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Obstacle Avoidance Method for a Mobile Robot

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Abstract

This paper presents a new obstacle avoidance method for mobile robots. Obstacles in any number and with any quadrilateral configuration can be accommodated in this developed model. Robot movement is considered to be on a two-dimensional Cartesian grid. Unlike most of the methods reported, this one deals with known obstacle geometry and locations. The robot will update location information with the help of a computerized software called DANSORK for controlling moves with collision-free path planning based on the vertex detection method. Obstacle avoidance has been studied in facility location problems and research. This paper attempts to transfer a new method developed in this area for the use in robotics.

Keywords: Mobile Robot, Obstacle Avoidance, Path-Planning, Vertex detection Method, Computational Software

1. Introduction

Determination of shortest path for movement is a topic of usual interest in robotics, especially in the case of mobile robots. Such shortest or optimal path planning has some similarities with the facility location decisions for optimal sitting of a new facility, such as a manufacturing plant or a warehouse, with is after based on the shortest path and minimum travel consideration. One major commonality among these problems is the presence of obstacles or forbidden regions that restricts movement. Obstacle avoidance frequently features in many articles in robotics research. Again, some researchers working on facility location issues attempted to formulate methodologies to take care of the obstacles or forbidden regions present in the solution space. Here also, the objective has been to determine a path that will bypass the forbidden geometry in such a manner that the shortest path can be used for material transfer.

This paper presents a computer based solution methodology that can be deployed suitably to path planning problems involving obstacles in robotics which have been developed to determine the optimal location of a new facility having interaction with other existing facilities in the presence of forbidden regions impeding straight line or Euclidean paths between facilities. Dan (2009) proposed a methodology for determining optimal travel path to and from existing facilities and the corresponding location of a new facility having physical flow interaction between them in different degrees translated into associated weights, in the presence of barriers impeding the shortest flow-path involving straight-line distance.

Much research in the field of robotics has attempted to deal with obstacle avoidance problems, including Borenstein et al (1991) who developed method, called as ‘vector field histogram’(VFH) for real-time obstacle avoidance. This method uses a Cartesian histogram grid which is updated continuously with the help of sensors and is based on a two-stage data reduction process. The first stage is to reduce to polar histograms, and in the second stage it determines the obstacle density in order to steer the robot. Souhila et al (2007) attempted to develop an algorithm for visual obstacle avoidance of an autonomous mobile robot. The navigation algorithm is based on the optical flow information extracted from the image sequence using an embedded camera. The strategy consists in balancing the amount of left and right side flow to avoid obstacles. In the work of (YangWang, 2008) an incremental decision tree method is used to navigate the robot reactively from the specified initial position to its destination avoiding obstacles in its path, and a genetic algorithm method is used to perform the deliberatie navigation. It proposes a waypoint-based robot navigation method. Based on the complementary characteristics of a web camera with structured light and sonar sensors, two different sensors have been fused (Kwak et al, 2008) to make a mobile robot explore an unknown environment with efficient mapping. Sonar sensors are used to roughly find obstacles, and the structured light vision system is used to increase the occupancy probability of obstacles detected by sonar sensors. The design and evaluation of an architecture for collision avoidance and escape of mobile autonomous robots operating in unstructured environments has been presented (Evans, et al, 2008) and the approach mixes both reactive and deliberative components. Collision-free, time-optimal navigation of a real wheeled robot in the presence of some static obstacles has been undertaken by Hui and Pratihar (2008). A Genetic-fuzzy system and a genetic-neural system with a conventional potential field approach were developed for this purpose. Blanco et al (2008) propose a framework where a kinematically constrained and any-shape robot is transformed in real-time into a free-flying point in a new space. Hamner et al, 2008 present an efficient system capable of following a previously designated path as well as being perceptive and agile enough to avoid obstacles in its way. The proposed system detects obstacles using laser ranging and a layered system continuously tracks the path, avoiding obstacles and replanning the route when necessary. Zeng and Weng (2007) considered the problem of developing local reactive obstacle-avoidance behaviors by a mobile robot through online real-time learning.

