Path Planning in Dynamic Environments

Haifeng Gao
Communication and Operating system
Electrical Engineering and computer Sciences, Technical University of Berlin
Berlin, Germany
Haifeng925@gmail.com

***Abstract*—Path Planning is very popular and important subject in robotics systems. Path Planning for robots is to find a collision-free route from start point to goal point. According to the different environments in which robots located, path planning can be classified into two types: path planning in static environments and path planning in dynamic environments. There are already lots of publications on the research of path planning in static environments, but comparatively fewer in dynamic environments, probably because path planning is harder than that in static environment, since all the obstacles are moving over times and even the goal point is in motion. To avoid the collisions among the robots and obstacles, more issues should be considered. This paper will first give a brief introduction of path planning problem, and then focus on the research of path planning in dynamic environments. The special issues of path planning in dynamic environment will be discussed. Especially two new algorithms, new potential field method and dynamic Voronori diagram will be interpreted in this paper. These new algorithms would be able to be used for operating system project.**

Keywords-component; path planning; dynamic environment; robots; roadmap;

I. INTRODUCTION

Path planning problem has already been researched for many years. It plays very important role in CAD-design, computer games and some other applications. It is also a very fundament and classic problem in the field of robotics systems. In recent years, more and more mobile robots are used in many industrial fields. Therefore studies of path planning have very important practical significance. Particularly, path planning for dynamic environment is closer to the reality. In the real world, almost everything is in motion, so the path planning should focus on the moving objects. So far, lots of algorithms have been developed to deal with path planning problem, such as A* algorithm, classic potential field and visibility graph can be used to deal with path planning in static environment and D* algorithm can be used for path planning in dynamic environment. Even so, the quality and efficiency of those algorithms cannot be guaranteed. Potential field method and Voronori diagram are two classic approaches for path planning. After some improvements, those two approaches can be developed into two useful methods to deal with path planning problem in dynamic environment. The new potential field method deals with velocity of the robots and obstacles to benefit the requirement of the dynamic environment and the dynamic Voronori diagram needs the updating of roadmap in a period.

A. *Concept of Path Planning*

Path planning for robots means to move the robots from the start point to the terminate point without collision. Moreover, for some optimal requirement, the path between start point and destination should be the shortest to reduce the processing time and energy consumption. Figure 1 indicates an abstract case of path planning. The black areas are obstacles which the robots should not go into, while the arrows show the safe path for the robots.

B. *Classification of Path Planning*

1) According to the different environments in which the robots are located in, the path planning methods can be classified into two types:

a) In static environment: This is the simplest case of path planning. All the obstacles and the goal point remain stationary during the movement of robots. The robots only need to know the location of the obstacles. And then the path can be calculated with the informaiton of those locations.

b) In dynamical environment: In such case, the obstacles may change their positions over time, even the goal point could be in motion. All those will enhance the difficulty of path planning. Figure 2 shows the path planning problem in dynamic environment

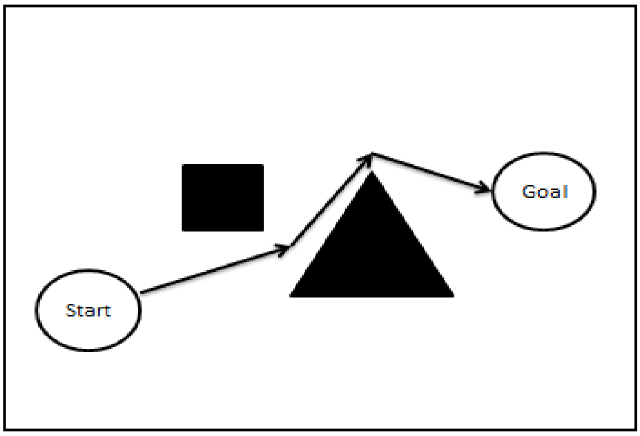

Figure 1. Path Planning from start point to goal point

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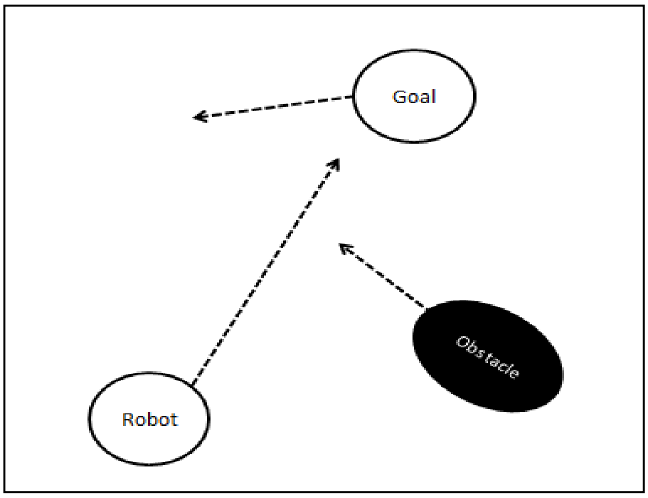

