Implementation of Laser Simulator Search Graph Approach for Detection and Path Planning in Roundabout Environments

MOHAMMED A. H. ALI, MUSA MAILAH AND TANG HOWE HING
Department of Applied Mechanics and Design
Faculty of Mechanical Engineering, Universiti Teknologi Malaysia
81310 UTM Johor Bahru
MALAYSIA
moh.ali.hashim@gmail.com, musa@fkm.utm.my, tanghh@fkm.utm.my

Abstract: In this paper, a Laser simulator search graph approach for free-path search graph in complex unstructured environments has been developed and implemented for a robust mobile robot navigation system through the roundabout environments 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 proposed approach gives the possibility for mobile robot to effectively track the path when countering a roundabout with and without obstacle and considering a number of scenarios. The algorithm is applied into tow kinds of setup: first it 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. Secondly it is used to recognize the roundabout in the real roundabout from sequence of images and enable the mobile robot for making decision process. From the 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.

Key-Words: - Path Planning, Free-Collision Search Path, Laser Simulator (LS), 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.

Brooks [3] has proposed Free space as generalized cones for path search finding. This method depends on generation of multi-cones in the space that represented by polygonal edges and the spine intersections of the cones determine the candidate points for the free-collision path.

Jarvis [4] has proposed path planning methodology based on distance Transform calculation. Three dimension are calculated for each cell in tessellated map x, y, and time. The evaluation of distance propagation for each cell is done in a certain manner from top to bottom and left to right, for time period in the map.

Dijkstra algorithm [5] 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. [6] 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.[7] 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 [8] 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 [9] has propsed 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.

Dorigo [10] has proposed a heuristic and visibility equation of state transition rules that simulate the function of Ant Colony System (ACS) when search for its food source, for solving robot path planning problem of finding the optimal path. The algorithm always evaluates the fitness path of each ant to reach the goal.

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 rectangloid 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 [11] 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 [12] 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. [13] 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.

Minguez et. al. [14] has developed path planning for mobile robots collision avoidance in complex scenarios, so called Nearness Diagram approach. The robot space is divided into sectors centered in the robot position with bi-sector angle. The relation between the robot and the obstacle distribution with a safety evaluation is obtained, which is used to define a set of situations that are represented in a decision tree. Tow functions are calculated in this method; Nearness Distance from the central Point (PND), which represents the nearness of the obstacles from the robot center and Nearness Distance from the Robot bounds (RND) which represents the nearness of the obstacles from the robot boundary.

Quinlan et. al. [15] have proposed a hybrid approach that adhere the global and local path planning methods, so called Elastic Bands. The world model free path is generated using map and the artificial potential field approach is applied to enable the robot for accommodating an uncertainties and reacting well to an unexpected and moving obstacles. The path generated from the planner is deformed in real time to deal with local changes in the environment that detected by sensors.

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 [16-20].

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 Principle of 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. As 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 *gm=f(x,y).* 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 *S(x,y)* and goal *G(x,y)* locations are totally known.

and

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. Let's assume the robot position is in *s(x,y)*. The equations for horizontal and vertical lines can be written:

Horizontal line equation as in Eq. 1:

$$y = x_p - i \qquad \text{where} \quad y_p = y_s \pm f \tag{1}$$

Vertical line equation as in Eq. 2:

$$x = y_p - j \qquad \text{where} \quad y_p = y_s \pm f \tag{2}$$

Where x_p , y_p are the coordinate system for the proposed point that can be chosen for the path , x_s, y_s are the start position location, *i* is the decremented counts of the grid map, *f* is the deviation to the position of proposed point to the start point.

It happens three cases if there is no obstacles can be detected:

- Two borders detection: The algorithm generates row of points start 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 centre 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. The start and end of each line can be described:

$$y_l = y_p - o_l(i)$$
$$y_r = y_p + o_r(i) \quad (3)$$

Where $o_{l(i)}$ and $o_{r(i)}$ are the left and right counts of grid starting from x_p, y_p to reach the two curbs.

