VISUAL PERCEPTION Lab Report .... Camera Calibration

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1 Abstract

The objective of the lab-work was to implement two camera calibration techniques using MATLAB. Halls and Faugeras calibration methods were implemented using data points with and without noise. Different number of data points were used to see its effect on the output. This was followed by a comparison of the two methods by determining their accuracy for noisy points. The experiment concluded by a three dimensional visualization of all the coordinate systems and projections involved in camera calibration techniques.

2 Overview of the Camera Calibration Techniques

Camera calibration process is the starting step in most computer vision applications. It involves estimation of the parameters of a pinhole camera model. The pinhole model illustrates the mathematical relationship between the coordinates of a point in space and its projection onto the image plane. In reality, as the model takes into account many assumptions, the model can only be used as an approximation of this mapping.

The camera parameters are commonly represented by a 3x4 matrix, often called the camera matrix. All camera calibration techniques can be divided into two steps. First a model representing the camera is determined, followed by the computation of the numerical values for each of the parameters of the model. Over time many camera calibration techniques have evolved, however the focus of this lab was on implementing the two basic camera calibration models known as Hall method and Faugeras method. They both use the pinhole camera model.

The main difference between them is that hall directly approximates the 3x4 matrix while faugeras divides the 3x4 matrix into two matrices: one representing the intrinsic parameters of the camera and one representing the extrinsic parameters (camera coordinate system with respect to the world coordinate system). Faugeras gives us more information about the camera model, however, it is computational expensive as compared to hall.

For implementation of lab tasks, lecture notes and the research paper provided with the lecture notes were used.

3 Methodology

3.1 Projection

In the first stage of the exercise, we were provided with a set of parameters for a given camera. The image size produced by the given camera model was 640 x 480 pixels. The parameters were input to the intrinsic and extrinsic matrices given in the lecture notes to define a transformation matrix that converts 3D data points in the world coordinate system into 2D pixels points in the camera coordinate system.

The range covered by the camera was given as [-480,480] in all dimensions. So, random data points were created next within this range. The number of these data points were varied to observe its effects on the output. 6 points are sufficient for calibration purposes in ideal situations. However in reality, many factors play a role resulting in inaccurate calibration. To improve the accuracy, more than 6 data points are normally used in order to decrease the effect of noise.

Next the transformation matrix was multiplied by these points to determine their location on the 2D image plane. When the resulted matrix was displayed, it was observed that the points were a multiple a variable 's'. In order to normalize, the third element of each point was kept to 1 by dividing all the elements of the point by that element. The resulting image plane for 6 random points is displayed in Figure 1.

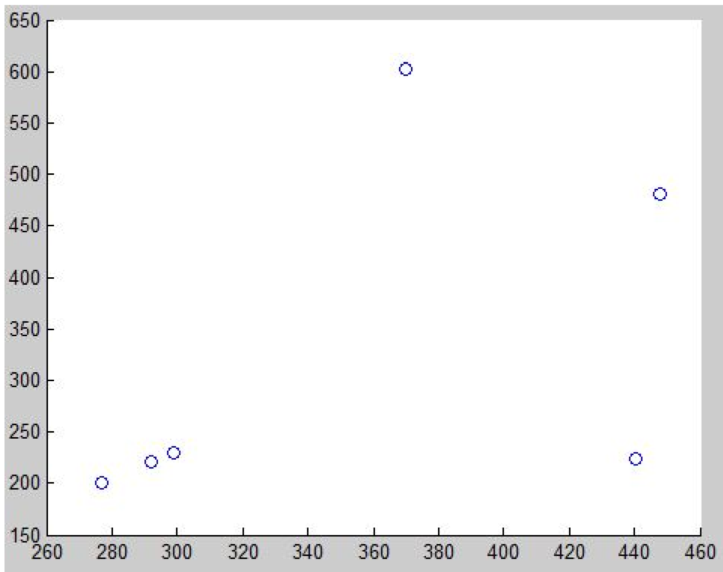

Figure 1: Projection of 6 random 3D world point on to the 2D image plane.

The points were observed to be distributed randomly dependent on the 3D points. After, many runs of the program, it was observed that the distribution of the points did not affect the output of the system. Both these point coordinates can be used as ground truth for validation of the calibration techniques. For the next sections, noise was added to these points to observe the response.

