COMPARISON OF BUNDLE BLOCK ADJUSTMENTS FOR CLOSE RANGE APPLICATIONS

Albert Wiedemann[1], John Moré[1], Tim Suthau[1], Iliana Theodoropoulou[1], Ulrich Weferling[2] and Bahadir Ergün[3]

[1] Photogrammetry and Cartography, Technical University of Berlin, Germany
[2] Brandenburg Technical University of Cottbus, Germany
[3] Geodetic Department, Istanbul Technical University, Turkey

For several projects in close range photogrammetry a bundle block adjustment is necessary, at least for orientation purposes, and sometimes also for the calibration of the used cameras. Based on the experiences of a few years in this field, we have compared several software packages, some commercial ones, some well established academic solutions and some recent developments at the Technical University of Berlin. One of the main topics of this paper is to provide criteria, for the evaluation of a bundle block adjustment program.

1. INTRODUCTION

There is a wide variety of software packages providing a bundle block adjustment on the market. The most famous ones for aerial applications are PAT-B and BLUH. There is a much bigger variety of packages available for close range applications, like ORIENT (TU Wien), Phidias (RWTH Aachen), Elcovision (PMS), CDW (Rollei), Pictran (technet), BINGO (Dr. Kruck), CAP (Hinsken & Kotowski), and many others. Overviews are given by *Faig* [1989] or *Fellbaum* [1992].

There is no way to compare all this packages. Therefore we selected two of these packages, compared it with some well established academic packages and some recent developments at the Technical University of Berlin. Thus the paper may only provide some criteria to mention, if anybody has to select a software for a special purpose.

They all provide the basic functionality of a bundle block adjustment, the calculation of exterior and interior orientation parameters and object coordinates of tie points (*Schmid*, 1958). But there is a wide variety in the amount of available tools. While the commercial packages include measurement tools, other packages like BLUH provide an enormous amount of tools for the data analysis.

Due to the availability we compared:

- Commercial Packages
  - Rollei CDW, Rolleimetric, Braunschweig
  - Pictran, technet gmbh, Berlin
- Established Academic Software Packages
  - BLUH, University of Hanover, K. Jacobsen
  - CUBA, City University of London, T. Short
- Experimental Academic Software Packages
  - IMBUN, TU Berlin, A. Wiedemann
  - VerTech, TU Berlin, J. Moré

2. SHORT DESCRIPTION OF THE USED SOFTWARE PACKAGES FOR A BUNDLE BLOCK ADJUSTMENT

2.1 Rollei CDW

Rollei CDW is a well established close range software package. It is based on developments by *Wester-Ebbinghaus* [1978, 1981], *Fellbaum* [1984] and others [e.g. *Dold & Suilmann* 1993] and is the successor of the Rolleimetric MR2, which was a pioneer in the distribution of analytical photogrammetry to customers outside the photogrammetric society. The software is widely used, especially for architectural photogrammetry. We used Rollei CDW in the Version 1.52 of 1997. The software is available on PC (Fig. 1).

