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Offline Stereo Camera Calibration of Raspberry Pi Compute Module

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Abstract*- Computer vision has become a very popular field due to its numerous applications. Stereo imaging, one of the areas of computer vision is frequently used in many applications like autonomous robots to calculate the free path, 3D reconstruction of environment, automatic cars, travel aid for visually impaired and many more. The major step in stereo imaging is establishing correspondence between multiple images. Errors within the camera and the method of arrangement of cameras can lead to wrong correspondence. Hence the depth information calculated will be incorrect. To increase the accuracy of depth matching in stereo imaging, we need to correct the camera imperfections. Stereo camera calibration is a method that can help predicting the internal and external parameters of the camera. There are many methods to perform camera calibration. In this paper, we explain the method of calibrating stereo raspberry pi cameras connected to raspberry pi compute module using 2D calibration object.

***Keywords:* Computer vision, stereo imaging, depth mapping, stereo calibration, raspberry pi, compute module.**

I. INTRODUCTION

Computer vision is an important field of research. Computer vision technique helps to model complex visual environment using various mathematical models. A stereo vision is an important field within computer vision that addresses an major research problem of reconstruction of three dimensional coordinated points for depth estimation [1]. A system of stereo vision consists of a stereo cameras placed horizontally. The two cameras capture images simultaneously and the captured images are processed for recovery of visual depth information.

Depth recovery depends on the concept of establishing correspondence between pixels of images captured by stereo cameras. Cameras internal parameters and alignment of cameras with respect to world coordinates govern at which pixel the image of a point on the object in focus will be mapped. This mapping will be different for both stereo cameras. So establishing correspondence is a two dimensional search in stereo images, to find the pixel in both the images that are projections of same point on the object under consideration. As image sizes are increasing the two dimensional search is a time consuming process. Many applications like electronic travel aid for blind [2], automatic robots that calculate path based on stereo imaging need a real time processing. Two dimensional search of stereo images, is a time consuming process, thus cannot be used where time is major constraint. Moreover, the accuracy of the recovered depth information also depends on the how accurately the algorithm can establish the correspondence.

Camera calibration is a process that helps us to calculate the internal and the external parameters of the cameras under consideration. Stereo camera calibration helps to establish relation of relative orientation between the stereo cameras. Once the relation is established, two dimensional search for correspondence can reduce just one dimensional search. This can reduce a lot of processing time and also increases the accuracy. Stereo camera calibration is a three step procedure used to introduce correction in the stereo images.

II. CAMERA CALIBRATION

Camera calibration is an essential and fundamental part of computer vision systems. Camera calibration is the process of estimating the parameters of cameras using a special calibration pattern. Parameters associated with a camera can be classified into two groups: Intrinsic parameters and extrinsic parameters. Intrinsic parameters are related to construction of a camera. This includes focal length of lens used, size of each pixel of CMOS sensor, aspectratio. Extrinsic parameters are related to the orientation of camera with respect to three dimensional worlds. This includes translation and rotation of camera.

The ideal pinhole camera model is applied in this paper to describe the stereo camera in our system[4]. Let X =$[X, Y, Z]^T$ and x =$[x, y]^T$ be a 3D point in the world coordinate system and its corresponding 2D point in the pixel coordinate system respectively. Let X =$[X, Y, Z,1]^T$ and x=$[x,y,1]^T$ denote their homogeneous coordinates. The result of camera calibration is projection matrix, which contains both the internal and external parameters and can be decomposed into constituent's matrices. The equation describing projection is as shown

$$x_i = PX_i \qquad (1)$$

$$x_i = K[\boldsymbol{R}\ \boldsymbol{T}]X_i \qquad (2)$$

where

$$K = \begin{pmatrix} \propto & \gamma & x_0 \\ 0 & \beta & y_0 \\ 0 & 0 & 1 \end{pmatrix} \qquad (3)$$

Where K is called the internal camera calibration matrix. $\boldsymbol{R}$ is 3x3 rotation matrix and $\boldsymbol{T}$ is the translation vector. The projection matrix P is thus a 3x4 matrix [5]. Some of the internal parameters of camera like focal length or the size of the pixel are available in EXIF file on the image. Thus we can reduce the number of unknowns in the equation and reduce the processing time.

