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AN APPROACH FOR CAMERA CALIBRATION FOR ROBOT NAVIGATION IN AN INDOOR ENVIRONMENT USING SINGLE 2D IMAGE OF CORRIDOR WALL AND WALL JUNCTION

Honnaraju B*

Associate Prof. Department of Computer Science andEngineering, Maharaja Institute of Technology Mysore, Mandya-571477 Karnataka, honnaraju.gowda@gmail.com

Abstract— An efficient method for camera calibration from 2D images is important in many computer vision tasks such as stereo vision, metrology, and 3D reconstruction. There are many of tasks that can benefit from camera parameter information, such as distance estimation, detecting and classifying of objects in addition to 3D view generation. Camera parameters are important for vision-based robot to move from one location to another. Without camera parameters it is difficult to find and evaluate the properties of the object. Camera parameters are important for the extraction of 3D spatial information of the object from a 2D image. Camera calibration is also critical for estimating information about 3D depth. Another prerequisite for camera calibration is the creation of a 3D view from a 2D view. Reconstruction of a 3D view of an indoor corridor is the main objective of this work. In order to achieve 3D reconstruction from a 2D camera, the parameters have to be taken into consideration. By using the camera parameters, distance estimation has performed for robot navigation. Using traditional calibration methods can become impractical because of a lack of objects for reference or even fixed patterns in the indoor environment.

Keywords— Calibration, distance, vanishing point, edges, skirting.

I. INTRODUCTION

Camera calibration is one of the key issues concerning computer vision. Camera calibration techniques are of two types: 1. Calibration photogrammetric, 2. Calibration on self-camera. Camera calculation is achieved by perceiving an object for calibration, the geometry of which can be utilized with reasonable accuracy in a 3D space. The object of calibration is normally composed of two to three orthogonal planes. In addition, a plane undergoing an accurately defined translation can also utilize. The camera calibration performed based on camera motion in a static scene. This is known as self-camera calibration technique, and it can be used effectively as it involves several images of a static scene. Camera calibration methods are classified into two steps:

i. Intrinsic Calibration.

ii. Extrinsic Calibration.

The camera parameters can be calculated by measuring the correlation in the images between two identical objects [1][3]. The use of single 2D image yields intrinsic parameters, such as focal length and center of camera focus. The image center parameter is important for locating the center of the image. The focal length parameter is associated with the focus of the camera. These two parameters are very important in our research for the extraction of 3D depth information and path generation. In the 3D depth estimation process, the position of the wall skirting within the frame becomes important. 3D depth information can estimated based on the position of wall skirting in the image (based on the reference of skirting height). Intrinsic parameters of the camera are derived from perspective geometry [2][4], which is the basis for the approach that determines the intrinsic parameter of the camera. The emphasis in the proposed research is on building an indoor 3D view of a corridor. To reconstruct the 3D view from 2D images, we need a series of images of the indoor corridors. Distance calculation has achieved based on the height of the skirting, which must also be included in the input images. The same images from the input can utilized for finding the vanishing points [8]. Further, the detected vanishing points become the basis from which intrinsic camera parameters can be estimated.

II. OBJECTIVE

The research aimed to fulfill the following objectives:

- Design and efficient method for camera calibration. Camera calibration is very important for robot navigation.
- Use single image for camera calibration.
- Use same image for distance estimation.

III. PROPOSED METHOD

Most of the images of the walls used for our research work are of our campus building and they consist of more than one color. The lower portion of the wall includes a 2.5" to 3" skirting. Two different colors are used for the areas above and below the skirting. This section is typically 2 to 2.5 feet in height. The different colors of the wall as well as the skirting has shown in figure 1.

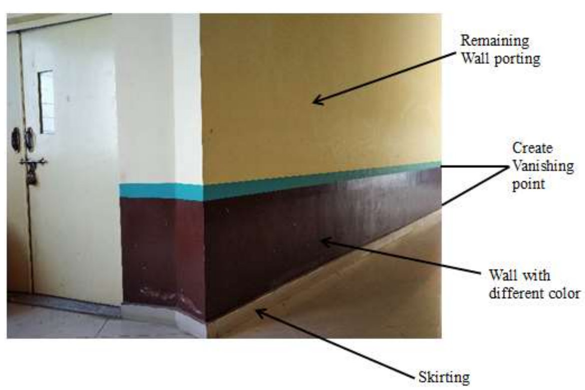

Figure 1: Image of the wall which produces vanishing points.

Parallel edges of the wall do not appear parallel in an image due to perspective distortion. The edges of the wall joining points (X1, Y1), (X2, Y2) form a straight line which is actually parallel to the edges that are formed by the joining the points (X3, Y3) and (X4, Y4) as shown in the figure 2.

As these lines got extend, they intersect at one particular point (Xn, Yn) and are known as the vanishing points. The line between points (X1, Y1) and (X2, Y2) shall be called line 1.

Similarly, line 2 is viewed as the line between points (X3, Y3) and (X4, Y4). The slopes of line 1 and line 2 are the S1 and S2 respectively.

