Path Planning of Mobile Robot for Autonomous Navigation of Road Roundabout Intersection

Mohammed A. H. Ali, Musa Mailah and Tang Howe Hing

***Abstract*:-** The aim of this research is to develop a robust navigation system for mobile robot in a road roundabout setting using laser range finder (LRF) and vision system. A new algorithm for combining the LRF and vision system is investigated to detect the open space area in a road roundabout. The study focuses on the simulation and experimentation of the mobile robot ability 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 experiments are performed using simple platform with laser range finder and the data are processed in real-time in Matlab. Good results from both simulation and experiments show the effectiveness of the proposed algorithm.

Key-Words:- Mobile robot, laser range finder, roundabout, path planning, vision system, robot path simulator in MATLAB.

I. Introduction

OUTDOOR navigation became recently one of the most active areas in mobile robotic research, either in unstructured, semi-structured or structured environments.

There are many systems used for autonomous mobile robot outdoor navigation. Global Positioning System and Global Navigation Satellite System are the revolutionary tools for conveying such kind of task, but due to some limitations, like accuracy and safety issue, especially in the road-environment, which can be occasionally blocked by car accidents or heavy traffic flow, it is often necessary to use on-board LRF and camera sensors for real-time decision making.

In road-environment, a number of useful features can be extracted from the environment to assist the mobile robot in its path finding, like road boundary, road curbs, road lane marks and traffic signals, which are the most utilized features in vehicle navigation systems.

Vision system has been used in mobile robot navigation for recognizing roads signs and lane structures detection [1], extraction of road edge in THMR-III mobile robot navigation [2] and detecting the road regions via planner region methodology [3]. Color image has been used for road-following and 3D obstacle avoidance during the navigation [4, 5], or in vehicles localization by roads signs recognition [6]. Multi-focal camera with odometry is used for navigating mobile robot (ARE) in unstructured environment with good human interaction [15]. Omni-directional Image sensor COPIS (Conic Projection Image Sensor) is used for avoiding static and moved obstacles in all directions during navigation of mobile robot [16]. Wireless camera with two infrared sensor is used for navigating mobile robot (ROBOTIS 2010) in roughness unstructured terrain [17]. Camera video with odometry is used for navigating land vehicle, road following by lane signs and obstacles avoiding [18]. VTR (Video Tape Recorder) camera is used for discovering road direction of autonomous vehicles [19]. Video camera is used for extracting road features and robust controlling of automated guided vehicle [20]. Vision system is used for tracking autonomous vehicle in inner-city intersections [21]. Virtual camera based on artificial neural networks is used for driving the vehicle in different types of roads like paved roads, interstate highways and road junctions [22]. Color camera is used for road following system YARF based on road features extraction [23], for navigating mobile robot when crossing roads [24]. Camera can be used with driver assistance system (ROMA) for detecting the lane of roads and road intersections [25].

LRF system can be used for: vehicle navigation over the roads in difficult situation (either at night or in day time) [7]; navigating robot in large scale environment using particle filter and grid map [8]; features extraction and natural landmarks detection in semi-structured environment [9]; or even for the detection of road boundaries [10]

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Since LRF system is more suitable to detect the natural features of roads and the vision system has the capability to identify lighting features in roads, the sensor fusion by combination of vision and LRF system is the common way for developing reliable navigation systems. For example, Matsushita and Miura [11] have described a method for on-line road boundary detection using LRF and camera, which can deal with various road shapes with or without the road branches.

Kim *et al.* [12] worked on a map-based localization of mobile robot, by depending on the detection of road curbs during the trajectory tracking.

Chand and Yuta [13] proposed a localization system with LRF and monocular camera for crossing the roads when the mobile robot is traveling along the pedestrian sidewalks in an urban outdoor environment.

Guivant *et. al.* [26] proposed navigation system using combination between GPS, LRF and Dead Reckoning for navigating vehicles in roads using beacons and landmarks . The system is examined with several shapes of beacons like cylindrical or V-shape objects that can be detected using LRF in road environment. The information filter (derived from Kalman filter) is used to gather sensors data, building map and determine the localization of robot.

Lee *et. al.* [27] proposed localization method using GPS and camera for navigating mobile robot in color marked roads . Two localization systems are used: the first one use camera vision system with particle filter and the second use two GPS with Kalman filter. The printed marks on the road like arrow, lane and cross is effectively detected through camera system and by processing this data, the robot can find current position within environment.

