PURDUE ENGINEERING

CE597–Digital Photogrammetric Systems

Fall 2018

LYLES SCHOOL OF CIVIL ENGINEERING

LAB 1: BUNDLE ADJUSTMENT WITH SELF CALIBRATION

Due Date: September 17th, 2017

Objective:

This lab aims at determining the camera's interior orientation parameters (principal point coordinates, principal distance, and distortion parameters) using a bundle adjustment with self-calibration procedure.

Given:

1. Eighteen images of a calibration test field are available through the course Blackboard website. A sample image of the calibration test field is shown in Figure 1. Also, an illustration of the relative location/orientation of the eighteen images with respect to the test field is shown in Figure 2.
2. Pixel size of the utilized camera is 3.69 um (microns).
3. Necessary files and SW for conducting the bundle adjustment with self-calibration procedure.
4. To define the position and orientation of the datum for the bundle adjustment with self-calibration procedure, six coordinates of the ground coordinates of three points are fixed. The scale of the datum is defined by some distance measurements. The axes of the datum and the fixed point coordinates are shown in Figures 2 and 3, respectively.

Figure 1: Sample image covering the calibration test field

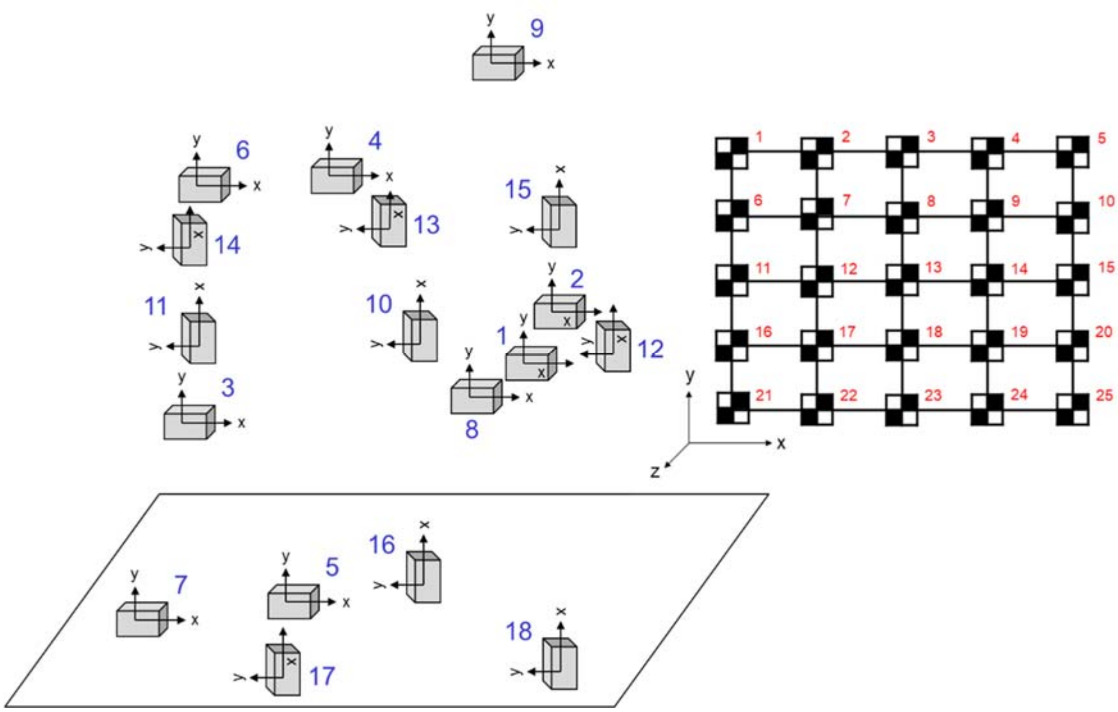

Figure 2: Illustration of the axes of the datum (ground coordinate system) and the relative location/orientation of the captured images with respect to the calibration test field

