Some Stuttgart Highlights of Photogrammetry and Remote Sensing

Dieter Fritsch

Keynote - The 55th Photogrammetric Week

Contents

1. Introduction

- April 1, 1966: Fritz Ackermann was appointed Full Professor at the University of Stuttgart and launched the Institute for Photogrammetry
- Excellent contributions in: Analytical photogrammetry (Independent Models, Bundle Block Adjustment, Digital Image Correlation, GPS Photogrammetry, Laser Profiling, automated Aerial Triangulation,..)
- June 1, 1992: Dieter Fritsch was appointed Full Professor at the University of Stuttgart and Director of the Institute for Photogrammetry
- The last 23 years: Contributions to Laser Scanning, ISO, automated 3D City Model Generation, Conflation, 2D & 3D Generalization, Hybrid GIS, Camera Certifications & Calibrations, Dense Image Matching, UAV Photogrammetry, Close-range Photogrammetry, Mobile Mapping (Streets, Rails), SAR Remote Sensing, Optical Remote Sensing, Augmented Reality, 4D Reconstructions, …

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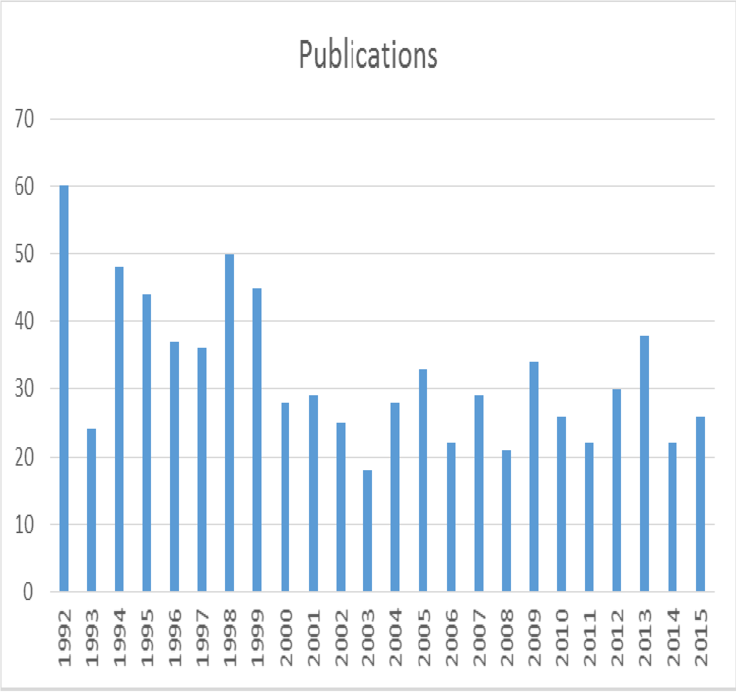
1. Publications Institute for Photogrammetry (1992-2015)



1992	60 Pubs	Congress
1993	24 Pubs	
1994	48 Pubs	
1995	44 Pubs	
1996	37 Pubs	Congress
1997	36 Pubs	
1998	50 Pubs	
1999	45 Pubs	
2000	28 Pubs	Congress
2001	29 Pubs	
2002	25 Pubs	
2003	18 Pubs	
2004	28 Pubs	Congress
2005	33 Pubs	
2006	22 Pubs	
2007	29 Pubs	
2008	21 Pubs	Congress
2009	34 Pubs	
2010	26 Pubs	
2011	22 Pubs	
2012	30 Pubs	Congress
2013	38 Pubs	
2014	22 Pubs	
2015	26 Pubs	
Total	**775 Pubs**	

2.1 Camera Calibration – Intro

- Camera calibration is one essential subject in photogrammetry
  - Self-calibration by using additional parameters (APs)
- Traditional self-calibration APs for analogue (film-based) photogrammetry
  - Physical APs: Brown (1971), Brown (1976)
  - Polynomials APs: Ebner (1976), Grün (1978)
  - They were originated for analogue single-head camera systems
- Do they still work well in digital aerial photogrammetry?

2.1 Camera Calibration - Intro

- Digital Airborne Cameras
  - Most frame cameras employ multi-head, virtual composition techniques
- Integration of GPS/IMU system
  - Direct georeferencing (ISO).
  - What is the impact of the self-calibration approach?
- Some criticisms on traditional APs (Clarke and Fryer, 1998)
  - Some ‘have no foundations based on observable physical phenomena’.
  - High correlations.