The robot operated in an unknown bounded 2-D environment populated by obstacles of arbitrary shape in static conditions or moving at a slow speed. The sensory perception was based on a laser range finder. The study by Alonso et al (2007) describes the application of fuzzy techniques to analyze motion problems in a mobile robot equipped with ultrasound sensors used for obstacle detection and analyzes the knowledge extraction process for the application using expert and induced knowledge in a cooperative way, dealing with integration and simplification issues. A method was introduced (Xidias et al, 2007) for finding a near-optimal path of a nonholonomic robot moving in a 2D environment cluttered with static obstacles. The method is able to deal with robots represented by a translating and rotating rigid body. Zhuang, et al (2006) presented a path planning method for mobile robots in an unknown environment with moving obstacles. With an autoregressive model to predict the future positions of moving obstacles, and the predicted position taken as the next position of moving obstacles, a motion path in a dynamic uncertain environment is planned by means of an on-line real-time path planning technique based on polar coordinates in which the desirable direction angle is taken into consideration as an optimization index. Pradhan et al (2006) investigated navigation techniques for several mobile robots in an unknown environment where each robot has an array of sensors for measuring the distances of obstacles around it and an image sensor for detecting the bearing of the target. Zhang et.al (2004) developed a recurrent neutral network for kinematic control of robot manipulators with obstacle avoidance capability. The neural network is simulated for motion control of the robot arm in the presence of point and window shaped obstacles. A modified potential field method for robots navigation has been described by Pradhan et al (2006) that takes care of both obstacles and targets. Wang et al (2005) presents multiple-mobile-robot collision avoidance path planning based on cooperative co-evolution, which can be executed fully distributed and in parallel. Large et al (2005) addressed the problem of vehicle navigation in dynamic environments where the motion of the obstacles populating the environment is unknown beforehand and is updated at runtime. Castro et al (2002) presented an obstacle detection algorithm and a reactive collision avoidance method where the sensory perception is based on a laser range finder (LRF) system. Clark et al (2004) focuses on navigation approaches applicable to mobile robots involving obstacle avoidance. A stochastic learning automaton provides the means of collision avoidance with unstructured obstacles. Arras et al (2002) dealt with obstacle avoidance and local path planning for polygonal robots by decomposing the task into a model stage and into a planning stage. It presents an analytical solution to the distance to a collision problem avoiding the use of look-up tables. Thongchai et al (2000) described as to how the fuzzy control can be applied to a sonar-based mobile robot and showed that at a certain level the behavior is obstacle avoidance. Vikenmark et al (2006) addressed the obstacle avoidance problem that operate in confined three dimensional workspaces. Hoffmann et al (2004) present a system for obstacle avoidance of a mobile robot. Here, a model is constructed from detected obstacles giving the robot a representation of its surroundings that integrates the current as well as the recent vision information. Iossifidis et al (2004) have generalized the attractor dynamics approach to enable a robotic assistant to autonomously reach for and transport objects while avoiding obstacles. Borenstein and Koren (1990) developed a method that permits the detection of unknown obstacles and avoids collision while simultaneously steering the mobile robot toward the target. This method uses a two-dimensional Cartesian histogram grid as world model. Mobile Robot Localization is concerned with uncertain sensory information as well as data association. Arras et al(2003) presents a probabilistic feature-based approach to global localization. Location hypotheses here are represented as a Gaussian distribution and are tracked using a geometric constraint based technique. Morales et al (2009) consider the presence of obstacle in trajectory planning for a stair-climbing robot.

Obstacle avoidance has also been an issue in the context of facility location. There are not many solution procedures for handling such location search problems involving barriers or forbidden areas in any number and shape which are present between facilities impeding a straight path. However, in the recent past, facility location problems involving barriers or forbidden regions have drawn the attention of the researchers in this area. Aneja et al (1994) have dealt with the barriers and forbidden regions based on a network formation approach in location problems while Batta et al (1989) proposed a solution with an approach of cell formation. Eckhardt, as mentioned by Katz et al (1981), dealt with some problems involving forbidden regions with polygonal configuration in which the paths are allowed through the forbidden region, but prohibiting the location of facilities within the region is prohibited. The new facility location for planar 1-median problem with convex polygonal forbidden regions has been addressed by McGarvey and Cavalier (2003) and a solution procedure using the Big Square Small Square branch-and-bound is developed for global optimization. Brady et al (1980) deployed interactive graphics to solve facility location problems with a minimax objective function involving single as well as multiple new facilities in the presence of a forbidden region having any arbitrary configuration. Katz and Cooper (1981) studied the problem of single facility location involving Euclidean distance in the presence of a circular forbidden region with minimum summation or mini-sum objective. Larson and Sadiq (1983) have solved location problems in the presence of irregular and multiple forbidden regions involving rectilinear distance. Hamacher and Nickel (1994) studied the location problem involving restrictions of the forbidden region for developing the solution algorithms for median problems in a plane. Most of the aforementioned studies consider either a single forbidden region or any specific shape of the restricted region.

