A Novel Path Planning Algorithm for Single Camera Based Mobile Robot Navigation

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***Abstract*—The present paper proposes a simple and efficient path planning algorithm for vision based mobile robot navigation. A single camera is utilized to capture the environment in front of a mobile robot and efficient image processing based path planning algorithm demonstrates its utility for obstacle avoidance and safe navigation.**

***Index Terms*— Autonomous mobile robot, vision based navigation, single camera based robot vision.**

I. Introduction

PATH planning for autonomous mobile robot navigation has been regarded as a popular research area for last few decades. There has been many attempts to solve the problems related to mobile robot navigation in both map based and map less environments [1], [2], [3]. Simultaneous Localization and Mapping (SLAM) technique for mobile robot navigation has also been popularly researched and several probable solutions to the problem have been proposed by the researchers [2], [4]. Earlier, robot navigation was mainly achieved by using different kinds of position sensors like IR, optical range finder, sonar sensors, etc [5], [6], [7]. The chief problem associated with this technique is that the data fusion algorithm, used to synchronize the sensory data, cannot process the data at the same time stamp due to the Out-of-Sequence Measurements (OOSM) problem. In order to make precise navigation, this OOSM problem should be solved. For this purpose, vision has become a popular alternative as a sensing mechanism [3], [8].

The present paper proposes a simple method of formulating the path of a mobile robot for its safe navigation through the obstacles, where vision is used as the primary sensing element for navigation [9], [10], [11], [12] to generate the reference path. In this paper, a single camera is used to capture the image of the environment with available floor area for navigation. Then, by a unique simple path planning algorithm, a reference path is planned. A suitable controller, then, can be applied to drive the robot according to the planned reference path. After a fractional navigation trough the reference path, a new image of the surrounding environment is acquired and the whole process of new reference path generation, control actuation generation and robot navigation for a specified fraction of the reference path is repeated again and again. This can be done with the objective of adapting the robot with dynamically varying environments, so that the navigation with dynamically varying positions of obstacles can still be carried out successfully.

The rest of the paper is organized as follows: section II presents the philosophy of mobile robot navigation. Section III details the path planning algorithm in both test case and with real environment and section IV concludes the paper.

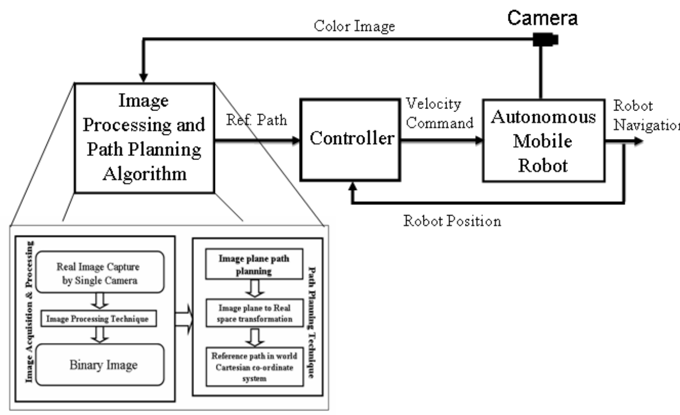

Fig. 1 Block diagram of the proposed vision based mobile robot navigation scheme.

II. Mobile Robot Navigation Philosophy

In this present work, the robot navigation objective is that, for a given reference trajectory and orientation of mobile robot, a controller must be designed that applies suitable torque such that the current robot position achieves the desired reference position. To accomplish this control objective, the system should be so designed that a torque is derived based on the differentially steered drive velocities to the left and right wheels of the robot. This objective can be satisfied by utilizing a controller that guides the robot to navigate a desired navigation path and simultaneously can ensure asymptotic stability, achieve satisfactory transient performance.

The proposed philosophy of the vision based mobile robot navigation is described in Fig. 1 as a block diagram representation. The reference path is calculated from the color image acquired by the camera, which acts as a vision sensor, by using the image processing and path planning algorithm block. The main objective here is to derive a suitable, safe navigation path for the robot, depending on the surrounding

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environment, whose characteristic features are captured in the acquired image. Then a control action has to be initiated to generate appropriate differential steering drive velocities, for the left and right wheels of the robot, in such a way that the required torque will be produced to track the reference path. A feedback signal containing the information about the current position of the robot is suitably utilized by the controller to generate the left and right wheel velocities [12]. The present paper focuses only on the image processing and path planning block of the mobile robot navigation as shown in Fig. 1.

III. Vision Based Path Planning

In this work, a simple but accurate path planning algorithm is proposed in the image plane and that path is subsequently projected in real world Cartesian coordinate system. At the outset, the proposed path planning algorithm is tested on some test binary images, and then the algorithm is applied to calculate the path for the real image captured by the single camera mounted on the robot, in such a way that the captured image carries the necessary information about the available floor area in the front for navigation, along with the other objects in the environment.

Algorithm 1: Generation of reference path in image plane.

```
BEGIN
1. Determine the size of the captured image C as (nrows x ncols).
2. Set i = 0.
FOR i = nrows to 1 (in steps of -1),
    3a. Store the pixel positions of white pixels along the complete image
    row in the array w_pixel(i,:).
    3b. Calculate the middle pixel position for ith row as middle_w_pixel(i).
ENDFOR
4. Set i = 0.
FOR i = nrows to 2 (in steps of -1),
    5. Connect middle_w_pixel(i) and middle_w_pixel(i-1) by a straight line
    segment.
ENDFOR
Set i = 0.
FOR i = nrows to 2 (in steps of -1)
    Set j = 0, and col(.) represent the column value corresponding to
    middle_w_pixel(.).
    FOR j = 0 to p     % p is dependent on the robot dimension.
        IF C(middle_w_pixel(i) + p, col(i)) is black,
        THEN  middle_w_pixel(i) = middle_w_pixel(i) – p.
        IF C(middle_w_pixel(i) – p, col(i)) is black,
        THEN  middle_w_pixel(i) = middle_w_pixel(i) + p.
    ENDFOR
ENDFOR
END
```

A. *Image Plane Calculations with Test Images*

A binary image is actually a collection of data in 0's and 1's structured in matrix form, where 0's represent the black pixels and 1's represent the white pixels. An algorithm is developed to calculate the reference path from the binary image as shown in Algorithm 1.

In step 3(b), if there is an even number of white pixels in a row, then there is no single middle value and the middle pixel position is defined to be the mean of the two middle values. But as it is known that a pixel position is always an integer number, thus in that case the mean value is floored to its next integer value. In step 5, connect the stored middle positions of the pixels by straight line segments to create the reference path, for that captured image. If there is any obstacle in the path, then the binary image will show two available paths, the algorithm will then decide which path is wider by measuring the white pixels as stored in step 3(a) and the reference path will be calculated along that path avoiding the obstacle. The results of some sample cases of image plane path planning are shown in Fig. 3. In Fig. 3 (b) and Fig. 3 (c), the planned paths are initially collide with the obstacles, thus, a modification is added to Algorithm 1 in step 6-11, but finally with the modified algorithm, which incorporates the physical dimension of the robot, the new planned path avoid the obstacle safely.

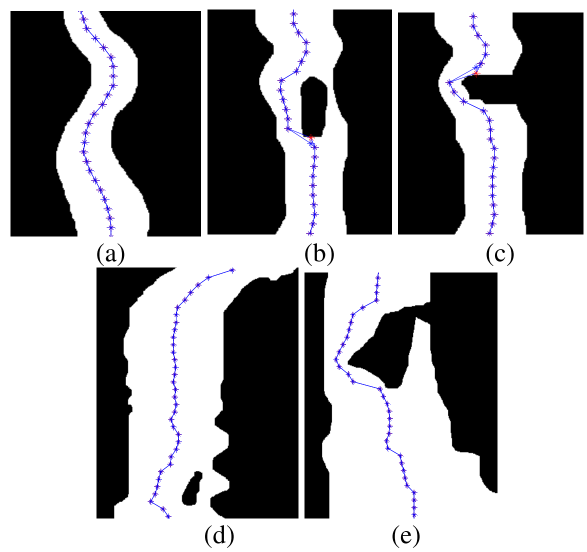

Fig. 2 Results of the image plane path planning for some sample cases.

B. *Image Plane Calculations with real Image*

During the process of navigation, the robot intermittently stops, the camera acquires image of the environment in front of the robot, image processing is performed on that image to determine the reference path, the controllers determine the suitable drive commands and the robot navigates for a desired duration. Then the robot stops again, acquires image and goes through the before mentioned steps once again. This process of navigating the robot for a desired duration and then stopping it and activating the vision sensor is carried out in an iterative fashion, until the robot completes the navigation job.

In the image processing step, first the image is captured by the auto-focusing camera mounted on the robot. Then this RGB color image is converted into a grayscale image for further processing. Gaussian blur filter is then used to de-noise this image. It is a common practice in computer vision based applications that, to enhance the image structure scales, Gaussian smoothing is used as a preprocessing stage. Also, the Gaussian blur filter can eliminate the high frequency components from the image. Next, the image is processed by contrast adjustment to sharpen the distinguishable boundaries of the objects in the image. Then geometric mean filter, a special type of non-linear mean filter, is applied which is more efficient in removing Gaussian type noise and preserving edge features, compared to the arithmetic mean filter. Once this series of image filtering steps is completed, then image segmentation technique is applied to the grayscale preprocessed image. For the segmentation purpose, region grow technique is used to create a binary image. Fig. 4 (a) to Fig. 4(f) show a sample situation where a raw captured image undergoes these preprocessing steps and final processed binary image is produced and Fig. 4(g) shows the planned path in image plane.

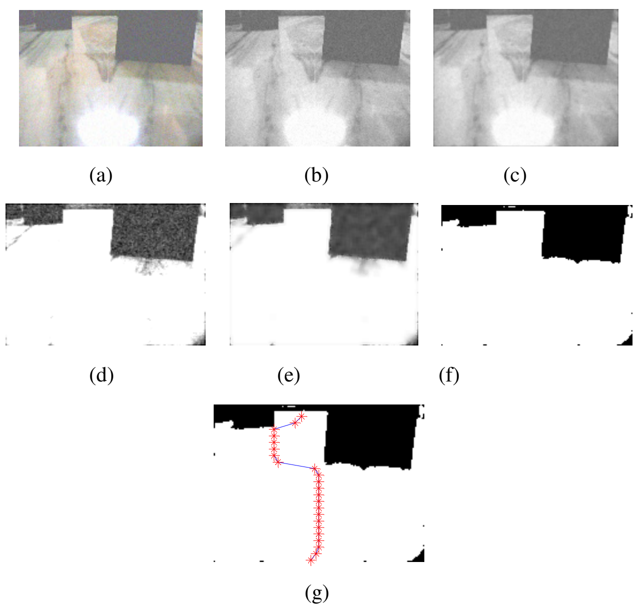

Fig. 4 Results of the image processing steps for a sample case: (a) captured RGB image, (b) gray-scale image, (c) Gaussian blur filtered image, (d) contrast adjusted image, (e) geometric mean filtered image, and (f) final binary image after thresholding, (g) planned path in image plane.

C. Image Plane to Real Space Conversion Technique

After calculating the reference path in the image plane, i.e. in terms of image pixel positions, it is required to project these locations to the real world coordinates, where the robot will actually navigate. The coordinate transformation is calculated by measuring four distances as shown in Fig. 5. These include the height of the camera from the floor, *h*. It is to be noted that there is always a blind area immediately in front of the robot. Hence, the distance of the nearest point that can be viewed by the camera is denoted as y_b.

The furthest point visible to the camera is at a distance ($y_b + y_l$) and the fourth distance is the furthest point to the left or right of the camera lateral view, denoted as x_l. With these measurements, the three transformation angles are calculated as:

$$\alpha = \tan^{-1}\left[\frac{h}{y_b}\right], \beta = \tan^{-1}\left[\frac{h}{y_b + y_l}\right],$$
$$\gamma = \tan^{-1}\left[\frac{x_l}{y_b + y_l}\right] \quad (1)$$

The point $P(x, y)$ in the world coordinate, which is obtained by transforming from the point $P'(u, v)$ in the image plane, is obtained as:

$$y = h\tan\left[(\frac{\pi}{2} - \alpha) + \left[\frac{u}{S_y}\right](\alpha - \beta)\right] \quad (2)$$

$$x = y\tan\left[\frac{2v}{S_x} \times \gamma\right] \quad (3)$$

where S_x and S_y are the number of image pixels in the vertical axis and horizontal axis respectively [19].

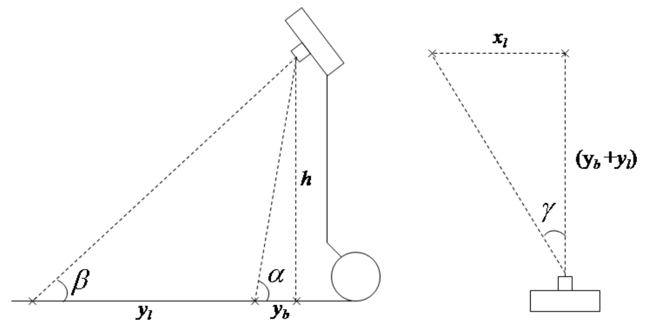

Fig. 5 Relationship between the image plane coordinates and the mobile robot real space coordinates.

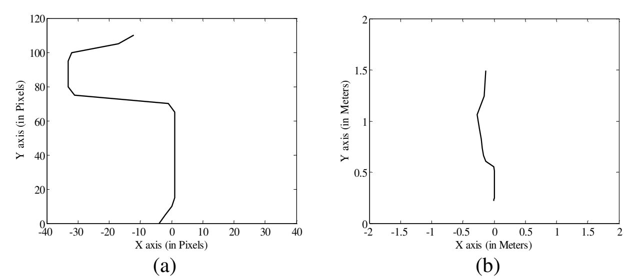

Fig. 6 Planned path in (a) image plane and (b) real space (world coordinate).

Fig. 6(a) shows the reference path calculated in terms of the pixel positions, corresponding to the binary image as shown in Fig. 4(f). Thus, after transforming the data in image plane to the real space coordinates, the reference path is created in the real space, as shown in Fig. 6(b).

Thus, once the reference path is generated in the image plane, it is projected on the real space of the Cartesian coordinate system now it is the task of a controller to navigate the robot tracking the reference path. However, one important point is that, during the process of navigating the robot, the environment may get changed and the algorithm should be flexible to cope with the changes in the dynamic environment. For this, the robot should intermittently acquire images of the environment and calculate reference path, each time, and perform navigation accordingly.

IV. Conclusion

The present paper proposed a novel idea for vision based path planning of mobile robot for safe navigation avoiding the obstacles. A single camera based vision sensor reduces the complexities of the sensor coordination and data fusion problems. The proposed algorithm is successfully implemented on both test and real images for planning paths for save navigation of a mobile robot. Periodic image acquisition and path planning technique facilitates the scheme to tackle the dynamic environment of navigation.

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