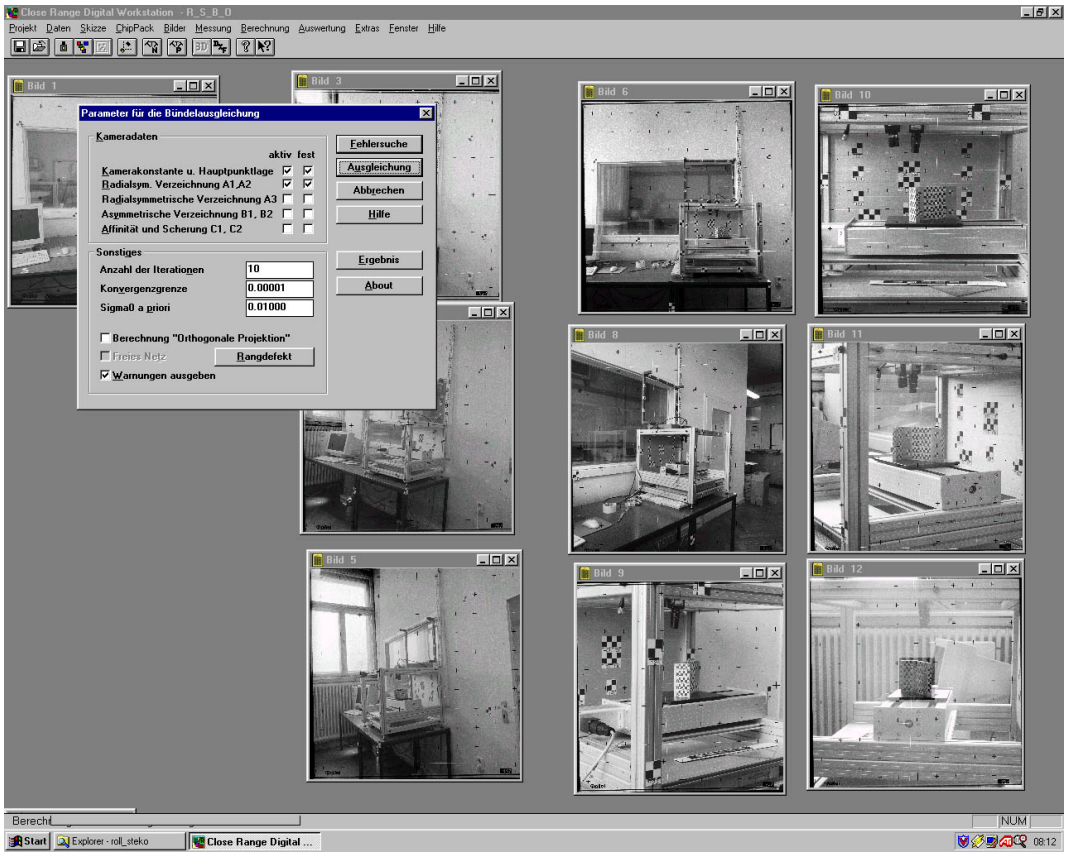

Figure 1: Screenshot of Rollei CDW

2.2 Pictran

Pictran is a slightly newer development than Rollei, but is now also well established. It has been developed by *Gründig & Bühler* [1985] and *Schewe* [1995]. We used the version 2.1.03 from 1995 on a Silicon Graphic Unix machine and a newer one on PC platform (Fig. 2).

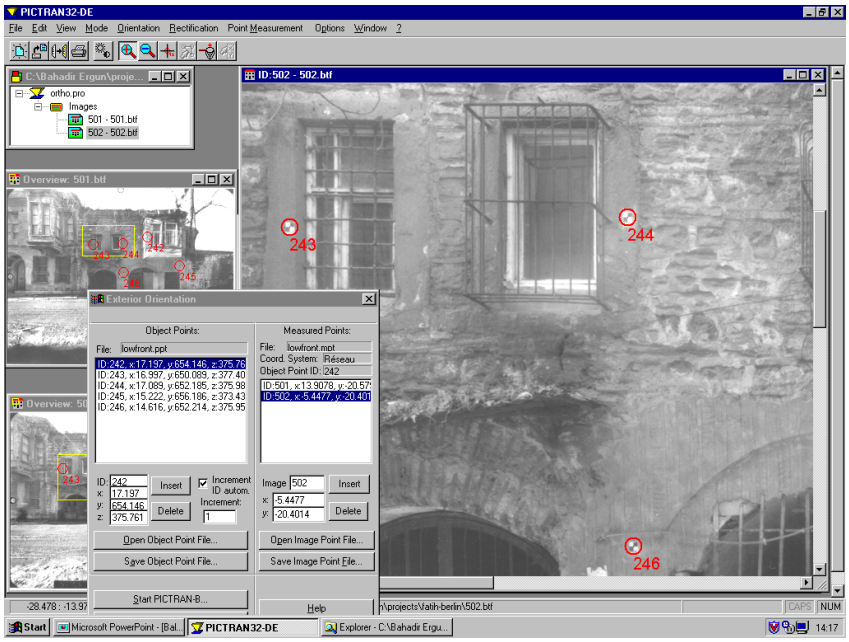

Figure 2: Screenshot of the Pictran

2.3 *BLUH*

The BundLe block adjustment of the University of Hannover (BLUH) is one of the most famous and established software packages for this purpose. Apart from being developed for aerial application by *K. Jacobsen* [1980, 1982], it has also been used for close range applications. We have the software available on UNIX (Silicon Graphics) and PC (last update 02/2001). The software has no graphical user interface, but is controlled by interactive menus.

2.4 *CUBA*

The software CUBA (City University Bundle Adjustment) has been developed and supported by *Tim Short* from the City University of London. It is available as public domain software on the internet (http://cesgi1.city.ac.uk/cuba). The URL may have been changed. We used the version 4.01 from January 1998. The program works under UNIX (Silicon Graphics) and PC.

2.5 *IMBUN*

The program IMBUN is a recent development at the Technical University of Berlin by *A. Wiedemann*. It has been developed for the special requirements of the orientation of historical images for the reconstruction of destroyed buildings [*Wiedemann et al.*, 2000]. Due to the lack of available control information, a lot of different available data can be introduced in the functional model. We used the version 2.0 from March 2001 for the project. The program works under UNIX (Silicon Graphics) and PC.