2.1 Camera Calibration - Intro

Using extended collinearity equations

- Transformation from **Image ➔ Object Space**

$$\bar{x} = \bar{z}\,\frac{r_{11}\Delta X + r_{21}\Delta Y + r_{31}\Delta Z}{r_{13}\Delta X + r_{23}\Delta Y + r_{33}\Delta Z} + \boxed{\Delta x}$$

$$\bar{y} = \bar{z}\,\frac{r_{12}\Delta X + r_{22}\Delta Y + r_{32}\Delta Z}{r_{13}\Delta X + r_{23}\Delta Y + r_{33}\Delta Z} + \boxed{\Delta y}$$

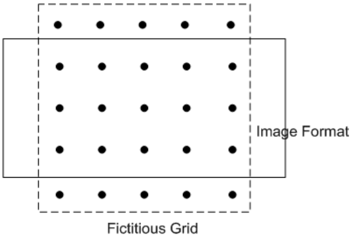
with

$$\Delta X = X - X_0 \qquad \bar{x} = x - x_0$$
$$\Delta Y = Y - Y_0 \qquad \bar{y} = y - y_0$$
$$\Delta Z = Z - Z_0 \qquad \bar{z} = z - z_0 = -c$$

- typically the standard model is amended by additional parameters (AP) $\boxed{\Delta x,\ \Delta y}$
- allow for compensation of **systematic errors** in image space and estimation **camera calibration parameters** (dependent on block geometry)
- models are functions of reduced image coordinates
- **classification** of AP sets
  - **physical models**, obtained from physical interpretable params
  - pure **mathematical models** without physical meanings
  - **combined/mixed models** (combination of former two)

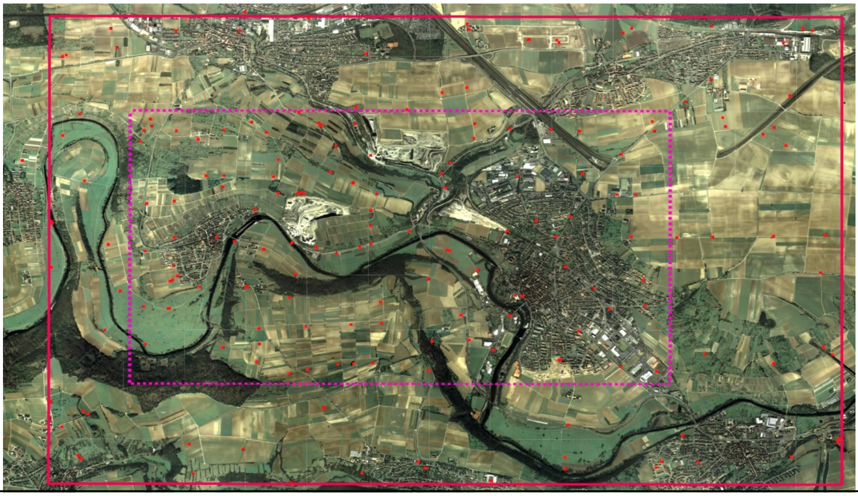
2.1 Camera Calibration - Reconsiderations

- Should the traditional APs be continued being used now?
  - If so, why?
  - If not, where are the new ones?
- Some challenges
  - Find the physical or mathematical foundations for APs
  - Decouple multi-corrections
    - Self-calibration APs
    - Misalignments
    - shift/drift effect in DGPS
    - IO parameters
    - EO
    - …



2.1 Camera Calibration – Testsite Vaihingen/Enz

- Testsite Vaihingen/Enz, since 1995
- Established for the assessment tests of the Digital Photogrammetric Assemby (DPA) – helped ifp to get worldwide reputation
- Many tests have been supervised by ifp: Film-based (with&without ISO), digital (with/without ISO), …



2.2 Camera Calibration – A Function Approximation Using Polynomials

- Weierstrass Theorem
  - Any univariate function can be approximated with arbitrary accuracy by a **polynomial** of sufficiently high degree.

$$\lim_{n\to\infty} p_n(x) = g(x)$$

- Orthogonal Polynomials
  - Discrete OPs
  - Continuous OPs

- Legendre orthogonal polynomials: continuous OPs

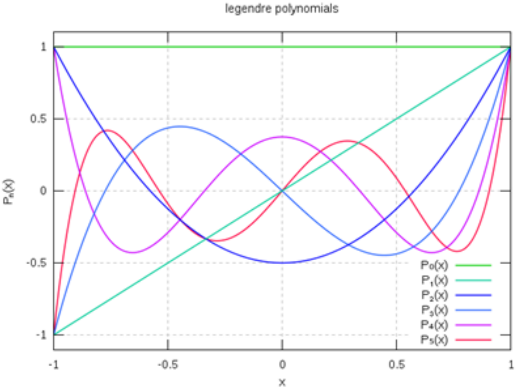
$$|L_m(x)| \le 1, \quad -1 \le x \le 1$$

$$\int_{-1}^{1} L_m(x) L_n(x)\,dx = \begin{cases} 0, & m \ne n \\ 1, & m = n \end{cases}$$

2.2 Camera Calibration – Legendre Polynomials

- Legendre polynomials possess the optimal approximation in the least-squares sense (Mason & Handscomb, 2002).

