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Path Generation for Robot Navigation using a Single Camera

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Abstract

The work focus on providing a path in an environment for a robot for its ease of movement, detecting and avoiding obstacles in an environment using a single camera and a laser source. Robot moves by identifying free space in floor. Wherever floor is visible and free, it moves. Novel method for floor segmentation has been used. Laser source emits light that falls on obstacle if any, and based on position of laser light on obstacle in the image and distance of obstacle from robot, robot change its direction with different angle and continues to move. This movement information is stored in text file which is used to create map of the environment. Absence of laser light with different floor mark will be treated as hole in the floor and will be skipped.

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Keywords: Floor Segmentation; Robot Navigation; Path Generation; GOPPA; Edge Detection; Threshold.

1. Introduction

The design and development of mobile robots which are capable of assisting humans in their daily activities are of great use. Mobile robots free from human interventions are of great use in robotics such as automated cars, missile guidance by machines, detection of enemy spots in defence, at homes and hospitals to reach specific points

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automatically. To achieve their tasks, mobile robots have to be intelligent. They should decide their own action. Path generation is a fundamental task for a mobile robot by which it moves in an environment avoiding obstacles, defects in the floor and generating a safe path. The path generation problem is as old as mobile robots and is a fundamental problem to the adaptation of artificial intelligence technology to robotics. The problem is to find a free-space path for a robot's navigation by detecting and avoiding obstacles in path of navigation. The environment is static or dynamic and may have a discrete or continuous representation. Path planning is to produce a continuous motion connecting starting position and destination avoiding obstacles and floor flaws when everything about scene is known in advance whereas path generation is to produce the same when scene is unknown. Several algorithms for path planning are available for implementation like visibility graphs, voronoi diagrams[1,5] whereas path generation is more challenging. Some of the important reasons of robot navigation are

- It provides path planning.
- It gives information about the position of the robot.
- It provides information about environment structure.

2. Related Work

O.Hachour[2] proposed a path planning strategy for unknown environment with static obstacles. The environment is represented in the form of square grid and is recorded as walkable or un-walkable. The robot navigates in the environment by avoiding the obstacles in its way to end point.

Shahed Shojaeipour, et al[3] presents a method that determines the depth of obstacles using laser range finder used within webcam. Environment images are captured using webcam and canny edge detector is used to find the presence of obstacles. Shahed Shojaeipour et al.[4] determines the shortest path to the destination through three actions: the first action is image capture; the second action is to transform the captured 2D image into 3D scene. At the end, cell is decomposed to recognise and remove the paths that are obstructed.

Rajeev Arya, et al.[5] implemented Dijkstra algorithm to plan a shortest path to reach the target, avoiding obstacle detected by a static camera mounted at an altitude above the arena. The source and the target are identified by their pre-acquired structural information. The feasible space is obtained by dilation process. The boundary of the available path is obtained after dilation to find the possibility of collision done by edge detection.

Soh Chin Yun et al.[9] proposed genetic algorithm (GA) to assist the mobile robot to learn the environment and move, identify the acute obstacles and reach the desired goal. This navigation technique will re-plan the new optimum free path in case of mobile robot encountering any dynamic obstacles. The proposed Goal Oriented Path Planning Algorithm (GOPPA) is goal oriented and reduces unnecessary search time.

Ananya Das et al.[10] proposed A* algorithm that makes the mobile robot navigate and find the shortest path from an initial position to a target position by avoiding the static obstacles. The proposed technique represents the environment in the form of a grid-map and divides into four quadrants. Robot will first check for the quadrant where goal is present and skip the other three quadrants at each step of movement and it considers only one quadrant every time to reach the goal and thus, finds the path.

The *D** algorithm is a dynamic version of the *A** algorithm. Daniel Cagigas[11] proposed an extension to the *D** algorithm. This hierarchical *D** algorithm uses bottom-up approach and a set of pre-estimated paths which gives optimum solution and low computation time. Hierarchical graphs are updated and adapted to help online path planning with materialization of costs and multiple hierarchical levels.

