Path planning of a group of robots with potential field approach: decentralized architecture

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Abstract: This paper deals with the path planning problem of a group of autonomous Wheeled Mobile Robots in a very dynamic workspace. The idea consists of considering the system of group of robots as a robot network with decentralized architecture. Each robot plans its trajectory according to its actual position, the position of the other neighbor robots, the position of the obstacles and the position of its target point. So each robot should interact with the other robots in the network to cooperate together in order to plan each robot trajectory. The path planning for every robot is planned based on the potential field approach. The network reacts with the changes of workspace in real time by updating the system equations associated for each robot. The main objective of this work is to avoid collision between robots and obstacles in order to ensure the safety of robots. The solution is tested and simulated with Matlab/Simulink and Solidworks/Simmechanics.

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1. INTRODUCTION

The use of wheeled mobile robots receives a considerable attention for the realization of delicate tasks. Sometimes, the execution of a given task needs the presence of multiple robots in the same workspace. The path planning between these robots is a fundamental process to improve efficiency and avoid the collision of the robots with static obstacles and between them and allowing mobile robots to move from a start point to the target point. So, when planning path, one of the constraints that arise in the trajectory planner is to determine a path that avoids obstacles.

Most research efforts have focused on the case of path planning for a single robot in a static or dynamic environment. Recently, the path planning for multiple mobile robots is gaining increasing attention. For example the use of Algorithm A* and the technique of priority for path planning a group of robots is proposed by (Bennwitz et al., 2001). Another example is proposed by (Yingchong, 2014) for cooperative path planning approach for mobile robots based on the visibility graph. Moreover, the example of work in (Mouad, 2014) proposed a control order for a multi-robot system. In addition, the author (Benzerrouk, 2011) presented a control architecture for maintaining formation of mobile robots moving in a dynamic environment. Finally, we present the work of (Defoort, 2009) which used the polynomial approach for the generation of trajectories of cooperative robots.

The potential field is widely used for planning the trajectory of a single mobile robot. But, it did not receive a great attention in the case of multiple mobile robots. In this optic, the authors in (Savvas et al., 2002) proposed a closed loop navigation algorithm for multiple holonomic robots. Another very recent application of potential fields proposed by (Guys, 2014) for planning the trajectories of several aircraft in a coordinated manner.

In this paper, we are looking for planning the trajectories of multiple wheeled mobile robots using the potential field technique. The reasons for choosing this technique is based on the possibility to use it in a dynamic workspace and in real time implementation for path planning of robots. To cooperate between robots, the decentralized architecture is adopted in order to have more flexibility for each robot, especially when there is no common task between robots.

The organization of this paper is as follows. In the first section an introduction is presented. The second section is reserved to present the artificial potential field concepts. The third section focuses on the architecture for the network of robots used. The fourth section presents the simulation results of cooperation between the robots in a dynamic workspace. In the last section, we present the conclusions.

2. ARTIFICIAL POTENTIAL FIELD

In the method of potential field, the robot is considered as a particle which moves in the lines of the current of a
potential field created based on the environment perceived by the robot. So, the target point produces an attractive force and the obstacles produce repulsive forces (Ahmed et al., 2015). The last ones have no influences when the robot is far from the obstacles and their intensity depends on the distance between the robot and the obstacles. The resultant forces of repulsive and attractive forces provided at each point of space orient the robot to the target point (figure(1)).

![Fig. 1. Combination of attractive and repulsive potential fields](image)

The workspace area exploited by a robot is noted \( W \) and \( q(x, y, z) \) is its position in this area. The potential field associated to the robot is noted \( U(q) \) and the potential force \( F(q) \) is calculated by (1):

\[
F(q) = -\nabla U(q)
\]

where \( \nabla \) is the gradient operator.

Note that we assume that all the robots have the same form and the same altitude, so the axes are chosen whereby \( z = 0 \) and the position coordinates are reduced to \( q(x, y) \). In the following, we consider \( N \) wheeled mobile robots which move in the workspace \( W \) where \( M \) static obstacles are installed.