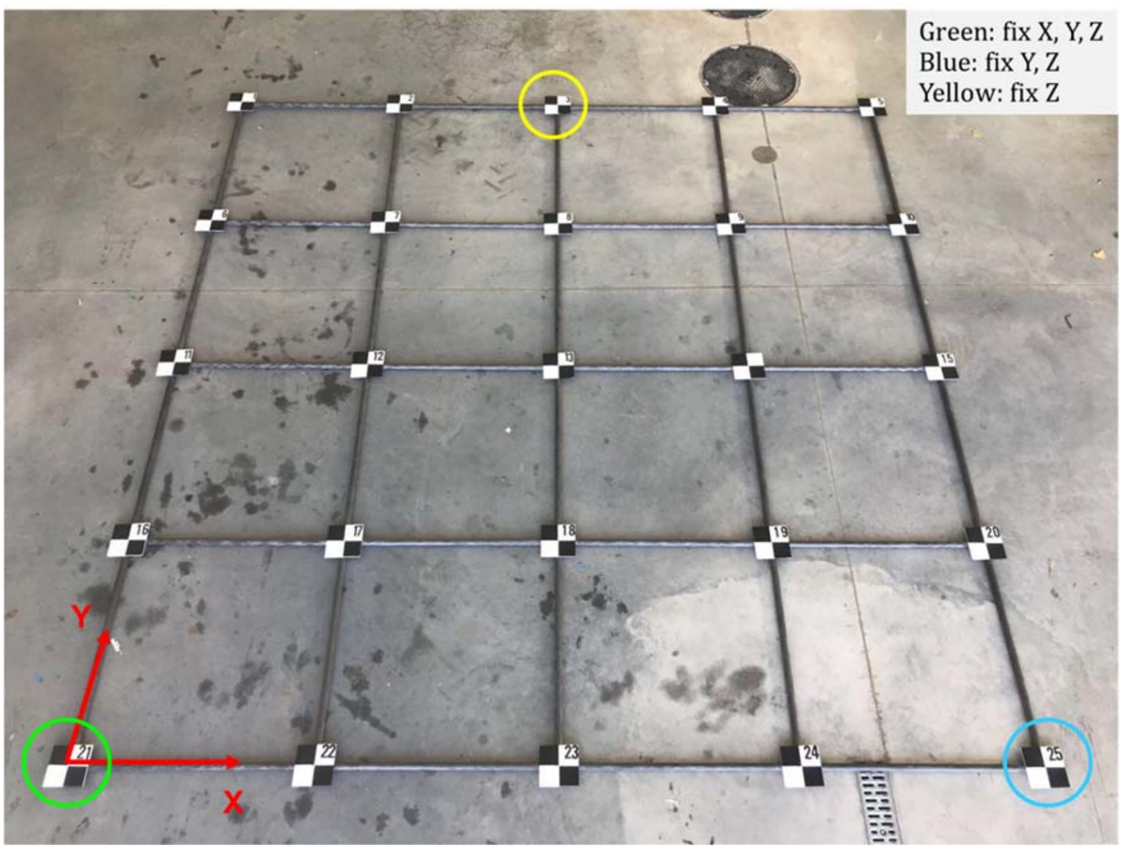

Figure 3: The utilized targets & coordinates for defining the axes of the datum for the self-calibration procedure **(**targets 3, 21, and 25**)**

Task:

Determine the Interior Orientation Parameters (IOPs) of the implemented camera (x_p, y_p, c, and distortion parameters) through a bundle adjustment with self-calibration procedure based on the provided eighteen images.

Description of procedure:

In this lab, the non-linear collinearity model is used to represent the relationship between the measured image coordinates and the corresponding object coordinates of tie and control points. The set of unknown parameters include the Exterior Orientation Parameters (EOPs) of all images, the camera's IOPs and the ground coordinates of tie points. Solving for those parameters requires the linearization of the collinearity equations with respect to the IOPs, the ground coordinates of tie point, and the EOPs.

Due to the complexity of this task as well as time constraints, a computer package for solving general bundle adjustment problems – **BASC** (Bundle Adjustment with Self-Calibration) – is furnished through the course Blackboard website together with the **POOM** image measurement software. Detailed descriptions of **BASC** and **POOM** can be found at the course Blackboard website as well.

Steps:

1. The first step requires the measurement of the image coordinates of tie and control points in the available eighteen images. To speed up this task, the measurements in sixteen of the eighteen images have been already provided. To get some experience, you need to measure the pixel coordinates of the tie and control points in the remaining two images (65_09_20180803.jpg & 65_17_20180803.jpg) using **POOM** and convert them to image coordinates – please, refer to the **POOM**'s user manual for details regarding image coordinate measurements and exporting these measurements. Please refer to Figure 2 for the identification codes (IDs) of the different targets.
2. The second step requires the approximations of the EOPs of the different images relative to the datum. To speed up this task, the EOPs of nine images have been already provided. You can use the illustration in Figure 2 as well as the provided EOPs to derive the missing orientation parameters.
3. Make sure that the **BASC** input files (project file, image coordinate file, ground control points file, camera file, orientation file, and distance file) are properly prepared – please, refer to the BSAC help directory for more details.
4. Run **BASC** using the prepared input files in the previous step.
5. Upon convergence, analyze the final results and prepare a final report.

