TEST Engineering & Management

January - February 2020
ISSN: 0193-4120 Page No. 16957 - 16964

Comprehensive Survey on Camera Calibration for Autonomous Vehicle

Sheetal M. Parate[1], Shirish K. Shandilya [2]

[1]Student, VIT Bhopal,[2]Professor, VIT Bhopal

Article Info
Volume 82
Page Number: 16957 - 16964
Publication Issue:
January - February 2020

Article History
***Article Received**: 18 May 2019*
***Revised**: 14 July 2019*
***Accepted**: 22 December 2019*
***Publication**: 29 February 2020*

Abstract

with the progression of autonomous vehicle, LIDAR are in use for detection of surrounding obstacles. The survey has been done to identify the low cost solution for autonomous vehicle by replacing LIDAR. From the overall survey it was observed that the calibration of cameras with different sensor is done from many years and using that we can detect the position and shape of an object. Autonomous vehicles are generally uses LIDAR in order to detect the depth of an object around it. The study on calibration of different sensors has been done from many years for detection of an object in real world. In this paper we survey on different sensor's calibration techniques such as camera calibration, camera to camera calibration, camera to LIDAR calibration, LIDAR to LIDAR calibration in order to provide low cost solution for autonomous vehicle.

Keywords; *Camera, Calibration, LIDAR, Autonomous Vehicle.*

I. INTRODUCTION

The calibration is generally performed on an instrument in order to set its value with respect to standard value. One the calibration of the instrument is done perfectly then the instrument is ready for accurate measurement. In this paper we are focusing on calibration of different sensors. For the calibration if we consider single sensor for example camera then we have to set it in such a way that it will be able to capture all data around its surrounding accurately. Similarly if we consider two sensors such as Camera to camera calibration or camera to LIDAR calibration or LIDAR to LIDAR calibration then we have to set parameters of one sensor with respect to others in order to get accurate output irrespective of change in position of an object. The main focus of sensor calibration is to obtain the 3-D information like location and shape of an object in real world. From overall survey it was observed that the calibration on sensor was taking place from many years. If we consider the camera calibration then the main parameters which are analyzed are intrinsic and extrinsic parameter. The intrinsic parameters of camera is nothing but it's focal length, skew, distortion, and image center whereas extrinsic parameter describe its position and orientation.

The paper is draft in the following manner. In section 1 the basic introduction about calibration of camera is described. In section 2, the camera models are described. In Section 3 different camera calibration methods are described. Section 4 describes the different types of sensors calibration. In section 5 there will be conclusion of overall survey. Section 6 describes the future scope and in section 7 there will be list of papers that referred for the survey.

II.CLASSIFICATION OF CAMERA MODEL

In the procedure of camera calibration the use of camera model plays the important role. The pinhole camera model and lens-based camera model are the two types of camera models which provide the

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different calibration result. Stereo camera model is used to estimate 3D information from 2D image.

A. Pinhole Camera Model

The pinhole camera model is the simple camera model where the image of an object is display in inverted form on plan. The structure of the pinhole camera model is given in figure 1.

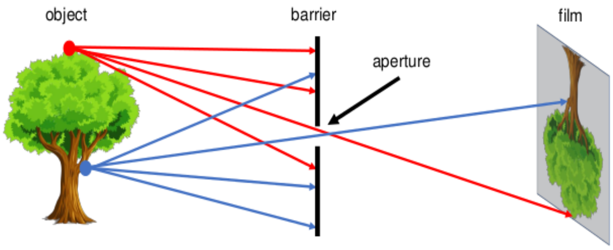


Fig.1: Pinhole Camera model [1]

Let us assume the object in 3D space with homogenous coordinate as P(x,y,z,1) and the perspective projection of that object in 2D image plane with homogenous coordinate is repented as P'(x',y',1). The transformation between 3D object P into 2D image P' is represented in figure 2.

