The Damped Bundle Adjustment Toolbox v0.2 for Matlab

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1 Introduction

1.1 Purpose

Matlab toolbox with freely available code for bundle adjustment. Intention to be state-of-the-art.

1.2 Limitations

What it can do.

What it cannot do.

1.3 Legal

1.4 Scientific publications

Refer to any of the papers...

Börlin and Grussenmeyer (2013a) Börlin and Grussenmeyer (2013b)

2 Installation

1. Download the package file `dbat_0.2.zip`.
2. Unpack the package into a directory *dbat*.
3. Inside Matlab, do the following initialization:
   ```
   cd dbat % the directory where you installed the files.
   dbatSetup % set paths, etc.
   ```
4. Test the installation by executing `loadplotdemo`.
5. If `loadplotdemo` runs without errors and generates a figure with a camera network, the installation is ok.

3 Usage

3.1 Demos

3.1.1 loadplotdemo

The `loadplotdemo` demo loads a modified Photomodeler text export file of the 60-camera, 26000-point project used in Börlin and Grussenmeyer (2013a). The camera network, as computed by Photomodeler, is plotted with camera 1 aligned to the cardinal axes. The result should look like Figure 1. The figure is a standard Matlab 3D figure and may e.g. be rotated or zoomed using the camera toolbar.

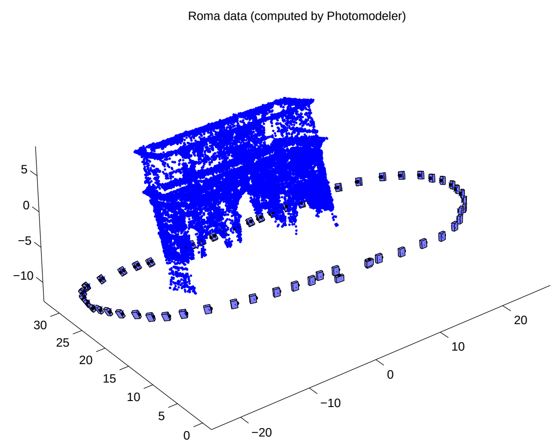


Figure 1: The figure generated by the `loadplotdemo` demo.

3.1.2 loadplotdemo2

The `loadplotdemo2` demo loads a modified Photomodeler text export file of a 21-camera, 100-point camera calibration project. The camera network, as computed by Photomodeler, is plotted and should look like Figure 2. The figure is a standard Matlab 3D figure and may e.g. be rotated or zoomed using the camera toolbar.

3.1.3 camcaldemo

The `camcaldemo` demo loads the camera calibration export file from Section 3.1.2 and runs a camera calibration. The EXIF focal length is used as the initial value. The other values are set to "default" values, e.g. the principal point at the center of the sensor and all lens distortion parameters equal to zero. The initial value for the EO parameters are computed by spatial resection (Haralick et al., 1994; McGlone et al., 2004, Chap. 11.1.3.4) using the control points defined for the Photomodeler calibration sheet. The initial OP coordinates are subsequently computed by forward intersection.

The bundle adjustment is run with Gauss-Newton-Armijo damping. The result is given in a number of plot windows and a Photomodeler-style result text file, listed in Appendix B.

The result plots are of two kinds: Plots that show the evolution of the iterations and plots that show the quality of the input or output data. The former plots may be useful to understand how the bundle adjustment works but also to "debug" a difficult network that has convergence difficulties. The latter plots give information about the quality of the result and may also provide clues on how to improve a network when the bundle did converge.

Evolution plots The evolution plots are collected in figures 3–5. Figure 3 shows a snapshot of the 3D trace figure at the beginning and end of the iterations. As default, the evolution is presented iteration by iteration with intervening presses of the return

