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A SIMPLIFIED POTENTIAL FIELD APPROACH FOR ROBOT'S PATH PLANNING IN A THREE-DIMENSIONAL WORKSPACE

Abstract: *In the paper a mobile robot performing various tasks is considered in a three-dimensional workspace populated with several obstacles. Thus, given an initial configuration of the robot, the planner must generate a free path using continuous sequences of the robot configurations, avoiding the contact with all obstacles, starting from the initial configuration and arriving at the goal configuration. This paper proposes a simplified potential field approach considering the forces directed along the most promising direction of motion and the path generation as a process running from the forces establishing.*

Because all the C-obstacles generate repulsive potential, the problem is to create a potential barrier around each C-obstacle region, that could not be crossed by the robot's configuration. Thus, a security zone is defined for each obstacle. The attractive force generated by the goal configuration must be created so that the robot might touch it without any collision with C-obstacles. The planning method presented in this paper approaches the robot modelled as a sphere of R radius moving in a three-dimensional workspace, populated with several obstacles. Original software was created to guide the mobil robot between the obstacles in order to stop it in the final configuration.

1. INTRODUCTION

A successful approach of motion planning both of articulated manipulators and of mobile robots is the potential field method. The basic idea of the potential field method is to consider the robot, represented as a point in configuration space, moving under the influence of an artificial system of forces produced of the goal configuration and C-obstacles too. Many different approaches using artificial potential fields for planning the motion of a moving system have been studied [4], [5], [6], [7], [8], [9], [12], [13], [15], [16], [18], [19].

Let is considered a mobile robot performing various tasks in a workspace populated with several obstacles. Thus, given an initial configuration of the robot, the planner must generate a free path using continuous sequences of the robot configurations, avoiding the contact with all obstacles, starting from the initial configuration and arriving at the goal configuration [1], [2], [3], [10], [11], [14], [17].

Because the C-obstacles generate repulsive potential, the problem is to create a potential barrier around each C-obstacle region, that could not be crossed by the robot's configuration. Thus, a security zone is defined for each obstacle. The attractive force of the goal configuration must be created so that the robot might touch it without any collision with C-obstacles.

The method was developed as an on-line collision avoidance approach applicable when the robot did not have a prior model of the obstacles (workspace), but could be informed about them during the motion execution. There are many real-life problems in which the geometry of the workspace can only be partially known during the planning time. If the planning method requires an on-line model of the environment, the robot must be fit out with a video-camera, in order to get all needed information. Thus, the uncertainty is smaller and it is reasonable to generate sensory-based motion plans those can deal with the robot motion. The mobile video-camera is used to guide the motion, and another video-camera (a fixed one) is used to monitor its execution.

2. METHOD PRINCIPLE

The robot is considered as a unit mass R radius sphere particle moving under the influence of the force field $\mathbf{F} = -\nabla U$. At every configuration A(**C**), the artificial force **F**(**C**) determines the acceleration of the robot. The robot is attracted toward its goal configuration and it must avoid any obstacle collision. The robot can perform a general motion (any translation and any rotation) in a three-dimensional workspace. The presented method imposes an upper limit for the robot's velocity. This supposition is validated by the physical reality. After *n* iterations, when the robot is inside the security zone (in other words, the robot is subjected only to the attractive potential), and it does not go into the repulsive field of any obstacle, the distance between two successive configurations of the robot is presented by equation (1), where *a* is the robot acceleration, *Δt* is the iteration duration.

$$\Delta d = \frac{1}{2}a(n\Delta t + \Delta t)^2 - \frac{1}{2}a(n\Delta t)^2 = \frac{1}{2}a(2n+1)\Delta t^2 \qquad (1)$$

Assuming that the influence distance of the repulsive field of some obstacle is d_0, after a number of iterations $n \geq \frac{d_0}{a\Delta t^2} - \frac{1}{2}$ it can be possible that the robot "breaks" the potential barrier and "touches" (knocks) the obstacle. In order to solve this problem, we are considered that the robot tries to move with a constant velocity **v**, conveniently chosen, toward its goal configuration.

The attractive potential associated with the goal configuration is independent of the C-obstacle region. There are known many attractive potential function [4], [14], [17]. The parabolic function is probably the most recommended. This function has good stabilising characteristics, since it generates an attractive force that converges linearly toward zero when the robot's configuration gets closer to the goal configuration.