Equations for line 1 and line 2 are given below:

$$(Y - Y1) = S1(X - X1) \quad \text{----------------------- (1)}$$

$$(Y - Y3) = S2(X - X3) \quad \text{----------------------- (2)}$$

Both lines are non-parallel and intersect at some point (X_n, Y_n) if stretched at either end. But, it only satisfies both (1) and (2) for the point (X_n, Y_n) at the point at which the lines converge. Hence we get (3) and (4) by rearranging this equation after substituting (X_n, Y_n).

$$(1) \Rightarrow X_n = \left(\frac{Y_n - Y_1}{S_1}\right) + X_1 \quad \text{------------------------- (3)}$$

$$(2) \Rightarrow X_n = \left(\frac{Y_n - Y_3}{S_2}\right) + X_3 \quad \text{------------------------- (4)}$$

2 unknowns and 2 equations, (3) and (4), are used for solving the value for which the coordinates (Xn, Yn) are given.

$$X_n = \frac{S_1X_1 - S_2X_3 - Y_1 + Y_3}{S_1 - S_2} \quad \text{--------------------------- (5)}$$

$$Y_n = S_1X_n - S_1X_1 + Y_1 \quad \text{--------------------------- (6)}$$

To detect the vanishing points, we use the Hough transform dependent method. Vanishing points are used for collecting geometrical cues.

(U1, V1) and (U2, V2) are the coordinates of the points VP1 and VP2 respectively, S is the slope of the line joining these 2 points VP1 and VP2, that is:

$$S = \tan \propto = \left(\frac{V_2 - V_1}{U_2 - U_1}\right) \quad \text{--------------------- (7)}$$

$$\alpha = \tan^{-1}\left(\frac{V_2 - V_1}{U_2 - U_1}\right) \quad \text{--------------------- (8)}$$

Slope of the line and subsequently the equation of that line having an angle $(180 - \phi)$ with the line joining two points VP1 and VP2 and pass through a point VP1 (u1, v1) on that line.

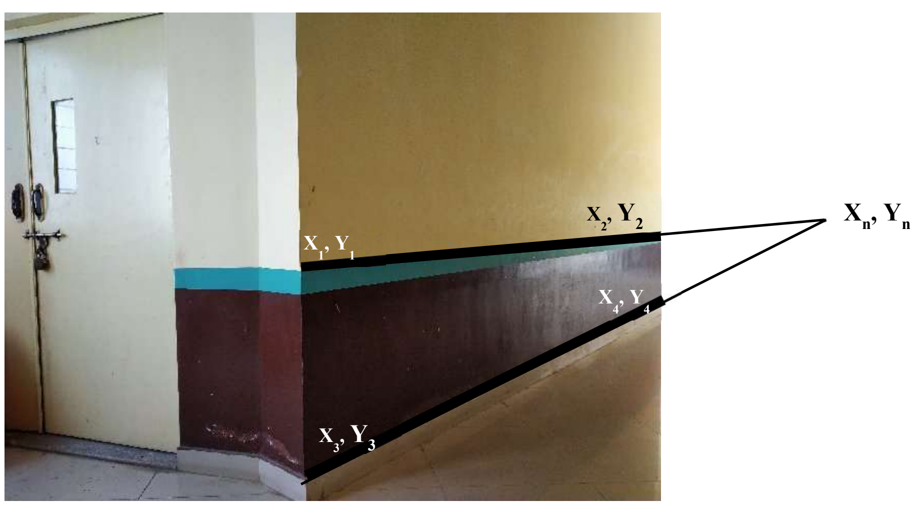

Figure 2: The description of vanishing point in the wall image

$$S1 = \tan[(180 - \varphi) + \alpha] \quad \text{----------------------------- (9)}$$

$$(Y - V_1) = S_1(X - U_1) \quad \text{----------------------------- (10)}$$

Where

$$\tan\alpha = \left(\frac{V_2 - V_1}{U_2 - U_1}\right) \quad \text{------------------------------------ (11)}$$

Similarly the equation of line passing through (U_2, V_2) with an inclination of θ to the line joining the points VP1 and VP2

The shortest distance from the camera point to the image plane is known as the focal length of camera. It is the difference between the IP and SP lines. The following relations are derived to get the focal length.

$$AA1 + BB1 = 0 \quad \text{----------------------- (12)}$$

Where (A, B) and (A1, B1) are the directional ratios of $\overrightarrow{VP_1VP_2}$ and $\overrightarrow{IPSP}$ that is,

$$(A, B) = [(U_2 - U_1), (V_2 - V_1)] \quad \text{---------------------------- (13)}$$

$$(A^1, B^1) = [(X_t - X), (Y_t - Y)] \quad \text{---------------------------- (14)}$$

$$IP(X, Y) \Rightarrow IP(U_1 + rl, V_1 + rm) \quad \text{----------------------------- (15)}$$

Where X_t and Y_t are coordinates of the camera point.

$$X_t = \frac{[(V_2 - S_1U_1) - (S_2U_2 + V_1)]}{(S_2 - S_1)} \quad \text{---------------------- (16)}$$

$$Y_t = S_1\left[\frac{(V_2 - S_1U_1) - (S_2U_2 + V_1)}{(S_2 - S_1)}\right] - S_1U_1 + V_1 \quad \text{--------------- (17)}$$