- 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. The tangent lines have the following equation:

$$y = (x - x_{\text{int}})\tan(\alpha) + y_{\text{int}} \quad (4)$$

Where x_{int} and y_{int} are the coordinate system of the curb where the algorithm starts to rotate. α is slope of new lines to the horizontal or vertical one.

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. Same equations can be used to generate lines as in Eq.4.

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

$$T = f(G(x,y)) + R(x,y) \quad (5)$$

f(G(x,y) is a function for determining the goal position, *R(x,y)* is a function described the constraints and rules to be followed.

- 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. Eq. 3 can be applied in this case. In this case there will be tow suggested trajectories can be selected. The nearest path to goal will be chosen Fig. 1 Case D.

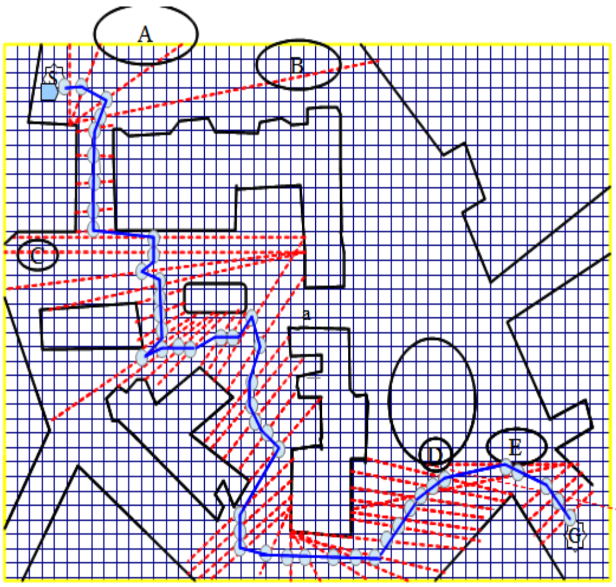


Fig.1: The laser simulator principle. Case A: One border detection. Case B: One border detection with too large line. Case C: The path covers from small range to big range. Case D: Obstacle detection. Case E: Choosing the nearest path to goal.

3 Implementation of Laser simulator for Roundabout Environment Open space Detection

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.

Du to that, there are some constraints have to be followed during movement in roundabout environments, the open space area of roundabout has to be recognized to the robot, in order to easily take decision for the direction that suppose to be tracked.

3.1 Developing of LS Algorithm

The algorithm will be developed to gives the possibility to identify the roundabout when occurred and therefore follow the roundabout rules.

The algorithm can be described as follow:

3.1.1 Detection of the right and left curbs of road

The curbs of roundabout have been clearly appeared as in Fig. 2. The following algorithm will be applied to find the curbs within the image.

- Generation of centre reference points in image: Due to that the robot and its camera are supposed to be stated in between of the curbs, the current position of camera can be approximately described as the mid horizontal line in grid. This point is called first reference centre point *c(x,y)*. The next reference centre points are generated by the following horizontal line equation (Eq. 6):

$$y = x_c + i \qquad (6)$$

The dimension of horizontal lines is located within the following limits as in Eq. 7:

$$y_{right} = y_c + R$$
$$y_{left} = y_c - L \qquad (7)$$

Where i states between 1 and the width of image. y_{right} is limits of the lines in the right side. y_{left} is the limit of these lines in left side. R is the numbers of pixels from the centre to the right curb. L is numbers of pixels from the centre to the left curb. The reference centre points can be then written as in Eq. 8

$$x_{cnew} = x_c - i$$
$$y_{cnew} = y_{left} + \frac{R+L}{2} \qquad (8)$$

- Generation of right and left curbs detection : To detect the curbs, the tangent lines with small angle are generated to each image of the video frame, starting from the references centre points that have been determined in the previous step. The choosing of these angles is accomplished according to experimentation.