Figure 2. Path Planning in dynamic environment

2) Depends on whether the information of obstacles is known by the robots, every type can be divied into two classes:

a) Known Environment: All the information about the environment, including positions of the obstacles and velocity of obstacles in dynamic environment, are known by the robots located in this environment before they start to move. In this situation, the path can be computed before they begin to move. It is called offline-computation. The path planning for static known environment is the simplest variant of path planning.

b) Unknown Environment: An unknown environment means that, the robots do not know all the information about environment they are located in before they begin to move. In this situation, the robots need to use sensors to probe the environment to acquire the information of the location, shape of the obstacles, and then using this information to do path planning dynamically.

C. Path Planning in Static Environment

The technique for path planning in static environment is relatively mature with lots of methods developed to solve this problem. In this case, the environment in which robots are located in only related to the locations of the obstacles, start points and goal points. Normally, potential field method and Visibility Graph are used to do the path planning in static environment. A* algorithm and Dijkstra's algorithm can also be used to find the shortest path on a map.

D. Path Planning in Dynamic Environment

Because the obstacles and the goal point move over time, path planning in dynamic environment is more complicated than that in static environment. If path planning in static environment can be considered as the problem in 2-demensions, then that problem in dynamic environment must be handled in 3 or more dimensions. The time space is a very important element that it should be considered. Figure 3 shows the path planning in the static environment, the problem can be described in 2-demensions. And Figure 4 shows the path planning problem in dynamic environment. t-coordinate indicates the time, x and y coordinates indicate the location of the objects. The curve R is the trajectory of the robot and curve O is the trajectory of the obstacles. The collision will happen at point C. At most time, velocity and acceleration of the robots and obstacles should also be considered. Sometimes, to simplify, the acceleration can be ignored by just assuming that, the robots always keep the maximal velocity.

The research of path planning in dynamic environment is evaluated quickly in recent years, but only limited methods can be used to deal with the motion obstacles. Generally, in dynamic environment, the robots need to compute a roadmap at beginning, then update the information of environment and adjust the roadmap after a while. If there are multiple robots, the communication and coordination among robots are necessary.

However, some approaches to the path planning problem can be identified, such as cell decomposition methods and D* algorithms. Some algorithms used in static environment are now being developed for path planning in dynamic environment, such as new potential field methods and the new Voronori diagram.