Goldbeck *et. al.* [28] proposed methodology that combined GPS with a video camera and INS for navigating the vehicles by lane detection of roads . The DGPS system calibrated with INS is used for ego-position estimation, which achieve high accurate digital map with accuracy equal to 3 cm. The function of video camera is to track the printed marks of boundary lane in the road using an edge-oriented method and extended Kalman filter is utilized for position estimation.

Langer *et. al.* [29] have developed algorithm for obstacle detection and avoiding. The LADAR system can detect the target obstacle by digital wave front reconstruction and beam forming with fast Fourier transformation technique. The vision system can detect the road geometry and extract lane features using control flow coordinator that able to compute the displacement of vehicle from the lane.

Beauvais *et. al.* [30] proposed methodology for road recognition process. The method is called Combined Likelihood Adding Radar Knowledge (CLARK), which can be described as following: the obstacles are detected in the visual image and the search for obstacle is detected by range data of radar. Then the obstacle is constructed using intensity gradient field algorithm and after that, the data of the detected obstacles is integrated with a lane extraction algorithm.

Actually, there are many studies on mobile robot navigation in road-environment, and the solutions are continuously sought out to further improve the autonomous vehicle navigation. In present, there is still not a complete navigation system to overcome all kinds of road-environment cases [11]. One of the important cases is the roundabout detection and navigation. The benefit of using a roundabout is that it can reduce the injury crashes by around 25–74% in comparison to the installation of traffic light signal [14]. Furthermore, the non-traffic signal feature is helpful in mobile robotic navigation, based on the challenges for detecting the signals of traffic light system.

The main difficulty of robotic navigation in roundabout environment is related to the open space area, which can’t be detected directly by the LRF or by the vision system alone [11]. Therefore, a novel algorithm, which was capable of overcoming the above-mentioned challenges, was developed and implemented in this study to improve the navigation capability of mobile robot.

The scanning data of LRF and vision system is required in the path planning of mobile robot. Most of the path planning algorithms like: A* algorithm; Djikstra algorithm; wave front-based planners; breadth first; depth first; and rapidly exploring random trees, are used in the finding of the shortest path between the start and the goal points. However, in the case of road-environment, there are a number of road traffic rules that must be strictly followed or adhered with. For example, 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.

In this study, a novel algorithm that involved the use of both LRF and camera vision system was developed to determine the most optimum travelling path for mobile robot navigation in roundabout environment, which has been represented in a grid map form.

Experiments using simple platform with LRF are performed to test the suggested algorithm in the case of laser range finder in this study.

II. Roundabout Detection

Roundabout is a circular junction or intersection in road that allow vehicle to change its direction without traffic signals, in almost. It leads to an efficient, cost-effective way to improve safety and traffic flow. As it has been discovered in some statistics, the roundabouts decrease severe injury and fatality collisions and allow drivers to get through intersections more quickly. Roundabouts also provide a safer way for pedestrians and bicyclists to navigate traffic.15

The modern roundabout intersection is looked like as in Fig. 1:

Fig. 1: Show the typical roundabout intersection

Although it is very easy for people to drive in such junction, many problems will occurs when the vehicle navigates this intersection autonomously. Therefore navigation of such places need to recognize the whole environments with high confidence and safety.

The LRF and vision system are two common tools that can be used in the recognition of road-environment. In this study, three types of road boundaries were considered: road following in entrance and exit of roundabout and roundabout in the center, obstacles detections and avoiding.

A. Road Following

In the entrance and exit of roundabout, the robot must continue its motion during starting the discovering process of the roundabout. In this section , we will discuss two scenarios of the entrance and exit conditions:

1)Roundabout with Two Sides Curb

In this scenario, the road has ended in the entrance or the exit of roundabout by two linear side curbs. LRF can detect these curbs as in Fig. 2 and then by signal processing using Eqs. 1 and 2, the path planning of mobile robot can be accomplished [12].

$$f = x_n \cos(\theta) + y_n \sin(\theta) \qquad -1$$

$f = x_n \cos\theta + y_n \sin\theta$. (1)

where f is the dimension of LRF signals, (x_n, y_n) is the n-th LRF measurement, $\theta = (0,\pi)$ and it is the angle between the measurement point and the mobile robot coordinate system.

$$\sqrt{(x_i - x_{i+1})^2 + (y_i - y_{i+1})^2} \le d$$
$$\tan^{-1}\left[\frac{y_i - y_{i+1}}{x_i - x_{i+1}}\right] \le \sigma \qquad 2$$

d is the limit distance between two respectively signals and σ is the slope between them. If the distance between adjacent two signals is within d and the slope between them is less than σ, the two signals are considered as the road surface, otherwise it is considered as curbs.