3. Proposed Work

Fig. 1 shows overview of our work. In this work, mobile robot mounted with a single camera is used for the navigation. Frames captured from the camera are transmitted to the system where every nth frame is segmented for floor identification. Floor segmentation is done as per section 3.1 to extract floor information from the scene. The robot is also integrated with laser source which is not used for depth estimation of objects but, for detection of obstacles and floor defects such as a hole. Captured Frames from this camera are 2D in nature, where depth information is lost. This depth information is extracted from the mathematical model[6]. The model is based on the relationship between the resolution of an object of interest and the distance from the camera as a growth series. Relationship between the resolution of an object of interest and focal length is also expressed as a growth series model. The object of interest is segmented out and its pixels account to its resolution, which is standardized and used to determine either the distance or the focal length of the camera or the vice versa. This model has been used to determine the depth of objects in our images during experiment. During the movement, robot records the movement information in text file which is used for map generation to assist in finding shortest path between any two points.

3.1 Floor Segmentation

Floor detection is an important task during robot navigation. By identifying the floor in a scene, the robot can avoid obstacles and can get the information that would be useful in generating a map of the environment. Many approaches are available for floor detection, such as edge based floor detection[7]. Here, floor detection technique has following steps: 1) Canny Edge detection 2) Line Fitting 3) Purring Line Segments and 4) Segmentation. Figure 2 shows the result of floor segmentation.