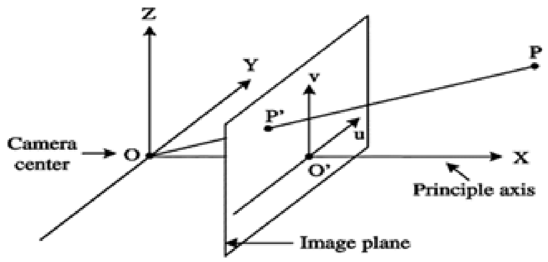


Fig.2: Camera Model without distortion

The perspective projection of P on image plane P' is given as:

sP'=M.C.P,

$$s\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} f_u & 0 & u_0 \\ 0 & f_v & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} R & T \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \quad (1)$$

Where s represents non-zero scale factor, M is camera projection matrix provides intrinsic parameter and C provides extrinsic parameters. Finding the intrinsic and extrinsic parameter is a two-step process. Here we describe matrix with all the intrinsic parameters such as fx is the focal length in x direction in unit pixel, fy is focal length in x direction in unit pixel, u0 and v0 are center point of image plane and extrinsic parameters such as R denotes rotation matrix and T denotes translation matrix. The equation 1 provides calibration for simple pinhole camera model along with intrinsic and extrinsic parameters. In many research this two-step process is used to calibrate the different sensors.

B. Lens-based camera model

In lens-based camera model the lens is taken for projection of an object on image plane. In lens based camera model there will be detection of distortion due to size and shape of lens. The structure of the lens-based camera model is described in figure 3:

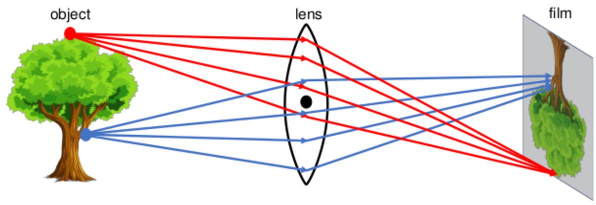


Fig.3: Lens-based Camera model [1]

Types of distortion are categorized as radial based distortion and tangential based distortion. The radial based distortion is caused due to varying shapes of lens.

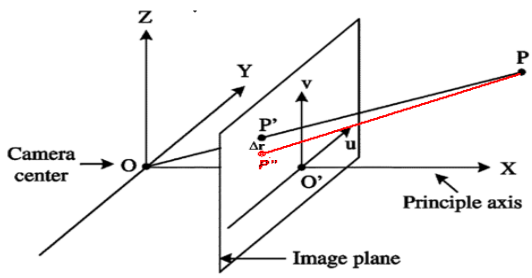


Fig.4: Camera Model with distortion

From the figure 2 we can analyzed that the projection of point P on image plan is obtained at P” instead of P' due to radial distortion. This radial distortion can be computed as:

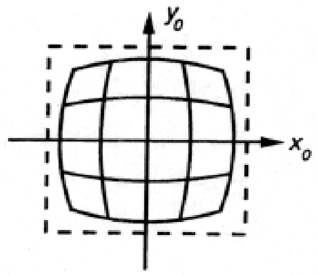
$$\Delta r = r - (f * \tan\alpha)$$

Published by: The Mattingley Publishing Co., Inc.

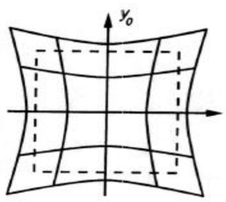
TEST Engineering & Management

January - February 2020
ISSN: 0193-4120 Page No. 16957 - 16964

where α is the angle between principal axis and ideal image point P', f is the focal length and r is the distance of actual point P" from principal axis. Radial distortion is further classified as barrel and pincushion distortion [2] as shown in figure 5.



(a)



(b)

Fig.5: Radial distortion with (a) Barrel distortion and (b) Pincushion distortion

Tangential distortion as shown in figure 6 is caused to due to varying assembling process of whole camera.

