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Scene Synthesis and Camera Calibration Techniques

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Abstract:
The fundamental concepts of how the camera calibration technique and pose estimation of the calibration objects is done as a series of tasks and experiments are explained in the paper. The brief about the proposed tasks and experiments is mentioned in the paper. In all the tasks, the basic concepts are studied, the applications to concepts are searched and some of the concepts are practically executed. Camera calibration is done with the help of camera calibration tool boxes (open source and free toolbox by Bouguetj and commercial package provided in Matlab2014a). A 3D model in Matlab is drawn using matlab functions and then visualizing and viewing the 3D model from different locations and positions. The graphic models of cameras are placed at different positions and the scene is captured. The main objective of this work is to estimate the scene that is taken by the camera. Here the projections involved like perspective, orthographic projections of the 3D model are obtained which is the main part of scene synthesis. Some of the main steps in camera calibration like computation of homography matrix and optimization procedures like Levenberg-Marquardt method are explored in the tasks performed. 'Perspective-n-Point' for estimating the pose of a calibrated camera given a set of n 3D points and their corresponding 2D projections is use combination of linear methods like DLT algorithm and non-linear methods for refinement of the results and these concepts are explored. Here, feature matching in images by extracting feature descriptors from image pairs and matching them which is helpful in extracting the camera paramters and studying the concept of generic calibration and implementing it is explored. Reprojection errors, Sampson errors and algebraic errors are seen from the calibration packages being implemented.

Keywords: Camera calibration, DLT algorithm, generic calibration, homography matrix, intrinsic and extrinsic parameters, Levenberg-Marquardt method, Perspective-n-Point problem, pin-hole model, RANSAC**.**

I. INTRODUCTION

Modern image and vision systems need calibration to be done as their preliminary task. New calibration techniques can compute the pose without the requirement of calibration objects. Calibration is performed by extracting features of images of the local environment in which they are placed. Various tasks and applications like motion estimation, geometric reconstruction, and tracking can be performed after the calibration step. After calibration, we are interested in scene synthesis, i.e, how the scene may appear if the images are taken from the camera placed at particular position in the specified orientation.

II. LITERATURE SURVEY

Hirokazu Kato and Mark Billinghurst have proposed a real-time conferencing system involving calibration of devices used for visual communication with the other users [1]. The camera calibration technique and pose estimation of the calibration objects i.e, the square markers is clearly explained. The procedure followed in the calibration technique is first choosing the world coordinate system, then transforming it to camera co-ordinate system and finally computing intrinsic and extrinsic parameters of the camera. The centre of the size known square marker is the chosen as origin of the world co-ordinate system and transformation matrix to camera co-ordinate system is found out. The 3D points corresponding to four vertices of square marker in the world co-ordinate system is noted. Also, the correspondences of the four vertices in the image i.e, the screen coordinates system are noted. Linear equations involving correspondences are solved to obtain the projection matrix. The projection matrix is further decomposed into intrinsic matrix (k) and (R|t) which is termed as the extrinsic matrix. For finding out the projection matrix, cardboard with gridlines is used as calibration object. The calculation of projection matrix (P) from many pairs of cardboard 3D co-ordinates (X,Y,Z) and camera screen co-ordinates (xc ,yc) that have been found out by image analysis techniques are clearly explained. Srikumar Ramalingam, Peter Strum and Suresh K. Lodha have worked on generic camera calibration which involves general imaging system and applicable to almost all types of lenses [2].The interesting topic in the paper is how each pixel in the image is assigned a 3D ray that projects onto the w orld space. The concept of generic cameras is applicable to all types of lens and hence the name generic calibration. All the operations involve matrices and rank of the matrix is an important consideration while estimating the 3D to 2D mapping to obtain t he projection matrix. Another paper by Aubrey K. Dunne and group have used synthetic image plane for projection and obtained calibration results[3].The position of the centre of the camera in camera co-ordinate system is estimated linearly. Two well known camera calibration techniques of Strum[4] and Wang[5] are incorporated in the is linear estimation stage. A synthetic image plane is inserted and projections onto this plane are observed using pin-hole model and homography equations, xi' = H * Xi, where xi' are the image points on the synthetic image plane, Xi are the points on the grid in its initial position is the homography matrix. Orientation of the synthetic image plane is determined such that most of the calibrated rays would intersect this plane perpendicularly. Taufiqur Rahman and Nicholas Krouglic of have proposed calibration technique considering radial and tangential distortions of the lens[6].Many procedures followed are explained in the paper and the following statements are directly picked from the paper. In the paper, they have said that though the camera models based on projective geometry are very easy to use and mathematical computation to obtain the results is very efficient and friendly. However, they are not used in applications of computer vision as the error margins are high for the results obtained[7].Thus, alternate methods i.e, other camera models are looked into like perspective projection-based (i.e., pinhole) camera model and it is used as the base model for performing all the preliminary operations. For example, the techniques by Tsai [8], Heikkila[9], and Zhang [10] can be cited.

