The Damped Bundle Adjustment Toolbox v0.2 for Matlab

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1 Introduction

1.1 Purpose

This purpose of the Damped Bundle Adjustment toolbox is to be a high-level toolbox for photogrammetry in general and bundle adjustment in particular. It is the hope of the authors that the high-level nature of the code will inspire algorithm development. The code is written in Matlab and is verified to work with Matlab version 8 (release R2012B). The intention is that at least the computation routines will be Octave-compatible. This has however not been tested yet.

1.2 Capabilities

The toolbox currently includes routines for (function names in parentheses):

- File handling:
  - Reading Photomodeler-style text export files (`loadpm`).
  - Writing Photomodeler-style text result files (`bundle_result_file`).
- Photogrammetric calculations, including:
  - Spatial resection (`resect`).
  - Forward intersection (`forwintersect`).
  - Relative orientation based on the Nistér 5-point algorithm (Stewénius et al., 2006) will be added in the future.
- Bundle adjustment
  - Bundle adjustment proper (`bundle`) using either Classical, Gauss-Newton-Armijo, Levenberg-Marquardt, or Levenberg-Marquardt-Powell damping schemes (Börlin and Grussenmeyer, 2013a). The latter two damping schemes are so far not included. They will be added in the near future, as will chirality damping.
  - Covariance calculations (`bundle_cov`) from the bundle result.
- Various plotting functions, including:
  - Plot image area covered by measurements (`plotcoverage`).
  - Plot camera network (`plotnetwork`), either static (as-loaded) or as an illustration of the bundle iterations.
  - Plot of the iteration trace of parameters estimated by bundle (`plotparams`).
  - Plots of quality statistics from the bundle result (`plotimagestats`, `plotopstats`).
- Demo functions using the above functions. The demo functions are detailed in Section 3.1.

This manual does not contain detailed information about how to use each function. More information may be found by typing `help <function name>` at the Matlab prompt, studying the source code of the demo functions, and reading the source code of each file directly.

Things to be added in the near future:

- Weights on the observations.
- Chirality damping.
- Levenberg-Marquardt and Levenberg-Marquardt-Powell damping.
- Test octave compatibility.
- Azimuth-tilt-swing camera model.

1.3 Legal

The licence detail are described in the `README.txt` file included in the distribution. In summary:

- You use the code at your own risk.
- You may use the code for any purpose, including commercial, as long as you give due credit. Specifically, if you use the code, or derivatives thereof, for scientific publications, you should refer to on or more of the papers Börlin and Grussenmeyer (2013a,b) that the code is based on.
- You may modify and redistribute the code as long as the licensing details are also redistributed.

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 the supplied demos described in Section 3.1.

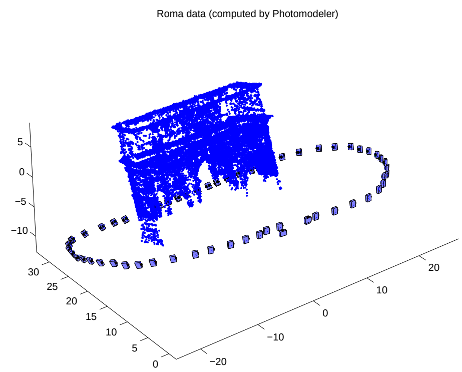


Figure 1: The figure generated by the `loadplotdemo` demo.

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.

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. 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

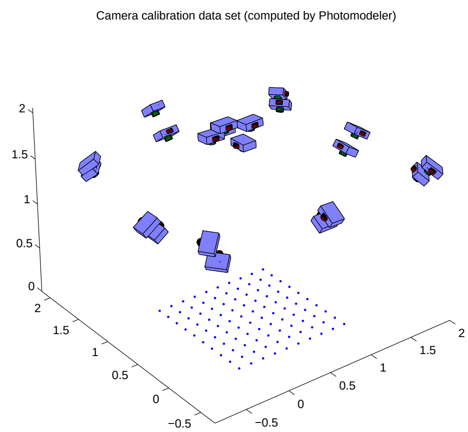


Figure 2: The figure generated by the `loadplotdemo2` demo.

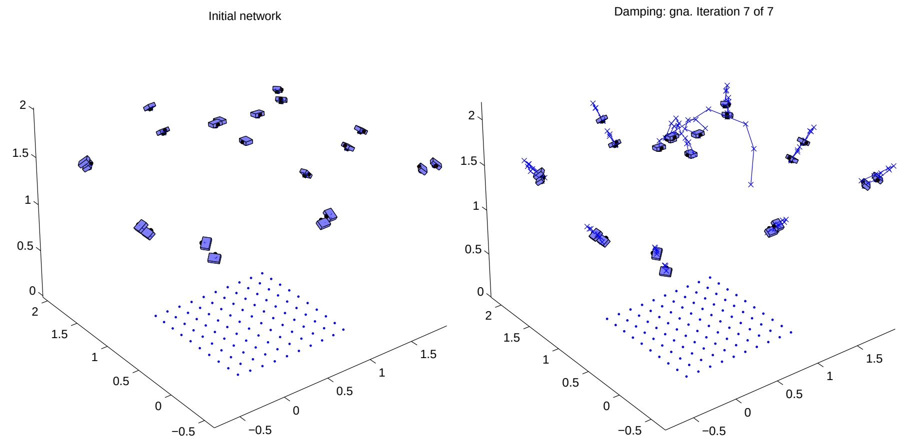
understand how the bundle adjustment works but also to "debug" a difficult network that has convergence difficulties. The latter plots give information about the quality of the result and may also provide clues on how to improve a network when the bundle did converge.