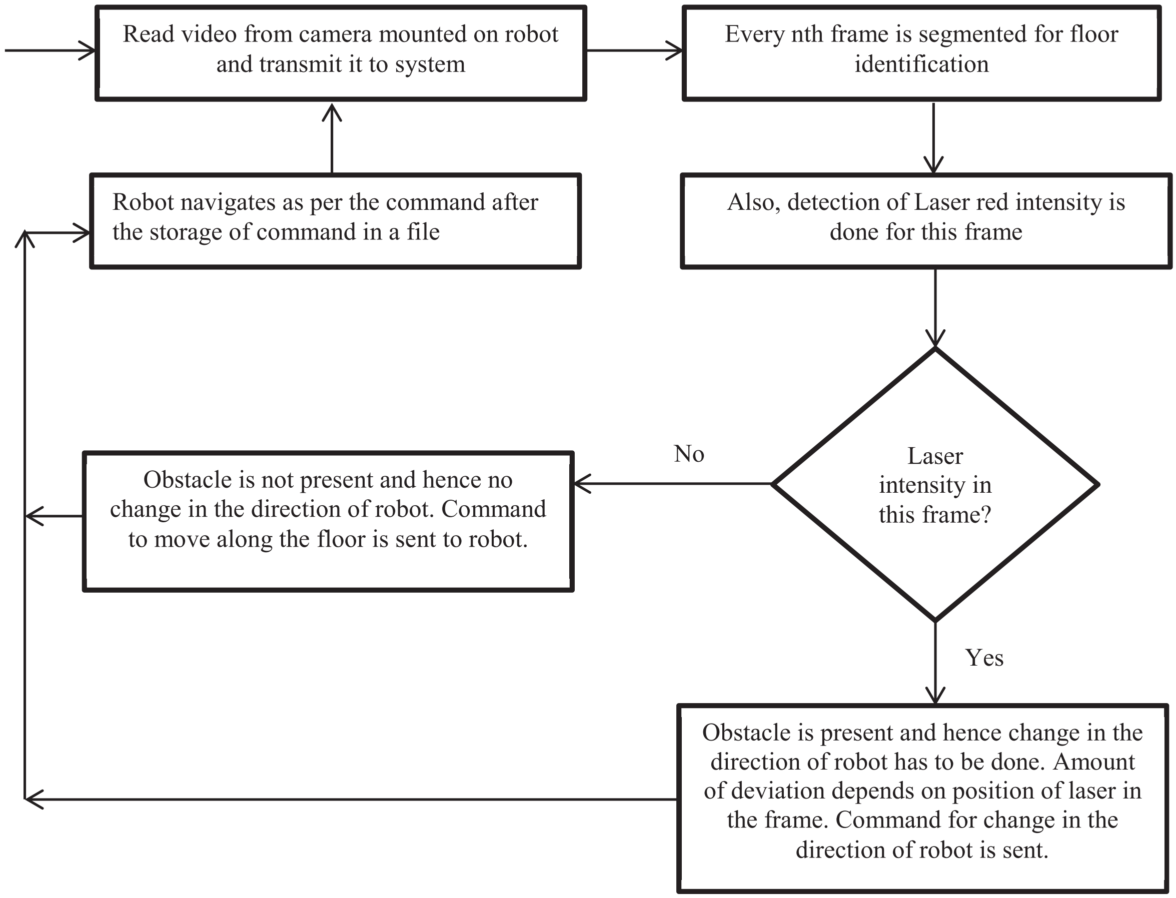

Fig. 1 : Overview of work.

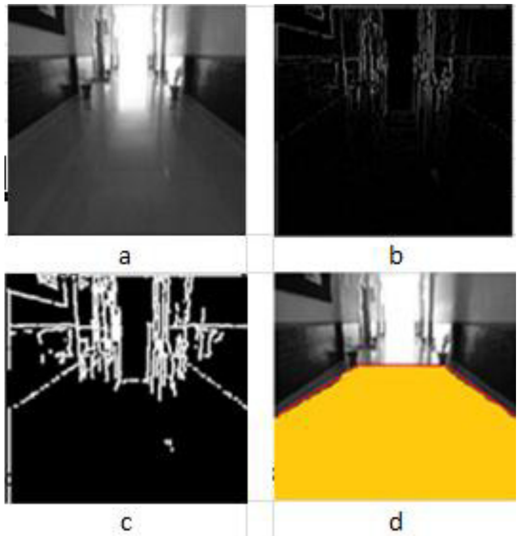

Fig 2: (a) Input Image (b) Edge Output
(c) Image after thresholding (d) Segmented Output

We propose a novel approach for floor detection in an environment which does not contain line edges. As camera is fixed on robot which is on floor, the floor is usually available at the bottom of captured image. Here we make use of structuring elements. Structuring elements are randomly selected floor patterns. Every structuring element is compared with input image by block wise individually and results are fused.

$$\text{if} \quad \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} f(m,n) == h(x-m, y-n) \quad (1)$$

$$\text{Then} \quad c = c + 1 \quad (2)$$

Where f is the input image, c comparison count, and h is the randomly selected mask. Here, each and every element of the input image is compared with the structuring element values. If c value is greater than the defined threshold, then it is considered as floor point, otherwise it is not. This process is iterative for all randomly selected structuring elements.

If (c > threshold) then

$$\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} Out(x-m, y-n) = 255 \quad (3)$$

Else

$$\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} Out(x-m, y-n) = 0 \quad (4)$$

Here threshold is manually selected. Block diagram of the proposed approach for floor detection is shown in figure 3. Once the comparison of all structuring element is over, fuse the resultant images into single image using image addition. Figure 4 shows the output of our proposed approach.