III. BRIEF DESCRIPTION

Camera calibration with the help of camera calibration tool boxes (Matlab2014a).Alternative calibration approaches are looked into like Calibration from known rotation and translation movements of the calibration object, Calibration without using calibration objects, by matching the correspondences of features extracted from the images. This approach is regularly used in visual odometry applications where 2D-2D correspondences are matched, i.e, the image features from SURF, SIFT descriptors are used for estimating the Essential Matrix (E) which helps in recovery of the pose. Using optical flow for motion estimation which is used for camera calibration.1.Geometric modelling of the scene and performing scene synthesis. Here, the parameters obtained from the calibration like Field Of View (FOV) are used in the experiment to observe how much volume or space is being projected onto the virtual camera object being placed in the scene modelling. This is the same as 3D Computer Graphics modelling.2. Simple transformations like conversion from world co-ordinate system to camera co-ordinate system, then further to screen coordinates are performed .Verifying the equations regarding pinhole model[u v] = k[R|t] (XYZ1). Here, u,v are screen coordinates, X,Y,Z are the world points. Verifying the parameters obtained from the calibration result like verifying rotation matrices and translation vectors(t). Rotation matrix(R) is verified by calculating Euler angles by using the elements of rotation matrix itself. Calculating projection matrix(P) using linear methods like DLT algorithms and algorithms improvising on the results by using by using nonlinear methods and optimisation procedures like least squares method and bundle adjustment. Homography estimation which is useful in calculating projection matrix (P).3.Feature matching in images by extracting feature descriptors from image pairs and matching them. 4. Studying the concept of generic calibration and implementing it. Studying nonparametric calibration technique which assigns 3D rays to each pixel and this principle is used for calibration. Trying to implement the concept with the help of 3D graphics.

IV. TASKS 1-10

In this beginning **task 1** conversion of, simple transformations like conversion from the world co-ordinate system to camera co-ordinate system, then further conversion to screen coordinate system are performed. Verifying the equations regarding the pinhole model [u v] = k *[R|t]* (X Y Z 1), is also a part of the task. Here, u,v are screen coordinates and X,Y,Z are the world points in the 3D space. Pre-requisites for performing the task:1.We should study the pin-hole model. The pin-hole model is chosen because it is the basic model and ideal for performing all the numerical calculations. The pin-hole model is explained briefly below: In the pin-hole model, the ray from a 3D point (X,Y,Z) in the 3D space is projected onto a 2D plane. Any point in the 2D plane can be represented in terms of orthogonal basis (u1 and v1). Here, x.y.z form the basis for the 3D space and u1,v1 form the basis for the 2D space.2.We should know the elements of intrinsic matrix(k).The study of paper by Hirokazu Kato and Mark Billinghurst [1] clearly explains the composition of the intrinsic matrix (k).Step1: Note down these values and use the same as input,i.e, camera co-ordinates(Xc ,Yc ,Zc).Step2: Apply the formula [u v 1] = k*(Xc ,Yc ,Zc), with
k(3x3) = 852 0 0; 0 846 0; 321 302 1].
and (Xc ,Yc ,Zc) = [-140.3 85 1047].
Step3: Note the numerical result obtained and compare with the actual values by using impixelinfo on the real images of calibration objects captured shown in the figure 1and2. The question asked when we start to calibrate a camera is ‘what is the difference between calibrated and uncalibrated lens? Why do we need to calibrate the camera?’Camera calibration is used to extract the metric related information from the images. An open source frees Camera Calibration Toolbox for Matlab is used. The toolbox is available at http://www. Vision. caltech. edu/ bouguetj/calib_doc/ [11].It is a Camera Calibration Toolbox for Matlab® with a complete documentation.