Pin hole cameras are considered linear, but, real world cameras are not linear. Real world cameras have lenses. These lenses introduce distortion. There are two types of distortion- tangential distortion and radial lens distortion. Radial distortion is given as

$$x_{distorted} = x(1 + k_1 r^2 + k_2 r^4 + k_3 r^6)$$

$$y_{distorted} = y(1 + k_1 r^2 + k_2 r^4 + k_3 r^6)$$

Tangential distortion introduced by lenses is given as

$$x_{distorted} = x + [2p_1 xy + p_2(r^2 + 2x^2)]$$

$$y_{distorted} = y + [2p_2 xy + p_1(r^2 + 2y^2)]$$

To predict the distortion, we need five parameters, known as distortion coefficients given be vector as shown

$$Distortion\ coefficients = (k_1 k_2 p_1 p_2 k_3)$$

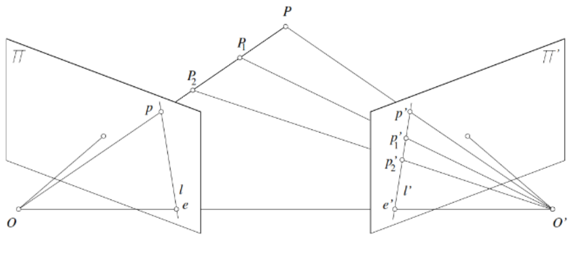

Figure 1 Epipolar constraints

In the above figure, if only left image was used to find the correspondence between pixel p and world points, then there are many points that lie along the line OP [5]. Different point on OP map to different points in the right image. So with two images, correct 3D point can be found used. The projection of the different points on OP form a line on right plane i.e. line l’. This is epiline corresponding to the point p. To find the point p on the right image, search should be carriedout along this epiline. This is called Epipolar Constraint.*O*and *O’* are the camera centers. Projection of right camera O’ is seen on the left image at the point, e. It is called the epipole. Epipole is the point of intersection of line through camera centers and the image planes. Similarly, e’ is the epipole of the left camera. We need to find the fundamental matrix *(F)* and essential matrix *(E)*. Essential matrix contains the information about the translation and rotation. This matrix defines the location of second camera relative to first camera.

III. PROPOSED WORK

Research is focused on developing a portable electronic travel aid for blind using computer vision [2]. The prototype arrangement is as shown in figure 1.

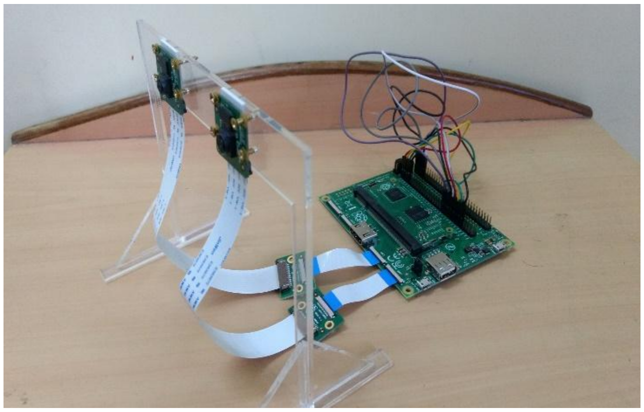

Figure 2 Travel aid prototype using raspberry pi

The prototype consists of raspberry pi compute module 3L, which is the main processing unit. Two raspberry pi camera modules are connected to the CSI slots of the board. The main advantage of using CSI cameras with raspberry pi is, these two cameras can be triggered simultaneously to capture stereo images. These cameras will be fitted around the vest of visually impaired person using orthopedic belt. The function of this prototype is to capture stereo images simultaneously at a fixed frame rate. Comparing the two images, obstacles in front of the user will be detected and necessary feedback to avoid that obstacles will be provided to used using vibration pattern. The accuracy of the system to detect obstacles depends on the arrangement of the camera. In the design the arrangement of the camera depends on the way user places the orthopedic belt. Slight misalignment can lead to wrong disparity. Hence we need the stereo camera calibration.

IV. STEREO CALIBRATION PROCESS

The main purpose of stereo camera calibration is to find out the internal parameters of each camera and the relative orientation of cameras with each other. There are many methods to calibrate stereo cameras. Calibration may be achieved using two techniques, one by acquiring a single image of a special 3D calibration objector multiple images of a 2D calibration object at varying rotations. These calibration objects consist of a precision-engineered geometric pattern, usually a checkerboard pattern, although camera calibration objects have been constructed from such objects as Lego pieces. The geometric pattern allows the exact location of real world points to be determined. These real world points are processed along side their corresponding image points to recover the projection matrix.