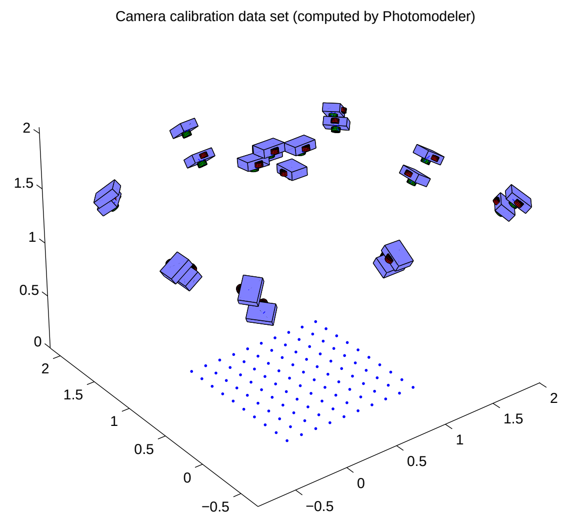
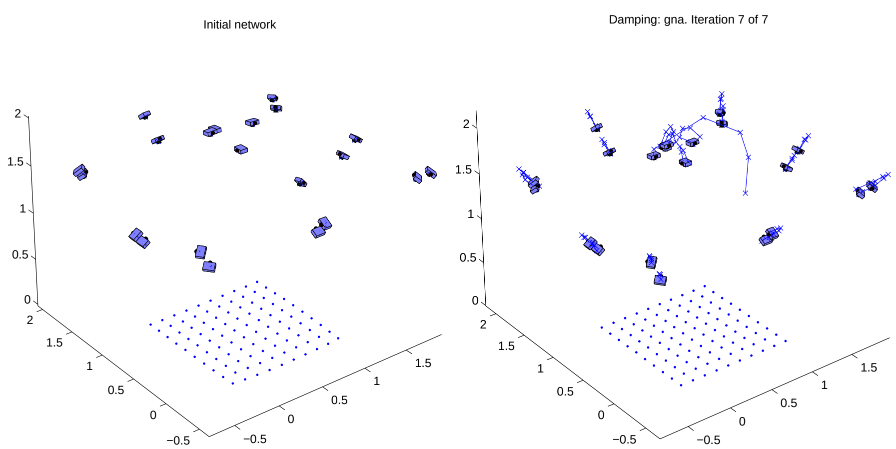


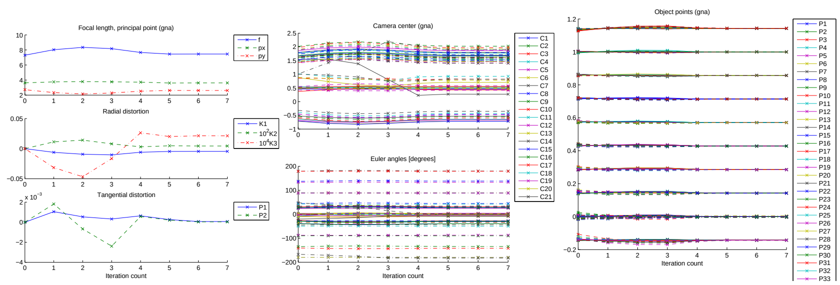
Figure 2: The figure generated by the `loadplotdemo2` demo.



(a) Initial network configuration.

(b) Network configuration after convergence, with camera center trace lines.

Figure 3: 3D network evolution during the iterations. Only the EO and OP parameters are illustrated. In this example, the variation of the OP coordinates is barely visible.



(a) IO parameters (b) EO parameters (c) OP parameters

Figure 4: Evolution of network parameters during the iteration sequence.

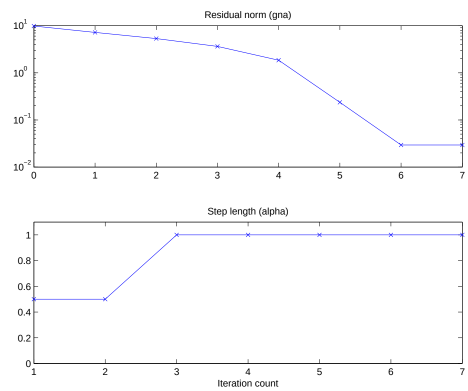
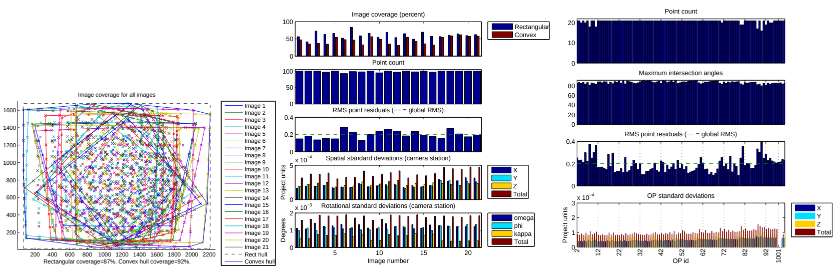


Figure 5: Residual evolution and damping behaviour during the iterations.

key. The figure window is interactive and may be rotated, zoomed, etc. In this example, it is clear in Figure 3b that one camera station had poorer initial values than the rest.

Figure 4 contains three plots showing the evolution of the internal orientation (IO), external orientation (EO), and object point (OP), respectively, during the iterations. The IO plot is split into a focal/principal point panel and a radial and tangential distortion panel, where the radial distortion parameters are scaled to provide more information. The EO plot contains a camera center panel and an ω-ϕ-κ Euler angle panel. The EO and OP plots are interactive. Lines in the plots or legends may be selected and all corresponding lines will be highlighted. In the top panel of Figure 4b, the motion of one camera stands out. Clicking that line reveals that it belongs to camera station 21, which can be further investigated to decide if it should be excluded from the calibration.