The equations that can describe these lines as follow:

Eq. 9 is used for the left side of the reference centre points:

$$x_l = x_{cnew} - f$$
$$y_l = y_{cnew} - (x_{cnew} - x_l)\tan\theta \qquad (9)$$

Eq. 10 is used for the right side of the reference centre points:

$$x_r = x_{cnew} + k$$
$$y_r = y_{cnew} - (x_r - x_{cnew})\tan\theta \qquad (10)$$

Where θ determines angle of slope of the tangent lines. *f=1: L. K=1:R.* Where L and R as described above the numbers of pixels that located between references centre points and left or right curb.

The number of pixels that can achieve this equation can be described as Eq. 11:

$$Pl=nl \qquad (11)$$

The same also for right side as in Eq. 12, the numbers of pixels can be written*:*

$$Pr=nr \tag{12}$$

Due to that the distance between the curbs as in realistic is approximately equal; the algorithm compares the pixels of two sequence tangent lines with each other asin Eq. 13:

$$Al = p_i l - p_{i-1} l$$
$$Ar = p_i l - p_{i-1} l \tag{13}$$

And if *Al* and *Ar* are exceeded threshold, which is inserted by the user, it means that the new line is not represented road curb and the curbs are stopped to be occurred.

3.1.2 Detection of center of the roundabout

The roundabout occurs in grid map Fig. 2 like ellipse. If the two curbs couldn't be detected as in previous step, the algorithm of roundabout detection will start work. From the last reference centre point that belongs to non-curbs on the right and left, the algorithm generates multi-tangent lines between the two last tangent lines that didn't detect the curbs. The intersection points for those lines with the ellipse that represent the roundabout centre are then determined. If those points can realize the ellipse equation as in Eq. 14, this means that the roundabout centre is found.

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}=1 \tag{14}$$

Where *a*,*b* are the radius in Cartesian coordinate system.

If we choose four points from the roundabout intersection points, we can use two of them to determine the radius *a* and *b* and then the other two can be used to verify if the shape is ellipse or not, which can realize the following conditions:

$$comp=\frac{x^2}{a^2}+\frac{y^2}{b^2}-1<ad \tag{10}$$

comp should be equal to zero. *ad* represent the allowed deviation from zero (in our program *ad=0.01*).

In general three conditions are used to detect roundabout; non-curbs detection on the left and right and discovering ellipse in the image as in Fig.2.

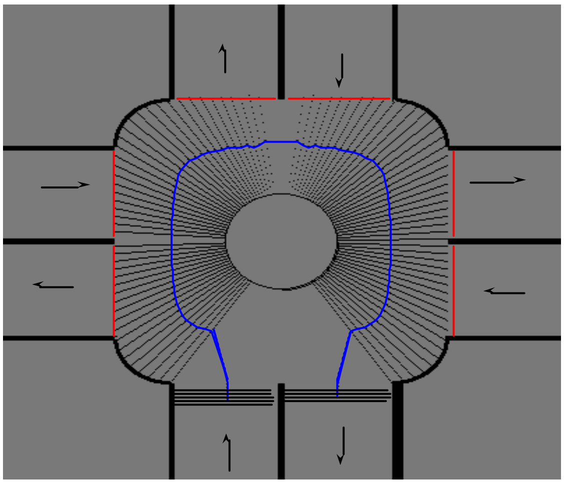
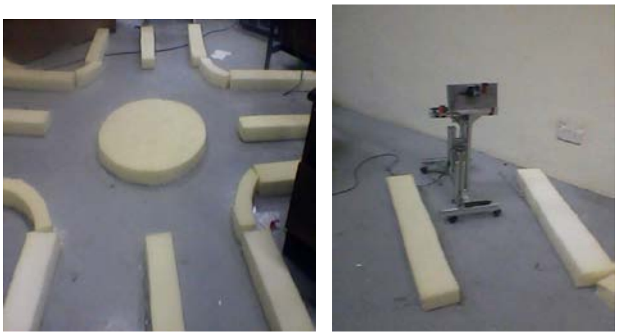


Fig 2: The roundabout setting and the laser simulator program.

3.2 Implementation of the Laser Simulator for Recognizing Roundabout

The proposed algorithm is applied in mini-roundabout map coming from images captured for the movement of simple robot platform in our LAB , as in Fig.3.