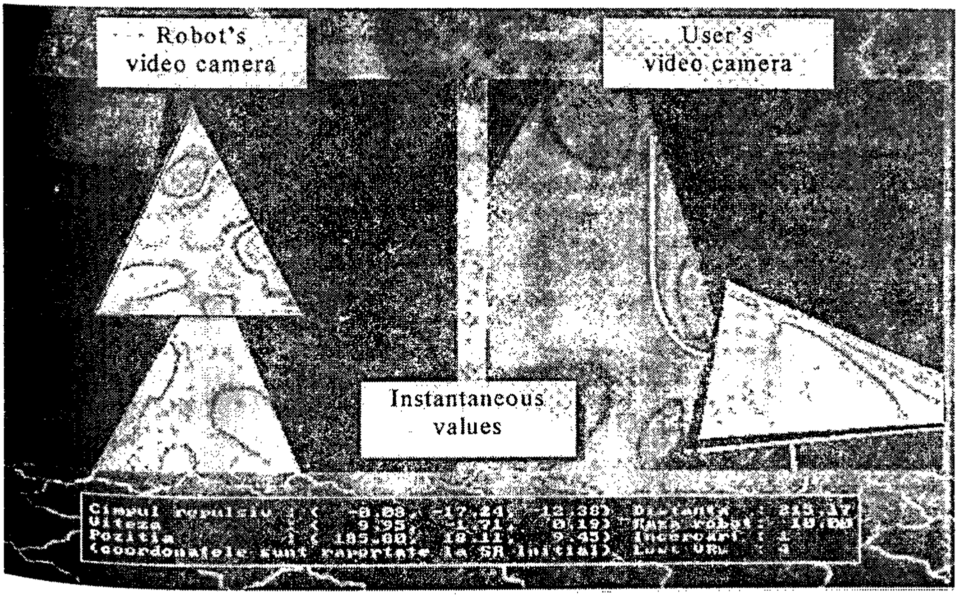
To find a path for the robot, both a global and a local planner are necessary. The global planner checks for the shortest path between the start (the current configuration) and the goal configuration with a minimum heuristic estimation of the chance of collision. Then, the local planner moves the robot along this path, modifying the robot's position and orientation as necessary to avoid collisions. The process is repeated until a solution is found.

Since the robot is modelled as a sphere, the obstacles can be considered with their real shapes. Specifying their surfaces, edges and vertices can represent obstacles. Moreover, the representation should allow efficient detection of collisions. Each obstacle generates a repulsive potential. Thus, the local maximum of the repulsive potential function occurs only into the obstacle (where U_r tends to infinite). Its influence distance defines the collision region. Inside the collision region, the repulsive potential field strictly decreases as the inverse of the distance outside the obstacle. When the robot is into the security zone, it is desirable that the repulsive potential does not affect the robot's motion. That is to say, it is enough far away from the obstacles. Thus, inside the security zone, it finds the minimum potential valley [6], [17].

3. COMPUTER SOFTWARE FOR ROBOT'S MOTION SIMULATION

The elaborated software is utilised to simulate the motion of autonomous robot under the influence of some forces generated by artificial potential fields. The robot has no prior knowledge about its three-dimensional environment. So, it proceeds a general motion and acquires, using a video-camera, any information about the workspace.

The display module of the software realises a projection of the robot's "visual field", by the Z-buffering technique. This projection is realised with the video-camera attached to the robot and oriented along the velocity vector of the robot's reference point. This projection is presented in the first window of the display. The workspace is equipped with a user's video-camera monitoring the robot's motion (second window of the display). The user's video-camera is situated on the median perpendicular of the segment that connects the initial configuration with the goal configuration. Thus, at any moment of robot's motion, the user can have on the display a local and a global view, and all the information about potential field, velocity, position, and current distance to the goal configuration (fig.1).



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(coordonatele sunt raportate la SR initial) Lant VR   : 4
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Fig.1 General view of display

The user must develop the following actions:

- to edit the obstacles;
- to select initial and goal configurations;
- to set all the needed parameters;
- to set the frequency of iterations for timer;
- to set the fixed video-camera position and orientation;
- to send the start command of the robot's motion.

In order to derive the repulsive potential field generated by an obstacle it must compute the resulting repulsive force acting on the robot (generated by each surface of the obstacle) (fig.2). Thus, it projects the robot's reference point on the obstacle surface. If this projection is inside of the considered surface, it computes the distance from the robot's reference to this surface. The repulsive force decreases with the square distance and is normal in the projection point to the obstacle surface. Likewise it must compute the repulsive force generated by edges and vertices, when the robot has an adjacent position to a vertex or an edge (fig. 3).