In **task 2**,-‘Camera calibration using calibration toolbox for Matlab’,the procedure followed in our task is:
1.Primary task is to capture the images using a camera. I have used the camera of the mobile phone.
2.Download the toolbox as zipped file and store the extracted folder with default name TOOLBOX_calib in the current working matlab directory which is very convenient for retrieval or storing of future data obtained from the calibration results.
3.Now, we have to load the photos. SHARE it is a free app used to transfer data from one device to another with the availability of wireless LAN (WiFi) connection. Note, both the devices must share the same internet (WiFi) connection.
4. The photos are transferred to the laptop (another device).Make a separate folder with name calib_photos and store it in the current working matlab directory. Name the photos as Image1, Image2, Image3, Image4,….. ImageN.
5. Now, run the matlab file named calib_gui.m and note the command window. A mode selection window appears on the screen and selects any mode.
6. Here, change the path to path containing the photos,i.e, calib_photos. Again run the calib_gui.m and a mode selection window appears on the screen and selects any mode.
7. Click on the Image names button in the Camera calibration tool window. Enter the base name of the calibration images (Image) and the image format (jpg).
8. Click on the Extract grid corners button in the Camera calibration tool window. After marking corners of the pattern, manually enter the number, size of squares along X and Y directions respectively.
9. Perform calibration: Click on the calibration button in the Camera calibration tool window.
10. Obtain the calibration results and visualize the extrinsic parameters. A similar procedure is given by Math Works in their webpage [12] for the calibration package provided by them. We also perform the **task 3**‘Camera calibration using Matab’, use the Matlab calibration package.

In **task 4**, ‘Matching images’, some of the exercises performed are matching of gray images using SURF descriptors [13]. Given the images, the SURF points are detected, extracted and matched and seen as montage image. Results are analysed. Our purpose is to remove these incorrect matching lines /incorrect matches obtained. One approach is to use built in Matlab

RANSAC algorithm embedded in the estimate Geometric Transformation function under Computer Vision toolbox. Another approach is to model the motion between the 2 images using some motion model like affine motion model. Applications: The matching of images is done in many tasks in the computer vision field. A lot of applications exist of feature matching like computation of homography, visual odometric applications used in automatic navigation systems, pose estimation applications. Detection, tracking and motion estimation systems also employ this feature matching task as their preliminary task. Monocular visual odometry has been the latest domain which employs the feature extraction from the images and matching the features i.e 2D-2D mapping from which the path traversed by the robot / vehicle on which the camera is placed can be found out accurately. The applications of feature matching involve matching the features which are further used for specific calibration methods and this type of on the spot / (plug and play type) of calibration itself is called on-line / self calibration where there is no need for external calibration objects.

In **task 5** – '3D model in Matlab', we visualize a 3D model using patch, plot3d functions. A simple construction representing 3D object is done using patch function and viewed using plot3d function. Viewing can be done by specifying view (az,el) function.
az = azimuthel = elevation. Lighting effects are also added. We are given the physical dimensions of the objects in the scene. The cameras are placed at different positions and the scene is captured .The main objective of this work is to estimate the scene that is taken by the camera. Suppose we just take scene to be indoor and consider a room. There are many objects in the room – chairs, table, fan positioned accordingly. Now, we capture the scene from the four top corners of the room. Our work is to estimate the scene from any different position and the world co-ordinates of the camera are given. For this purpose, we have used the camera toolbox provided by Matlab.This process combines part of the procedures involved in scene viewing, scene analysis, scene synthesis, scene simulation and estimation. A separate camera toolbar consisting of inbuilt functions camview( ),campos( ),viewmtx( ), camva( ) for viewing created graphics object is available in Matlab. From the above functions, the viewing angle, position and field of view can be specified and can be employed in many experiments and applications.
The **task 6** is 'Homography using normalized DLT algorithm'. Homography relates two scenes taken from the same camera held at the same position but in different orientations. Procedure:
Step 1: How to normalize the given points xi ? Compute a similarity transformation T that takes points xi in image 1 to a new set of points xi_n such that the centroid of the points xi_n is the co-ordinate origin and their average distance from the origin is sqrt(2).
Step 2: How to normalize the given points xi ' ? Compute a similarity transformation T ' that takes points xi ' in image 1 to a new set of points xi '_n.
Step 3: Apply DLT algorithm using xi_n and xi '_n to obtain the normalized homography matrix Hnorm.
Step 4: Unnormalize matrix Hnorm using the formula given by H = inv(T ') * Hnorm * T.
Common procedure for normalization:
1.Find the mean of all the points xi. Subtract the value of the mean from all the points xi.
2. Scale points to have average distance from the origin by multiplying all points xi by scale factor given below:
scale = sqrt(2) / mean(sqrt(sum(xi .^2)));

Homogeneous co-ordinates are obtained by increasing the dimension of the points in the specific space i.e,consider 2D space, the points are denoted by (x,y) and the point can be converted into homogeneous co-ordinates by simply appending 1 to get (x ,y,1). Since we are working in homogeneous co-ordinates, the relationship between the 2 points (xi_n and xi '_n) can be written as

c * (xi ' 1) = H *(xi 1).