3.2 Hall Calibration Method

Now we have sample 3D world point and their corresponding 2D image points. The transformation matrix between the two coordinate systems was computed using the Halls method next. The equations used for computing the matrix were taken form the lecture notes. A system of 11 unknowns and 12 equations was formed with the help of the 6 random points. Linear least square method was used to obtain all the 11 parameters of the transformation matrix. In order to obtain a unique solution the twelfth parameter was kept constant as 1. The solutions obtained were reshaped in the shape of the matrix.

The result of the hall's method was compared with the transformation matrix obtained by the camera parameters given to us for the lab exercise. They were found to be a perfect match.

The above case is for ideal circumstances. Unfortunately, in practice it is very hard to find an ideal scenario. So, noise was added to the 2D data points and the transformation matrix recomputed. This time, it was observed that the resultant matrix was slightly different for the one computing using camera parameters provided. The resultant transformation matrix was applied to the 3D points and their result was plotted on the image plane as shown in Figure 2.

3.3 Faugeras Calibration Method

Next, the transformation matrix between the two coordinate systems was computed using the Faugeras method. Faugeras determines the intrinsic and extrinsic camera characteristics separately. The equations used for computing the matrix were taken form the lecture notes.

As in the case of Hall, a linear system of 11 unknowns and 12 equations was formed with the help of the 6 random points. Linear least square method was used to obtain the result. Both intrinsic and extrinsic parameters were extracted from the result using equations provided in the lecture notes. The parameters obtained were used to form the transformation matrix matrix as in the first case. It was observed that when only the parameters were compared, the result was different. This was observed to be caused by the rounding off error of MATLAB when displaying values. For this the new transformation matrix was computed and compared with the previous ones to obtain a perfect match.

Similarly, as with the case of the halls method, noise was added to the 2D data points and the transformation matrix recomputed. This time, it was observed that the resultant matrix was slightly different as compared to the one computed using the given camera parameters. The resultant transformation matrix was applied to the 3D points and their result was plotted on the image plane as shown in Figure 2.

3.4 Comparison between the Calibration Models

The results obtained by the two methods were then validated using different criteria. A sample result of the 2D points obtained from the two methods is shown in Figure 2.

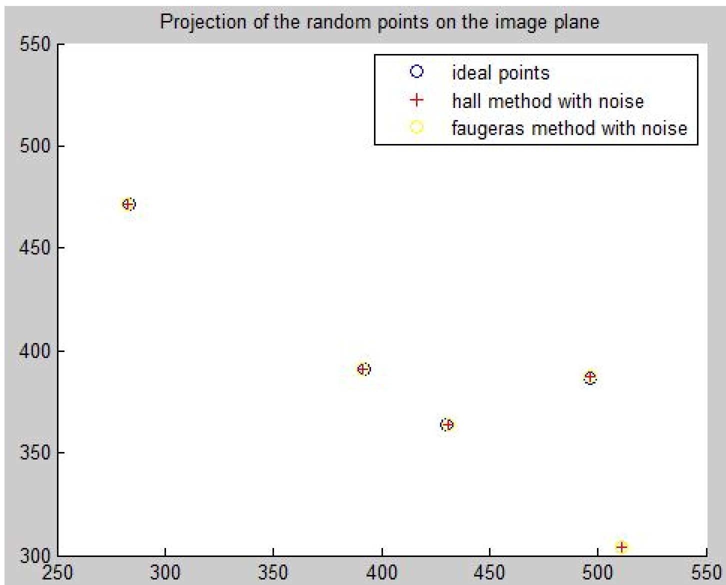

Figure 2: Resultant 2D image points obtained from the two calibration methods (with noise taken into account) and the ideal scenario.

After computing the resultant transformation matrices for the two methods, the transformation were applied on the same points to compare the methods. Discrepancy in the result was observed by calculating the mean euclidean distance between the results. The above process was repeated for different number of points and the result plotted as shown in Figure 3. It was observed that since both the methods gave the same transformation matrix as a result, the accuracy of the two methods was same. Also, as the number of points are increased, the result is more accurate. Different level was noise were also added to conclude that the more the error in the points, lesser the accuracy.

A strange behavior in results was noticed. Sometimes, the points on the image plane were not confined in the 640x480 image size. This is probably due to the fact that image sizes are normally governed by parameters u0 and v0 and when we take double of these two parameters, the answer is a little more than 640x480.

