MOBILE ROBOT NAVIGATION BASED ON POTENTIAL FIELD

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Abstract

This paper presents a case study of mobile robot obstacle avoidance based on the potential field method. Attractive and Repulsive Potential field functions, which are associated to the robot goal and the environment obstacles respectively, are described. The motion planning and obstacle avoidance of a soccer player robot are studied and simulation results are shown. The involved problems are discussed and future work perspectives are proposed.

Keywords: Mobile Robot, Navigation, Potential Field.

1. INTRODUCTION

The capability of planning its own motion in order to achieve a given task is a fundamental condition for any implementation of an autonomous robot system.

Let the robot be a single rigid body **A** moving in a Euclidean work space $\mathbf{W} \in \mathbf{R}^2$ populated of fixed rigid objects (obstacles) $\mathbf{B_1}$, ..., $\mathbf{B_q}$. In its simplest form, the motion planing problem can be stated as (Latombe, 1998):

Given an initial configuration (position and orientation) $q_{ini} = (x_{ini}, y_{ini}, \theta_{ini})$ *and a goal configuration* $q_{goal} = (x_{goal}, y_{goal}, \theta_{goal})$ *of* **A** *in* **W**, *generate a path* τ *specifying a continuous sequence of configurations q of the robot* **A**, *starting at* q_{ini} *and terminating at* q_{goal}, *avoiding contact with the obstacles* $\mathbf{B_i}$'s. *Return this path, if it exists, or report failure otherwise.*

There are several techniques that provide means of solving this problem, however, not all of them solve the problem in its general case. Despite of particular differences, all these methods can be grouped in three general approaches: *Roadmap* (Nilsson, 1969), (Ó'Dúnlaing & *et al*, 1983), *Cell Decomposition* (Schwartz & *et al*, 1987), (Brooks & Lozano-Pérez, 1983) and *Potential Field* (Khatib, 1986), (Koditschek, 1989). In the first two approaches, the motion planning problem is reduced to the search of a shortest path in a *connectivity graph*, which captures the global topological properties of the workspace. On the other hand, potential field methods are based on a completely different idea. The robot movement is guided by the influence of an *artificial potential field* U(q), function of the robot configuration q, whose local variations reflect in some degree the structure of the free space. In most implementations, the potential function is defined as a sum of an attractive potential, which pulls the robot toward the goal, and a repulsive potential, which pushes the robot away from the obstacles.

In this paper, a case study of mobile robot motion planning and obstacle avoidance based on the potential field method is presented. The studied case is the motion planning and obstacle avoidance of a soccer player robot. Section 2 gives a brief description of the problem. Section 3 describes the implementation issues of the potential field method. Simulation results are shown and analyzed in Section 4. The final conclusions and perspectives for future works are given in Section 5.

2. DESCRIPTION OF THE PROBLEM

The problem under study is the motion planning and obstacle avoidance of a soccer player robot according to the FIRA robot competition rules. In this competition, two teams are in contend. Each team consists in three soccer players, which are mobile robots of cube format, with a size of 7.5x7.5x7.5 cm^3. The workspace is a rectangle of 130x150 cm^2, as shown in Figure 1. Thus, the navigation problem can be considered as a two dimensional one. The robot configuration can be parameterized as $q = (x, y, \theta)$, were (x,y) represents the position of the origin of the robot coordinate frame $\mathbf{F_A}$ (which is fixed on the center of the axis of its drive wheels), expressed with respect to the workspace coordinate frame $\mathbf{F_W}$. Similarly, the coordinate θ represents the orientation angle of the robot frame with respect to the workspace frame. Due to cinematic constraints of the robot, the orientation θ must always be tangent to the trajectory (differential drive model (Borenstein et al., 1996)). The configurations of the robots and the ball are captured by a PC-based vision system, by means of a camera localized over the workspace.

In a first approach, the navigation problem to be solved by the robot is the following: to find a path from its actual configuration until the goal configuration, avoiding the obstacles (the other five robots). In this case, the goal configuration will be the ball position. In a simplified initial version of the problem, the other robots will be considered as obstacles in fixed positions.