$$L_0(x) = 1$$
$$L_1(x) = x$$
$$L_2(x) = \frac{1}{2}(3x^2 - 1)$$
$$L_3(x) = \frac{1}{2}(5x^3 - 3x)$$
$$L_4(x) = \frac{1}{8}(35x^4 - 30x^2 + 3)$$
$$L_5(x) = \frac{1}{8}(63x^5 - 70x^3 + 15x)$$
$$L_6(x) = \frac{1}{16}(231x^6 - 315x^4 + 105x^2 - 5)$$



2.2 Camera Calibration – Legendre Polynomials

- Development of Legendre self-calibration APs
  - Width and length of images: $2b_x, \ 2b_y$

$$l_m(x,b_x) = L_m(x/b_x)$$
$$l_n(y,b_y) = L_n(y/b_y)$$
$$f_{m,n} \triangleq f_{m,n}(x,y;b_x,b_y) = l_m(x,b_x)\, l_n(y,b_y)$$
$$p_{m,n} = 10^{-6} f_{m,n}, \quad |p_{m,n}| \le 10^{-6}$$
$$\int^{b_x}\int^{b_y} p_{i,j}\, p_{m,n}\, dx dy = 0 \quad \text{if} \quad i \ne m \quad \text{or} \quad j \ne n$$

$p_{0,0}$

$p_{1,0}, p_{0,1}$

$p_{2,0}, p_{1,1}, p_{0,2}$

$p_{3,0}, p_{2,1}, p_{1,2}, p_{0,3}$

$p_{4,0}, p_{3,1}, p_{2,2}, p_{3,1}, p_{0,4}$

......

  - Each distortion term is approximated by the combinations of $\{p_{m,n}\}_{m,n}$

2.2 Camera Calibration – Legendre Polynomials

- Selecting M and N

$$m = 0, 1, \ldots, M, \quad n = 0, 1, 2, \ldots, N$$

- Eliminating two constant terms and four highly correlated terms.
- The number of Legendre APs

$$L_{AP} = 2(M+1)(N+1) - 6$$

$$\begin{aligned} &M = N = 2, \quad L_{AP} = 12 \\ &M = N = 3, \quad L_{AP} = 26 \\ &M = N = 4, \quad L_{AP} = 44 \\ &M = N = 5, \quad L_{AP} = 66 \\ &\ldots \\ &M = 3, N = 4, \quad L_{AP} = 34 \end{aligned}$$

- So far, Legendre APs are successfully constructed.

2.2 Camera Calibration - Fourier Series

- Fourier series are also **optimal** base function for developing self-calibration APs
  - Laplace’s Equation and Fourier Theorem
- Construction of bi-variate Fourier APs

$$\cos(mx \pm ny), \sin(mx \pm ny), \quad m, n = 0, \pm 1, \pm 2, \ldots$$

$$u = \bar{x}\pi / b_x, \quad v = \bar{y}\pi / b_y, \qquad u \in [-\pi, \pi], v \in [-\pi, \pi]$$

$$c_{m,n} = 10^{-6} \cos(mu + nv), \quad s_{m,n} = 10^{-6} \sin(mu + nv)$$

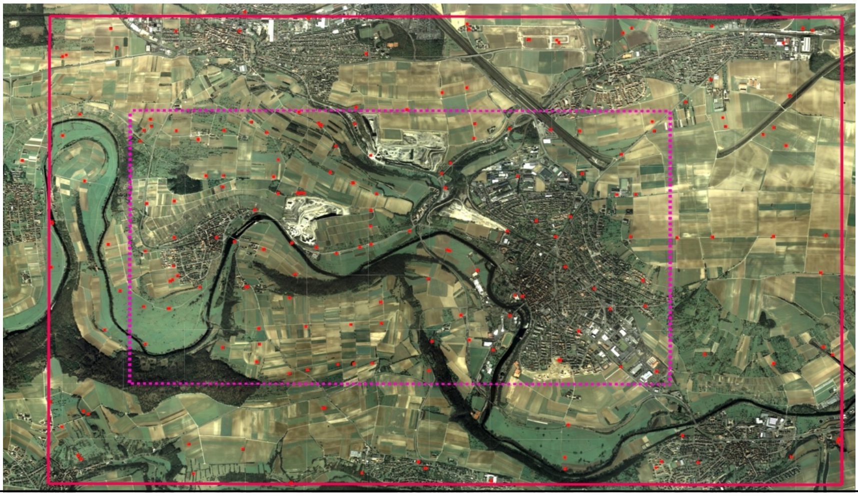
$$\Delta x = \sum_{m=1}^{M} \sum_{n=-N}^{n=N} \left(a_{m,n} c_{m,n} + b_{m,n} s_{m,n} \right) + \sum_{n=1}^{N} \left(a_{0,n} c_{0,n} + b_{0,n} s_{0,n} \right)$$

$$\Delta y = \sum_{m=1}^{M} \sum_{n=-N}^{n=N} \left(a'_{m,n} c_{m,n} + b'_{m,n} s_{m,n} \right) + \sum_{n=1}^{N} \left(a'_{0,n} c_{0,n} + b'_{0,n} s_{0,n} \right)$$

