A Technique For Autonomous Underwater Vehicle Route Planning

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Abstract—**If an underwater vehicle is to be completely autonomous, it must have the ability to plan paths around obstacles in order to safely operate. Many solutions to the problem of planning the path of a robot around obstacles have been posed in recent years, but all have limitations of one form or another. Presented is an algorithm which uses artificial potential fields to aid in the path planning. The planning consists of applying potential fields around the obstacles and using these fields to select a safe path for the robot to follow. The advantage of using potential fields in path planning is that they offer a relatively fast and effective way to solve for safe paths around obstacles. In the method used here to accomplish path planning, a trial path is chosen and then modified under the influence of the potential field until an appropriate path is found. By considering the *entire path*, the problem of being trapped in a local minimum is greatly reduced, allowing the method to be used for global planning. The algorithm was tried with success on many different planning problems. The examples in this paper illustrate the algorithm applied to two- and three-dimensional planning problems.**

Keywords—**Autonomous underwater vehicle, robot, planning.**

I. Introduction

PLANNING the path of an undersea vehicle through an obstacle-strewn region is a problem which must be solved if completely autonomous vehicles are to safely operate. Presented in this paper is an algorithm for planning the path of a robotic submarine around obstacles by using artificial potential fields.

In the technique to be described here, artificial potential fields are placed around the obstacles, and the resulting field is used to choose an appropriate path. To accomplish this, a trial path is chosen and then modified under the influence of the potential field. By considering the entire path, the problem of becoming trapped by a potential field local minimum is greatly reduced, allowing the method to be used for global planning.

Background

The path-planning problem in robotics has attracted quite a bit of attention in recent years. Most of the approaches to the problem can be classified into a few areas. The two main areas are the graph searching and potential field methods. The graph searching techniques are so named because a chart or graph is produced, showing free spaces where no collision will occur, and forbidden spaces where a collision will occur. Based on this graph, a path is then selected by piecing together the free spaces or by tracing around the forbidden spaces. Since the technique presented in this paper is potential field-based, these methods will not be discussed in detail.

A common technique is to map the workspace into the configuration space (C-space) of the robot [1]. Configuration space is a multidimensional space spanned by a set of generalized coordinates that describe the position and orientation of a rigid body. The advantage of using C-space is that the position and orientation of a moving body are represented as a point, and the obstacles are represented by forbidden regions. The planning problem is then reduced to moving the point representing the robot configuration from the initial to the goal position without entering any of the forbidden regions.

A variety of potential field methods have been presented in the past few years, but most have a common theme. These methods use artificial potential fields applied to the obstacles and goal positions and use the resulting field to influence the path of the robot which is subject to this potential. Although not as thorough as the graph searching techniques, the speed of the algorithms and the easy extension to higher dimensions make them as excellent alternative to the graph searching techniques. An early researcher who used artificial potential fields in path planning is Khatib [2]. Positive (repulsive) potential fields are placed around the obstacles, and negative (attractive) potential is placed at the goal position which acts on the robot. The result is that the position to be reached is an attractive pole for the robot, and the obstacles are repulsive surfaces for the robot's parts. The sum of the potentials is then placed into a Lagrangian formulation along with the robot kinetic energy to determine the equations of motion of the robot. These can be solved to determine a free path to the goal position.

The major problem with this type of potential field method is that it is very susceptible to local minima in the potential field. Since the planner tends toward lower potential areas, it can reach a state of equilibrium, or a potential basin, and become trapped. This state of equilibrium occurs when the repulsive forces due to the obstacles are balanced by the attractive forces of the goal. The previous potential field methods are very effective at obstacle avoidance, but they are not as effective at goal achievement due to the local minima problem. Attempts have been made to overcome this problem by altering the shape of the potential fields [3]–[5]. Although it was reduced in severity, the problem was not eliminated.

Arkin [6] presented a motor schema system which is potential field-based. Different schemas are produced for such things as obstacle avoidance, path following, move-to-goal, etc. These are combined to produce the potential field on which the planning is based. When local minima in the po-

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tential field are produced and trap the robot, the gains on the lower priority schemas are reduced to adjust the potential field and allow the robot to continue. When local minima in the obstacle avoidance schema are encountered, the path planning is deferred to a higher level planner and the potential field technique is temporarily abandoned.

Krogh and Thorpe [7], recognizing that previously reported potential field algorithms perform well for local planning, developed a hybrid planning system. They begin by determining a preliminary path using an A^* search with a coarse grid. Next, "path relaxation" is performed so that a total cost for the path is minimized. This is done by adjusting the path nodes. Finally, points along this path are used as intermediate goals, and the potential field planning algorithm proceeds using sensor information to update the potential fields. Although primarily a graph-searching technique, it does use the benefits of the potential fields in local planning.