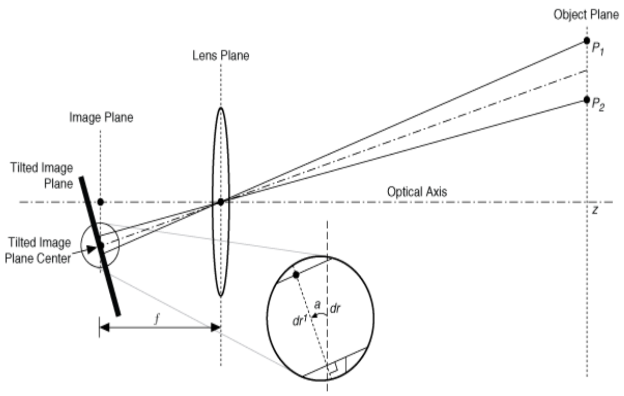


Fig.6: Tangential distortion

In camera calibration procedure the distortion is taken into consideration and solved using different methods in order to provide correct depth information.

C. Stereo Cameras

With the progression of autonomous vehicle system the stereo cameras are using for the depth measurement. As we know the basic working of human's eyes, same concept is used in stereo cameras. One camera (left) is keep at some distance on x axis and constant in y axis with respect to another camera (right) in order to estimate the depth information of an object captured by the stereo cameras. Let us say the point P(X,Y,Z) in 3D is captured in left camera as PL(xl,yl) and in right camera as PR(xr,yr).

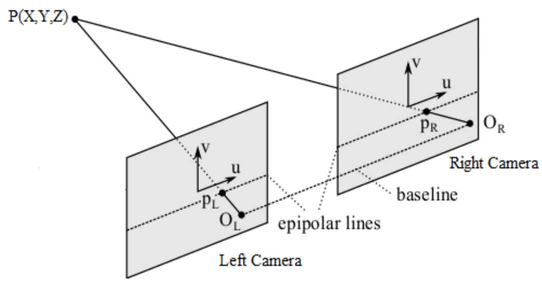


Fig.7: Image captured in Stereo Cameras

Two cameras are calibrated to each other so that the depth of object can be detected. Juber Sheikh and Joshi [3] proposed a SAD and GRAD algorithm for calculating the depth information from stereo images within fraction of seconds. They modified the algorithm for minimizing the time required for computation of disparity map. Self-calibration method for moving stereo camera is given by [4] with good real time performance and high resolution.

III. CAMERA CALIBRATION METHODS

From the research of camera calibration in [5] authors describe the calibration of pinhole camera model without distortion which is very simple but the low precision result is obtained whereas in [6] author solve the distortion coefficient of radial distortion by computing center of radial distortion in order to find the intrinsic parameters of camera. Due to the use of different types of cameras with their different camera lens non-linear degree of distortion Zhang Y. Proposed a portable method for camera calibration [7] where proper calibration method is chosen based on radial and tangential distortion. In survey it was observed that the methods of camera calibration are categorized in different ways. On the basis of computation the two types of camera calibrations are Non-linear camera calibration [8] and linear camera calibration [9]. Linear camera calibration are simple with low time cost but providing low precision, whereas non-linear camera calibration provides high precision but complicated and high cost time. In [9] authors describe the camera calibration with distortion model where he describe that lens distortion is always non-linear and decentering distortion is arises due to displacement of center of optical lens with respect to center of camera. In [10] calibration of multi-camera or stereo camera are done with the help of multi checkerboard targets which provides combined intrinsic and extrinsic calibration of multi-camera rings with large amount of different observation for calibration.

In some research the camera calibration are categorized as [11]: Traditional methods of camera calibration, calibration based on active vision and Self-calibration. Camera calibrations techniques are also classify on the basis of reference target object's dimension use for calibration and the categories are [12]: 0D or Self calibration, 1 Dimension line-based, 2 Dimension plane based, 3 Dimension reference object based calibration [13].