2.6 *VerTech*

The program VerTech is also a recent development at the Technical University of Berlin by *J. Moré* (former *Schumann*). It is a program, providing several geodetic and photogrammetric solutions. It was developed during his diploma thesis, concerning the common adjustment of geodetic and photogrammetric observations [*Schumann 2000*]. It is one large, menu based program. The program works under UNIX (Silicon Graphics) on the PC and the MacOS.

3. COMPARISON

To compare the software packages, a first step was to determine which observations can be introduced and which unknowns can be determined. Further questions concern the capacity of the programs and comparability of results. It seem to be ideal, if each potential unknown can be interpreted as fix (not an unknown but a constant), observed with a known a priori error or unknown and only a initial value is available. In a ideal software package, this initial value can be calculated by the software.

3.1 Observations

One question of high importance for close range applications is the availability of control information. In some cases, there is no way to provide sufficient control information. Therefore the definition of a datum remains problematic. Some advanced software packages provide a free network adjustment (under development for VerTech) to avoid this problems. A further problem raises, if per camera only one image is available. Due to the high correlation between interior and exterior orientation in this cases, a large amount of tie points is not always sufficient to solve this problem. Additional observations help, to eliminate correlations and datum defects. Suitable are observed or known orientation data, straight lines or planes in the object room, observed or known differences between coordinates of several points, geodetic observations, GPS data or a knowledge on the identity of unknowns. Table 1 shown the available observations of the tested programs. All packages allow the use of image coordinates and useable object coordinates for a soft fitting of the model.

Table 1: Observations

	Rollei CDW	**Pictran**	**BLUH**	**CUBA**	**IMBUN**	**VerTech**
Image Points	yes	yes	yes	yes	yes	yes
Object Points	yes	yes	no	yes	yes	yes
Interior Orientation Data	yes	yes	no	yes	yes	no
Exterior Orientation Data	yes	P0	no	yes	P0, rot (terr/aerial)	P0, rot. (terr/aerial),
Straight Lines	no	no	no	no	yes	no
Planes	no	yes	no	no	no	no
Coordinate Differences	dX, dY, dZ	dX, dY, dZ	no	no	dX, dY, dZ	dZ
Geodetic Observat.	s	s	no	s, s_h, z, hz, niv, az	s, s_h	s, s_h, z, hz, niv
GPS Data	no	no	yes	yes	no	no
Others	no	no	no	plumb lines	identity of unknowns	identity of unknown angles

3.2 Unknowns

An other important criteria for the evaluation of a bundle adjustment is the possibility to calculate different unknowns. All packages allow the determination of interior and exterior orientation parameters and the object coordinates of tie points. But they have to be determined due to the model of the interior orientation and other unknowns.

Table 2: Unknowns

	Rollei CDW	**Pictran**	**BLUH**	**CUBA**	**IMBUN**	**VerTech**
Interior Orientation	c_k, x_h, y_h, A1, A2, A3, B1, B2, C1, C2	c_k, x_h, y_h, A1, A2, C1, C2	24 different parameter	c_{kx}, c_{ky}, x_h, y_h, A1, A2, A3, B1, B2, C1, C2, C3	c_k, x_h, y_h, A1, A2, A3, B1, B2, C1, C2	c_k, x_h, y_h, A1, A2, B1, B2, C1, C2
Exterior Orientation	P0, rot. (terr, aerial)	P0, rot. (Quatern.)	P0, rot. (terr, aerial)	P0, rot. (terr, aerial)	P0, rot. (terr & aerial)	P0, rot. (terr & aerial)
Object Points	yes	yes	yes	yes	yes	yes
Straight Lines	no	no	no	no	nes	no
Planes	no	yes	no	no	no	no
Geodetic Observat.	no	no	no	ref. orientation	no	ref. orientation

3.3 Capacity

In the past, the capacity of the programs was sometimes limited due to the limited resources of the computers. This has changed. Latest programs and available updates have more than sufficient capacities. The only occurred shortcoming was the only 5 cameras of Pictran.

Table 3: Capacity

	Rollei CDW	Pictran	BLUH UNIX / PC	CUBA	IMBUN	VerTech
Cameras	max. 750 unknowns, bigger versions are now available	5	10 cameras max. 192 / 24 Parameter	unknown	50	limited by RAM
Images		100	1999 / 600	unknown	50	limited by RAM
Object Points		1 000	10 000 / 4 000	unknown	10 000	limited by RAM
Image Points	limited by RAM	15 000	240 000 / 96 000	unknown	50 000	limited by RAM

Of higher importance is today the performance of the programs. Here all commercial programs showed a good performance, whereas the performance of BLUH was excellent, the performance of CUBA was poor, IMBUN and VerTech performance is weak.

