

3 Demonstrations

3.1 Simulation

The potential field method has been implemented in different simulated environments. Simulations were conducted

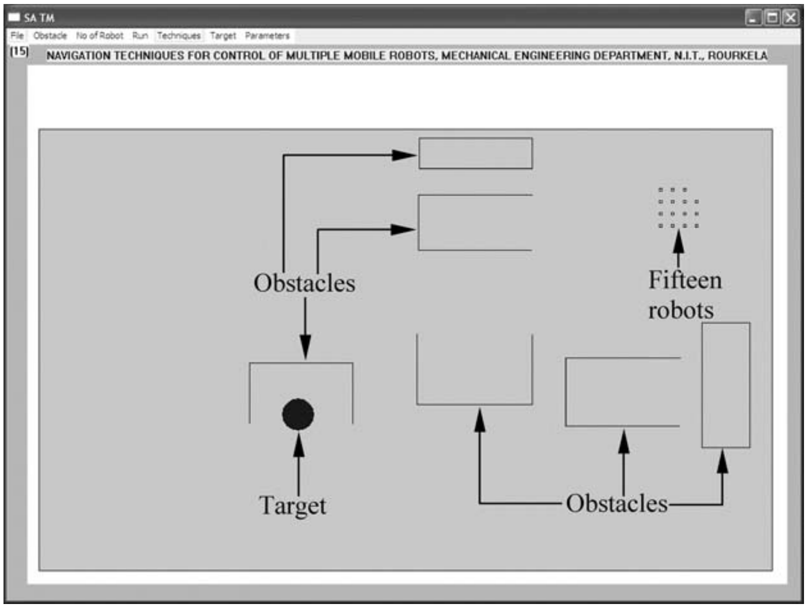


Fig. 8 Escape from dead ends by ten mobile robots using potential field method (Initial State)

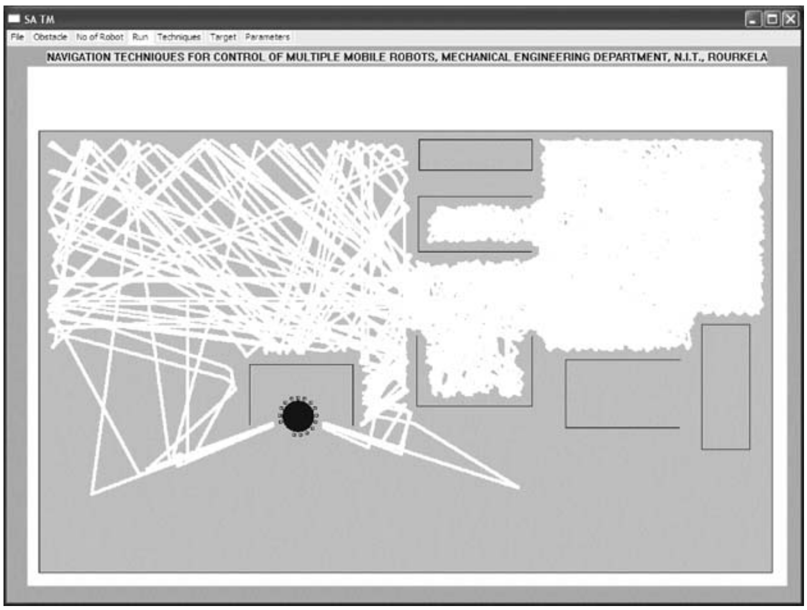


Fig. 9 Escape from dead ends by ten mobile robots using potential field method (Final State)

using the Window-based simulation software package 'ROBPATH' (Appendix B) developed by the authors for robot navigation. The environments have been generated artificially containing static obstacles as well as static targets.

3.1.1 Obstacle avoidance and target seeking by multiple mobile robots

This exercise shows that the mobile robots can navigate without colliding to the obstacles and can find targets in a cluttered environment using potential field method. Ten robots enclosed in U-shaped enclosure are involved together with several obstacles including two targets enclosed in U-shaped enclosures. Figure 6 shows the initial state of the beginning of the exercise. Figure 7 represents the final position where the robots are able to locate the targets while successfully avoiding collision against the obstacle.