A. Traditional Methods of camera calibration

In traditional methods of camera calibration, the interior and exterior parameter of cameras are calculated by considering some target image and then perform mathematical transformation like translation, rotation on it to calibrate the camera. In Tsai's two step calibration method [14] calibration is taking place in two steps. In step one the extrinsic parameters of camera calculated and in step two the intrinsic parameter are calculated. Dual plane camera calibration, Zhang Zhenggyou calibration method [15], is some traditional camera calibration techniques on which extreme work were done. On the basis of dimension of target object use for calibration the different categories of camera calibration are:

1) 3D reference object-based calibration:

In this calibration technique the 3D object is us as target reference object for calibration procedure. 3D object can be formed by taking two planes orthogonal to each other. The apparatus used for 3D reference object calibration are very complex and also the speed is very slow.

2) 2D plane-based calibration:

In this calibration technique the 2D plane object is us as target reference object for calibration procedure. In [6] Zhang had provided a very easy technique to calibrate a camera using planar pattern. He uses the software called MATLAB where a tool is available called calibrator to calibrate a camera. The planar board is used with different orientation.

3) 1D line-based calibration:

In this calibration technique the 1D object such as line is us as target reference object for calibration procedure [12].

B. Self-calibration

Self-calibrations don't require any target reference object for calibration. It just needs to observe the surrounding environment and calibrate automatically. In the research of self-calibration method the main concentration were given on constant and variant intrinsic parameters of camera. Self-calibration based on Kruppa equations is given in [16] which overcome the problem of active vision methods and provide more accurate results with high convergence rate. In [17] author compute the infinite homography from scene depths by referring a known camera using three images where two images are generated by the uncalibrated camera from pure translation and one image generated by the known reference camera and compute the infinite

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ISSN: 0193-4120 Page No. 16957 - 16964

homography between an arbitrary uncalibrated image which is readily decomposed for camera calibration. It provides the accurate result for solving online camera calibration problems. Luong and Faugeras [18] work on moving camera setup and estimate it's motion where extrinsic calibration between the cameras is estimated by solving the hand-eye calibration problem. It calibrate the motion based camera by estimate the extrinsic calibration of a stereo camera without using overlapping fields of view. In [19] authors work for self-calibration of varying intrinsic parameters of cameras. In case zooming cameras self-calibration is possible if aspect ratio is known and no skew is present but the result was not up to the mark hence in [20] proposed a robust and easy self-calibration in two steps method.

C. Calibration based on active vision

In computer vision the study on calibration on active vision is the recent research area were work has done and the progress is still going on. Using this feature of active stereo camera calibration the depth information can be easily calculated which helps for many applications. In general for calibration the set of images are obtain by capturing it with special motion of camera and then calculate the exterior and interior parameter of camera. The work in terms of three orthogonal translation motions, orthogonal motion method based on planar homography matrix was done in recent year. In [21] author show the calibration of single camera via multiple views at different angle with respect to tilt and pan by watching stable contours in a scene. From the recorded images the centre of camera lens and focal length is estimated by using mathematical expressions given in this paper. [22] Calibrate the active stereo by a closed-form solution and estimate the position and orientation of the pan and tilt angle of camera axis. In [23] multiple cameras are used for solving the problem of parameter calibration. By analysing geometric model of image intrinsic parameter are obtained. In [24] author use the pre-calibrated static camera network for calibration of pan-tilt cameras.

IV. SENSOR CALIBRATION

In autonomous vehicle many sensors are used such as LIDAR, Radar, cameras etc. shown in figure 7. LIDAR scanning constantly and uses laser beams to generate a 360-degree image of overall surroundings area near car whereas radar is used to measure the distance of obstacles from the car and the cameras are used to detect the actual object such as traffic lights, signs, pedestrians, bicyclists etc. and provides its actual two dimension image.