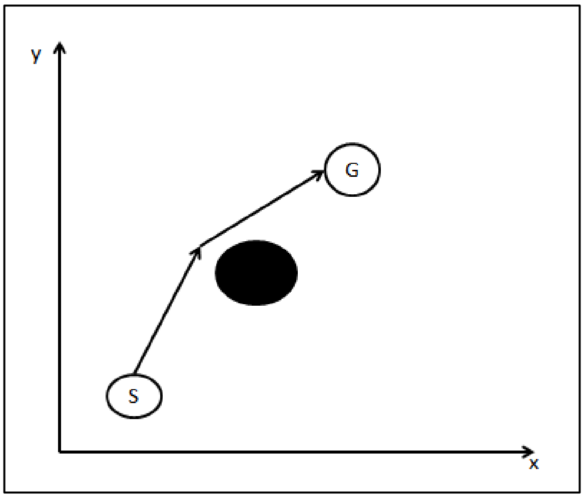

Figure 3. Abstract path planning in static environment in 2-demensions

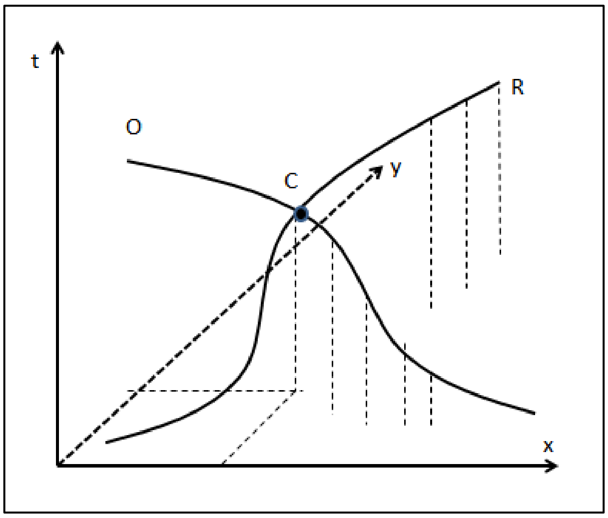

Figure 4. Abstract path planning in dynamic environment in 3-demensions

II. ROBOTS PATH PLANNING IN DYNAMIC ENVIRONMENTS

Compare to path planning in static environment, path planning in dynamic environment has more practical senses. In the real world, most obstacles are in motion. For example, in the Robocup, two teams of robots chase the ball while the ball and all other robots in the game are moving, the robot should find a way to chase the ball and avoid the collision with other robots. And to make the case even more complicated, the robots should cooperate with team members.

To execute the path planning in dynamic environments, new potential field method and dynamic Voronori diagram are improved to benefit those requirements.

A. New Potential Field Method

1) Classic Potential Field Method

The basic concept of potential field method is to fill the robot's workspace with an artificial potential field in which the robot is attracted to its goal position and is repulsed away from the obstacles [1].

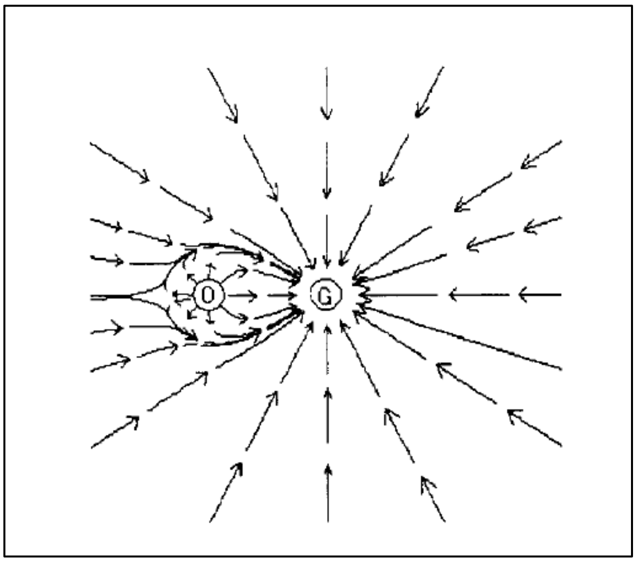

Figure 5. Artificial potential field [2]

Figure 5 shows the artificial potential field. All the points around the goal position will get an attractive force from the goal point and a repulsive force from obstacle. The robot will move toward the goal though those two forces. Figure 6 indicates the forces of robots in the potential field. The strength of the force is related to the distance between the robot and the goal position or obstacle, so the general force of robots can be calculated as follow:

$$F_{(q)} = F_{attq}(q) + F_{attq}(q) \quad (1)$$

2) Potential Field Method in Dynamic Environment

In the new potential field method, the function of the attractive force and repulsive force will not only be related to the distance, but also to the velocity and acceleration.

a) Attracictive Force: Figure 7 indicates the process to get the attractive force from the goal position with velocity and acceleration. As Figure 7 indicates, now the attractive force $F_{att}(q, v, a)$ from the goal position consists of three parts: the force $F_{attq}(q)$ relates to distance, the force $F_{attv}(v)$ relates to the velocity and the force $F_{atta}(a)$ relates to the acceleration. The following formula shows the components of the attractive forces.

$$F_{att}(q, v, a) = F_{attq}(q) + F_{attv}(v) + F_{atta}(a) \quad (2)$$

b) Repulsive Force: Besides the attractive force from the goal position, the robots also get a repulsive force from obstacle. Similar to the attractive force from goal position, the repulsive force also consists of three forces: one force with distance, one with velocity and one with acceleration. Figure 8 indicates the process to get the repulsive force from obstacle. The formula will be written as follow:

$$F_{rep}(q, v, a) = \begin{cases} F_{repq} + F_{repv} + F_{repa}, \\ if \ (\rho_{obs} - R_{obs}) \le \rho_0 \ and \ v_{r0} > 0 \ and \ a_{r0} > 0 \\ F_{repq} + F_{repv}, \\ if \ (\rho_{obs} - R_{obs}) \le \rho_0 \ and \ v_{r0} > 0 \ and \ a_{r0} \le 0 \\ 0, \quad if \ (\rho_{obs} - R_{obs}) > \rho_0 \ or \ v_{r0} \le 0 \end{cases} \quad (3)$$

Where ρ_0 is a positive constant reflecting the influence distance of the obstacles, ρ_{obs} is the distance between the robot center and the nearest point on the obstacle, R_{obs} is the radius of the robot, v_{r0} and a_{r0} are the relative velocity and acceleration between the robot and obstacle.