3.1.2 Escape from dead ends

Figures 8 and 9 show the ability of the robots, which are trapped within dead ends, able to escape from those dead ends and find the target. Figure 8 shows the situation at the beginning of the exercise. Fifteen robots are involved in the exercise. Rectangular and U-shaped obstacles are representing a dead end. From Fig. 9, it can be seen that all the robots

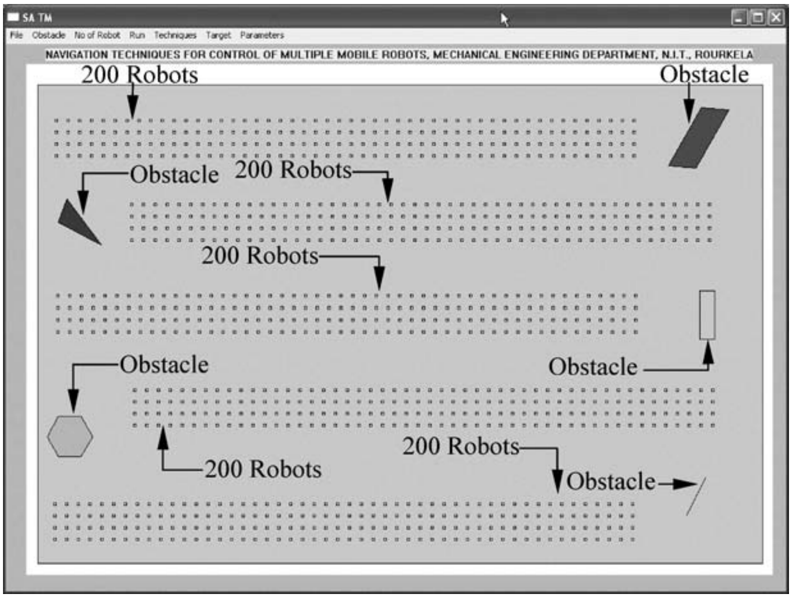


Fig. 10 Navigation scenario of one thousand mobile robots using potential field method (Initial State)

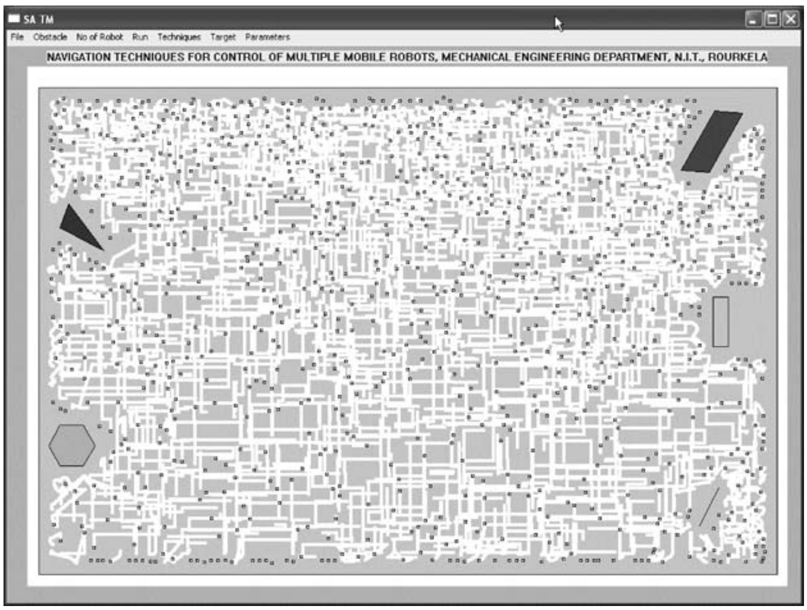


Fig. 11 Navigation of one thousand mobile robots using potential field method (Intermediate State)

that have stayed inside have escaped and are able to negotiate with dead ends and find the target successfully.

3.1.3 Navigation of several mobile robots

Obstacle avoidance by 'one thousand' robots using potential field method is shown in Figs. 10 and 11. Figure 10 depicts the state at the beginning of the exercise where as Fig. 11 shows the situation some time after the exercise has begun. It can be seen that the robots can stay well away from the other robots as well as from the obstacles.

3.1.4 Inter robot collision avoidance

This exercise relates to a problem designed to demonstrate that, the robots do not collide with each other even in a highly cluttered ambience. Figure 12 depicts the beginning of the exercise where as Fig. 13 shows the trajectories of the robots for the potential field method. It can be noted that the robots are able to resolve conflict and avoid one another and reach the target successfully. In this exercise only two robots have been employed for proper visualization.

