A Novel Approach for Visibility Search Graph based Path Planning

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Abstract: - In this paper, a novel search graph approach has been developed to find a free-collision path in a complicated unknown environment. This algorithm gives the possibility to consider some constraints based on the real world path as in road or factory environments. The main feature of the proposed approach is its capability to deal with unknown environments. To assess the capability of this algorithm to navigate through complex environment, it was implemented in a roundabout setting. A simulation study on the laser simulator based on the proposed algorithm for mobile robot system was performed using the MATLAB computational platform. In this simulation, a grid map of road roundabout environment was created and it was used in the selection of most optimum traveling path, based on the respective road traffic rules. The effectiveness of the developed navigation system was evaluated by including obstacles into the mobile robot’s working environment. From the results, it is confirmed that the performance of the proposed path planning algorithm is outstanding and mobile robot is able to track the best path from selected start to the goal point, especially when detecting obstacles.

Key-Words: - Path Planning, Free-Collision Search Path, Laser Simulator, Road Roundabout, Road Curbs, MATLAB.

1 Introduction
Path planning for a mobile robot is one of the main complicated tasks during autonomous navigation in unstructured, semi-structured or structured environments.

In the path planning process, the path-free collision trajectory between start position and target position is determined continuously. There are two types for path planning of mobile robot: Global Planning or deliberative technique: in which the terrain surrounding of mobile robot is known totally and then the collision free paths is determined off-line. The other approach is local planning or sensor based planning, in which the surrounding terrain of mobile robot is partially or totally unknown and we have to use sensor with feedback for real-time plan of path through environment step by step [1]. In general, path planning of mobile robot includes the following main problems: firstly modeling the robot's environment in the useful way and secondly foundation of collision-free path from start to the end of robot’s motion [2]. Also the seeking of goal is marked as the third problem. Several approaches have been innovated to perform the search graph task.

Dijkstra algorithm [3] is one of the first and most important algorithms for graph search and permits to find the minimum path between two nodes of a graph with positive arc costs. The algorithm chooses the path with lowest cost between a certain vertex and every other vertex. In general, It can be used for finding shortest paths from a single vertex to a single destination vertex by stopping the algorithm once the shortest path to the destination vertex has been determined.

Hart et al. [4] has proposed A* algorithm, which is a best-first graph search algorithm that finds the shortest path from a given initial node to one goal node. It depends on two cost functions: the going movement cost to move from the starting point to each cell on C-space grid and the heuristic estimated movement cost to move from each cell on the grid to the final destination with ignoring obstacles. The path is generated by repeatedly choosing the cell with the lowest sum of cost functions.

Stentz et al.[5] has proposed D* algorithm, which...
produced optimization to \( A^* \) in the sense of the cost of functions, which can be calculated in real-time in \( D^* \). It consists primarily of two functions: Process – State and Modify- Cost. Process- State is used to compute optimal path costs to the goal and Modify- Cost is used to change the arc cost function and entering the affected states during movement.

Khatib [6] has proposed artificial potential fields method for path determination. The environments are represented in configuration space and the force vectors are generated from the target position (attractive) and obstacles (repulsive). Under these artificial computed forces, the robot is treated as point that forced to move towards the goal.

Nearchou [7] has proposed genetic heuristic algorithm for path planning of mobile robot that moves and picks up loads on its way. The robot surroundings are represented by graph-vertices in a known map and the GA search is performing using bit-string encoding to determine optimal path.

In the roadmap approach, the start point is connected to the destination by curved or straight lines. The nodes of the C-space graph are the start, destination points and vertices of obstacles (polygons). Those nodes which are visible from each other are connected together. Tow common methods are used in road-map: visibility graph and Voronoi diagram. In the visibility graph, the cost of all lines from initial node to target node are evaluated and the algorithm chooses the minimum path distance to target that doesn’t intersect any obstacles. Whereas in the Voronoi Diagram path, the path is generated by set of points that are equidistant from the surrounding obstacles which after that are connected to generate the Voronoi edges.

Cell decomposition methods have been used for robot path planning determination. In which, the C-space is decomposed into simple regions (cells). The decomposition of the free space can be trapezoidal and triangular cells as in exact cell approach or rectangle in approximate approach. The connectivity graph is generated to determine the adjacency relation between the cells, the sequence of consecutive cells from this graph are matched through connecting the mid-points of the intersection of two consecutive cells.