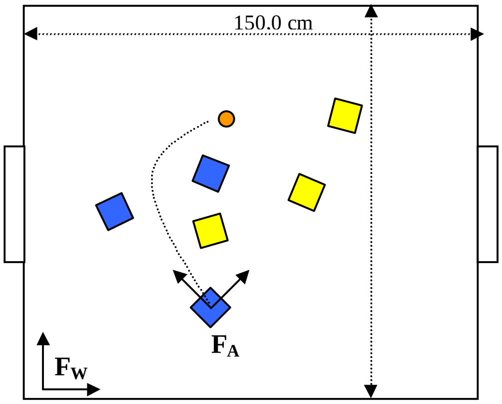

Figure 1. The robot and its Workspace

3. THE POTENTIAL FIELD METHOD

The potential field method was originally proposed for on-line collision avoidance in unstructured environments, when the robots does not have a prior model of the obstacles, sensing them on-line, as in the case of robot soccer. Navigation methods based in this approach are quite efficient, reasonably reliable and fast in a wide range of situations. In this method, the robot is treated as particle under the influence of an artificial potential field. The potential function is expressed as the sum of an attractive potential $U_{at}(q)$, pulling the robot to the goal, and a repulsive potential $U_{rep}(q)$, pushing the robot away from the obstacles:

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

The attractive potential function can be considered as a "valley" of the potential surface. It is defined as a parabolic surface with a global minimum of the potential function at q_g:

$$U_{at}(q) = \tfrac{1}{2}\hat{\imath}\left\| q - q_{goal} \right\|^2 \tag{2}$$

where ξ is a positive gain. The attractive potential function is shown in Figure 2.

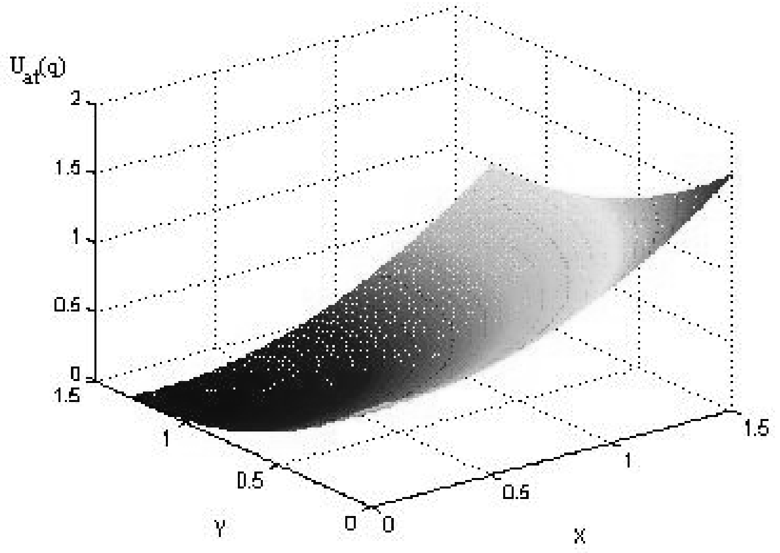

Figure 2. The attractive potential surface

The repulsive potential forms a potential barrier around the obstacles, which impedes the robot to collide with them. The repulsive potential created by each obstacle B_i is defined by:

$$U_{Bi}(q) = \begin{cases} \frac{1}{2}\varsigma\left(\frac{1}{d_B(q)} - \frac{1}{d_{B0}}\right)^2 & \text{if} \quad d_B(q) \le d_{B0} \\ 0 & \text{if} \quad d_B(q) > d_{B0} \end{cases} \tag{3}$$

where η is a positive gain and $d_B(q)$ is the minimum distance from the robot (at configuration q) to the obstacle (at configuration q_B). The positive parameter d_{B0} is the *distance of influence* of the obstacle. Beyond this distance, the potential created by the obstacle is null, having no effect on the robot. For this reason, the potential field methods are often referred to as local methods. The potential function grows in the neighborhood of the obstacle and tends to infinity as the robot gets closer to its boundaries. The repulsive potential acting over the robot is the sum of the potentials created by each of the obstacles:

$$U_{rep}(q) = \sum U_{Bi}(q) \tag{4}$$

The Repulsive potential function is shown in Figure 3.