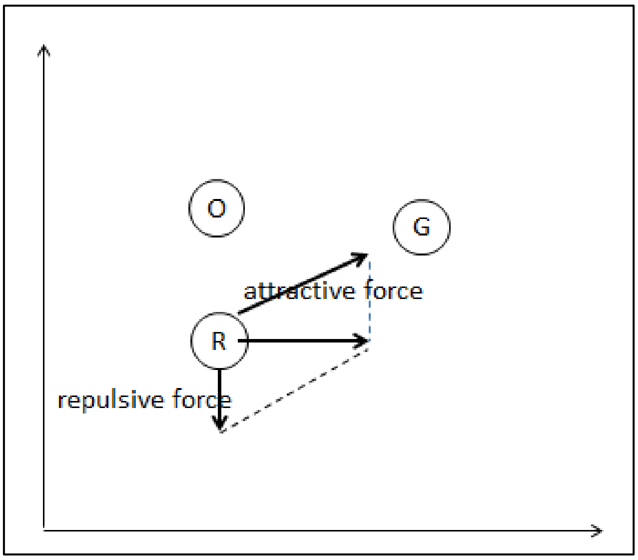

Figure 6. Forces over the robots in potential field

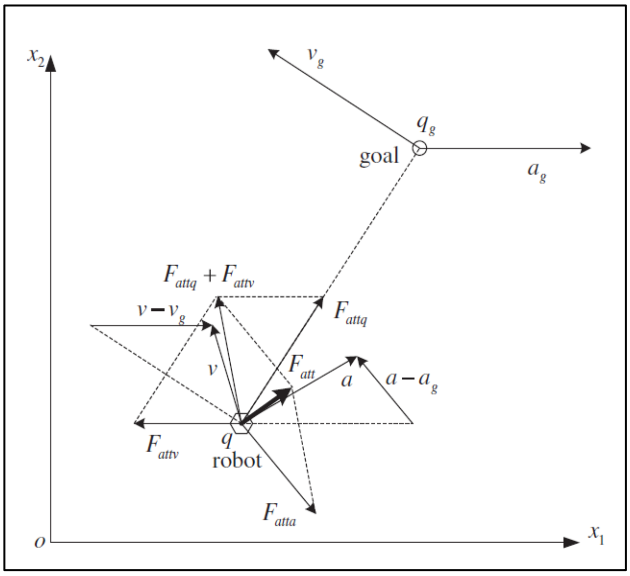

Figure 7. Attractive force with velocity and acceleration[2]

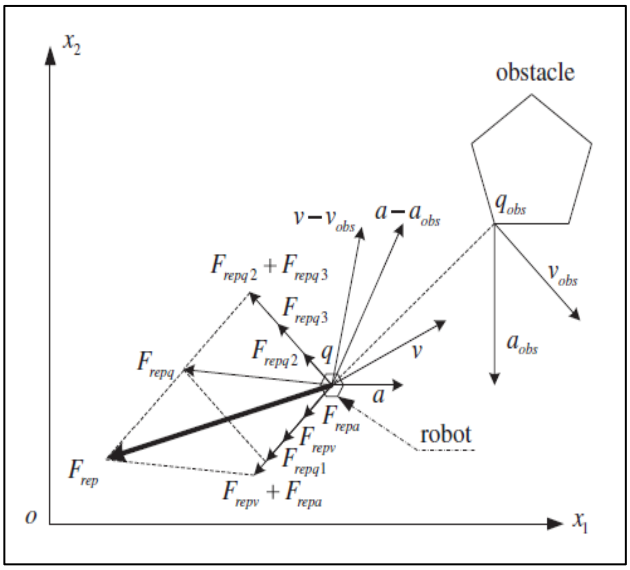

Figure 8. Repulsive force with velocity and acceleration[2]