Buckley and Leifer [8] suggested that an entire trajectory could be hypothesized between two known endpoints and perturbed into admissible regions. They developed a technique for determining the minimum distance between the trajectory and obstacles, or the amount of penetration if the trajectory passed through an obstacle. Although no formal path-planning algorithm was presented there, the idea of adjusting the entire trajectory was introduced.

A technique for the obstacle avoidance of AUV's was introduced by Hyland [9]. He used a simulated sonar system to guide the AUV through an unknown obstacle field in a process similar to maze solving. This is accomplished by moving towards the goal and turning when an obstacle is encountered. The procedure is repeated until the goal is reached. Although it is effective in unknown environments, there are more efficient path planners when the obstacle field is known.

II. Path-Planning Algorithm

Most previously reported potential function schemes have concentrated on the potential fields affecting a point which represents the position. The high potentials on the obstacles force the point into the low potential area around the goal, and a path is traced out by the moving point. An alternative planning scheme has been developed [10] in which an artificial potential field is produced on the C-space of the robot, and an arbitrary path is constructed through the potential field with all points along the path being subject to the potential simultaneously. The difference to note is that the potential affects the *entire path* simultaneously and not just one position. The technique is similar in principle to that described in [8]. This will be shown to be much more effective at global path planning. Using optimization techniques, the path is altered so that it passes through the minimum potential and, therefore, avoids the obstacles. Although not entirely eliminated, with careful selection of the potential fields the problem of local minima has been greatly reduced. This idea can be readily extended into any higher dimensions, but the development shown here will be in two- and three-dimensional space.

The path relaxation technique described in [7] begins with the safe path which was determined by the grid search, and then adjusts it to reduce a total cost function. In the algorithm to be presented here, an initial straight path is produced, and it is adjusted until it becomes safe. This eliminates the costly grid search. However, it does so at the expense of completeness.

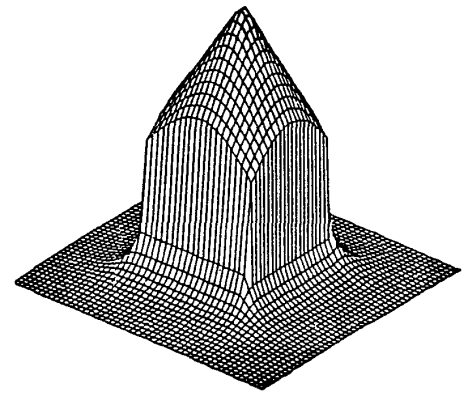

Fig. 1. Potential field.

Since an arbitrary initial path laid through the obstacle-strewn region will probably pass through the obstacles, a potential function must be selected so that the path is driven away from the obstacle. The total potential field will be broken down into two parts—points inside an obstacle and points outside. The potential field selected for points inside an obstacle U_{in} is one such that the maximum value is inside the obstacle and the potential decreases linearly as the distance away from the centroid is increased. The expression for the potential inside an obstacle was written as:

$$U_{\text{in}} = U_{\max}\left(1 - \frac{R_{\text{in}}}{R_{\max}}\right) + U_{\text{offset}} \tag{1}$$

where $U_{\max}$ is the maximum potential allowed, R_{in} is the distance from the point in question to the centroid, R_{max} is the distance from the centroid to the farthest point on the boundary of the obstacle, and U_{offset} is an additional potential applied to all points on the obstacle used to produce more of a penalty for crossing an obstacle. For the two-dimensional case, this can be envisioned as a cone placed over the obstacle, with the vertex of the cone directly above the centroid of the obstacle. The nice feature of using this type of potential field is that the path is driven away from the centroid of the obstacle. In most cases, the resulting path will be the shortest path around the obstacle.

Points outside the C-space obstacles will be subject to a lower potential. This is to ensure that driving the path off the obstacle will be given top priority. This potential U_{out} may be based on the inverse of the distance to the closest boundary:

$$U_{\text{out}} = 0.5U_{\text{offset}}\left(\frac{1}{1 + R_{\text{out}}}\right) \tag{2}$$

where R_{out} in this case is the distance to the closest boundary of the obstacle. This limits the influence of the potential outside of the obstacle to the immediate vicinity of the obstacle. The purpose of the potential outside of the obstacle is to provide a margin of safety. Fig. 1 illustrates the potential field associated with a two-dimensional square obstacle.

is required for the potential methods of the past. However, the benefits of global planning outweigh this in problems with limited uncertainty. Also, when "new" obstacles are discovered, they can be included and a new route planned based on the updated obstacle field.

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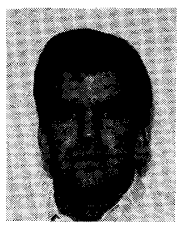

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