3.4 Results

Due to different approaches for the elimination of blunders, each program used different points. Therefore some different results have been delivered.

Table 4: Results

	Rollei CDW	Pictran	BLUH	CUBA	IMBUN	VerTech	Calibrat. Report
Detected blunders in calc. without calibration	04/79,119	03/3002 04/78,79,119 06/63,64,81,82,83 08/81,3002	image No 06 126,128,131	03/78,3002 04/78,79,119 05/175 06/83 08/71,81	04/79,119 06/71 08/71	01/123,129,140 02/123,129,205 04/79,119,123,201,205 06/123,129,140	
Interior orient. with 3 paramet.	0.014±0.037 0.471±0.056 52.285±0.042	-0.138±0.027 0.084±0.028 51.944±0.039	0.226±0.036 -0.042±0.042 51.991±0.057	-0.117±0.012 0.068±0.013 51.986±0.018	-0.123±0.025 0.145±0.040 51.901±0.028	-0.158±0.027 0.097±0.029 52.008±0.040	-0.100 -0.030 51.825
Other significant interior orient. param.	-0.114±0.024 0.142±0.038 51.896±0.027 A1=-1.95e-5 A2= 1.01e-8	-0.153±0.009 0.058±0.009 51.843±0.013 A1=-1.98e-5 A2= 1.02e-8	0.119±0.012 -0.044±0.013 51.705±0.018 + 4 Parameter (9-12)	-0.138±0.013 0.058±0.014 52.151±0.018 A1=-1.96e-5 A2= 9.70e-9	-0.130±0.012 0.060±0.012 51.839±0.017 A1=-1.96e-5 A2= 9.68e-9	-0.101±0.007 0.047±0.007 51.822±0.010 A1=-1.90e-5 A2= 8.65e-9	-0.100 -0.030 51.825 A1=-2.17e-5 A2= 1.14e-8

4. EVALUATION - PROS AND CONS

The different packages have been used for several projects. The following resume is the result of a subjective judgement by the authors. Some shortcomings may be removed in latest versions, but we had no unrestricted access to this versions.

4.1 Rollei CDW

The Rollei CDP Pros:

- Complete restitution system, including measurement tools
- Easy to use
- Good blunder detection

The Rollei CDP Cons:

- Weak in the combination of inhomogeneous data sets
- Insufficient automatic calculation of initial values
- Bad error handling

4.2 Pictran

The Pictran Pros:

- Complete restitution system, including measurement tools
- Easy to use
- Good tools for calculation of initial values

The Pictran Cons:

- Static mathematical model:
  - Rotations can not be introduced as observations
- Unclear stochastical model
  - Statistical parameters are difficult to interpret
  - Position of singularity unclear
- Small number of supported cameras

4.3 BLUH

The BLUH Pros:

- High performance
- Large amount of support software and data analysis tools available

The BLUH Cons:

- Static mathematical model for close range applications
- Control points have to be found in at least two images
- Difficult to learn menu user interface

4.4 CUBA

The CUBA Pros:

- Flexible mathematical model
- Geodetic adjustment integrated

The CUBA Cons:

- Poor performance
- Bad error handling
- Confusing naming conventions for output files
- Confusing user interface
- No automatic calculation of initial values

4.5 IMBUN

The IMBUN Pros:

- Source code available
- Adaptable for special purposes
- Flexible elimination of unknowns

The IMBUN Cons:

- Weak performance
- Overloaded output files
- No graphical user interface
- No automatic calculation of initial values for the orientation data

4.6 VerTech

The VerTech Pros:

- Source code available
- Simple to use menu user interface
- Adaptable for special purposes
- Geodetic adjustment integrated

The VerTech Cons:

- Weak performance
- Separation between calibration and network adjustment
- No automatic calculation of initial values for the orientation data

5. CONCLUSIONS

There is no way to select one of the software packages as winner of the contest. Each has it's pros and cons. Depending on the special task, a suitable solution has to be selected. If this paper helps to find the right criteria, it fulfills the tasks of this paper. You may come to other conclusions when you test the software by yourself. Our conclusions depend on expenses of a lot of sometimes non-conventional projects. We learned that for a research institution it is necessary to have a software with the opportunity to adapt it to the tasks occurring every day.

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