The objective of the present study is to verify the formulation and procedure for obstacle avoidance, developed (Dan, 2004) for facility location analysis, for path-planning of mobile robots with known obstacles present in the movement space. The space is defined as a two-dimensional Cartesian grid over which the robot will move in a straight line and the travel is measured based on Euclidean distance. This model is generalized in the sense that it considers the obstacles in multiple numbers with any quadrilateral shape including rectangles or irregular polygons to cover most of the applications using a single solution framework. Most of the reported methods for collision-free movement consider unknown obstacles. The use of sensors becomes essential to detect them. Solutions with known obstacles are practically unavailable, although that would be the case in certain applications. This paper addresses the path-planning issue with known quadrilateral shaped obstacles with reduced dependence on sensors, as the information regarding obstacles are recorded as permanent input to the software. Here, the inputs regarding the coordinate locations of the obstacle vertices and the goal or target location point with reference to the Cartesian grid is to be recorded as input. The starting location at any arbitrary point, however, will be based on feedback with the help of sonar or other suitable sensors. The goal or target point in turn may become the starting location for the successive move, and the corresponding locations can be determined using the computational procedure of the developed software DANSORK (Dan, 2004) for controlling movement, that can run on a PC. Test results, using this software, have been presented for a simulated situation.

2. A Methodology for Computation of Distance through Successive Identification of Obstacles

2.1 Distance Computation

The minimum distance between starting location and the target in presence of a quadrilateral obstacle with vertex co-ordinate points (x_1, y_1) ; (x_2, y_2) ; (x_3, y_3); (x_4, y_4) will be with the possibilities as stated below:

It will either be the path connecting the points (x_e, y_e) ; (x_2, y_2) ; (x_m, y_m) , that is, through one vertex point of the barrier quadrilateral or through the path, connecting the points (x_e, y_e); (x_4, y_4); (x_3, y_3); (x_m, y_m) , that is, through two adjoining vertices of the barrier quadrilateral. It may also be through the path, connecting the points (x_e, y_e); (x_4, y_4); (x_3, y_3); (x_m, y_m) , that is, through two adjoining vertices of the barrier quadrilateral. The Minimum of these computed distances is the shortest path between the starting location and the target position at any arbitrary location. Any of the paths will be treated as shortest when they are equal.

To obviate the complexity of computation for the second case, that is, for computation of path length through two adjoining vertices of the barrier, a simplified distance computation procedure with a degree of approximation has been adopted, which will still produce reasonably accurate results in practice. The distance in this case is the summation of two distance segments, namely, the distance from the respective starting location to the nearest vertex of the obstructing quadrilateral and from the same vertex to the target position at any arbitrary point. This is the approximate substitution of the combination of three distance segments, namely, the distance of the starting location point from the nearest vertex of the obstructing quadruple, the distance of target position from its nearest vertex and the distance between these two vertices. This is supported experimentally with three hundred random samples. Most of the distance computations, as derived from the simulated experiment, are oriented with the involvement of a single vertex of the barrier quadrilateral where the need of such an approximation is absent altogether while in other cases, the distance computations involve consideration of the adjoining vertices where the aforementioned approximation will be necessary. Thereby the overall effect of such approximation error is minimized, and in fact, is within one percent as has been observed in the results of a sideway experiment. Path planning with shortest distance is realised as Figure 1.

