

Camera Calibration and Semi Global Image Matching

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Abstract— the paper deals with the building of 3D models with photogrammetric image matching based on stereo-pairs. The semi global matching (SGM) is widely used in photogrammetry for building 3D models from stereo-pairs. The quality of the produced model depends on many factors including the SGM modes, minimum-disparity, maximum-disparity, block-size, and uniqueness-ratio. The experiments showed us that the quality and accuracy of the camera calibration directly influences the quality of the output disparity map. The other important issue is the ratio between the photo-base and the distance of object points. Increasing the photo-base the disparity map quality is decreasing. The example calculations are carried out in MATLAB.

Keywords— SGM, camera calibration, image matching, disparity map

I. INTRODUCTION

For testing, a stereo-pair was used to build a disparity map, which enables to build the 3D model later. A Sony Alfa A350 digital SRL camera was used, which was calibrated by chessboard test field. The calibration procedure was carried out in MATLAB application [3]. Using the camera calibration data stereo-pair of the taken scene was oriented based on common points. The common points were identified automatically using the SURF function in conjunction with the appropriate gross-error filtering methods. The translation vector and the rotation matrix were calculated as the elements of the relative orientation. Based on these elements the essential and the fundamental matrix were generated as well. After this the images were transformed into a normal case image to have parallaxes only horizontally. This rectification procedure enables and makes easier the identification of common points for generation of the disparity map using the SGM (Semi Global Matching) image matching method. The result of the disparity map depends on the setup of the initial parameters. The most sensitive parameter is the disparity range. The disparity range can be adjusted only with manual measurements which makes the SGM method not a full automatic process. The whole procedure is summarized on Fig. 1.

II. TEST SCENE

For testing, an artificial scene was used with some objects having rectangular and spherical forms in different colours and textures as it is seen on Fig 2. The background was relatively flat

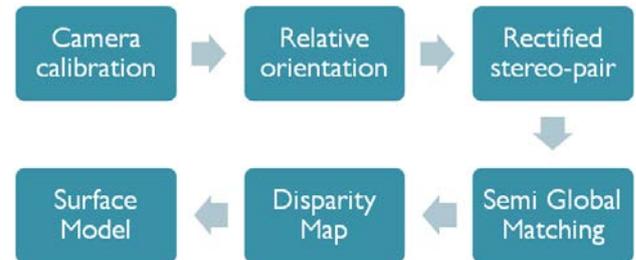


Fig. 1 Procedure of the image matching process



Fig. 2 Test scene

The object distance was about 1 m with a basis of 20 centimetres. Which means the ration between the basis and the object distance was 0,2. Two photos were taken close to normal case.

III. 3. CAMERA CALIBRATION

For the further calculations and orientation procedure we need the intrinsic date of the applied camera. The calibration procedure was carried out in MATLAB using the built-in Single Camera Calibration application. During the calibration the following parameters were calculated:

- Radial distortion parameters (K1, K2 and K3)
- Tangential distortion parameters (P1 and P2)
- Skew parameter (s)

These parameters describe the distortion effect of the lens system and the skew of the sensor area.

A. Preparation

The photos were taken with a Sony Alfa A350 DSRL camera. For camera calibration, a chessboard test-field was used as it is seen on Fig. 3.

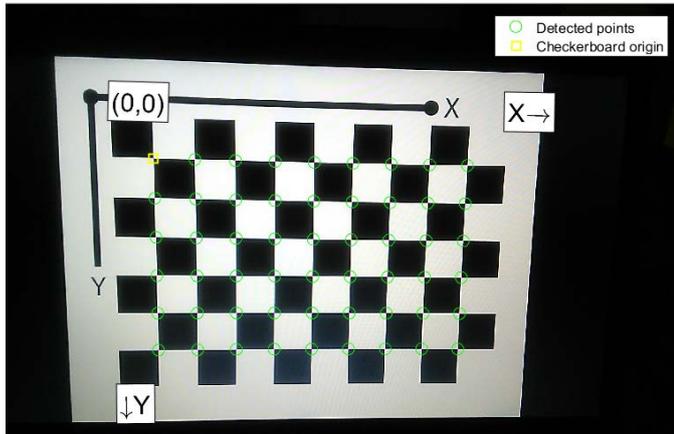


Fig. 3 Calibration field

The photos were taken from different direction trying to cover the whole sensor area. During the shooting the camera body was also rotated with 90 degrees. The series of photos was filtered, and the unfocused images were dropped out.