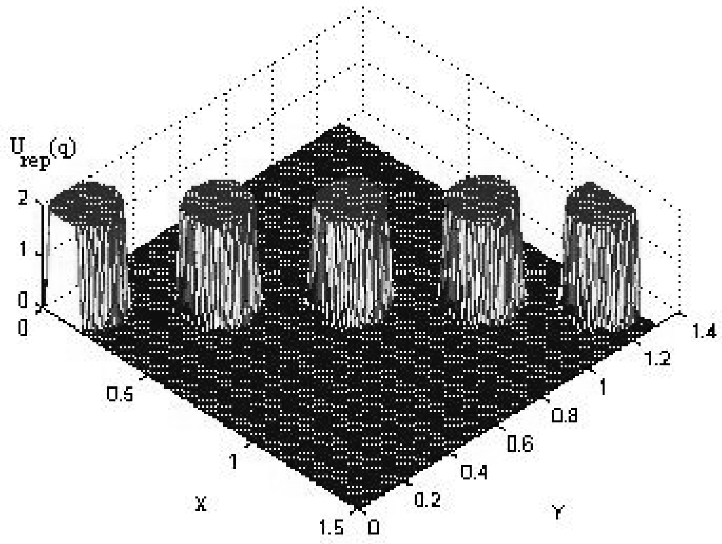

Figure 3. The repulsive potential surface

The potential field approach belongs to the family of *steepest descent* optimization methods. At each iteration, the most promising direction for robot motion is the direction of the artificial force induced by the potential function:

$$\vec{F}(q) = -\vec{\nabla}U(q) \tag{5}$$

Thus, the robot follows the negated gradient of the potential function, descending from the "mountains", which are created by the obstacles, to the "valley" created by the goal in the potential surface. This potential function is depicted in Figure 4.

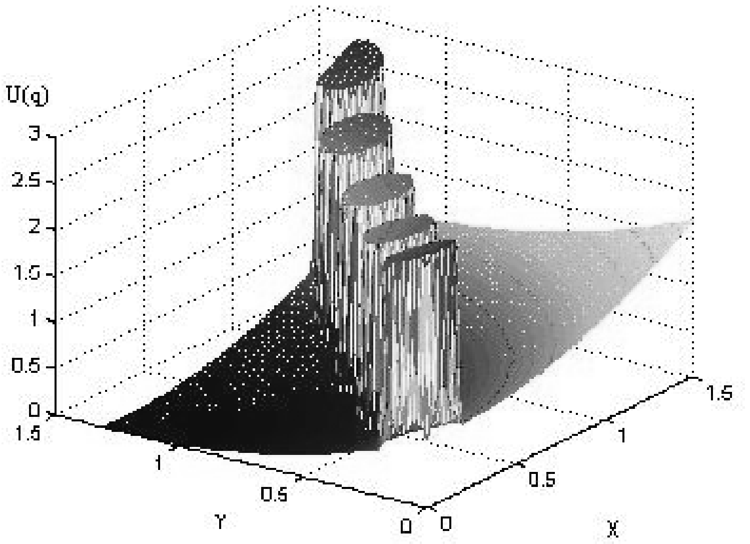

Figure 4. The potential surface

At each iteration i, the new configuration, q_{i+1}, is obtained from the previous one, q_i, through a small displacement δ_i, in the direction of the artificial force:

$$q_{i+1} = q_i + \ddot{a}_i \cdot \frac{\vec{F}(q)}{\left\| \vec{F}(q) \right\|} \qquad (6)$$

Since, due to cinematic constraints, the robot orientation must be tangent to the path, the expression above is applied only to the position coordinates. The robot orientation at each iteration was obtained from the direction of the segment lying the actual position (x_i, y_i) to the next position (x_{i+1}, y_{i+1}).

4. SIMULATION RESULTS

In order to investigate the feasibility of the potential field method in motion planning and obstacle avoidance of the soccer player robot, simulation experiments were performed. The parameters were obtained by trial-and-error, and their best found values are shown in Table I.