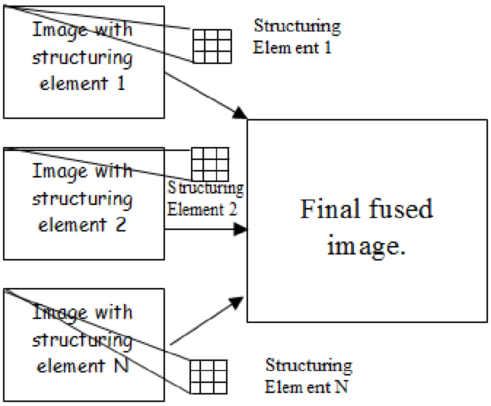

Fig 3: Block diagram of the proposed approach

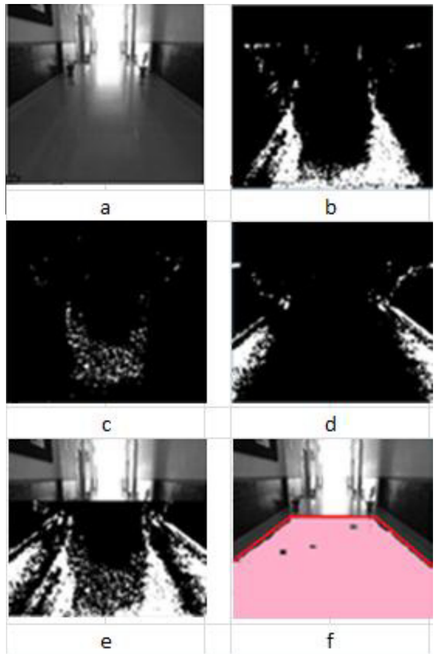

Fig 4: a) Input frame b) Structuring element 1 output c) Structuring element 2 output d) structuring 3 output e) Final fused output f) post processed output.

3.2 Obstacle Detection

The scene is captured as a video using the camera mounted on a robot. Every nth frame is used for path generation as processing of all frames increases complexity. The existence of obstacle must be detected before generating a path for the robot to traverse. For identifying obstacle, laser beam is used. The RGB frame is transformed to grayscale image. The presence of obstacle is identified by entropy based thresholding process. Entropy based thresholding method exploit the distribution of the gray level in a scene. The maximization of the entropy of the threshold image is interpreted as indicative of maximum information transfer.

Steps of Entropy Based Thresholding Algorithm[8]

1) Read the image frame I.
2) Calculate the histogram for the input image I.
3) Calculate the probabilistic histogram P for the image I.
   If gray level i contains ni number of pixels
   Then, p(i) = ni/M*N
4) Calculate Hn, the entropy of the image.
5) Selection of the threshold. Start from the gray level 0.

$$H(A) = -\sum_{i=0}^{k} \frac{P_i}{\omega_k} ln \frac{P_i}{\omega_k}$$

$$H(B) = -\sum_{i=k+1}^{L-1} \frac{P_i}{1-\omega_k} ln \frac{P_i}{1-\omega_k}$$

6) Calculate the Object Function value.
7) If Object function value O>max, then max=O ,Threshold = k.
8) Increment k, k=k+1.
9) If k equals 256, exit with the desired threshold value
   else go to selection step 5.

Figure 5 shows the output of the segmentation process.

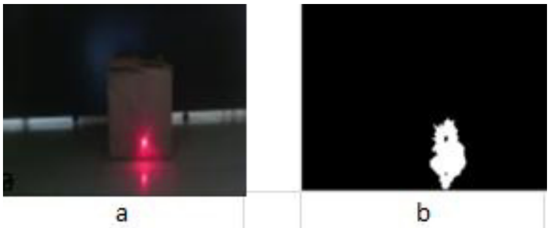

Fig 5: (a) Input image sent to system
(b) Segmented Image for laser light detection

Once the image is segmented, we need to find the presence of the laser beam in the image frame. If laser point is present, then find the position of the laser point on the obstacle. For finding the position, we divide the frame into six vertical blocks as shown in the figure 6.

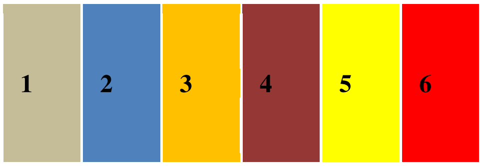

Fig 6: Vertical blocks of a frame.

- When laser light is in position 1, robot has to rotate by 30 degrees right of obstacle and move.
- When laser light is in position 2, robot has to rotate by 30 degrees right of obstacle and move.
- When laser light is in position 3, robot has to rotate by 90 degrees left or right and move.
- When laser light is in position 4, robot has to rotate by 90 degrees left or right and move.
- When laser light is in position 5, robot has to rotate by 30 degrees left of obstacle and move.
- When laser light is in position 6, robot has to rotate by 30 degrees left of obstacle and move.

Amount of rotation is recorded and used during the generation of synthetic map. The robot's navigation depends mainly on the position of the obstacles, as shown above. In the above image fig.5, position of the obstacle is placed in a region number 4 of the image frame.