B. Calculation of Intrinsic Parameters

After uploading the remaining images, the calibration software identified automatically the corners of the chessboard table and the intrinsic parameters were calculated with an adjustment procedure. The mean errors calculated from the residuals were displayed and the user could adjust the level of outliers manually. The Fig. 4. indicates the reprojection errors. From the figure we see that the overall mean error is around 0.22 pixels for all images.

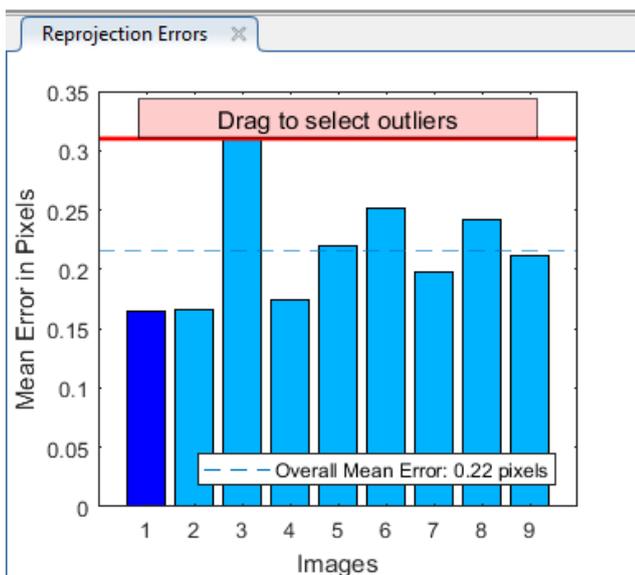


Fig. 4 Reprojection errors

The user can decide which parameters should be included in the adjustment procedure. We can try different combinations. We can choose only K1, K2 parameters or we can add K3 parameter the unknowns. Or we can include P1, P2 tangential distortion parameters, and all this can be combined with inclusion of the skew parameter. The result can be visualized in a 3D scene of the camera and the taken images (Fig. 5).

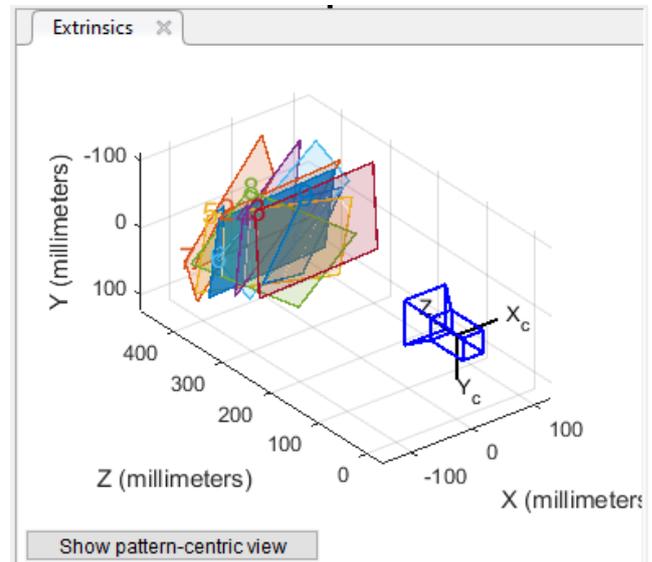


Fig. 5 Orientation of images relative to the camera position

IV. 4. RELATIVE ORIENTATION

C. Identification of Common Points

The identification and measurement of common points is a multi-step procedure on a stereo-pair of images. First, we must identify the objects itself on both photos with the help of a segment based algorithm. Here the SURF function was used to separate and identify the object points. After this the program tries to make pairs of points as common points on the stereo-pair. In this phase some matching of points can have real big errors as it is seen on Fig 6.