The final evolution plot, shown in Figure 5, illustrates the evolution of the norm of the total residual and the damping behaviour, if any, during the bundle iterations. In this example, the Gauss-Newton-Armijo linesearch damping is active during the first two iterations. For further details on the damping, see Börlin and Grussenmeyer (2013a).



(a) Image coverage (b) Image statistics (c) Object point statistics

Figure 6: Plots of input/output statistics.

Quality plots The quality plots a gathered in Figure 6. Per-image quality statistics is shown in Figure 6b. The statistics presented for each image are the image coverage; the number of measured points; the average (RMS) point residual; and the standard deviations for the EO parameters for the camera stations. In this example, the data does not give any obvious support to exclude the suspected image 21 from the calibration.

The image coverage is detailed in a separate Figure 6a. The plotted data is selectable. All observations from a specific image, including their convex hull, will be highlighted when a point or line is selected.

Finally, the per-OP quality statistics in Figure 6c show the number of observations per OP; the maximum ray intersection angle; the average (RMS) point residual; and the OP coordinate standard deviation. The presentation may be zoomed to show only a subset of the OPs by activating the “zoom” function of the window.

3.1.4 romabundledemo

3.2 Using your own data

3.2.1 Enabling text export from Photomodeler

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Some versions of Photomodeler do not have the text file export option enabled by default. In that case, follow the following steps to enable it:

1. Right-click on the main window toolbar, select *Customize toolbar...*.
2. In the *Commands* tab, select the *File* category.
3. Drag the *Export Text File...* command to a toolbar of your choice.
4. Now you should be able to export your project as a text file by clicking on the *Export Text File* button.

3.2.2 Export from Photomodeler

To import a Photomodeler project into the toolbox, the following steps are valid in Photomodeler Scanner 2012:

1. Export the project using *Export Text File*. If the *Export Text File* command is not available, follow the instructions in Section 3.2.1.
2. After export, open the *Project/Cameras...* dialog and select the camera that was used in your project.
3. Open the generated text file in a text editor.
   (a) On the 2nd line (usually reading `0.00005 20`), append the width and height in pixels of your images, e.g. to `0.000500 20 5616 3744`.
   (b) Inspect the 4th line. For instance, the original data in `roma.txt` was (some trailing zeros removed):
   `24.3581 18.1143 12.0 35.96404 24.0 0.00022 -0.0 0.0 0.0 0.0`
   The values correspond to the following camera parameters:
   `focal pp_x pp_y format_w format_h K1 K2 K3 P1 P2`.
   Notice that most of the significant digits of K1–K3 were lost in the text export.
   (c) Update the parameter values on the 4th line with values from the camera dialog *for each parameter with a larger number of significant digits in the dialog*. This usually means all parameters except `format_w`. In the `roma.txt` test case, the 4th line was modified to:
   `24.3581 18.1143 12 35.96404 24 2.174e-4 -1.518e-7 0 0 0`.

3.2.3 Loading into Matlab

1. In matlab, run step 3 from Section 2 if not already done.

2. Set the variable `fName` to the text export file name `fName='c:/path/to/exported/file.txt';`, or select it using `[f,p]=uigetfile('*.txt'); fName=[f,p];`

3. Run the `loadplotdemo` script. A figure with your camera network, aligned with the first camera and rotated to have +Z 'up', should now have been generated.

References

N. Börlin and P. Grussenmeyer. Bundle adjustment with and without damping. *Photogrammetric Record*, 28(144):396–415, Dec. 2013a. doi: 10.1111/phor.12037.

N. Börlin and P. Grussenmeyer. Experiments with metadata-derived initial values and linesearch bundle adjustment in architectural photogrammetry. *ISPRS Annals of the Photogrammetry, Remote Sensing, and Spatial Information Sciences*, II-5/W1:43–48, Sept. 2013b.

R. M. Haralick, C.-N. Lee, K. Ottenberg, and M. Nölle. Review and analysis of solutions of the three point perspective pose estimation problem. *Int J Comp Vis*, 13(3): 331–356, 1994.

C. McGlone, E. Mikhail, and J. Bethel, editors. *Manual of Photogrammetry*. ASPRS, 5th edition, July 2004. ISBN 1-57083-071-1.