BASC Background:

The **BASC** (Bundle Adjustment with Self-Calibration) program follows the USGS Simultaneous Multi-frame Analytical Calibration (SMAC) Distortion Model which is briefly explained as follows:

For years, the USGS has been using the SMAC model for calibrating film cameras. This model can be adopted for the calibration of digital cameras as well. For this model, all measured points (x, y) must be referenced to the center of the image coordinate system and then translated to the principal point (x_p, y_p), Equations 1.

$$
\begin{aligned}
\bar{x} &= x - x_p \\
\bar{y} &= y - y_p
\end{aligned}
\tag{1}
$$

Radial Lens Distortion:

Radial lens distortion is manifested in a change in the direction of the incident light ray after passing through the lens' perspective center. It is caused by large off-axial angles and lens manufacturing flaws. Radial lens distortion takes place along a radial direction from the principal point. To compute the correction for the radial distortion ($\Delta x_r, \Delta y_r$) of the measured point, one can use the coefficients of radial distortion (K_0, K_1, K_2, K_3) as shown in Equations 2.

$$
\begin{aligned}
\Delta x_r &= \bar{x}\left(K_0 + K_1 r^2 + K_2 r^4 + K_3 r^6\right) \\
\Delta y_r &= \bar{y}\left(K_0 + K_1 r^2 + K_2 r^4 + K_3 r^6\right)
\end{aligned}
\tag{2}
$$

where; $r = \sqrt{\bar{x}^2 + \bar{y}^2}$.

De-centering Lens Distortion:

De-centering lens distortion is caused by misalignment of the elements of the lens system along the camera's optical axis. The de-centering lens distortion has radial and tangential components. To compute the corrections for de-centering lens distortion ($\Delta x_d, \Delta y_d$) of the measured point, one can use the coefficients (P_1, P_2, P_3) as in Equations 3.

$$
\begin{aligned}
\Delta x_d &= \left(1 + P_3 r^2\right)\left(P_1\left(r^2 + 2\bar{x}^2\right) + 2P_2\overline{xy}\right) \\
\Delta y_d &= \left(1 + P_3 r^2\right)\left(2P_1\overline{xy} + P_2\left(r^2 + 2\bar{y}^2\right)\right)
\end{aligned}
\tag{3}
$$

<u>**Note**</u>: In this lab, consider only 5 distortion parameters (K_1, K_2, K_3, P_1, P_2) as the unknown distortion parameters.

To run **BASC,** you need to prepare a set of input text files. These files are already available in the course Blackboard website – refer to the BASC help directory for detailed description of these files). Following is a brief description of these files.

- Project File (this file provides the necessary thresholds for running BASC as well as the availability of support data - e.g., GPS/INS and distance measurements)
- Image Coordinate File (You need to use POOM to measure and export the image coordinates for the remaining two images – please refer to Figures 2 & 3 for the identification codes of the different points)
- Ground Control Points File (this file provides the ground coordinates of the control points as well as the approximate ground coordinates of tie points)
- Camera File (this file includes the approximate values for the unknown IOPs)
- Orientation File (this file includes the approximate values for the unknown EOPs as well as the accuracy of the image coordinate measurements for the different images – the provided file includes the EOPs for only nine images, you need to come up with the approximate values for the remaining nine images)

- Distance File (this file includes measured distances between tie and/or control points)

Important Notes:

- For this lab, the datum is defined by fixing six out of the nine coordinates for three well-distributed points as well as some distances between some points. The fixed coordinates are introduced in the Ground Control Points File (refer to Figure 3 for an illustration of the involved points and fixed coordinates) while the measured distances are introduced in the Distance File.
- In the orientation and camera files, camera ID should be the same (spelling and letter case).
- In the orientation and image coordinate files, image ID should be written in the same way (spelling and letter case).

Deliverables and Report Preparation

Prepare a standard report with the following information included:

- Measured image coordinates in mm as exported from **POOM**
- The rationale and procedure behind preparing the initial approximations of the unknown parameters (exterior orientation parameters for the remaining images)
- The final camera characteristics including distortion parameters (found in *.out file)
- Tabulate your results for the EOPs of all images (found in *.out file)
- The final residuals of image coordinates (found in *.res output file)
- The calculated variance component for each iteration (found in *.sigma file)
- Explanation of any problems encountered