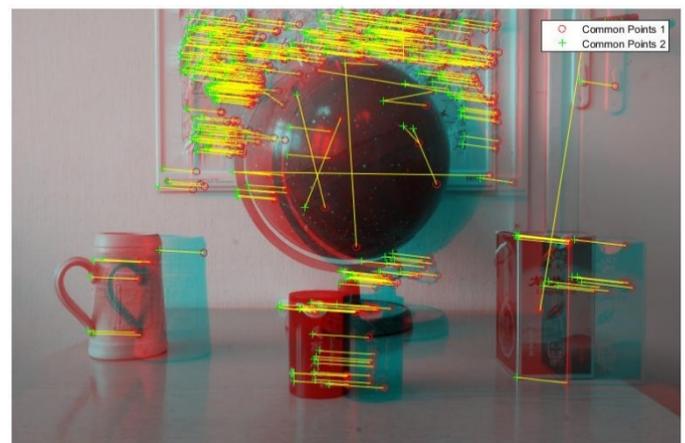


Fig. 5 Common points including matching points with large errors

The next step is the calculation of the Fundamental Matrix, which is stored as a 3-by-3 matrix. The Fundamental Matrix relates the two stereo cameras, such that the following equation must be true [3]:

$$[P_2 \ 1] * FundamentalMatrix * [P_1 \ 1]^T = 0$$

Where P_1 , the point in image 1 in pixels, corresponds to the point, P_2 , in image 2.

With a similar calculation the Essential Matrix is calculated, which is stored as a 3-by-3 matrix. The Essential Matrix relates the two stereo cameras, such that the following equation must be true [3]:

$$[P_2 \ 1] * EssentialMatrix * [P_1 \ 1]^T = 0$$

Where P_1 , the point in image 1, corresponds to P_2 , the point in image 2. Both points are expressed in normalized image coordinates, where the origin is at the camera's optical centre. The x and y pixel coordinates are normalized by the focal length of f_x and f_y .

During the calculation we try to eliminate the errors with the Least of Median of Squares method. This method uses the input points that are already putatively matched. Using the algorithm, we can eliminate any outliers which may still be contained within putatively matched points. The result is shown on Fig 6.

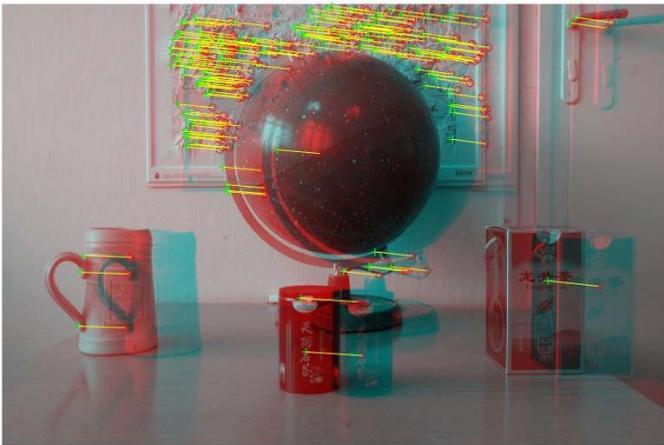


Fig. 6 Common points after eliminating the large errors

After this step we can build up the Stereo Parameters objects in MATLAB. For this we need to follow the following code:

```
1. [relativeOrientation, relativeLocation] =
   relativeCameraPose(EssentialMatrix, cameraPa
   rams_Sony, cameraParams_Sony, inlierPoints1, i
   nlierPoints2);
2. [rotationOfCamera2, translationOfCamera2]=ca
   meraPoseToExtrinsics(relativeOrientation, re
   lativeLocation);
3. stereoParams =
   stereoParameters(cameraParams_Sony,
   cameraParams_Sony, rotationOfCamera2, transla
   tionOfCamera2);
```

In line 1 we calculate the relative orientation using the previously calculated `EssentialMatrix`, the intrinsic camera parameters (`cameraParams_Sony`) and the common points (`inlierPoints1, inlierPoints2`).