2.3 Camera Calibration – The Novel Approach

Practical Tests

- Test datasets
  - DGPF project 2008-2010: Evaluation on the performance of digital airborne cameras.
  - It was carried out using flights over the Vaihingen/Enz testfield



2.3 Camera Calibration – The Novel Approach

Tests on DMC and UltracamX Cameras

- Block overview
  - Two cameras: DMC and UltracamX
  - Two fly heights: GSD 20cm and GSD 8cm
  - Two block configurations
    - Dense GCPs and high side-overlap (60%)
    - Sparse GCPs and low side-overlap (20%)

Context	In-situ calibration	Operational project
Sensor orientation	ISO	ISO
Forward overlap (p)	60% ~70%	60% ~70%
Cross strip	NO	NO
Side overlap (q)	60%	20%
Image number		
DMC (GSD 20cm)	3 lines × 14/line = 42	2 lines × 14/line = 28
Ultracam-X (GSD 20cm)	3 lines × 12/line = 36	2 lines × 12/line = 24
DMC (GSD 8cm)	5 lines × 22/line = 110	3 lines × 22/line = 66
Ultracam-X (GSD 8cm)	5 lines × 35/line = 175	3 lines × 35/line = 105
GCP/ChP distribution		
DMC (GSD 20cm)	47 GCPs /138ChPs	4GCPs/181ChPs
Ultracam-X (GSD 20cm)	47 GCPs /138ChPs	4GCPs/181ChPs
DMC (GSD 8cm)	49 GCPs /69ChPs	4GCPs/114ChPs
Ultracam-X (GSD 8cm)	48 GCPs /68ChPs	4GCPs/112ChPs

2.3 Camera Calibration – Practical Tests

- Two examples of Legendre APs

M=N=5 (66 APs)

$$
\begin{aligned}
\Delta x = {} & a_1 p_{1,0} + a_2 p_{0,1} + a_3 p_{2,0} + a_4 p_{1,1} + a_5 p_{0,2} + a_6 p_{3,0} + a_7 p_{2,1} \\
& + a_8 p_{1,2} + a_9 p_{0,3} + a_{10} p_{4,0} + a_{11} p_{3,1} + a_{12} p_{2,2} + a_{13} p_{1,3} \\
& + a_{14} p_{0,4} + a_{15} p_{5,0} + a_{16} p_{4,1} + a_{17} p_{3,2} + a_{18} p_{2,3} + a_{19} p_{1,4} \\
& + a_{20} p_{0,5} + a_{21} p_{5,1} + a_{22} p_{4,2} + a_{23} p_{3,3} + a_{24} p_{2,4} + a_{25} p_{1,5} \\
& + a_{26} p_{5,2} + a_{27} p_{4,3} + a_{28} p_{3,4} + a_{29} p_{2,5} + a_{30} p_{5,3} \\
& + a_{31} p_{4,4} + a_{32} p_{3,5} + a_{33} p_{5,4} + a_{34} p_{4,5} + a_{35} p_{5,5} \\
\Delta y = {} & a_2 p_{1,0} - a_1 p_{0,1} + a_{36} p_{2,0} - a_3 p_{1,1} - a_4 p_{0,2} + a_{37} p_{3,0} + a_{38} p_{2,1} \\
& + a_{39} p_{1,2} + a_{40} p_{0,3} + a_{41} p_{4,0} + a_{42} p_{3,1} + a_{43} p_{2,2} + a_{44} p_{1,3} \\
& + a_{45} p_{0,4} + a_{46} p_{5,0} + a_{47} p_{4,1} + a_{48} p_{3,2} + a_{49} p_{2,3} + a_{50} p_{1,4} \\
& + a_{51} p_{0,5} + a_{52} p_{5,1} + a_{53} p_{4,2} + a_{54} p_{3,3} + a_{55} p_{2,4} + a_{56} p_{1,5} \\
& + a_{57} p_{5,2} + a_{58} p_{4,3} + a_{59} p_{3,4} + a_{60} p_{2,5} + a_{61} p_{5,3} \\
& + a_{62} p_{4,4} + a_{63} p_{3,5} + a_{64} p_{5,4} + a_{65} p_{4,5} + a_{66} p_{5,5}
\end{aligned}
$$