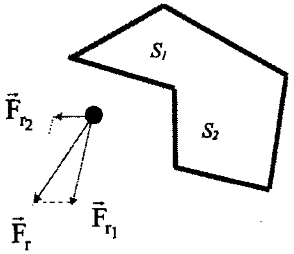

Fig.2. Repulsive force generated by a surface

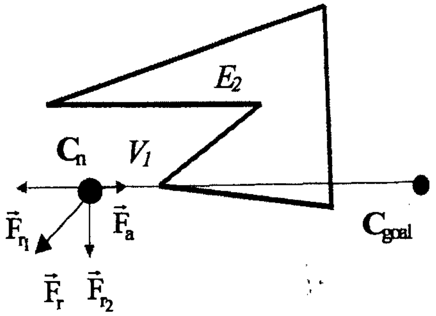

Fig.3. The resulting repulsive force is generated by a vertex and an edge and the attractive force is generated by the goal configuration

The algorithm for repulsive potential field generated by an obstacle has three steps. It needs a list containing all the obstacle vertices. First, all these vertices are non-marked.

Step 1. Surfaces. Let us consider one face of an obstacle. It determines the projection of the robot's reference point (sphere center) onto the surface of the obstacle. When the robot can be projected, it computes the potential field whose value is $U_r = \eta\left(\frac{1}{d}-\frac{1}{R}\right)^2$ where d is the distance from the robot's reference point to the face of the obstacle and R is the sphere radius. Its direction is oriented along the **OO'** vector (O is the robot reference point and O' is the projection point; O' belongs to the considered surface). It marks all the vertices of the considered face in mentioned list. Repeat step 1 for each surface of obstacle.

Step 2. Edges. If both the ends of the considered edge already have been marked, then that edge belongs to one of the faces treated in the first step (the length of the projection is already computed). Therefore, this edge is neglected. If the edge has still a non-marked end, and the robot's reference point can be projected on this edge, the repulsive field is computed both as value and orientation. It used the same relationship as the surfaces. Both ends of the considered edge will be marked. Repeat *step 2* for each edge of the obstacle.

Step 3. Vertices. At this step, it can compute directly the value and orientation of the repulsive potential for all the vertices still non-marked. In the case of local minimum, the software points out it. In order to solve this problem, a chart was created. In this chart, the last 100 values of the robot's positions are memorised. Thus, at each iteration, these values are compared, and if the maximum difference on each axis is smaller than an acceptable minimum value, then a minimum of potential was occurred. In the case of a blocked situation, the software decides itself if the iteration may be continued or not. If the decision is to continue the path generation, and the robot is not capable to get out from the local minimum, the software reports failure and the iteration is interrupted. The robot can return to a new initial configuration and the algorithm is repeated.

In fig. 4 is presented the robot's path in a three-dimensional workspace, obtained with the described software.

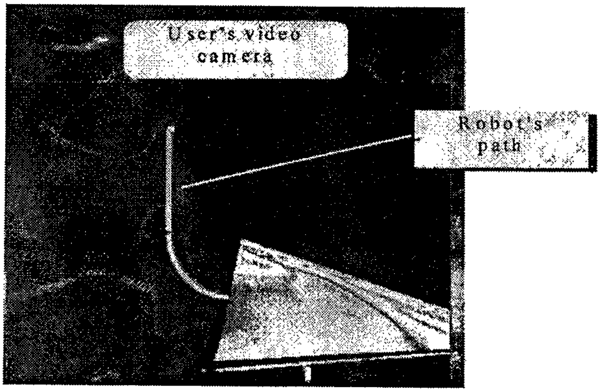

Fig.4. Robot's path recorded by the user's video-camera

4. CONCLUSIONS

The collision-free path found by the proposed algorithm is not optimal in the sense of the minimum length and orientation change. Also, this algorithm does not solve in all situations the problem of local minimum, but it is very efficient and fast in a wide range of situations.

The algorithm can be applied both in 2D and 3D workspace, for any robot and any workspace: static or dynamic one. While the robot is modelled as a sphere, the calculus and construction of the C-obstacle region are not more necessary. Thus, the method applied on-line performs as a fastest procedure. The calculus complexity of motion planning increases with the number of obstacles in the robot's workspace. Using the second video-camera, the user has a global view of the path generating. The algorithm can be applied in the case of movable obstacles too.

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