Fig. 12 Collision avoidance by two mobile robots using potential field method (Initial State)

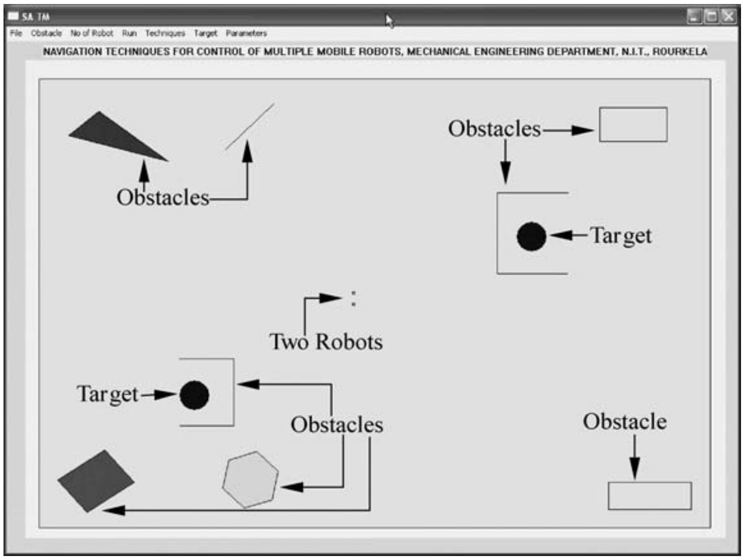
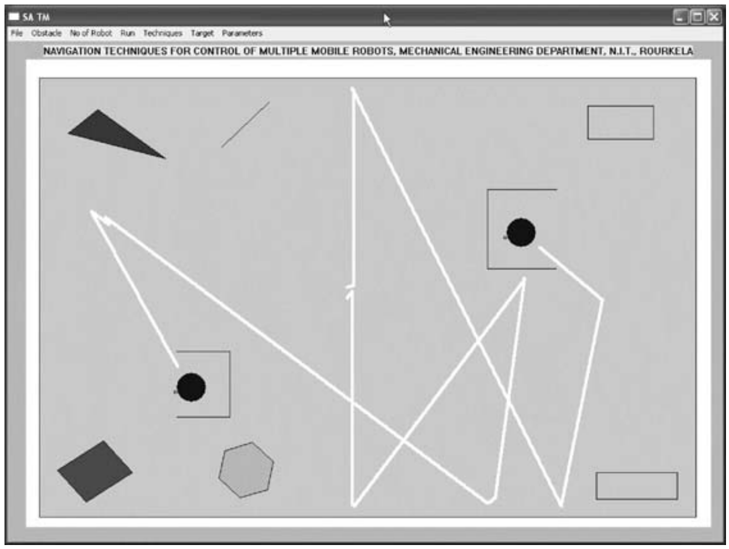


Fig. 13 Collision avoidance by two mobile robots using potential field method (Final State)



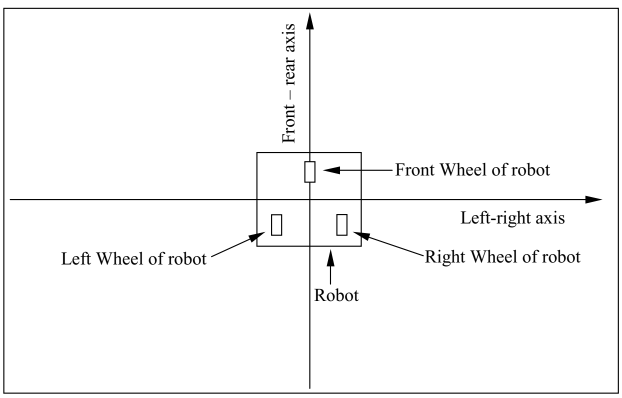


Fig. 14 Front-rear axis and Left-right axis of the robot

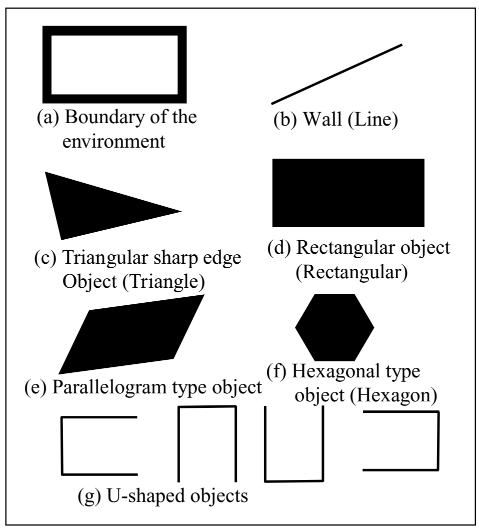


Fig. 15 Obstacles

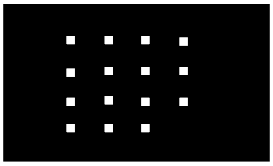


Fig. 16 Fifteen mobile robots

4 Conclusion

This paper has described potential field method for controlling and navigation of multiple mobile robots in a highly cluttered environment. New repulsive potential functions have been developed, considering the shortest distance between the target and the robot. The developed repulsive potential function ensures that the target is the global minimum of the total potential field. This technique employs potential forces, which are calculated by taking into account the distances of the obstacles around the robots and the bearing of the target, and subsequent calculation of the changes required in steering angle of the robot. With the use of Petri net model the robots are capable of negotiating with each other. It has been seen that, by using potential field method the robots are able to avoid any obstacles (static and moving obstacles), escape from dead ends, and find targets in a highly cluttered environments. Using this method as many as one thousand mobile robots can navigate successfully neither colliding with each other nor colliding with obstacles present in the environment.