M=4, N=3 (34 APs)

$$
\begin{aligned}
\Delta x = {} & a_1 p_{1,0} + a_2 p_{0,1} + a_3 p_{2,0} + a_4 p_{1,1} + a_5 p_{0,2} + a_6 p_{3,0} + a_7 p_{2,1} \\
& + a_8 p_{1,2} + a_9 p_{0,3} + a_{10} p_{4,0} + a_{11} p_{3,1} + a_{12} p_{2,2} + a_{13} p_{1,3} \\
& + a_{14} p_{4,1} + a_{15} p_{3,2} + a_{16} p_{2,3} + a_{17} p_{4,2} + a_{18} p_{3,3} + a_{19} p_{4,3} \\
\Delta y = {} & a_2 p_{1,0} - a_1 p_{0,1} + a_{20} p_{2,0} - a_3 p_{1,1} - a_4 p_{0,2} + a_{21} p_{3,0} + a_{22} p_{2,1} \\
& + a_{23} p_{1,2} + a_{24} p_{0,3} + a_{25} p_{4,0} + a_{26} p_{3,1} + a_{27} p_{2,2} + a_{28} p_{1,3} \\
& + a_{29} p_{4,1} + a_{30} p_{3,2} + a_{31} p_{2,3} + a_{32} p_{4,2} + a_{33} p_{3,3} + a_{34} p_{4,3}
\end{aligned}
$$

2.3 Camera Calibration – Practical Tests

- Fourier APs, 16 params (maximum degree 1)

$$
\begin{aligned}
\Delta x = {} & a_1 c_{1,0} + a_2 c_{0,1} + a_3 c_{1,-1} + a_4 c_{1,1} \\
& + a_5 s_{1,0} + a_6 s_{0,1} + a_7 s_{1,-1} + a_8 s_{1,1}
\end{aligned}
$$

$$
\begin{aligned}
\Delta y = {} & a_9 c_{1,0} + a_{10} c_{0,1} + a_{11} c_{1,-1} + a_{12} c_{1,1} \\
& + a_{13} s_{1,0} + a_{14} s_{0,1} + a_{15} s_{1,-1} + a_{16} s_{1,1}
\end{aligned}
$$

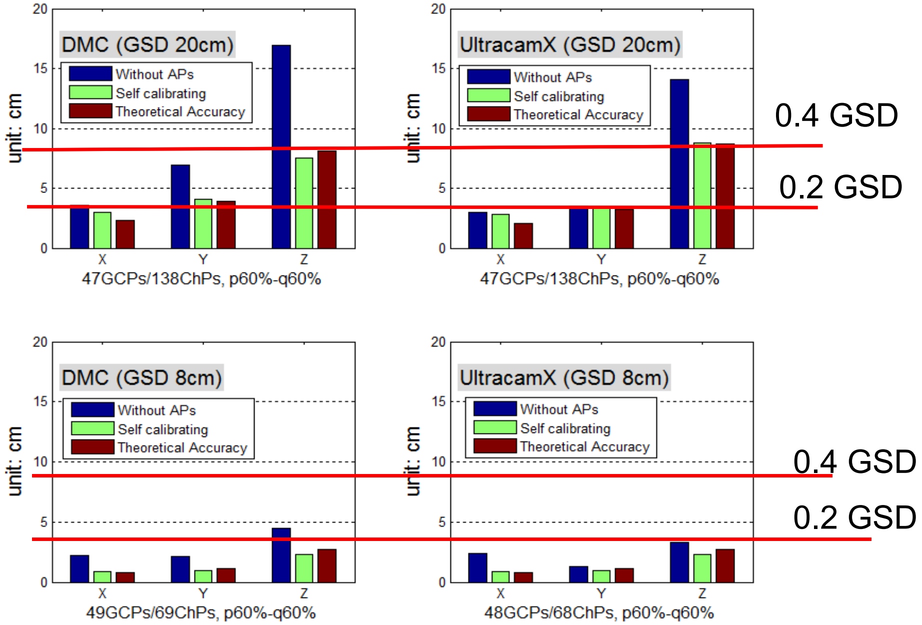
- Fourier APs, 48 params (maximum degree 2)

$$
\begin{aligned}
\Delta x = {} & a_1 c_{1,0} + a_2 c_{0,1} + a_3 c_{2,0} + a_4 c_{1,-1} + a_5 c_{1,1} + a_6 c_{0,2} \\
& + a_7 c_{1,2} + a_8 c_{1,-2} + a_9 c_{2,-1} + a_{10} c_{2,1} + a_{11} c_{2,-2} + a_{12} c_{2,2} \\
& + a_{13} s_{1,0} + a_{14} s_{0,1} + a_{15} s_{2,0} + a_{16} s_{1,-1} + a_{17} s_{1,1} + a_{18} s_{0,2} \\
& + a_{19} s_{1,2} + a_{20} s_{1,-2} + a_{21} s_{2,-1} + a_{22} s_{2,1} + a_{23} s_{2,-2} + a_{24} s_{2,2}
\end{aligned}
$$

$$
\begin{aligned}
\Delta y = {} & a_{25} c_{1,0} + a_{26} c_{0,1} + a_{27} c_{2,0} + a_{28} c_{1,-1} + a_{29} c_{1,1} + a_{30} c_{0,2} \\
& + a_{31} c_{1,2} + a_{32} c_{1,-2} + a_{33} c_{2,-1} + a_{34} c_{2,1} + a_{35} c_{2,-2} + a_{36} c_{2,2} \\
& + a_{37} s_{1,0} + a_{38} s_{0,1} + a_{39} s_{2,0} + a_{40} s_{1,-1} + a_{41} s_{1,1} + a_{42} s_{0,2} \\
& + a_{43} s_{1,2} + a_{44} s_{1,-2} + a_{45} s_{2,-1} + a_{46} s_{2,1} + a_{47} s_{2,-2} + a_{48} s_{2,2}
\end{aligned}
$$