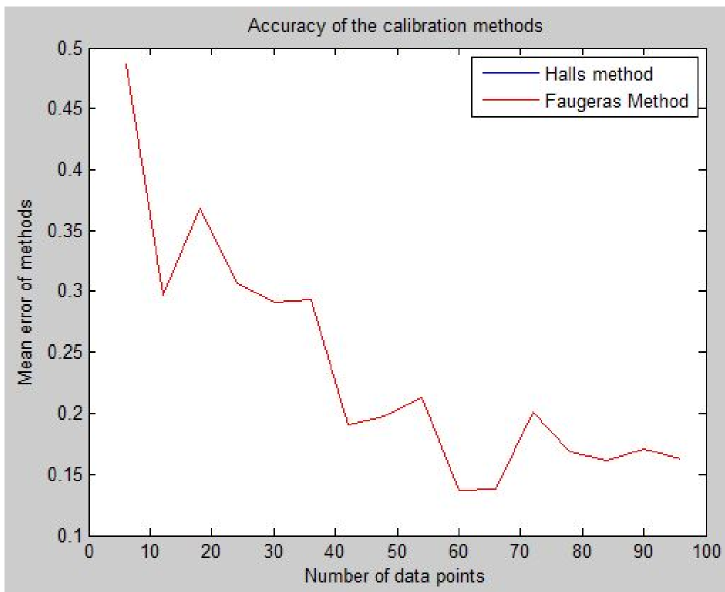

Figure 3: Mean error of points obtained form the two methods. For both the methods, noisy points were used to obtain the transformation matrix.

3.5 Visualization of Image planes

In this section, we had to perform a visualization of all the physics happening inside the camera. A few points were drawn to represent the world and camera coordinate systems. Next, the image plane was drawn at a distance 'f' on z-axis of the camera coordinate system. Random 3D points were chosen and there projection onto the image plane drawn. All the above drawing were made using 'plot3' function of MATLAB in one window. It was noted that all the projection seemed to pass through one point (but not exactly). This point is defined as the focal point of the camera lens. The result is displayed in Figure 4

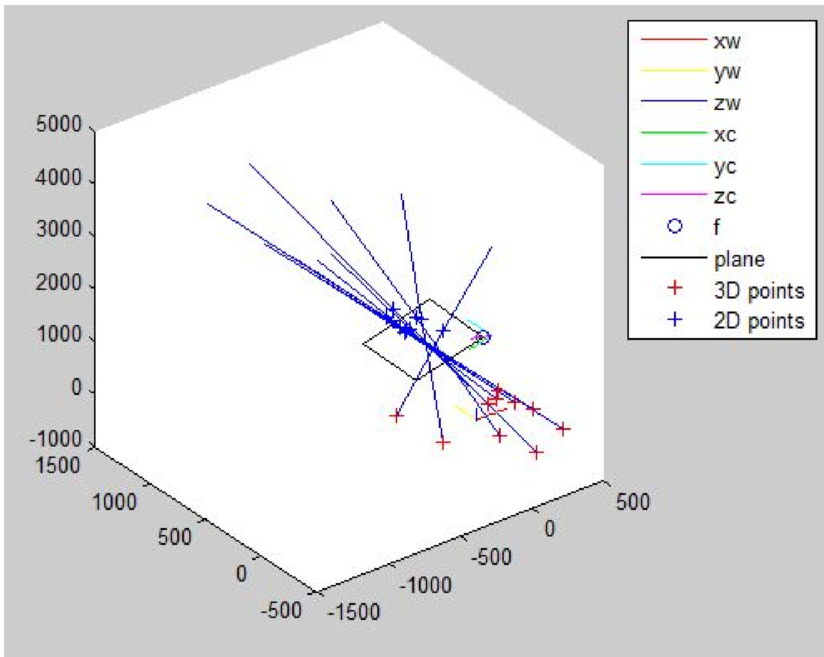

Figure 4: Visulaization of the internal geometry of the camera along with all the projections.

4 Conclusion

In this lab work, a successful implementation of two common camera calibration techniques was done. Camera matrix for a given camera was computed using Hall and Faugeras techniques. Real case scenarios were also tried out to compare the results of the two methods. This was followed by a very interesting exercise in which we had to visualize the internal structures of the camera and how they perform their tasks. The exercises were completed during the lab times whereas the report was written during the coming week at home.