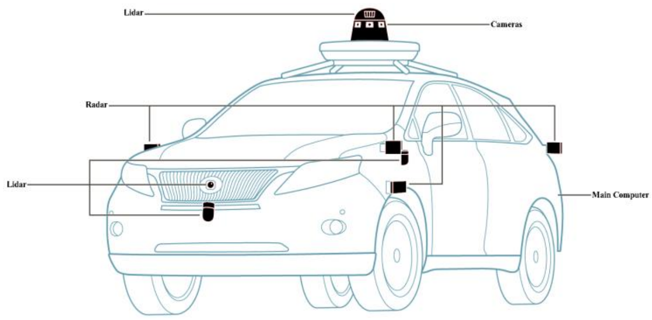

Fig.7: Autonomous Vehicle with different sensors

In autonomous vehicle system the calibration of different sensor is a recent research topic. Sensor like LIDAR is used to find the 3D information in real world. With the help of its laser beam we can estimate the depth information which in and important part of autonomous vehicle system. So many researches have done on calibration of sensors like LIDAR and camera. In calibration of LIDAR and camera the by extracting feature points information from 3D LIDAR and 2D cameras the depth and position of an object is determined. Calibration between two sensors can be performed for determining the intrinsic parameters and extrinsic parameters in on-line and off-line mode. Here is some work which describes rigidly mounted sensors with off-line calibration with different reference target object. [25] Estimates the extrinsic calibration of a line-scan LIDAR with a perspective projection camera with a black line over the white planar board as reference object. In [26] authors perform the extrinsic calibration of Camera and laser

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rangefinder using 3 input plane of chessboard pattern. In [27] author calibrates many sensors with each other with simple method for large systems with less human time and minimum calibration error. [28] Enhance already recorded data without special calibration setups and improve the existing calibration of a VelodyneLiDAR sensor. [29] Presented calibration of LiDAR-camera systems by using infrared (IR) images to establish laser-pixel correspondences for determining intrinsic and extrinsic parameters of the LiDAR and camera in two-stage where in first stage extrinsic parameters are obtained using PnP algorithm and in second stage optimization of extrinsic and intrinsic parameters are performed using nonlinear algorithm. In [30] represent the automatic calibration of camera and LIDAR using chessboard extraction algorithm where the corners of large chessboard target are detected and get aligned with the laser points automatically.

V. CONCLUSION

From the overall survey it is observed that the camera calibration techniques are categorized in different manner such as traditional methods of camera calibration, calibration for active vision and self-calibration. In the survey of camera calibration for autonomous vehicle system it is observed that the online calibration is difficult with traditional camera calibration method where as active vision based camera calibration method required more cost and precise control on camera movement. As per the requirement for autonomous vehicle system self-calibration can achieve calibration for uncontrollable situation but again it is nonlinear and highly sensitive to noise. On the basis of computation the two types of camera calibrations are linear camera calibration and Non-linear camera calibration. Camera calibration techniques are also classify on the basis of reference target object's dimension use for calibration and the categories are 3D reference object-based calibration, 2D plane-based calibration, 1D line-based calibration and 0D Self calibration. Using the calibration technique the actual position and size of object can be identified. The calibration of different sensors such as Camera calibration, Camera to camera calibration, Camera to LIDAR calibration and LIDAR to LIDAR calibration are also done for different application.

VI. FUTURE SCOPE

After analyzing the overall survey on camera calibration which were taking place from many years and are still working is going on for accuracy purpose, it will be used more effectively in autonomous vehicle system. The main purpose of camera calibration is that it identifies the position and shape of an object in real world. In autonomous vehicle system the LIDAR is used to determine the position of an object which is too costly. And the camera calibration is also providing the depth information of the object. So we can replace the LIDAR by stereo camera will reduce the cost of autonomous vehicle system. But the main challenges for doing that are the speed and more accuracy as in real time to get the accurate and fast information of nearby object autonomous vehicle system is very important for smooth execution of autonomous vehicle system.

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