2.3 Camera Calibration – In-situ Scenario

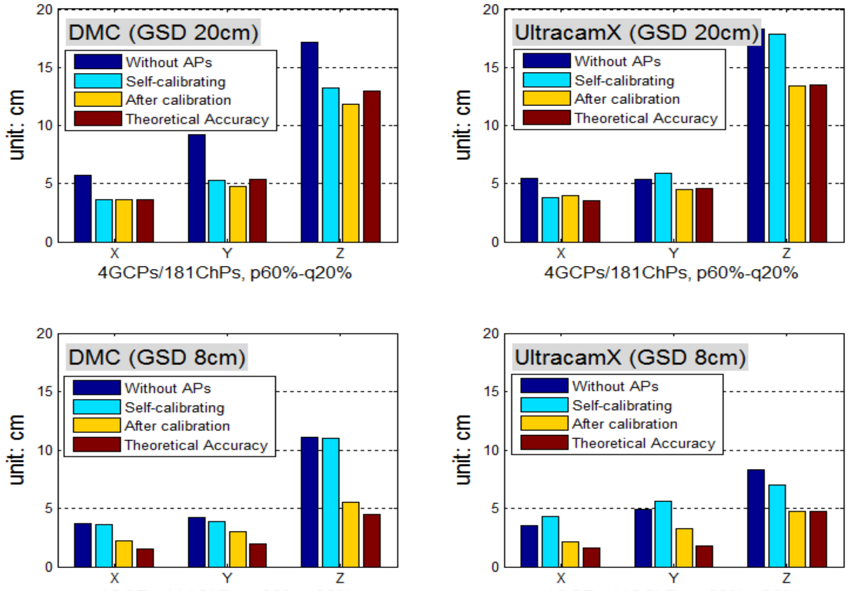
- Dense GCPs and 60% side-overlap



2.3 Camera Calibration – The Novel Approach

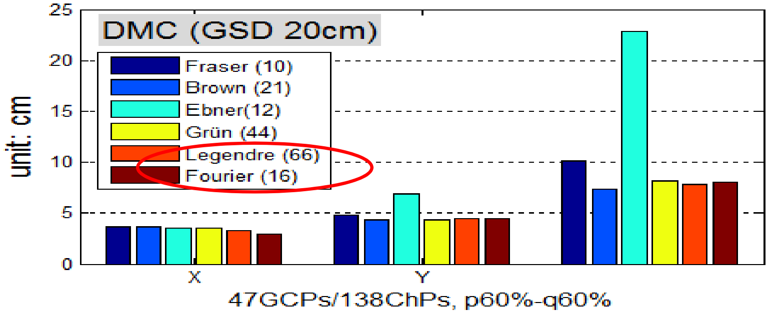
Operational Project Scenario

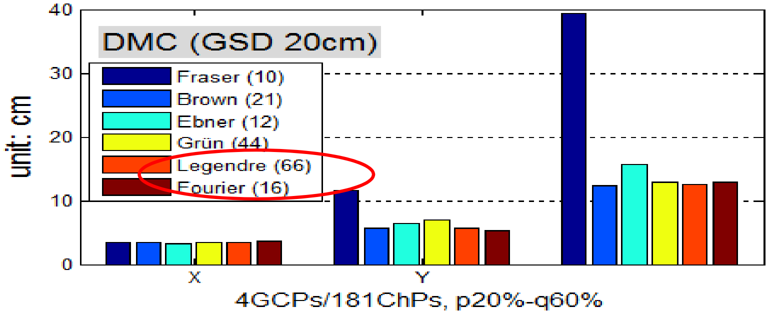
- 4 GCPs and 20% side-overlap



2.3 Camera Calibration – The Novel Approach

Accuracy Comparisons





2.3 Camera Calibration – The Novel Approach

Correlation Analyses

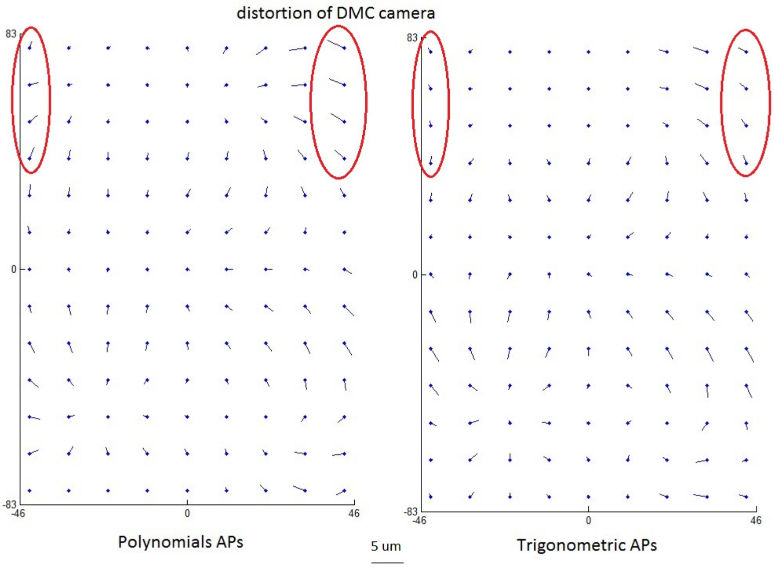
APs	**corr.**	**EO**	**IO**	**IMU**	**Intra-corr**
Brown APs (21)	< 0.1	98%	78%	86%	78%
	max	0.19	0.87	0.55	0.92
Grün APs (44)	< 0.1	100%	80%	83%	88%
	max	---	0.73	0.53	0.93
Legendre APs (66)	< 0.1	100%	97%	100%	96%
	max	---	0.44	---	0.57
Fourier APs (16)	< 0.1	100%	89%	92%	92%
	max	---	0.45	0.20	0.53

- Legendre APs and Fourier APs perform similarly best

2.3 Camera Calibration – The Novel Approach

Distortion Determination

- DMC (GSD 20cm)



2.4 Summary

The new families of Legendre and Fourier self-calibration APs are excellent

- Use mathematical base functions to approximate the unknown distortion function
- Fourier APs are rigorous, flexible and uses a lower number of additional parameters – just 16 are sufficient!
  - Many other datasets were tested with DMC II, UltracamXp, DigiCAM cameras in different test fields.
- Fourier APs vs Polynomial APs
  - Fourier APs are theoretically preferable
  - Fourier APs are more efficient (less APs)
  - Fourier APs obtain more realistic distortion results