LaValle [8] has proposed a probabilistic method for path planning called Rabidly-Exploring Random Trees. In this algorithm a tree is grown from the initial configuration to explore C space. In each step a random sample in C is taken. Starting from the nearest vertex in the tree, a new edge pointing at the sample is added. This nearest vertex expansions implicitly adds a Voronoi bias to the C space exploration. As the vertices on the boundary of a tree have the largest Voronoi regions, they will be chosen for expansion of the path.

Borenstein [9] has proposed path planning methodology called Vector Field Histogram for detecting, and avoiding unknown obstacles in real-time. The first step is to generate a 2D Cartesian coordinate from each range sensor, and increments that position in the histogram grid C-space. The next step is to filter these two dimensional grid down into a one dimensional structure. Finally, it calculates the steering angle and the velocity controls from this structure.

Fox et. al. [10] has proposed Dynamic Window approach for path planning of synchro-drive mobile robot based on the motion dynamics analysis. The space search of robot is divided into a sequence of circular arcs which are determined by the velocity vectors. Tow dimensional velocity space is constructed and only admissible velocities are chosen for safety purpose. The proposed path of the dynamic window is limited to the velocities reachable within a short time interval.

The above-mentioned path planning approaches have been used to search for the shortest path, optimal path to reach goal, avoiding static and dynamic obstacles and navigate in a complex environment, but none of these methods can be used in road environment navigation, where there are a number of road traffic rules that must be strictly followed or adhered with (i.e. intersections rules, turning rules, priority rules, etc.). Owing to the constraints, previous classical path planning algorithms are no longer suitable for the robotic navigation in roundabout setting [11, 12].

In this study, a novel path planning algorithm was developed to determine the most optimum traveling path in complex environments with applying multiple constraints for the motion. It was tested in mobile robot path navigation in roundabout environment, which has been represented in a grid map form, to find the path between start and goal position with robustly avoiding obstacles.

2 Laser simulator search graph approach

In some applications, the shortest path between the start and goal position is not always required, due to some special constrains and conditions.
mentioned above, most of search graph algorithms for path planning search for the shortest path between the start and goal positions with avoiding obstacles. However, our algorithm gives the possibility to make some constraints in trajectory motion as in real-time world (i.e., road environments, factories environments, etc.). In addition, the main feature of the proposed approach in comparison with the other search algorithms is the capability to deal with unknown environments. This approach can be abbreviated as follow:

1) The environments of mobile robot should be represented in two dimension grid map. The borders of environments and obstacles are represented as polygonal (straight, tangent and circular lines) in the map. The obstacles can be static or inserted later during navigation as dynamic obstacles.

2) Start and goal locations are totally known.

3) The Laser Simulator is working as laser range finder behaviour, where the algorithm generates row of points starting from 1mm in-front of its current place position (1ICP) to right and left as horizontal or vertical lines, always perpendicular to the motion trajectory. It happens three cases if there is no obstacles can be detected:

   - Two borders detection: The algorithm generates points starts from 1ICP to the left and right as horizontal or vertical lines. Then the algorithms choose one points of this line as its proposed path (in Fig. 1, we choose this as a center of line). Important case can occur when the path covers from small distance to big distance or vice verse as in Fig. 1 Case C to avoid getting large drift, the distance between the row points of lines should always be increased.

   - One border detection: When there is only one border can be detected, the algorithm will generate rotationally a series of tangent row of points as lines (see Fig. 1 Case A). The rotation of the generated lines starts from the existing border's point and ends when detecting another border as shown in Fig. 1 Case A. Important case can occur, when the end of the line can be too large (see Fig. 1 Case B). In order to avoid this situation, the distance between the existed border point and proposed path will remain the same as before rotation during rotation process.

   - Non borders Detection: In the case of non borders can be detected, the algorithm starts to generate tangent line from the current place position till discover one or two borders.

4) The choosing of free-collision path when there are more than one way to reach goal will be performed using following constraints:

   - choosing always the nearest way to goal Fig. 1 Case E.

   - In the case of existence of rules to be followed as roads, we should add some constraints. These constraints can be done using Image processing or artificial intelligence algorithms. (More details are explained in next section).

5) When the obstacles are found, it's edges will be detected by laser simulator algorithm and will be consider as one border of the line's end. In this case there will be tow suggested trajectories can be selected. The nearest path to goal will be chosen Fig. 1 Case D.

3 Implementation of Laser Simulator Approach in Road Roundabout Environments

We have applied the laser simulator approach to the road roundabout, which is remarked as complex
environments that contain a lot of constrains like intersections rules, turning rules, priority rules. Thus, it needs a high capability algorithm to make decision to choose the optimum travelling path from its entrance to exist.