Camera calibration method used in the design is offline calibration process. This process makes use of chessboard design as shown in figure. This is a 9x6 array chess board with side of each square equal to 24mm. Each intersection. of two black square is given a coordinate. The top left coordinate is (0,0,0), next is (1,0,0) and so on.

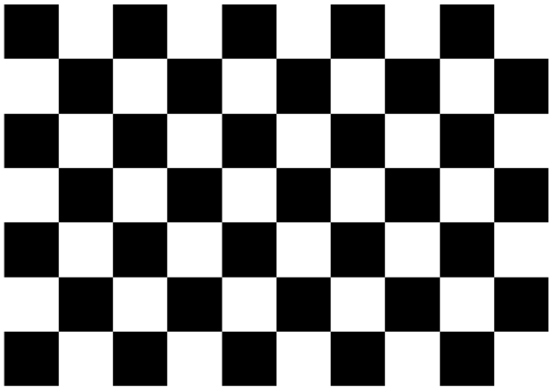

Figure 3 Chess board pattern used for calibration

The world coordinates information of the intersections is stored in the program. In this process we assume that the chessboard is placed in the plane Z = 0 and camera is rotating around capturing various views. of chess board. This makes the calibration process simple. To have better accuracy of calibration, multiple stereo images of chessboard from various angles should be captured. Following are the steps that should be followed to obtain good calibration results

1. Establish relation between world coordinates of intersection stored in the system and the pixel coordinates of the images of the intersection
2. Repeat step one for left image and right image and for the set of complete stereo images.
3. Use the relation between world coordinates and pixel coordinates to calculate the camera matrix and distortion coefficients for each camera.
4. The camera matrix and distortion coefficients and the relation between world and pixel coordinates are used to calculate the fundamental matrix.
5. We check if the calculated fundamental matrix is correct by using the equation
$$p^T F p' = 0$$
6. Fundamental matrix is used to calculate the relative rotation matrix and translation vector between two cameras.
7. Rotation matrix, translation vector calculated in step 6, along with the camera matrix of both images are used to calculate the rectification that should be applied to both images, so that the epipolar lines are parallel.

Once this process of stereo camera calibration is complete, the rectification matrix can be directly applied to captured stereo images and disparity map can be obtained.

V. RESULTS

Complete programming was done in openCV python. To increase the speed of performance of the program, minimum Linux debian OS was installed on raspberry pi compute module 3L. Following are the camera matrix and distortion coefficient of the left camera.

$$\begin{pmatrix} 838.43 & 0 & 542.25 \\ 0 & 845.38 & 401.31 \\ 0 & 0 & 1 \end{pmatrix}$$

$$(0.208 \quad -0.521 \quad 0.0000.001 \quad 0.314)$$

Camera matrix and distortion matrix for right camera are as shown

$$\begin{pmatrix} 833.75 & 0 & 550.83 \\ 0 & 840.48 & 393.09 \\ 0 & 0 & 1 \end{pmatrix}$$

$$0.195 \quad -0.464 \quad 0.0010.002 \quad 0.192)$$

Comparing the two matrix we can see that distortion coefficients are not significant. First and fifth element of both the camera matrix have similar values indicating that the focal length of both cameras is same. Comparing the third and sixth elements of camera matrix, we find that there is distortion along x-axis and y-axis.

After stereo calibration of cameras, the obtained rotation matrix is a shown

$$\begin{pmatrix} 0.999 & 0.016 & 0.004 \\ -0.016 & 0.999 & -0.016 \\ 0.003 & 0.016 & 0.999 \end{pmatrix}$$

Rotation matrix suggest that there is no major rotation among the two stereo cameras. The translation vector is given as

$$(-59.222 \quad 0.987 \quad -3.764)$$

Translation vector suggest that there is translation along all three axes. The translation is more along x-axis.

VI. CONCLUSION

In this paper, we present a method to perform stereo camera calibration on raspberry pi compute module3L. Stereo camera calibration techniques like using 3D calibration object, SIFT feature matching method were implemented in openCV python on raspberry pi compute module. When compared with chessboard based stereo calibration, it was observed that the offline calibration provided the best calibration results.

Compared to other methods, this method consumes maximum time. Speed of the calibration process can be optimized by changing the number of stereo images captures for calibration.

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