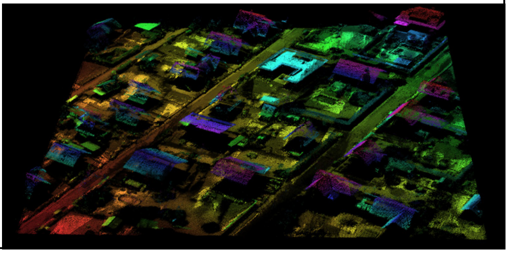
Fourier APs should be integrated in every Bundle Block Adjustment software!

2.5 References

- Tang R., Fritsch, D., Cramer M. & Schneider, W., 2012a: A flexible mathematical method for camera calibration in digital aerial photogrammetry. *Photogrammetric Engineering & Remote Sensing (PE&RS)*
- Tang, R., Fritsch, D. & Cramer, M., 2012b: New rigorous and flexible Fourier self-calibration models for airborne camera calibration. *ISPRS Journal of Photogrammetry and Remote Sensing*, 71: 76–85.
- Tang, R., Fritsch, D., 2013, Correlation Analysis of Camera Self-Calibration in Close Range Photogrammetry. *The Photogrammetric Record*, 28/141: 86-95.
- Tang, R., 2013, Mathematical Methods for Camera Self Calibration in Photogrammetry and Computer Vision. Deutsche Geod. Kommission, Reihe C, Nr. 392, Muenchen.

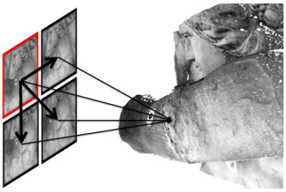
3.1 SURE History – SUrface REconstruction

- 2007-10: DGPF Camera Test, Working Group “Generation of Digital Terrain Models (Lead: N. Haala) – Fritsch became interested!
- 10/2009: After PhoWo’09 Interests of Vexcel Imaging GmbH on Study “Multiray Photogrammetry”
- 11/2009: Fritsch’ offer to Mathias Rothermel for PhD studies at ifp, started Jan 15, 2010, pilot programming of SGM algorithms
- 03/2010 Interests of LVG Munich on SGM, user of first ifp SGM pilot software, end 2010
- 05/2010: Kick-off meeting with Vexcel Imaging, study delivered Jan 12, 2011
- 04-12/2010: Master’s Thesis Konrad Wenzel in cooperation with Trimble inpho