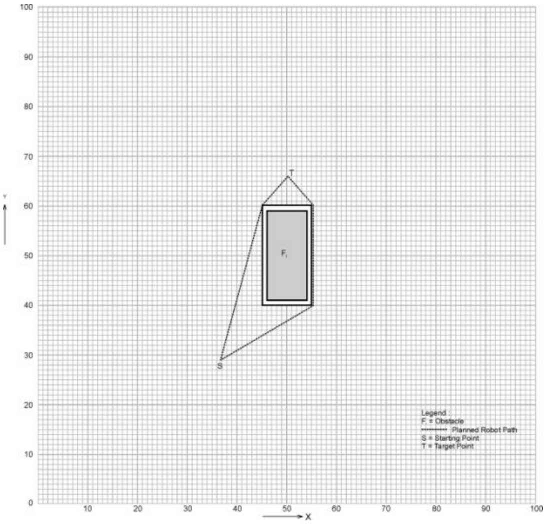

Figure 1. Path Planning with Shortest Distance

2.2 Identification of Obstructive Quadrilateral

In order to establish a relationship between the starting location point and the corresponding obstructive quadrilateral, impeding a straight path to the target position, a mathematical identification of the particular obstacle is necessary for iterative computation through a computer program. If a quadrilateral poses an obstruction on the straight line formed by joining the starting and target locations, then logically the line has to intercept at least on two arms of that polygon. It is imperative to check mathematically as to whether the intercepting intersection points are on and within the polygon arm segment. The polygon would be treated as an obstacle if more than one such intersection points are obtained for any particular polygon. The mathematical equation of a polygon arm can be expressed in the general form as:

$$ax + by + c = 0 \qquad \ldots(1)$$

Where, x and y are cardinal variables; and a ,b ,c are coefficients.

Such coefficient values [a; b; c] for each arm of a particular polygon connecting two vertices (x_s, y_s) and (x_t, y_t) would be given by: $[(y_t-y_s)/(x_t-x_s);\ -1;\ y_s-(y_t-y_s)/(x_t-x_s)*x_s]$

Similarly, the coefficients $[a'; b'; c']$ for the line equation joining target location point (x_m, y_m) and the starting location point (x_e, y_e) would be given by: $[(y_m-y_e)/(x_m-x_e);\ -1;\ y_e-(y_m-y_e)/(x_m-x_e)*x_e]$

The coefficients of line equations for each arm of all polygons as well as of lines joining the target point and the starting point are computed using a developed software. The aforementioned intersection points, x_{int} and y_{int} are derived as follows:

$$[x_{int}; y_{int}] = [(c'–c)/(a–a'); (c'a–a'c)/(a–a')] \quad \ldots(2)$$

Subject to the following sets of conditions:

$(x_s \geq x_{int} \geq x_t)$ or $(x_s < x_{int} < x_t)$; while, $[y_{s\ (or\ t)} \geq y_{int} \geq y_{t\ (or\ s)}]$ or $[y_{s\ (or\ t)} < y_{int} < y_{t\ (or\ s)}]$ and

$(x_e \geq x_{int} \geq x_m)$ or $(x_e < x_{int} < x_m)$; while, $[y_{e\ (or\ m)} \geq y_{int} \geq y_{m\ (or\ e)}]$ or $[y_{e\ (or\ m)} < y_{int} < y_{m\ (or\ e)}]$

A quadrilateral would be treated as an obstacle provided that the above conditions are satisfied together. The next step is to compute the minimum distance bypassing the polygon, in case the same has been identified as an obstacle, and is presented in the following section.

2.3 Minimum Distance through Vertex Detection

Lines joining target point and all the four vertex points of the particular obstructive polygon, would generate equations of two lines that are tangent to the polygon at two vertices and two other lines that will intersect the polygon. The subsequent computational step is to identify a couple of tangent vertices out of all four in a polygon. This is accomplished by following a similar procedure adopted for identification of obstacles.

3. Salient Features of the Developed Software for Path planning

3.1. Reconfiguring Obstacle Boundary with Dimensional Allowance

The position of the robot here is marked with a coordinate point on the Cartesian grid. The robot does actually have a dimension on the X-Y plane containing the grid. The allowance for the radial dimension or clearance has been provided, in the modeling, on the obstacle boundary. The actual obstacle boundary would be extended by adding dimensional allowances in terms of grid-units, the boundary is to be just greater than the radial dimension of the robot. This is provided to avoid collision. In the simulated experimental study, the robot radius is considered to be just less than one grid-unit in measurement. Therefore, to design a collision-free condition, one grid-unit length on all four sides of each obstacle is added on its dimension in order to provide the aforementioned clearance and the boundary thereby is reconfigured. Figure 2 (next page) depicts actual obstacles shaded with colour ‘gray’ in the inner rectangle and the reconfigured obstacle as the outer rectangle. The coordinates of the vertices on the outer boundary are to be provided as input information to this software. The starting point is indicated as S_1 and corresponding target as $T_{1,}$ which in turn becomes the starting point for subsequent moves and is expressed as S_2 , or actually as $S_2/T_{1,}$ and so on.