### 2.1 Attractive forces

The attractive potential acts to guide the robot to the target. This expression is calculated depending on the actual position of the robot and the position of goal point quoted from (Matoui et al., 2015). The equation of the attractive force generated by the goal point \( g_i \) and applied to the robot \( i \) at the position \( q_i \) where \( i = 1...N \) is in (2):

\[
F_a(q_i, g_i) = -\xi p(q_i, g_i)
\]

with \( \xi \) is a positive scale factor and \( p(q_i, g_i) \) is the distance between robot \( i \) and the target point \( g_i \).

\[
p(q_i, g_i) = \|q_i - g_i\|
\]

with \( \| \| \) is the euclidian distance.

Note that each robot \( i \) has its own goal point \( g_i \) for \( i = 1...N \). If we gather all the robot attractive forces in the same vector, we obtain:

\[
\begin{bmatrix}
F_a(q_1, g_1) \\
F_a(q_2, g_2) \\
\vdots \\
F_a(q_N, g_N)
\end{bmatrix} = 
\begin{bmatrix}
-\xi p(q_1, g_1) \\
-\xi p(q_2, g_2) \\
\vdots \\
-\xi p(q_N, g_N)
\end{bmatrix}
\]

### 2.2 Repulsive forces

The repulsive forces produced by the obstacles indicate the presence of the robot at the threshold radius of obstacle. This force reacts to push the robot far from the dangerous zone of obstacle (Matoui et al., 2015).

In this section, \( q_o_j \) is the position of the obstacle \( j \) (\( j = 1, 2, ..., M \)) and \( p(q_i, q_o_j) \) is the distance between the robot \( i \) and obstacle \( j \). The equation of repulsive force generated by an obstacle \( j \) and applied to the robot \( i \), is presented in (4):

\[
F_{ro}(q_i, q_o_j) = \begin{cases}
\frac{1}{p(q_i, q_o_j)} & \text{if } p(q_i, q_o_j) \leq p_{o_j} \\
\frac{1}{p^2(q_i, q_o_j)} & \text{if } p(q_i, q_o_j) > p_{o_j}
\end{cases}
\]

with \( p_{o_j} \) is the threshold radius of obstacle \( j \) and \( p(q_i, q_o_j) \) is the distance between robot \( i \) and obstacle \( j \). If we use \( M \) obstacles in the workspace of robot \( i \), the equation (4) is updated as expression (5):

\[
F_{ro}(q_i) = \sum_{j=1}^{M} F_{ro}(q_i, q_o_j)
\]

Besides, each robot \( k \), neighbor to robot \( i \), is considered as an obstacle so a repulsive force should be calculated according to the robot \( k \) position, \( q_k \). The expression of the repulsive force generated by the robot \( k \) and applied to the robot \( i \) is given in (6):

\[
F_{rr}(q_i, q_k) = \begin{cases}
\frac{1}{p(q_i, q_k)} & \text{if } p(q_i, q_k) \leq p_{r_k} \\
\frac{1}{p^2(q_i, q_k)} & \text{if } p(q_i, q_k) > p_{r_k}
\end{cases}
\]

with \( p(q_i, q_k) \) is the distance between robot \( i \) and robot \( k \), and \( p_{r_k} \) is the threshold radius for the robot \( k \). If we use \( (N - 1) \) robots in the workspace of the robot \( i \), the equation (6) is updated as expression (7):

\[
F_{rr}(q_i) = \sum_{k=1, k\neq i}^{N} F_{rr}(q_i, q_k)
\]

We note that in the real production site, the use of multiple robots with the presence of multiple obstacles at the same workspace is very frequent. So, The expression of repulsive forces in the general case can be written by (8):

\[
F_r(q_i) = F_{ro}(q_i) + F_{rr}(q_i)
\]

### 2.3 The resultant forces of potential field

The robot is considered as a particle subjected to the influence of an attractive potential of the target and a repulsive potential from the obstacles to avoid collisions. The resultant force at each point of the environment direct the robot to the goal point. In every position of workspace, the forces applied to the robot are calculated depending on:

- The distance between the robot and its goal point,
- The distance between the robot and the obstacles,
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