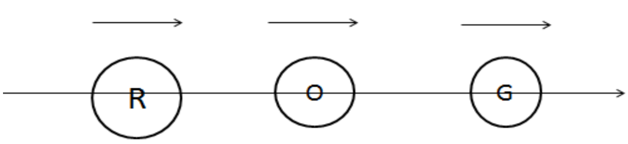

Figure 9. Minimal problem [2]

c) Local minimal problem: With the new potential field method, the path planning problem can be well executed, but there is also a weakness in this method: the local minimal problem exists. Local minimal problem means that, in some situation the robots will never reach the goal point. Figure 9 shows an example of minimal problem. Assuming the robot, obstacle and goal point moving in the same direction and the *obstacle located between the robots and goal point. In this situation, the robots can never overtake the obstacle.*

d) Solve local minimal problem: the simplest way is to keep robots moving and wait for obstacle changing its direction. If it does not work after a long time, just assuming that the obstacle will never leave this situation, then the potential field method should be place with other path planning method.

B. Dynamic Voronori diagram

Voronori diagram is usually used for path planning in static environment. It is very simple to be implemented. After a little improvement, Voronori diagram can also be used for path planning in dynamic environment.

1) Concept of Voronori Diagram

In most general form , the Voronoi diagram is VD(S) of a set S of n objects in a space E is a subdivision of this space into maximal regions, so that all points within a given region have the same nearest neighbor in S with regard to a general distance measure *d* [3]. Figure 10 shows a simple Voronori diagram with 7 obstacles. The black point is the obstacles in the environment. The whole space is partitioned into sever regions, denoted as P1,P2, ..., P7, each contains one obstacle. In each region, any point in the region has a shorter distance to the obstacle in this region than those to the other obstacles. After constructing the Voronoi diagram for the space, the edges are the safest path to avoid collision with obstacles.

To divide the space and construct the Voronoi diagram, we only need to draw the perpendicular bisector of every two obstacles.

2) Dynamic Voronori Diagram

In dynamic environment, while the position of every obstacle changes with time, the Voronori Diagram is also needed to be merged and updated over time.

In multiple robots environment, all other robots will also be seen as moving obstacles. The Voronori Diagram will be more complicated as the number of robots grows. The Voronori Diagram is not efficient for multi-robots environment.

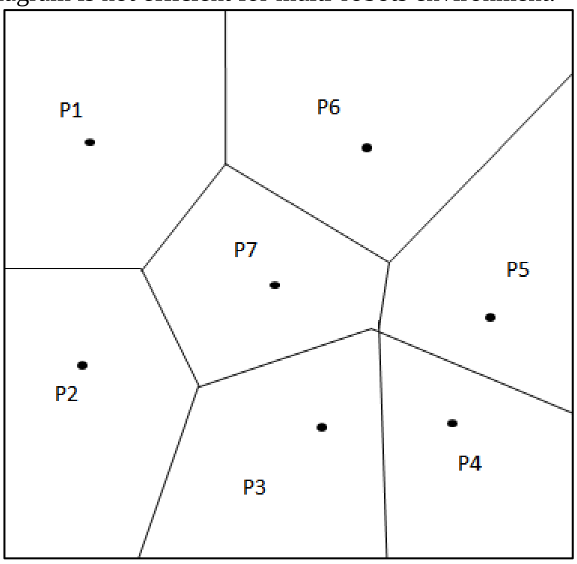

Figure 10. Voronori diagram with 7 obstacles.

C. Multiple robots path planning

1) Issues to be handled

Path planning in dynamic environment for multiple robots is more complicated than path planning for single robot. Besides planning a collision-free route for every robot, the communication and cooperation among robots should also be considered. Therefore, there are some strategies used in cooperation among the robots.

2) Stragegies for Multiple rotbots path planning in dynamic environments

Assuming every robot is assigned a different priority. So if at one point there is a collision between two robots, the following strategies can be used to solve this problem.

a) The robot with low priority should stop at that place, wait and let the robot with hight priority to pass first.

b) The robot with low priority do not stop, but chose another way to avoid the collision with the robot with hight priority.

III. CONCLUTION

This paper makes a brief introduction of the path planning in dynamic environments for the robots and compared with the path planning in static environment, essentially dealing with issues of path planning in dynamic environment. The most important feature of the dynamic environment is that all the obstacles are in motion. To deal with this specific characteristic, time, velocity and acceleration should be considered. New potential field method which bases on the classic potential field method uses both velocity and acceleration to benefit the requirement of dynamic environment. With those elements new potential field can be used to avoid the collision with the motion obstacles. But to solve the local minimal problem, other technique should be used.

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