Table I. Control Parameters

Parameter	Value
ξ	1.00
η	2.82
d_{B0}	0.14 m
δ_i	0.0008 m

Experiment I:

In the first experiment, the robot, in the configuration (1.1m,0.1m,100^o), must reach the ball, in the position (0.1m,1.2m), avoiding the obstacles located at positions: (0.2,0.2), (0.4,0.4), (0.6,0.6), (0.8,0.8) and (1.0,1.0). In this situation, the obstacles are between the robot and the ball, but there is enough space to allow the robot pass through them. The obtained results for this experiment are shown in Figure 5.

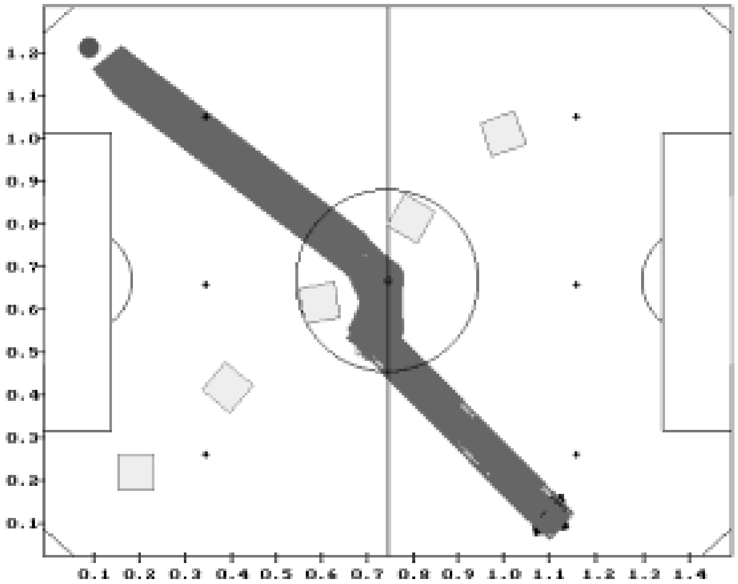

Figure 5. Experiment I

It can be noted from Fig. 5 that the robot is attracted by the goal until reach the distance of influence of the obstacle, being repelled by it. In this case, the robot contours the obstacle without any problem, reaching the goal.

Experiment II:

A more difficult situation was simulated in experiment II. The initial position of the robot, ball and obstacle are respectively: (1.15,0.25), (0.15,0.95), (0.95,0.30), (1.00,0.75), (0.75,0.65), (0.40,0.60) and (0.40,0.95). In this situation, the robot has several obstacles between it and the ball. Also, the ball is not visible from the robot initial position, as shown in Figure 6.

Again, although this obstacle configuration is more unfavorable than the previous one, the robot found a free path to the goal, despite of the multiple obstacles between its initial position and the ball. When the robot approaches the distance of influence of an obstacle, the repulsive potential impede the collision, and the robot passes around its neighborhood.

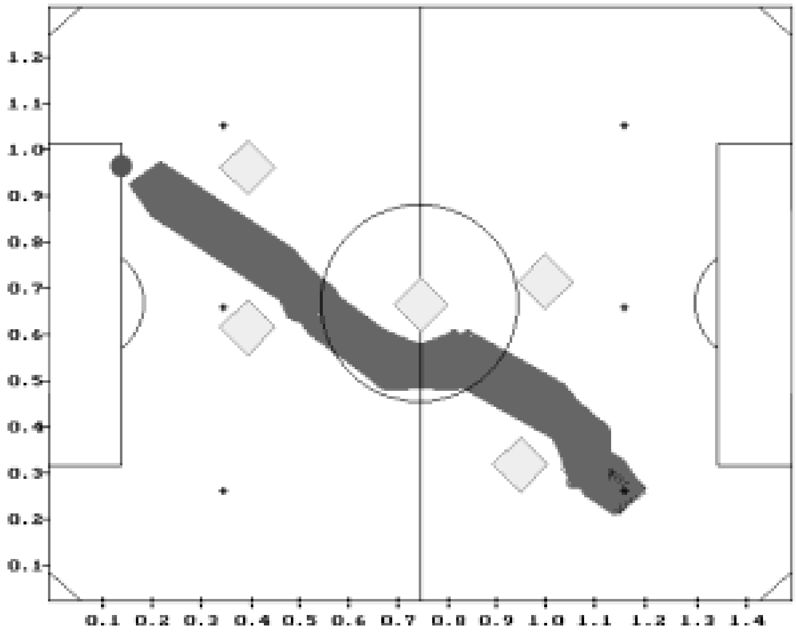

Figure 6. Experiment II

Experiment III

In this case, a worst case situation was studied. The Robot, in the initial position (0.85,0.45), is surrounded by a barrier formed by the other five robots, which are in the positions (0.95,0.75), (0.70,0.70), (0.60,0.60), (0.65,0.50) and (0.70,0.35). The ball is in the position (0.40,0.80), behind the obstacle barrier. The corresponding simulation results are shown in Figure 7.