Three components of road-environments are modelled in this simulation: side curbs, middle road curbs and the roundabout intersection. The grid map is used for representing the road-environment. It is done in MATLAB using image processing properties, where each pixel represents a cell of the grids; and by increasing or decreasing the resolution of images, the grid cells dimension can be changed. The simulator generates row of points as lines to detect the border and curbs of the road. The program generates a row of points as horizontal/vertical lines between the borders of road, where there is no roundabout and in turn will generate a row of points like tangent lines when discovering the roundabout as shown in Fig. 2 with applying image processing algorithm to detect edge of lanes and intersection.

Three regions of road roundabout environments can be discussed as follows:

3.1 Entrance and Exit Region

In this region, the two sides of curbs are existed. A row of points as horizontal/vertical lines are used to detect the two curbs of the road. In the case of detecting the obstacles, the robot avoids them by generating a row of points between the one curb and obstacles.

3.2 Roundabout Centre:

In this region, the robot rotates gradually around the roundabout using laser/vision simulator. There are three kinds of boundary that can be found in roundabout: i.e., roundabout border, corner border, and open space (no border). A row of points as tangent lines are generated always in a perpendicular direction to the robot position from the roundabout border to the roundabout corner border or the border determined by the lane recognition strategy (red-line in Fig. 2) in open space area. In the case of obstacles, a row of points as tangent lines is generated between the roundabout border and the obstacles.

3.3 Region between the Entrance/Exit and Roundabout Centre:

It is the region, where the robot must change its position from horizontal/vertical status to start rotation around the roundabout. The program generates a row of points that starts in the entrance part as the horizontal/vertical lines with a slight slope; they reach the tangent lines in the roundabout centre.

Fig 2: The result of the laser simulator program.

Fig. 3 shows the search graph path simulation of the robot path in three scenarios for start and goal positions with avoiding obstacles.
3.4 Results and Discussion

The laser simulator algorithm has been tested in the road roundabout environment Fig. 3, which includes some rules and constraints to the movement. As described in section 3.1-3, the laser simulator algorithm is applied in MATLAB and it moves from a certain start point to a certain end point with ability for detecting the curbs, open space area in roundabout and the obstacles that can be found in the way, all with several scenarios.

This algorithm has provided good capability to deal with the roundabout constraints; for example in Fig. 3.b the most existed path planning algorithms will choose the shortest path between the start and goal points just by passing the middle curb between them and without rotating through roundabout; but in this algorithm, the robot must follow the roundabout rules and go from start point through roundabout to find the goal position with suitable rotation about the roundabout and choose the best most optimum path (See Fig. 3.b). During that, the robot localizes itself when tracking between the two border curbs to one border curbs which are six open space area as in Fig. 3. b using algorithm that has been reviewed and described in section 3.1-3. The obstacle is detected and avoided while continuing movement towards its goal.

The same thing happened in Fig. 3.c, the shortest path can be from start to goal points without rotation on roundabout, but the algorithm has found the optimum path between the start and goal points with taking in consideration the roundabout rules and avoiding the obstacle.

Fig. 3: Illustrate three scenarios of start and goal points for each intake road with obstacles avoiding, (a) Left-Rot. 180°-Straight (b) Left-Rot. 360°-Straight. (c) Left-Rot. 270°-Straight.

The program chooses the best path between the selected start and end points, which are inserted by the user. Fig. 4 shows an overview of the algorithm used in this program.

Fig. 4: The implemented algorithm in MATLAB
4. Conclusion

Laser simulator approach for free-path search graph in complex unstructured environments has been developed and then implemented via the simulator program for a robust mobile robot navigation system through the roundabout settings. The principle and methodology of laser simulator approach was clearly presented and explained for visibility searching of the optimum path in unknown environments with existence of some motion constraints and rules. The study has focused on the using the proposed approach in a simulation of the mobile robot to effectively track the path when countering a roundabout with and without obstacle and considering a number of scenarios. The system is simulated using MATLAB with the grid map used to create the road roundabout environment and select the path according to the respective road rules. The simulation results show the capability of the proposed algorithm to determine the effective path in complicated unstructured environments. The constraints of the path have been generated using image processing in MATLAB to enable the robot to avoid the open space area of the roads and choosing the correct trajectory during searching for it's goal. From the simulation results, it is verified that the performance of the proposed approach is excellent and that the mobile robot is able to track the best path from the selected start position to the goal point even in the presence of the obstacles.

References:


