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Reproduction of 3-D Model of Indoor Environment by Moveable Robot with Single 2-D camera for Navigation

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Abstract:- The creation of a 3-D model of indoor environments is increasingly gaining more importance due to the wide variety of applications. Applications are the representation of building, indoor facilities information representation, etc. This paper represents an approach to create visually persuasive 3-D models of indoor corridor based on the mobile robot that is connected to a single 2-D camera. The sequence of images acquired from the 2-D camera and distance between surrounding and the robot is determined. In this paper, the new approach for distance estimation between the wall and the robot is proposed. Distance estimation is achieved using skirting height as a reference. The panoramic stitching of images generates the walls of the indoor corridor. Doors in the corridor are identified using an edge-based approach. The proposed approach is tested for real datasets and getting visually effective results. The proposed approach is intended to address navigation in complex buildings.

Keywords: distance, panoramic stitching, skirting, 3-D modelling, segmentation, door detection.

1. Introduction

3-D models of indoor environment give a quick and more exhaustive overview of a scene. For example, consider the college campus 3-D model. The model helps students and parents get to know the structure of the college building, department area, library details, and much other information about the college. Biber et al.[1] presented a method which uses a panoramic camera and only one horizontal laser range finder to create a 3-D model. The images from which the textures are created are taken using a panoramic camera. Combined with a Fleck [2] method that can create 3-D point clouds from pairs of panoramic images, some additional 3-D information is applied to the models [3]. A different approach was presented by Thrun et al. [4] who use a vertical laser range finder to collect 3-D range data. A panoramic camera textures planar surfaces derived from these data with the RGB images captured.

3-D depth information is very much essential for building the 3-D model. Traditional 3-D depth information is determined using range sensors such as ultrasonic sensors or laser range finders for mobile robots, but the lack of vision-related information. This visual information is valuable and useful, mainly when the data collected by the robot is to be interpreted by humans. Such as texture or color of the wall, presence of the door, height and width of the door, objects present on the wall.

This paper proposes a method for creating 3-D models based on a 2-D image sequence, which is acquired by using a mobile robot. First, to identify walls, doors, and estimate the distance between the wall and the robot, we extract a collection of horizontal and vertical lines segmented from the 2-D images. This set of information serves as a floor plan for the 3-D model. Image stitching is used to combine a sequence of 2-D images having some overlapping into a composite image. Image stitching has played an essential role in the 3-D model generation. Estimation of the distance between the wall and the robot is done based on the height of skirting as the reference.

2. Related Work

Biner et al.[1] presented a method which uses a panoramic camera and a single horizontal laser range finder to create 3-D models. Using a panoramic camera, they capture the image that produces the textures from. In combination with Fleck [2], which can generate point clouds from a pair of panoramic images, some more 3-D information is added to the models [1]. C. Wolf et al. [3] suggested using mobile robots and laser range finders to create lightweight urban 3-D maps. Environmental 3-D representation is accomplished by using point clouds. The point cloud gives a very detailed description of the environment. Generation of a point cloud map based on odometry, IMU, GPS, and range information. The graphs were plotted using a standard VRML tool that enables us to navigate virtually on the map. Thrun et al.[4] addressed a different approach, using a second vertical laser range finder to collect data from the 3-D range. A panoramic camera textures planar surfaces derived from these data with RGB images. C Weiss and A Zell [5] were presented as a method to create 3-D models of indoor environments. The 3-D model is based on a 2-D map, which is generated using a single laser rangefinder. The data-driven method using point cloud for the reconstruction of structural elements and a model-driven approach for the recognition of closed doors using a generalized Hough transform was presented by Vilarino [6]. Q Wu[7] tried to reconstruct the 3-D model of buildings based on information on the floor plan and components of the buildings. The proposed method for collecting knowledge about building materials and indoor storage from CAD floor plans. To determine the windows, parallel lines and line boundaries are used. Different door types are identified based on the number of circles in the door block and the number of arcs. H. Tran et al., [8] have proposed a stochastic method for automated 3-D interior space reconstruction models from point clouds. Point clouds are segmented into horizontal (i.e., floor and ceiling) structure and vertical (i.e., wall) structure. An interior space's 3-D model is a collection of cells consisting of both geometric {V, F} data, and semantic {type} data.

3. Methodology

In this proposed method, a single 2-D camera is used for the 3-D model creation. A distance between mobile and wall is determined from the single 2-D image

The key parameter in the 3-D model generation is depth estimation. To determine the depth information, stereo camera, or multiple captured from 2-D cameras, are required. But in this proposed work, the single monocular 2-D camera is used. A camera that is used in the present work is set to produce the video sequence at 30fps and frame 640x480 (width X height). The idea of the proposed approach is to build a visually convincing 3-D model of an indoor corridor. The mobile robot is the corridor; the robot records the sequence of images. From this recorded image sequence, depth is determined, and the 3-D model is generated. The method proposed is composed of the following steps:

a. Image Acquisition and Distance Estimation
b. Creation of the Line model
c. 3-D Models generation

The Block diagram of the proposed approach is shown in figure.1.

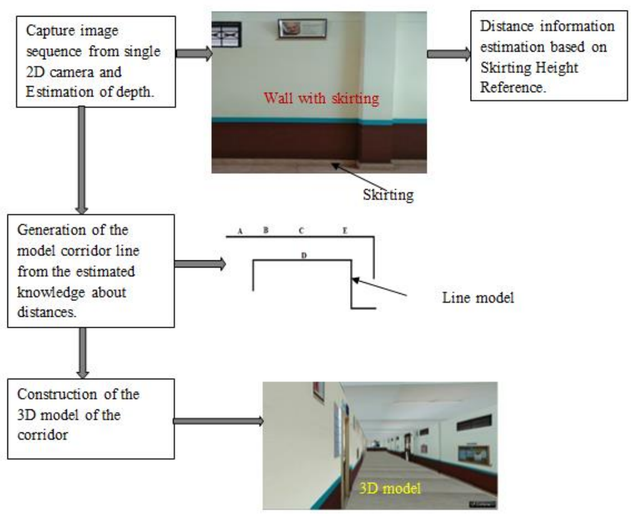


Figure 1: Block diagram of the proposed approach

3.1 Image Acquisition and distance estimation

Most of us have to skirt in our office, hotel, hospital, homes, and etc. They are called baseboards by Americans; others refer to them as Kickboards or moldings. In the earlier days, they were called "mop boards" because they allowed owners to mop the floors without soaking the wall. Figure 2 shows the images with skirting.

Skirting is pottery, concrete, or natural stone from the earthwork. The skirting is usually 5 to 15cm in height and can be stained or painted, and they can be carved with molding or flat. In this paper, the height of the skirting is considered as a reference for determining the distance between the wall and the mobile robot.

Figure 2: Wall image with skirting

When the robot moves near the wall, then skirting height of the image is increased. If the robot is far from the wall, the height of the skirting is decreasing. Variations of the skirting height with different robot positions are analyzed. During the skirting extraction process, the robot may not get the skirting because the door area doesn't contain skirting. So, before estimating the skirting height, identification of the wall and door is required. Below figure 3 shows the block diagram of proposed distance estimation work.

Distance determination consists of two steps. The first step is the door detection, and the second step is the skirting height measurement.

In this work, the small mobile robot is used to collect the image data. The robot is equipped with a single 2-D Omni-directional camera system. The robot is driven around the corridor, and the 2-D distance information map constructed using the proposed depth estimation technique. The final 2-D distance map consists of a set of scan points in a global coordinate frame. Scan points are considered as wall points. During distance estimation, the robot stops approximately every 3 meters and takes three images; one to the front of the robot, one to the left, and one to the right. The left side image is used for estimating the distance between the left wall and the robot.

Similarly, the right side image is used for estimating the distance between the robot and the right sidewall. The first image is used for determining the corridor end. Each image is saved along with the robot's current pose estimate and orientation. These two distance information gives the width of the corridor.

i. Door detection:

The task of door detection is to know the captured image contain skirting or door. Since the wall image can be assumed to be the plan and contain skirting. The door area doesn't include the skirting, and then distance estimation is not possible. Once the door is identified, door position information is recorded. In order to estimate the distance information, an image must contain the skirting.

The main objective of this process is to develop a fast processing algorithm to detect the presence and recognize the status of the door in the indoor environment where lighting conditions are uneven.

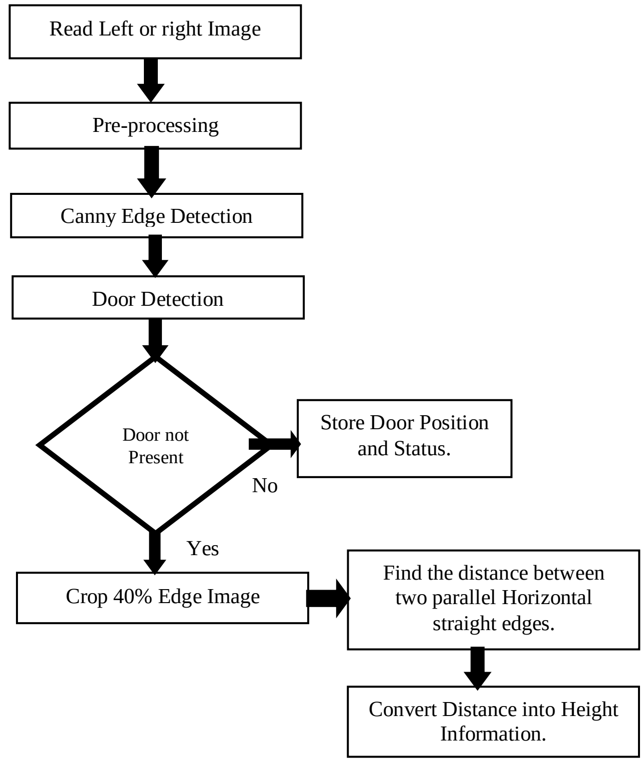


Figure 3: Block diagram of the proposed distance estimation process.

The process of extracting information from a video frame is one that involves a series of stages. The following steps: pre-processing, detecting edges, removing line segments from the edge images, and finally matching the lines together to classify doorway candidates. Pre-processing often involves a conversion of RGB space to gray format as preliminary steps to decrease the overall order of magnitude of the operations performed throughout information extraction. This initial step helps the developed algorithms for the fast processing of the streamed video frames. Figure 4. shows the block diagram of the door detection process.

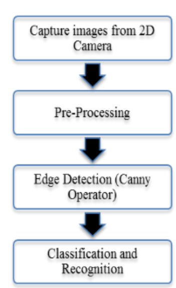


Figure 4: Different stages involved indoor detection process.

Capture images from a 2-D camera:

In this stage, the camera is connected to the robot for the streaming of the continuous image frames at 30fps and the dimensions of the frames are 640x480 (width x height). The camera used is a low-cost web camera that is available in the market. The streaming of the video from the camera starts as soon as the system is initiated.

Pre-Processing Stage:

In the pre-processing stage, we are converting an RGB video sequence streamed from the camera sensor to a gray-scale. This is the only operation that is performed at this stage.

Detection of change in the material property:

At this stage, the material property of the wall and door is detected using edge features. For the present implementation work, the Canny edge operator is used. Edge magnitude in horizontal and vertical directions are considered for nullifying the wrong edges.

Classification and Recognition Stage:

At this stage, all the points both in the horizontal and vertical direction are aligned between the present and the next levels, and this helps in merging this points based on criteria that the distance between the two successive edge points in the present and next degree should be greater than or equal to the width between the two levels. When the two edge points satisfy the criteria, these two points are joined two forms a secure line.

After extracting ROI (Region of Interest) from the input image sequences, some test conditions and the probability of occurrence of line segments in ROI are considered to detect the presence and status of the door and are inferred.

ii.Skirting extraction and distance estimation

If the door is not identified in the previous step, the next process is skirting extraction. The block diagram of the skirting height estimation process is shown in Figure 5.

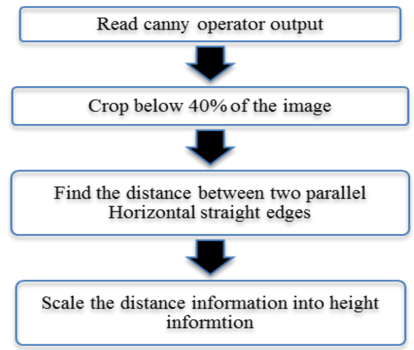


Figure 5: Different steps involved in the distance estimation process.

Read Canny edge operator output: Canny edge detection operation is performed during the door detection process. So, the production is output is used for estimation.

The crop below 40% of the image:

For wall distance estimation, whole image processing is not required. The skirting is always present at the bottom of the image. So, 40% of the base image is enough for the distance estimation process. Thus, this process reduces processing time and reduces the misclassification of the skirting edges and other edges. If the robot is very close to the wall, skirting may not be visible. Then, the robot will change its position and takes the images.

Find the distance between two parallel Horizontal Straight edges: The first step of the proposed method is to extract the edges by applying Canny edge operator. A-line fitting method is used to the Canny edge output to determine the line segments of the wall and floor. Line segments are classified into two categories: horizontal lines and vertical lines. We considered vertical lines belonging to the wall and some cases floor based on a broad set of corridor images and the ground truth images. But, skirting contains two parallel horizontal lines. Figure 6.c shows edge output. The output image includes both diagonal horizontal and diagonal vertical edge.

But vertical edges are not considered in the skirting height measurement. To extract straight horizontal edges, the Hough transform is used. Parallel lines have the same slope. If the slope of a line is,' then -1/m is the slope of a line perpendicular to it. The below equation is used for finding the distance between two parallel straight lines.

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (1)$$

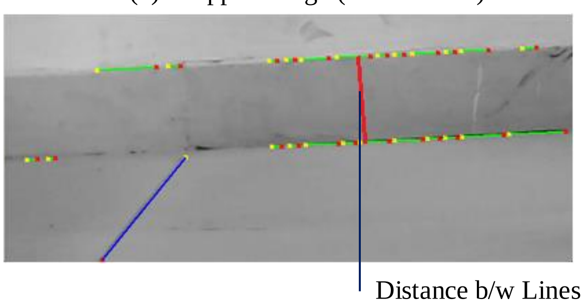
The output of straight line detection and distance calculation output is shown in Figure 6.

Scale the distance information into height:

Distance information is converted into height based on the initial learning experience. During the learning, process distance is measured for the broad set of images with different robot positions.

(a) Input RGB image

(b) Cropped image (40% bottom)



Distance b/w Lines

(c) Distance Estimation

Figure 6: Outputs of the distance estimation process.

3.2 Creation of line model

The next step is to the 2-D distance map, which is a set of unrelated 2-D points, into a set of line segments. Each line segment represents one wall of the 3-D model, i.e., each line segment is the wall's projection onto the floor. To extract lines from the 2-D distance map, the Hough transform has been used. The final line model for the 2-D distance map is shown in figure 7. The line segments a, b, c, d, e, g, and h were manually inserted. These lines are corresponding to door locations. This information was identified during the door detection process.

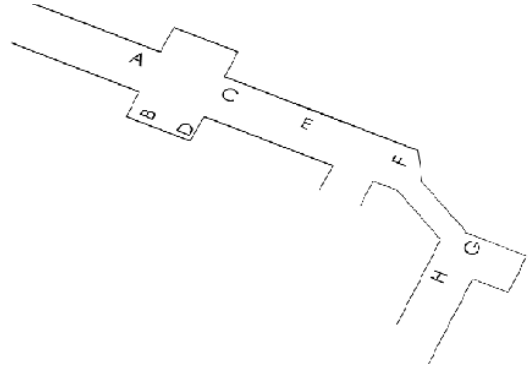


Figure 7: Generated line model of the indoor environment.

3.3 3-D models

The line model provides the floor plan for the 3-D model generation, where each line segment represents a wall. The images taken by the single 2-D color camera are used to texture the walls. The outline of the wall creation process is as follows:

1. The sequence of images is captured during the distance estimation process. We need to determine the three suitable images to generate panorama of the wall using the image stitching method.

2. Find the length of each panoramic image to adjust the wall length.

3. The intensities of the neighboring wall images are adjusted to hide seams.

Figure 8 and figure 9 displays the output of the 3-D model.

To generate the visually impressive 3-D model of the corridor, an image must meet the following conditions. First, the photograph position 'p' of the image must be located such that 'p' is on the corridor or room side of the wall. Third, the wall must be seen entirely on the image with skirting. Camera position and orientation must be constant in the entire image acquisition process. Finally, it is advantageous if the wall is presented nearly frontally on the image; the angle between the viewing direction of the image and the orientation of the wall provides a measure for this condition.

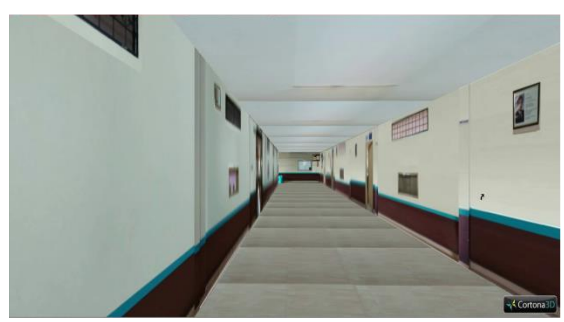


Figure 8: VR- Model of Information Science Dept. Corridor

Figure 9: VR- Model of the MBA Dept. Corridor

4. Results and Discussion

During the door detection process, the door location information is identified. To construct the 2D line model, the starting point and the end of the navigation are essential. Along with navigation points, the width of the wall in the captured image is also necessary.

The length of all segments of the door line is of the same size. We obtained copies of the indoor corridor in our experiment. The height and width of all doors at our institute are identical. Figure 10 shows the sample door images of our institute. Only door locations are shown in the 2D-line model. Yet door status is not reflected whether the door is opened or closed.

Figure 10: Sample door images of our institute.

The output of the line creation model gives the floor plan of the building. From this output, the user can quickly get to know about several rooms in the corridor and the length of the passage. This information is also beneficial for predicting the time needed for robot navigation.

5. Conclusion and Future Scope

This paper presents a method to generate 3-D models of indoor environments. The 3-D model is based on a 2-D distance map, which is built using a single 2-D camera based on skirting height as a reference. Then transform the point-based 2-D distance map into a set of line segments, where each section represents a wall and door. The depth information extracted from the proposed method. The proposed method is best suited to indoor corridor-like environments, and rooms with walls included skirting. Wall images are stitched using blinding model algorithms. The proposed way is very cost-effective. No physical hardware sensor is not required to determine the distance information. One of the limitations of the proposed method is that the captured must contain the skirting, and skirting height must be constant in all the captured images.

6. Acknowledgment

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