3.3 Map Generation

As robot moves, its movement is recorded in text file as shown in fig.9 and will be used to create synthetic map of the scene as shown in fig.10. As long as all the paths in scene are not covered, map is incomplete. Labelling at rotation junction is made as vertex for map. Map is used to find shortest path later for the selection of optimum path. The path information can be used by the other robots with no vision. The synthetic map is converted to 300 X 300 binary image where black pixels represent path. In this work, image is scaled down in the range of 2 pixels per 5 centimetre of robot walk. Synthetic map is continued in next image of 300 X 300 size in case, robot moves beyond current map frame. Later, maps in different images are stitched according to robotic movement. Based on wheel rotation and dimension of wheel, distance covered is calculated.

4. Experiment

Figure 7 shows robot we used in our experiment. Before the movement of robot, the camera which we mounted on the robot is to be calibrated using the Zhang method. Once we calibrate the camera, we get focal length from which we are supposed to find coefficients 'a' and 'b' from the model[12]. The image is automatically segmented using entropy based thresholding algorithm, object is extracted for 300X300 condensed image and its depth is obtained as per the method discussed in paper[6] and results are tabulated as shown in Table 1. As specified in paper 6, depth is verified from stereo pair of left image and right image. The depth which is in terms of pixel is converted to inches based on the conversion model constructed using the existing dataset. Then perform floor segmentation and obstacle extraction. Path planning is performed based on the obstacle position. Based on the obstacle position, robot takes the move 30 degree to right or 30 degree to left or 90 degree in any direction. If obstacles are detected immediately after rotation, again robot has to be rotated further in order to avoid wider obstacles. Robot also stores the path information in the text file which is used to generate map of scene as shown in fig.8. This path information may be used by other robots (without vision) for the movement in static environment, thus reducing computational time in every other robot.

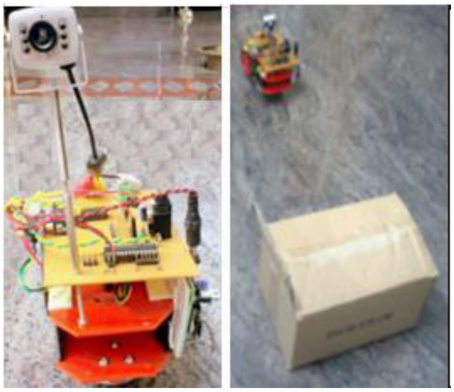

Fig. 7: Real time working of Robot Navigation with single camera and Laser beam.

Table 1 . Results Set giving Distortion for different Depths and Focal lengths.

Focal Length	Depth	Movement of point from left image to right image	Distortion as per our model
1mm	56”	48”	47.8”
2.5mm	24”	8”	7.7”
4.5mm	36”	4”	3.7”

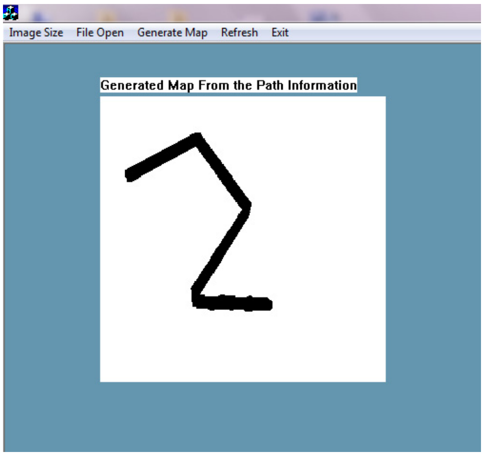

Fig. 8 : Generated Map from path information file.

5. Conclusion

This paper provides a method of mobile path generation using the robot connected to wireless camera and laser source. The wireless camera capture the image frame, each frame is transferred to the system. Laser beam is used for the detection of obstacles and floor flaws and depth is estimated through single camera. Then, system will process every nth frame to identify the floor and obstacle. Based on the obstacle position, robot moves by 30 degree right or 30 degree left or 90 degree right or left. System stores the path information in the text file and used to generate map for optimal path detection. This path information may be used by other robots (without vision) for the movement in static environment. The robot‘s navigation depends mainly on the position of the obstacles.

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