In line 2 we calculate the rotation matrix and the translation vector of camera 2 relatively to camera 1.

In line 3 and 4 we finally build the `stereoParams` object which is necessary for the rectification of images into a normal case.

D. Rectification of Images

The rectification of images is necessary to build a normal stereo-pair where the parallaxes between the common points exist only horizontally. During the rectification, applying the `rectifyStereoImages` function, the distortion effects are also considered and eliminated. The result is shown on Fig. 7.



Fig. 7 Anaglyph image of rectified images

Using the Image Tool application in MATLAB we can measure the distances (horizontal parallaxes) between some common points (Fig. 8). Visually we can select and decide the maximal parallax which will be useful later when we try to setup the disparity range during the SGM processing.



Fig. 8 Measuring parallaxes in Image Tool

E. Building the Disparity Map and the 3D Point Cloud

Applying the SGM algorithm we try to match points between I_1 as left image and I_2 right image with maximum accuracy, then we are looking for the minimum value of the following energy function [1], [2]:

$$E(D) = \sum_p \left(C(p, d_p) + \sum_{q \in N_p} P[|d_p - d_q| \geq 1] \right)$$

The first member of the function summarizes the C cost spent for matching a given pixel p , where d_p is the parallax between images I_1 and I_2 . Since the matching is done by individual pixels, only the $I_1(p)$ and $I_2(q)$ intensities are considered for calculation of the cost. The second member of the function means a penalty for those q pixels where the difference in parallaxes is larger than 1 for the p pixel considering the N_p neighbourhood. It means that the P penalty member can cause an unsuccessful matching even in those case where the difference in intensity between $I_1(p)$ and $I_2(q)$ equals zero, but the parallax is too large relatively to neighbouring pixels. The resulting d_p parallaxes are stored separately in one D matrix having the same dimension as I_1 image.

In MATLAB we can setup several parameters to refine the result when applying the `disparityMap` function. These parameters are:

- Number of directions: 4 or 8.
- The smallest disparity.
- The biggest disparity.
- Block dimensions: how many pixels should be considered when calculating the energy function?
- Maxima disparity between the adjacent pixels (left/right neighbour).
- Uniqueness-ratio: limit, where the best energy value is the winner.

From these parameters the most important is to setup correctly the disparity range (smallest and largest disparity) according to Fig. 8. The disparity map as a result is shown on Fig. 9. The grey colours are representing the depth information.

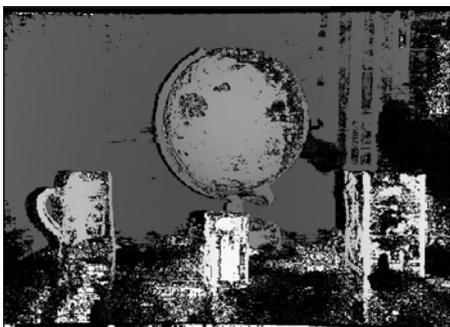


Fig. 9 Disparity map

On Fig. 9 we can notice disturbances and missing areas (in black colour). Because of the occlusion some parts are missing from our model. In MATLAB we can generate the point cloud with the help of the `reconstructScene` function. The visualized point cloud is demonstrated on Fig. 10, where the white areas mean holes in the model.



Fig. 8 Error ellipses on new points

V. CONCLUSIONS

As a summary we can say that the implementation of the SGM algorithm is greatly depending on the setup of parameters. The other important issue is that the SGM algorithm works only with stereo-pairs. In case of more stereo-pairs we need to integrate the separate models. The occlusion problem remains a problem. The experiments showed us that it is better if the parallaxes are not too large, so we need to take photos with small basis, but in this case the accuracy issues can play an important role.

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