(a) (b)

Fig. 3: Show the Experimental Setup: (a) The mini-roundabout (b) robot platform built in our LAB

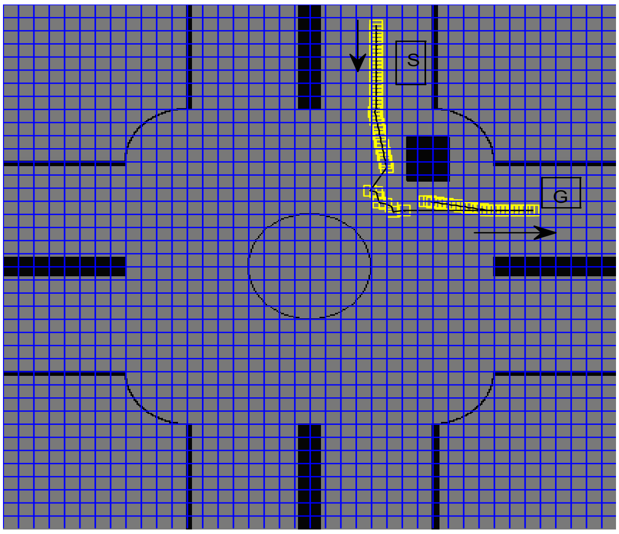
The camera is used to figure out the roundabout environment in the image which then is processed in

MATLAB to extract the features of the roundabout as in Figs.4,5. The laser simulator is applied to the processed image to recognize the roundabout as in Figs.4.b and Fig. 5.b.

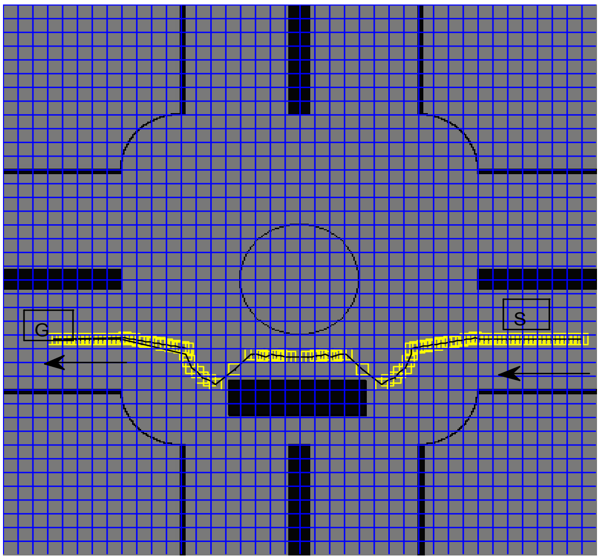
4. Results and Discussion

The laser simulator algorithm has been used for path generation in the road roundabout environment as in Fig. 2, which includes some rules and constraints to the movement. As described in section 3.1, the laser simulator algorithm is implemented in MATLAB and the path 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. The open space area and roundabout detection algorithm as in section 3.2 help to estimate the location of roundabout and follow the roundabout rules.

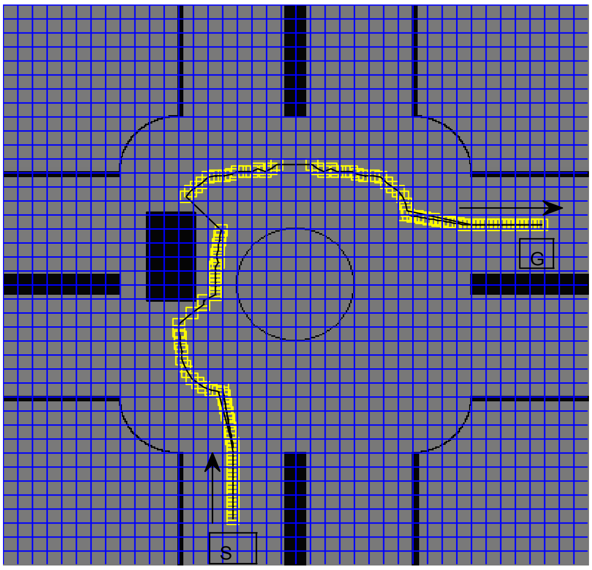
Fig. 3 shows the search graph path of laser simulator of the robot path in 4 scenarios for different start and goal positions with avoiding obstacles.