The **task7**- 'Levenberg-Marquardt method' involves analyzing how the Levenberg-Marquardt (LM) algorithm works. It can be thought of as a combination of steepest descent and the Gauss-Newton method. When the current solution is far from the correct one, the algorithm behaves like a steepest descent method: slow, but guaranteed to converge. When the current solution is close to the correct solution, it becomes a Newton method[14].

In the **task 8** - 'Reprojection errors, Sampson errors and algebraic errors' are studied. Errors need to be taken into account if we need to obtain accurate results. If we need to increase the accuracy of the results, we need to minimize the error in our experiments and tasks. In many problems in computer vision, errors are not minimized in a single step but an iterative approach is followed. In the first step, initialized values are taken and outputs are obtained. The outputs obtained are fed back as inputs and partially refined values as outputs are obtained. These partially refined values are again fed as input and the procedure is iteratively carried out till the errors / error functions are minimized. Reprojection error is mentioned in OpenCV documentation page as the sum of squared distances between the observed projections image Points and the projected (using project Points function) object Points. All the optimization procedures are performed by minimizing the cost function[15,16,17].Some of the cost functions used are:Algebraic distance,Geometric distance / Eucleadian distance, Reprojection error.

In **task 9**-'Generic camera calibration' is a procedure followed for calibration of the camera where the type of lens used is ignored and a particular camera model like perspective model or pin-hole model is selected for calibration. We can easily visualize where the rays of the lens are falling on the planar calibration object being placed at different locations in different orientations[18,21].Generic calibration procedure can be applied to any type of lens and not specific to a particular kind of lens.

The**task10** - 'Perspective-*n*-Point' is the problem of estimating the pose of a calibrated camera given a set of *n* 3D points in the world co-ordinate system and their corresponding 2D projections in the image co-ordinate system. It is typically a mapping from 3D space to 2D space. Since the transformation is a perspective transformation, meaning the mapping is non-linear if we want to achieve accurate results. The general procedure involved is to find the matrix which maps 3D space to 2D space. This matrix is found out using the linear method by solving for the least squares. The result is refined by using non-linear optimization methods like using convex optimization techniques, the Levenberg-Marquardt (LM) algorithm, quasi-linear methods, solving a system of polynomial equations using methods like hidden variable method, Grobner basis method for solving polynomial equations[19,20],etc to obtain accurate results.

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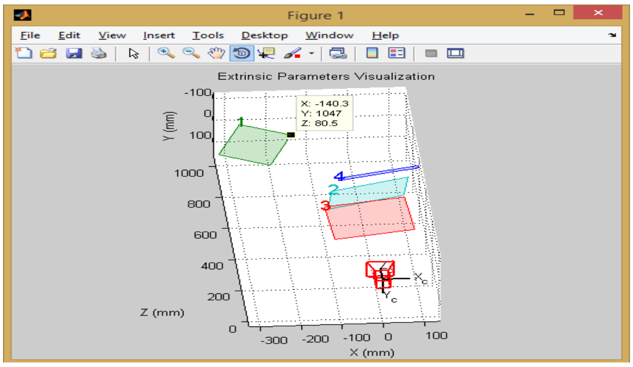
VI. FIGURES

Figure 1 capturing the camera co-ordinates.Here, (Xc ,Yc ,Zc) =[-140.385 1047]. Figure 2 showing the pixel co-ordinates for the corner of the checkerboard. From the given camera co-ordinates and intrinsic matrix(k),pixel co-ordinates are found out. Figure 1and 2.



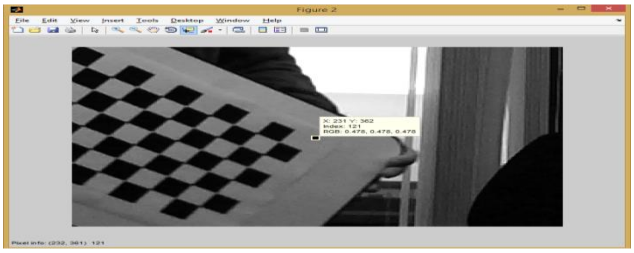


Figure 2
File Edit View Insert Tools Desktop Window Help
X: 231 Y: 362
Index: 121
RGB: 0.478, 0.478, 0.478
Pixel info: (232, 361) 121