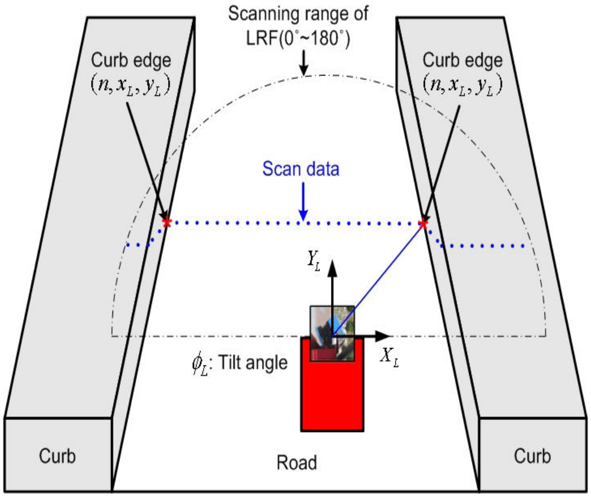

Fig. 2: LRF principle for detecting the road curbs.

2) Roundabout without curbs in the sides of roads

In this case of missing curbs on the sides of the exit or entrance, the borders of roads will be detected using camera and image processing as in Fig. 3 .

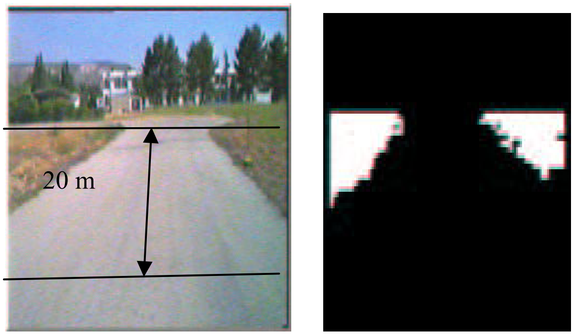

Fig.3: Illustrate the non-curbed roads detection using vision system

The algorithm will use the following operations to accomplish the detection of the roads in distance equal to 20m:

- Image acquisition and size reduction
- Image segmentation using (Hue-Saturation-Intensity) transformation with special constraints.
- Morphological operations with filtration.
- Small object removal.
- Shade and brightness processing.
- Estimation of width, edges and centers of road.
- Updating the HSI transformation.

B. Roundabout in center

As described above, the roundabout in the center has open space area as in Fig. 4 bellow, and therefore LRF can detect only the circular curb of intersection. In order to solve this problem, a combination between vision system and LRF with special algorithm are used.

Fig. 4: Illustrate the open space area in center of roundabout.

There are two functions for using vision system with image processing in this case. Firstly, It is used to locate the roundabout when it has been identified. Secondly, It helps to detect the lane corners of the roads like A and B as in Fig. 7 in the open area, and then find the slope of the line A-B (Fig. 7) by image processing

The lane recognition technique through image processing is used here to extract the edges and borders of road's lanes and intersection through the following processes:

Edge detection.

Boundary tracing.

Regions filtration.

More detailed can be found in references 31-34.

Fig. 5 shows some useful operations for extracting the lane of road from the image.

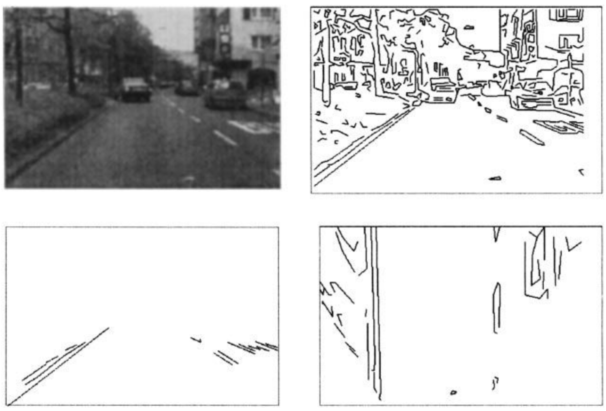

Fig. 5. Lane recognition. (a) Source image. (b)Edge image. (c) Bird's eye view. (d) Lane detection.