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 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).

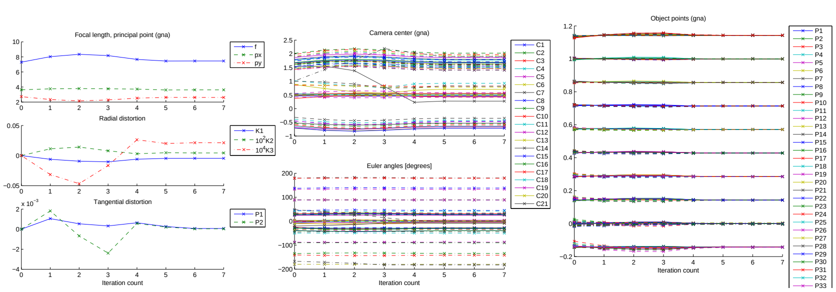
Quality plots The quality plots a gathered in Figure 6. Per-image quality statistics is shown in Figure 6b. The statistics presented for each image are the image coverage; the number of measured points; the average (RMS) point residual; and the standard deviations for the EO parameters for the camera stations. In this example, the data does



(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.

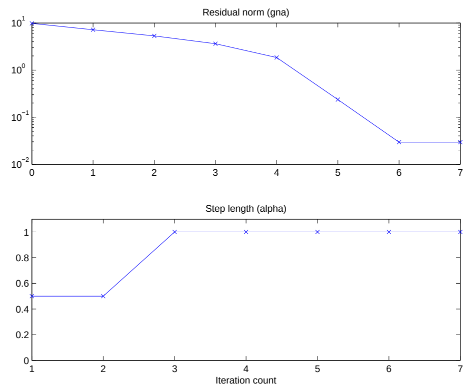
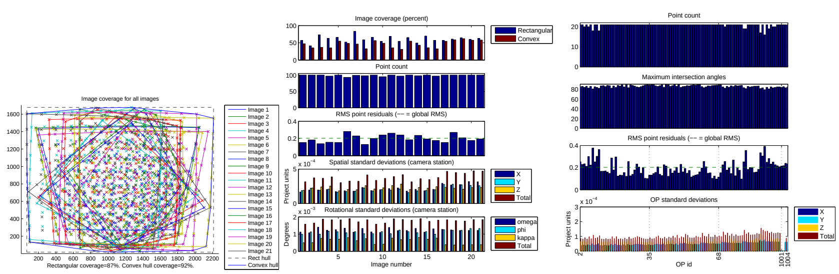


Figure 5: Residual evolution and damping behaviour during the iterations.



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

Figure 6: Plots of input/output statistics.

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 figure window.

Result file The result file is modelled after the Photomodeler result file. The result file is listed in Appendix C.

3.1.4 romabundledemo

The `romabundledemo` function loads the project from Section 3.1.1 and present essentially the same plots and the `camcaldemo`. This demo uses the Photomodeler file as input to the bundle adjustment that runs a few iterations until convergence. The same result file and result plots as `camcaldemo` are essentially generated. Since the project is larger (60 cams/26 000 points) than the previous example (20 cams/100 points), the computation will take a bit longer. Computation time was around one minute running on a HP compaq dc7800 with an Intel Core2 Quad CPU Q9300 @ 2.50GHz under 64-bit Ubuntu 12.04 (kernel 3.5.0-45).

3.2 Using your own data

This section describes how to import you own data using Photomodeler text export files. If you have another type of input file, you may be able to write your own loader. Otherwise, if you have a text file you wish to import, feel free to mail the file to the the toolbox authors and request an import function. Althought we cannot guarantee anything, we may adhere to the request, time permitting.

3.2.1 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 the *Export Text File* menu command. If the command is not available, follow the instructions in Appendix A.
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`.

3.2.2 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

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D. C. Brown. Close-range camera calibration. *Photogrammetric Engineering*, 37(8): 855–866, 1971.

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.

H. Stewénius, C. Engels, and D. Nistér. Recent developments on direct relative orientation. *ISPRS J Photogramm*, 60(4):284–294, June 2006.

A 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, the following steps worked in Photomodeler Scanner 2012:

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.

B Camera model

Currently, the only supported camera model is the omega-phi-kappa Euler angle camera model (McGlone et al., 2004, Ch. 2.1.2.3) with the Brown (1971) lens distortion model.

C 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 (see below).
   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
```