Appendix A: Robot navigation

With the help of sensors the robot will detect obstacles around it in the environment. Accordingly the robot will calculate the repulsive navigation forces (Fig. 14).

Let $\sum F_{\text{Front-rear}}$ = Resultant repulsive navigation force along the direction of front-rear axis of the robot due to the obstacles which influence the robot.

$\sum F_{\text{Left-right}}$ = Resultant repulsive navigation force along the direction of left-right axis of the robot due to the obstacles which influence the robot.

θ = Current heading angle at which the robot moving in the environment.

Change in steering angle (Phir [ir]) required for obstacle avoidance is

$$\text{Phir}\,[\text{ir}] = \text{Tan}^{-1}\left[\frac{F_{\text{Front-rear}}}{F_{\text{Left-right}}}\right] \tag{A1}$$

$$\text{New heading angle } \theta_{\text{new}} = \theta + \text{Phir[ir]} \tag{A2}$$

Appendix B: Software used for robot navigation

The 'ROBPATH' used for navigation demonstrations reported in this paper is developed by the author. The software runs on a PC operating under WINDOWS

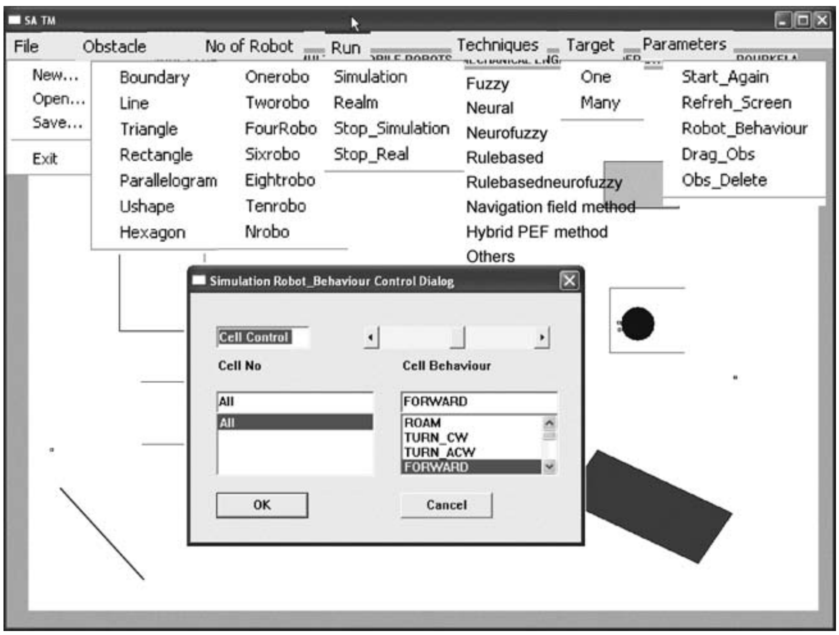


Fig. 17 View of the software (ROBOPATH) front-end user for navigation of multiple mobile robots

NT/95/98/2000/XP. The menus incorporated in the software are described below.

Obstacle Menu: The Obstacle Menu allows the user to draw different types of obstacles in the robots' environment. The obstacles that can be constructed are shown in Fig. 15.

Number of robot Menu: Using this menu, a user can draw any number of robots (in between 1 to 1000) as required to be placed in the environment. For example fifteen robots are shown in Fig. 16.

Run Menu: With this menu, the user can choose to run the software in simulation mode or control the navigation of real mobile robots. The menu is given in Fig. 17.

Techniques Menu: This menu enables the user to select the techniques to control the navigation of the robots. The menu is shown in Fig. 17.

Target Menu: This menu is for placing targets in the environment. Any number of targets can be Chosen for the robot environment (Fig. 17).

Manual Command (*Parameter Menu*)*:* This menu contains four commands (Fig. 17).

(a) Start_Again: This command is for re-starting a process with exiting software.
(b) Refresh_Screen: This command is for cleaning the screen. It has the same action as clicking the right button on the mouse.
(c) Robot_Behaviour: This command activates a dialog box that enables the user to select a particular robot and control its movements manually. The dialog box can be seen in Fig. 17.
(d) Drag_Obs: Using this sub-menu the user can drag any obstacle to any place in the environment at any time to re-arrange the cluttered environment.
Obs_Delete: By the help of this menu the user can delete any obstacle at any time from the environment.

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