In the other hand, the LRF can detect the existed roundabout border curb side as in Fig. 6 and the other side is determined by vision system calculation as mentioned above.

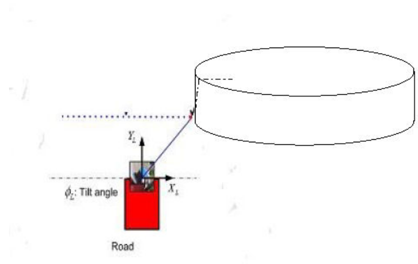

Fig.6: Illustrate detection of roundabout center by LRF.

In general, this research will A new algorithm for finding the path and controlling the robot rotation is investigated depending on the following assumptions:

The left and right wheel of mobile robot will be controlled using a suitable strategy to perform balancing rotation around roundabout from entrance to exist side.

Signal and image processing of LRF/vision systems with an algorithm that give the correct path of robot.

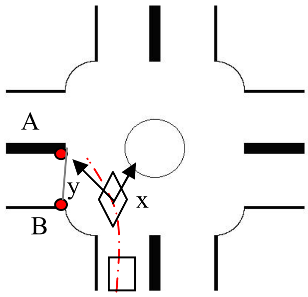

Fig. 7: Roundabout environment and the useful features for detection.

III. Mobile Robot Path Simulation in MATLAB

Three components of road-environments are modeled: 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. As mentioned above, this simulation is concerned on the imitation of the previous behavior of LRF and vision system in road roundabout environment. For this purpose 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. 9 with applying image processing algorithm to detect edge of lanes and intersection.

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

A. Entrance and Exit Region

In this region, the two sides of curbs exist. 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 raw of points between the one curb and obstacles.

B. Roundabout Center

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 lane recognition strategy (red-line in Fig. 5) in open space area. In the case of obstacles, a raw of points as tangent lines is generated between the roundabout border and obstacles.

C. Region between the Entrance/Exit and Roundabout Center

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 entrance as horizontal/vertical lines and by small slope, they reach the tangent lines in roundabout center.

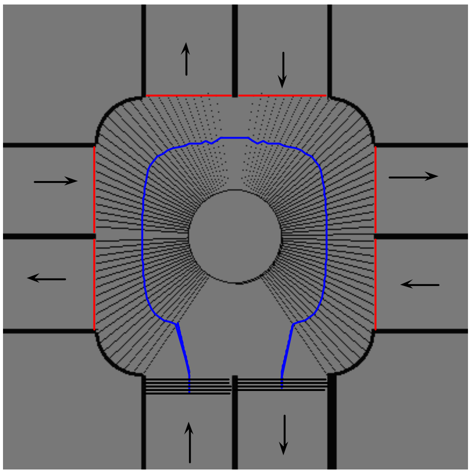

Fig. 9: The result of the laser/camera simulator program.

The program chooses the best path between the selected start and end point, which are inserted by the user. Fig. 10 bellow shows an overview of the algorithm used in this program.

Fig. 11, bellow shows simulation of the robot path in four scenarios of the position of the start and goal points for each intake road that are considered in the study: Left-Rotation 90°-Left, Left-Rotation 180°-Straight, Left-Rotation 270°-Straight and Left-Rotation 360°-Straight. For each scenario, the path can be a collision-free or with obstacle.

IV. Experimental Performance

A. Experiments Setup

The laser range finder used to perform the experiments is URG-04LX-UG01 with resolution 1 mm, scan angle 240, angular resolution 0.36°, time of scan 100msec/scan, range limit 5m and Semiconductor laser diode with λ=785nm. The experiments is done in laboratory considering the flat area of laboratory as road and two boxes as the curbs of road as in Fig. . The laser range finder is supported on simple platform with 70 mm height and 9 degree diagonal from vertical plane as in Fig. 10 . The platform is just for perform motion of laser range finder manually. The laser range can be scanned from range between -120° to 120° with 682 points measurements, which used to identify the environment. As example Fig. 11 show one scan of laser range finder measurements and the objects that occur in this measurements.

Fig. 10: show the platform and laser range finder setup

B. Experiments results

First Laser range finder driver for reading data from USB connection in real-time is developed in MATLAB. The algorithm for detecting the curbs of road is developed also. It is assumed that robot move in 1cm/s.