As shown in Figure 7, the robot cannot pass through the potential barrier created by the obstacles and gets stuck in the resulting local minimum. This problem was expected, since the potential field approach is, in fact, a steepest descent optimization method and no technique was utilized to escape the local minimum.

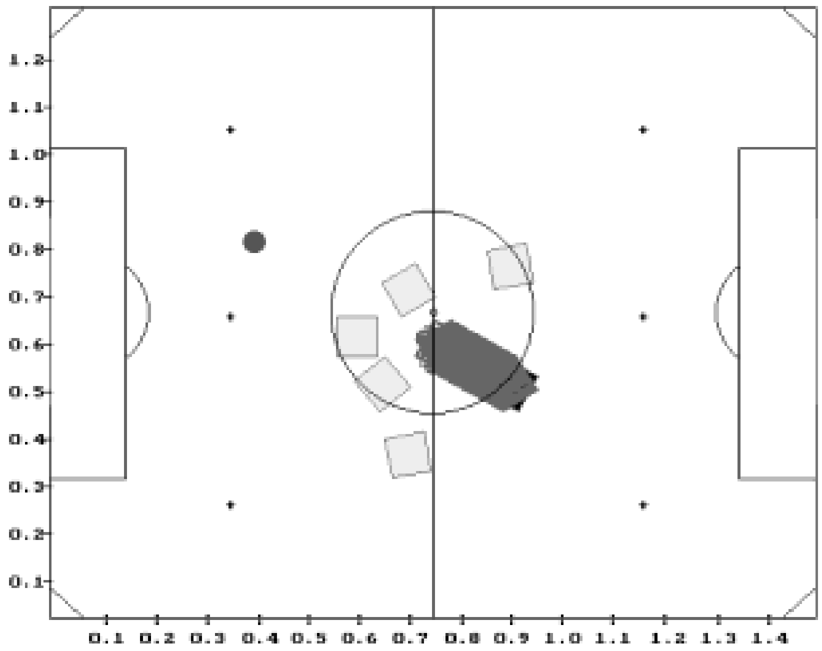

Figure 7. Experiment III

Although local minima are a serious problem in steepest descent-based optimization methods, there is not the case in present situation. In fact, the potential field method won't be utilized alone. A higher hierarchy control instance will be utilized to generate intermediate goals according to a predefined game strategy. The function of the studied potential field technique in the robot navigation will be essentially the obstacle avoidance and, according to these previous simulation results, the method seems to achieve this objective in an efficient and reliable way.

For simplicity, in this previous study, the direction in which the robot approaches to the goal was not taken in consideration. Currently, a modification of the potential function in order to treat with the approaching direction is under study. The idea is to include preferential directions in the attractive potential function by establishing a "ditch" in the potential surface on the approaching side of the goal and a potential barrier in the opposite side. It is expected that, with this artifice, the robot will contour the goal and will approach it from the right side.

5. CONCLUSION

In this paper, the application of the potential field method to the motion planning of a soccer player robot was studied. The obtained simulation results suggest that this method can be applied to implement a reliable and efficient robot obstacle avoidance capability. In extreme worst case situations, problems with local minima were observed, but this is not really a great impediment for the application of this method to the case under study, since it will be utilized together with a higher control level that will define intermediate goals according to a game strategy. So, it is expected that mainly of the difficulties due to local minima will be solved.

A modification on the potential function is under study in order to include the goal approaching direction on the motion planning.

For simplicity, the movement of the other robots was not taken in consideration. In future works, the method will be modified to take into account the predicted movements of the obstacles.

Currently, a robot soccer team is under construction in the Robot Laboratory of the Electrical Engineering Department of the UFRN and the studied technique will be implemented in the real robots.

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