3.2. Data Entry Scheme

The software for the path-planning analysis has been constructed for graphical representation of the optimality framework and can run on a PC and is structured on integrated functional modules. Data Entry for various input of the basis, those are necessary for defining the problem conditions, associated with robot path planning analysis, pertaining to the coordinate location of starting point, target point and obstacle vertices. Based on the data entry sequence, the quadrilateral obstacle vertices are numbered like F011, F012, F013, and F014, where the alphabet (F) denotes the forbidden barrier or obstacle, the succeeding two digits represent the obstacle reference number, while the third digit indicates each vertex number of that specific quadrilateral that needs to be keyed-in following a sequential order for defining the barrier configuration, i.e., the obstacle.

4. Experimental Result

A simulated experimental study involving three obstacles is presented in this section. The results of optimality and corresponding travel distances using the control software are also presented with the graphical representation of the planned paths. The problem is formatted in a 100*100 grid space.

Experimental Problem-Set: for Path Planning Analysis

Obstacle Number	Coordinate of Vertices of Quadrilateral Obstacle	
	Actual	Reconfigured
1	(41,41) ; (41,39) ; (79,39) ; (79,41)	(40,42) ; (40,38) ; (80,38) ; (80,42)
2	(29,61) ; (31,61) ; (31,89) ; (29,89)	(28,60) ; (32,60) ; (32,90) ; (28,90)
3	(51,61) ; (59,61) ; (59,79) ; (51,79)	(50,60) ; (60,60) ; (60,80) ; (50,80)

Successive Location		Phase-1	Phase-2	Phase-3.
Points	S1 (30, 30)	T1/S2 (70, 60)	T2/S3 (40, 90)	T3 (10, 80)
Distance (in Grid-Units)		50.61	44.72	32.59 .

Figure 2. depicts graphically the planned path on the Cartesian grid

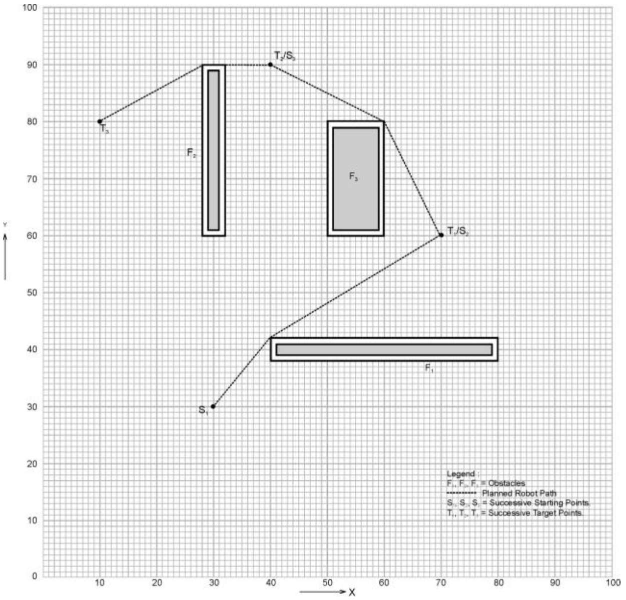

Figure 2. Robot Path Plan for Obstacle Avoidance

5. Conclusion

The validity testing of the new computational software is established through comparing the results in section-5 with the one using manual computation. With manual computation it provides the very same value as has been obtained through the DANSORK software for the constrained problem conditions as illustrated in the referred section. This establishes the ability of this software and the new obstacle search algorithm for constrained conditions in facility locations or robot movement. Trade-off between accuracy and approximation to speed up the computation needs to be considered, which has been done in this work. Therefore, this solution may not be suitable for high severity oriented situations due to collision, but can certainly be considered where minor adjustments are possible on account of the approximations considered in the computation.

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