A Camera model

B Result file example

```
Damped Bundle Adjustment Toolbox result file
   Project Name: Bundle Soln PhotoModeler Calibration Project
   Problems and suggestions:
      Project Problems: Not evaluated
      Problems related to the processing: (1)
         One or more of the camera parameter deviations has a high correlation (
   Information from last bundle
      Last Bundle Run: 05-Feb-2014 07:47:15
      DBAT version: 0.2.0.136 (2014-02-04 12:25:53)
      Status: OK (0)
      Sigma0 (pixels): 0.15106
      Sigma0 (mm): 0.000482148
      Processing options:
         Orientation: on
         Global optimization: on
         Calibration: on
         Constraints: off
         Maximum # of iterations: 20
         Convergence tolerance: 0.001
         Singular test: off
         Chirality veto: off
         Damping: gna
      Total error:
         Initial value comment: Camera calibration
         Number of stages: 1
         Number of iterations: 7
         First error: 9.28313
         Last error: 0.029411
      Precisions / Standard Deviations:
         Camera Calibration Standard Deviations:
            Camera1:
               Focal Length:
                   Value: 7.45885 mm
                   Deviation: 0.001 mm
               Xp - principal point x:
                   Value: 3.61622 mm
                   Deviation: 0.0008 mm
               Yp - principal point y:
                   Value: 2.60928 mm
                   Deviation: 0.0009 mm
               Fw - format width:
                   Value: 7.25319 mm
               Fh - format height:
                   Value: 5.43764 mm
```

```
      K1 - radial distortion 1:
          Value: 0.0045807 mm^(-2)
          Deviation: 2e-05 mm^(-2)
      K2 - radial distortion 2:
          Value: -4.34359e-05 mm^(-4)
          Deviation: 2e-06 mm^(-4)
          Correlations over 95.0%: K3:-97.9%.
      K3 - radial distortion 3:
          Value: -2.12972e-06 mm^(-6)
          Deviation: 9e-08 mm^(-6)
          Correlations over 95.0%: K2:-97.9%.
      P1 - decentering distortion 1:
          Value: -6.54637e-05 mm^(-2)
          Deviation: 3e-06 mm^(-2)
      P2 - decentering distortion 2:
          Value: -3.13246e-05 mm^(-2)
          Deviation: 4e-06 mm^(-2)
Photograph Standard Deviations:
   Photo 1: P8250021.JPG
      Omega:
         Value: -39.351215 deg
         Deviation: 0.008 deg
      Phi:
         Value: -1.118308 deg
         Deviation: 0.008 deg
      Kappa:
         Value: -179.789856 deg
         Deviation: 0.004 deg
      Xc:
         Value: 0.457102
         Deviation: 0.0002
      Yc:
         Value: 1.791883
         Deviation: 0.0002
      Zc:
         Value: 1.470536
         Deviation: 0.0002
   .
   .
   .
   Photo 21: P8250041.JPG
      Omega:
         Value: -8.620606 deg
         Deviation: 0.009 deg
      Phi:
         Value: 1.135801 deg
```

```
            Deviation: 0.01 deg
         Kappa:
            Value: -182.602049 deg
            Deviation: 0.003 deg
         Xc:
            Value: 0.271704
            Deviation: 0.0003
         Yc:
            Value: 0.818510
            Deviation: 0.0003
         Zc:
            Value: 1.906171
            Deviation: 0.0002
Quality
   Photographs
      Total number: 21
      Numbers used: 21
   Cameras
      Total number: 1
      Camera1:
         Calibration: yes
         Number of photos using camera: 21
         Photo point coverage:
            Rectangular: 41%-83% (61% average, 92% union)
            Convex hull: 31%-62% (46% average, 87% union)
   Photo Coverage
      References points outside calibrated region:
   Point Marking Residuals
      Overall point RMS: 0.202 pixels
      Mark point residuals:
         Maximum: 0.793 pixels (OP 8 on photo 19)
      Object point residuals (RMS over all images of a point):
         Minimum: 0.097 pixels (OP 67 over 21 images)
         Maximum: 0.392 pixels (OP 90 over 16 images)
      Photo residuals (RMS over all points in an image):
         Minimum: 0.131 pixels (photo 8 over 98 points)
         Maximum: 0.281 pixels (photo 6 over 93 points)
   Point Precision
      Total standard deviation (RMS of X/Y/Z std):
         Minimum: 8.1e-05 (OP 22)
         Maximum: 0.00016 (OP 88)
      Maximum X standard deviation: 7.2e-05 (OP 90)
      Maximum Y standard deviation: 7.7e-05 (OP 90)
      Maximum Z standard deviation: 0.00012 (OP 88)
   Point Angles
      Minimum: 79.6 degrees (OP 90)
```

```
Maximum: 90.0 degrees (OP 43)
Average: 86.4 degrees
```