Tow parameters can be found from this measurements as in Fig. 12:

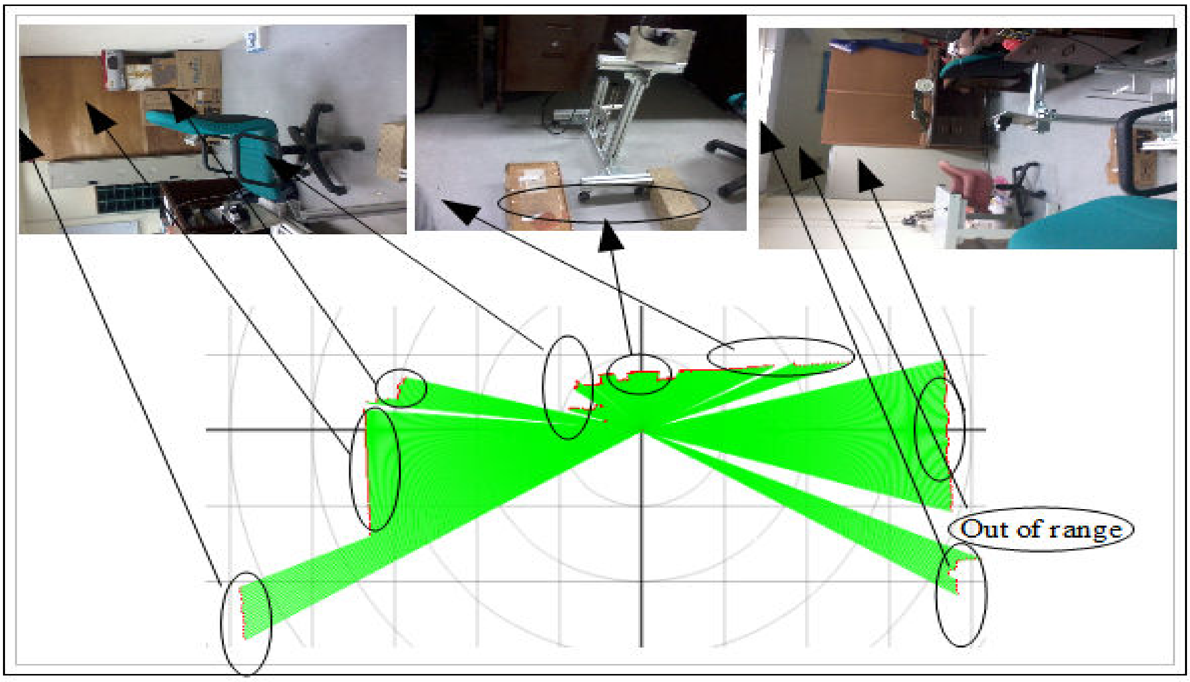

Fig. 11: show laser measurements and the occurred objects in its environment

road fluctuations (height of objects regarding to laser device):

$$rf_n = r_n \cos(\theta) \qquad -3$$

road width (distance of measurements to laser device)

$$rw_n = r_n \sin(\theta) \qquad -4$$

where r is the dimension of LRF signals for n-th LRF measurements, θ = (0,240°) and it is the angle between the measurement point and the platform coordinate system.

The developed algorithm starts calculation from the point measurement existed at 0° which its rf value is used as reference and then it goes to the left and right from this point with comparing the deviation between new points measurements values (rf) and reference one. This operation is repeated till it reach pre-defined range d as in the following equation:

$$rf_i - rf_{i-1} \geq \pm d \qquad -5$$

d is the limit distance between two respectively signals. If the distance between adjacent two signals is within d , the two signals are considered as the road surface, otherwise it is considered as obstacles or curbs.

Fig. 12 bellow show how the curbs of roads is detected in real-time by MATLAB algorithm for the experimental setup as in Fig.10.