The directional cosines (l, m) of $\overrightarrow{VP_1VP_2}$ are given by

$$(l, m) = \left(\frac{A}{\sqrt{A^2B^2}}, \frac{B}{\sqrt{A^2B^2}}\right) \quad \text{-------------------------- (18)}$$

Solving equation (12), using (13, 14, 15 and 18), we get the only unknown r. This is the radius of the vector.

$$r = \frac{A(X_t - U_1) + B(Y_t - V_1)}{Al + BS} \quad \text{------------------------------- (19)}$$

Substituting (18) and (19) into (15), we get the values for X and Y at the point IP. Using the distance formula for points IP(X, Y) to $SP(X_t, Y_t)$, we can extract the distance, i.e. the focal length.

$$[\overrightarrow{IPSP}] = \sqrt{(X_t - X)^2 + (Y_t - Y)^2} \quad \text{-------------------------- (20)}$$

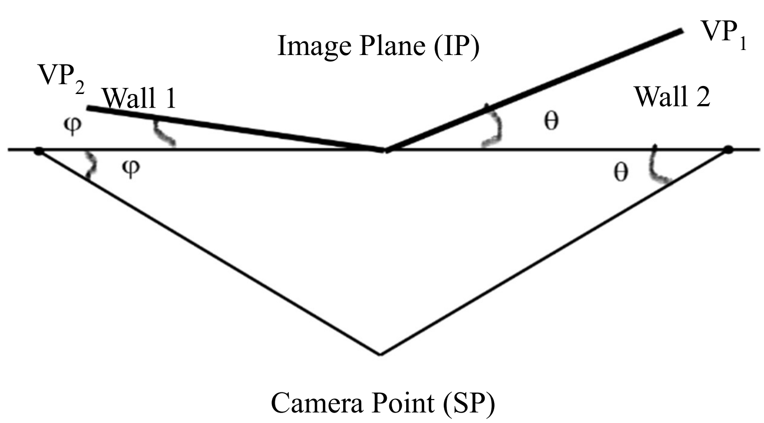

Figure 3: Representation of the camera point viewed from the top.

Algorithm for extracting camera parameters:

Input: Read wall junction image (The image must contain the wall with its skirting). The size of the input is 640 x 480.

Output: Camera parameters (Image center and focal length)
Steps:
1. Capture the wall junction image (RGB Image).
2. Extract line edges by performing the canny edge detection operation.
3. Apply the Hough transform method for the extraction of the horizontal straight line.
4. Extract the vanishing points from the extracted parallel lines.
5. Find the camera center and focal length using the vanishing points.

IV. DISTANCE ESTIMATION

Most of us see a skirting on the base of a wall in any houses, hotels, office, college, hotel, bus stops, railway stations, hospital, and such buildings. A skirting is essentially a board that is fixed between the interior wall and the floor around the boundary. It covers the flawless edges, avoids furniture scratches and gives a good finish to a room. By using the skirting height information in the image, robot can determine the distance between the walls. In general, robots attached with different hardware sensors to determine the distance between obstacles and the dimension of the free space area. The distance estimation method based on skirting height [10] is requires to camera parameter. Estimation of distance information is very difficult with knowing the camera parameters. In the proposed approach, both camera calibration and the distance estimation is achieved in single 2D image.

V. EXPERIMENT

The proposed method has tested on real indoor corridor wall images of our college building. There was no predefined wall junction dataset available for camera calibration. So, to test the proposed method, large numbers of wall junction images were captured and the require dataset was prepared. Wall junction images were captured while robot in the movement. The one constraint for capturing images concerns the presence of intersection of the wall with skirting. During the image capturing process, a constant distance needs to maintained between the robot and the wall. A distance of approximately 5 feet is maintained between the robot and the wall along with a 90^0 degree orientation. A USB camera has been utilized to acquire images. The size of the input image is 640 x 480. The experiments were conducted in the MATLAB platform and Python with an OpenCV environment. A Canny edge operator is used to detect first line edges and is preferable to Robert, Prewitt and the Sobel edge operators which are sensitive to noise. Hence, the Canny edge operator was chosen in the proposed approach to detect the edges. A Hough transform has been used to extract the straight lines. The Hough transform output was also used to detect the vanishing points. Camera intrinsic parameter focal length is determined by using two vanishing points VP_1 and VP_2. Figure 4 shows the vanishing points detection output.

a. Floor Junction input image b. Canny edge output

c. Line Detection d. Vanishing point detection

Figure 4: Vanishing point detection.

CONCLUSION

Camera calibration is seen to perform well when based on the wall feature (Wall junction point). Initially, the parallel edges were detected using a Canny edge operator. Later the vanishing points were detected using the Hough transform. The requirement of the captured image needing to contain the image of the wall along with the skirting having various colors is the constraint of this approach. The captured image must necessarily contain the place of the intersection of the wall; otherwise the vanishing points cannot be determined easily. The advantage of this approach is that it can be implemented and executed an efficient manner.

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