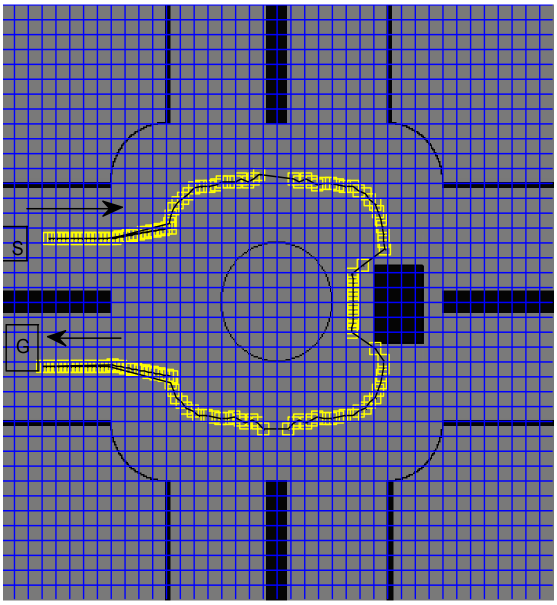
(a)



(b)



(c)



(d)

Fig. 3: Illustrate four different scenarios of different start and goal points for roundabout entrance and existence with obstacles avoiding, (a) Left-Rot. 90°-Straight. (b) Left-Rot. 180°- Straight. (c) Left-Rot. 270°-Straight. (d) Left-Rot. 360°-Straight

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.

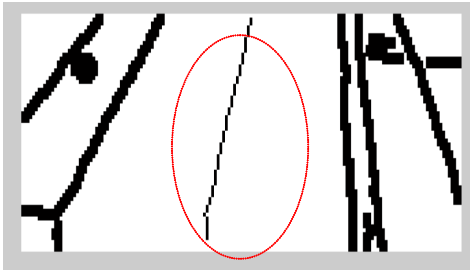
The same thing happened in Fig. 3.c, the shortest path can be from start to goal points without rotation on roundabout, but the algorithm has found the optimum path between the start and goal points with taking in consideration the roundabout rules and avoiding the obstacle.

The results of using this algorithm with real roundabout are shown in Figs.4,5 :

The path of laser simulator will be continuous when the robot still before the roundabout as shown in Fig.4,b (the path is located in red ellipse of image) between the curbs of road (black lines in the side).

The continuous path will be stopped then when the roundabout occurs as in Fig.5,b.

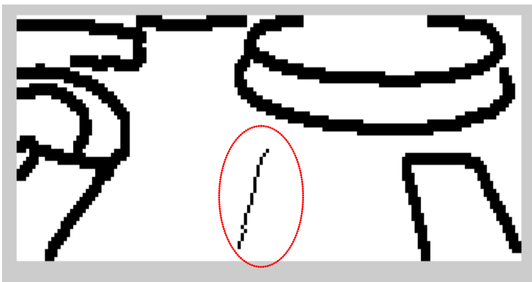
(a)



(b)

Fig. 4: show laser simulator path when still the roundabout doesn't occur. (a) Original image. (b) Processed image with laser simulator path.

(a)



(b)

Fig. 5: show laser simulator path when the roundabout occurs. (a) original image. (b) Processed image with laser simulator path.

4. Conclusion

A laser simulator search graph approach has been implemented 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. Two methods have been used in this paper to test the capability of this algorithm. First, A simulation study on the laser simulator based on the proposed algorithm for mobile robot system was performed using the MATLAB computational platform. And then the algorithm is used for identification and detection of mini-roundabout.

In the 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. However, in the real roundabout, the laser simulator is applied to recognize the features of roundabout and then enable the robot for making decision and path determination during navigation in the roundabout.

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.

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