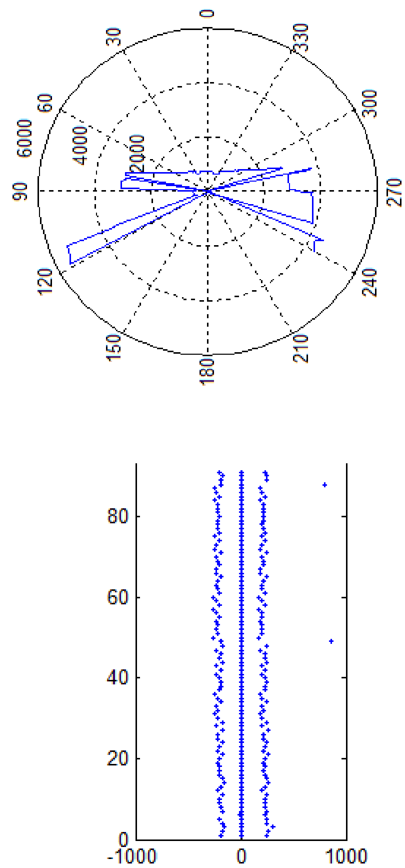

Fig. 12: Show the laser measurements for the experimental setup: (a) laser measurements(mm). (b) road curbs(mm)

V. CONCLUSION

A new algorithm has been developed and implemented via the simulator program for a robust mobile robot navigation system considering roundabout settings. This algorithm combines the LRF and vision system to detect the open space area of a road roundabout. To assess the capability of mobile robot in the tracking of pre-planned path in a roundabout setting, a simulation study on the developed algorithm and the corresponding mobile robotic system was conducted by 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 travelling 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 simulation results, it is confirmed that the performance of the proposed navigation algorithm is outstanding and mobile robot is able to track the best path from selected start to the goal point, especially when detecting obstacles.

The simulation of mobile robot path finder using the image's pixels as grids in MATLAB has some pros and cons. The important advantages are that the grid cell dimension can be adjusted as desired and there are many algorithms that can be applied for image processing. The major disadvantage is that the calculation results of the algorithm in image processing must be approximated to integer values. The previous problem is solved by using small steps in the loops, which can repeat some values but it gives enough approximation.

When there is no obstacle, the simulator program will choose the middle point of the horizontal or tangent lines between roads borders for path tracking. However, it chooses the middle point of lines between obstacles and road borders when there is an obstacle. Future work is to apply the suggested algorithm in real world roundabout environments.

The experiments results show the capability of the proposed algorithm in matlab to identify the terrain using data coming from laser range finder.

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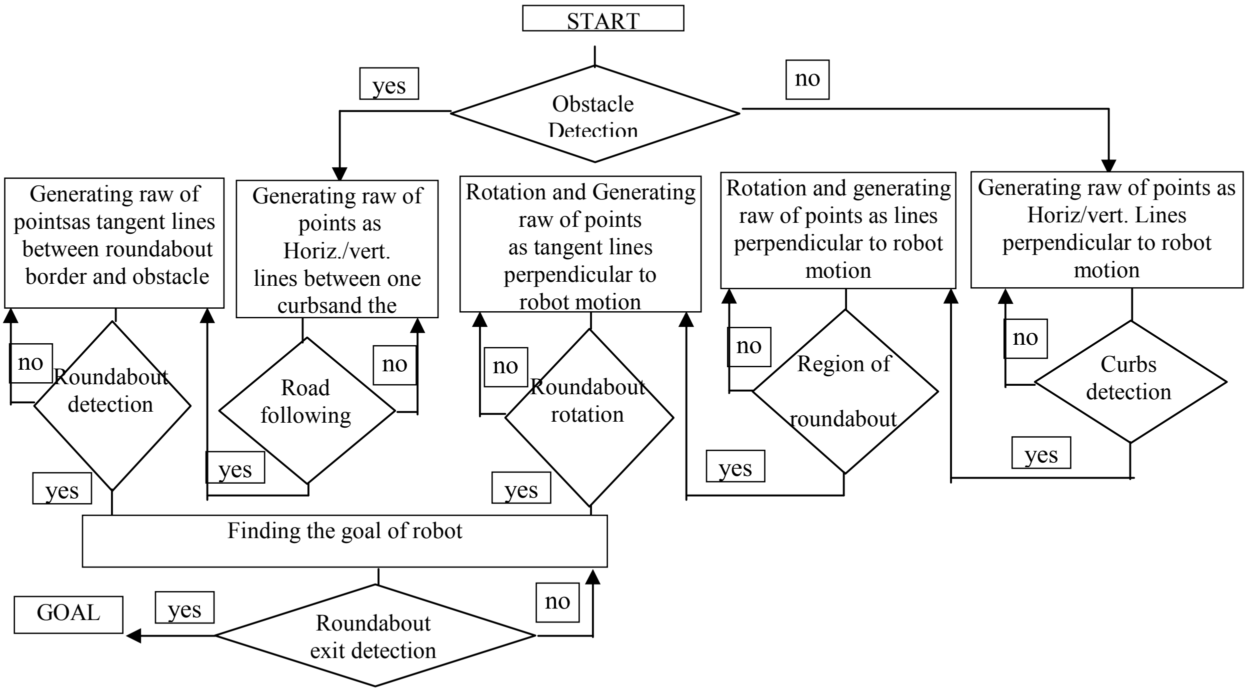

Fig. 5: The proposed algorithm for the MATLAB program.

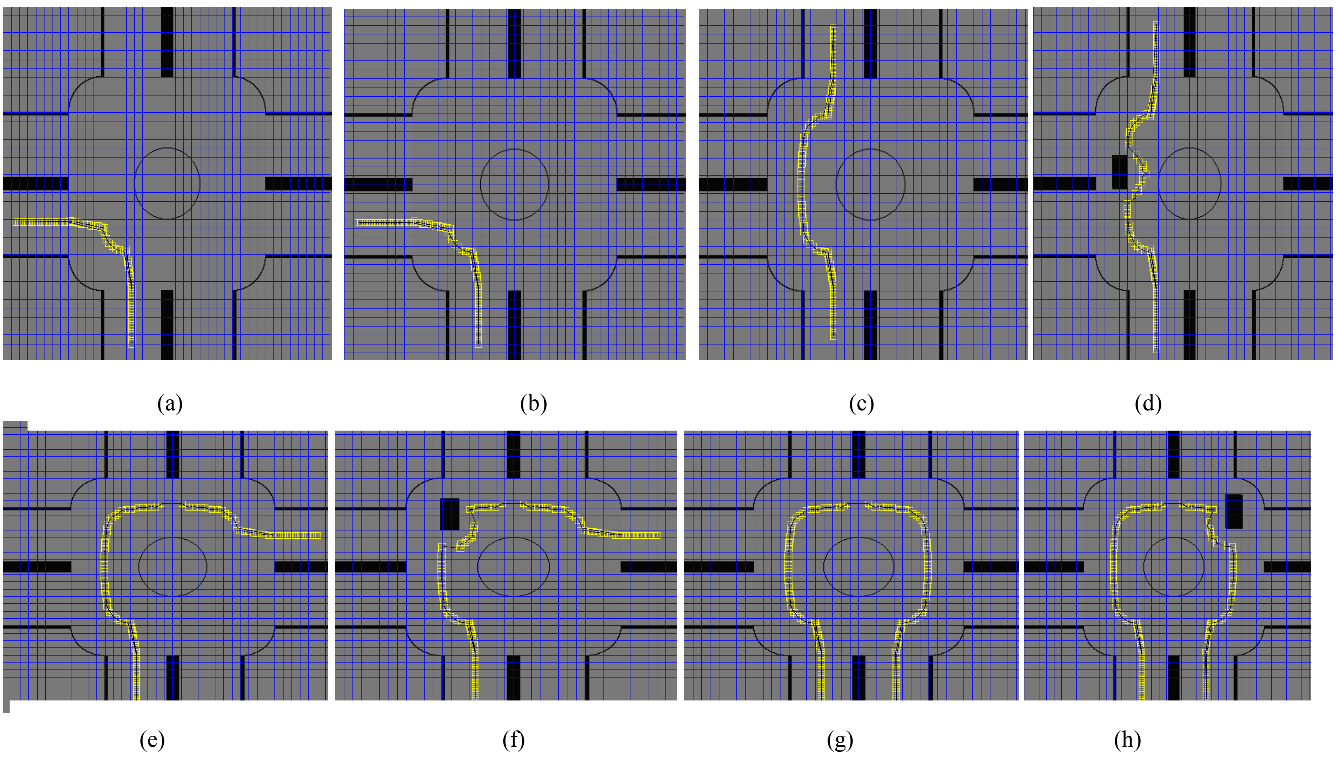

Fig. 6: Four scenarios of start and goal points for each intake road , (a) Left-Rot. 90°-Left (b) Left-Rot. 90°Left with obstacle (c) Left-Rot. 180°-Straight (d) Left-Rot. 180°-Straight with obstacle (e) Left-Rot. 270°-Straight (f) Left-Rot. 270°-Straight with obstacle (g) Left-Rot. 360°-Straight (h) Left-Rot. 360°-Straight with obstacle.