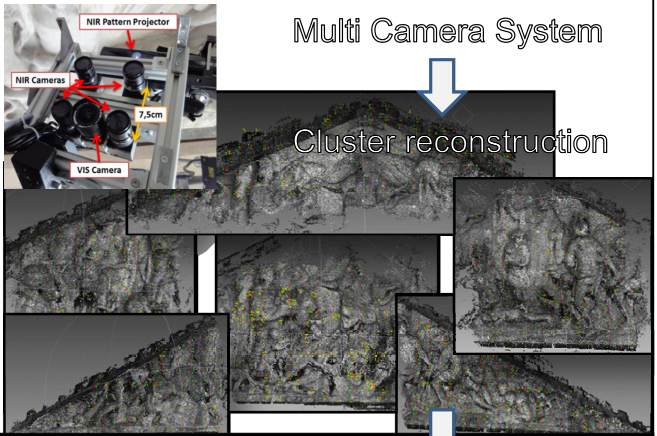
3.1 SURE History – SUrface REconstruction

- 10/2010: Contact with IB Christofori to reconstruct the 2 Tympana of the Amsterdam Royal Palace by Dense Image Matching using Close Range photogrammetry
- 11/2010: Fritsch' offer to Konrad Wenzel for PhD studies at ifp, started Jan 01, 2011, pilot programming of SGM algorithms
- 03/2011: Data collection in Amsterdam
- 10/2011: Delivery of dense point cloud to IB Christofori
- During period of data processing ifp developed own strategy for Structure-from-Motion and tSGM



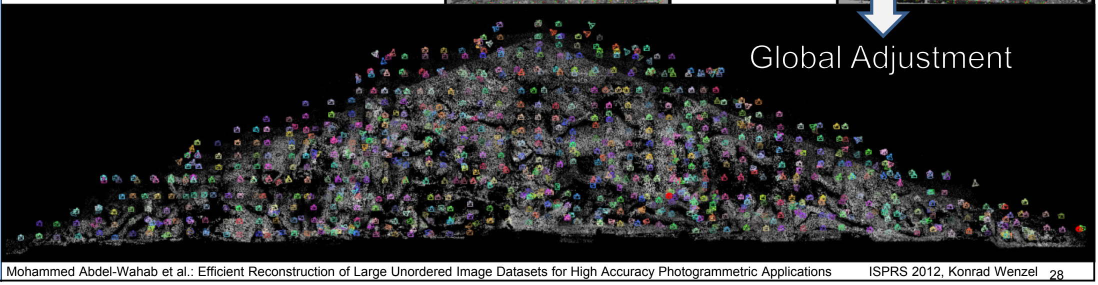
3.1 SURE History – The Amsterdam Project
West Façade

- Multi-Camera System
  - 5 industrial cameras
- About 4000 images
- 6 Clusters
- Global Adjustment
  - 1.1 Million points
  - RMS: 0.5 pixels
- Dense Matching (SGM): **1.1 Billion points**



Multi Camera System

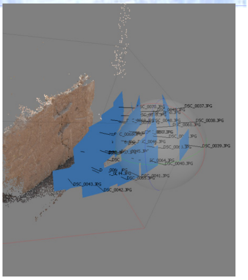
Cluster reconstruction

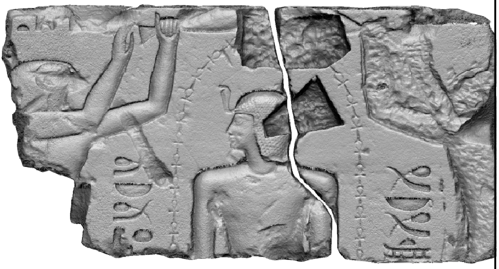


Global Adjustment

Mohammed Abdel-Wahab et al.: Efficient Reconstruction of Large Unordered Image Datasets for High Accuracy Photogrammetric Applications ISPRS 2012, Konrad Wenzel 28

3.1 SURE History - HD Hieroglyphs (Cairo, Eg)

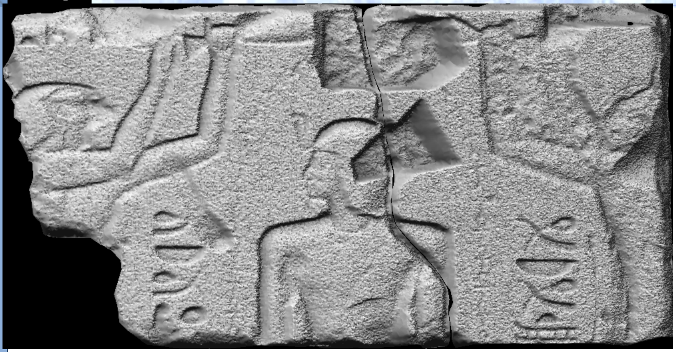




Reconstruction of the Akhenaten Temple in Heliopolis/Cairo (Joint Project of Univ Leipzig, Univ Stuttgart and German University in Cairo)

- First explorations/excavations 2011 & 2012
- Pilots for 3D reconstructions using laser scanning & photogrammetry
- Bundle Adjustment: **Visual SFM, bundler**
- 34 images, Nikon DX2, 14MPix, c=24mm
- Dense Image Matching: **SURE** > 5.5 million points

3.1 SURE History - HD Hieroglyphs (Cairo, Eg)



Laser scan, 1.4 Mio points
GSD 1-2mm

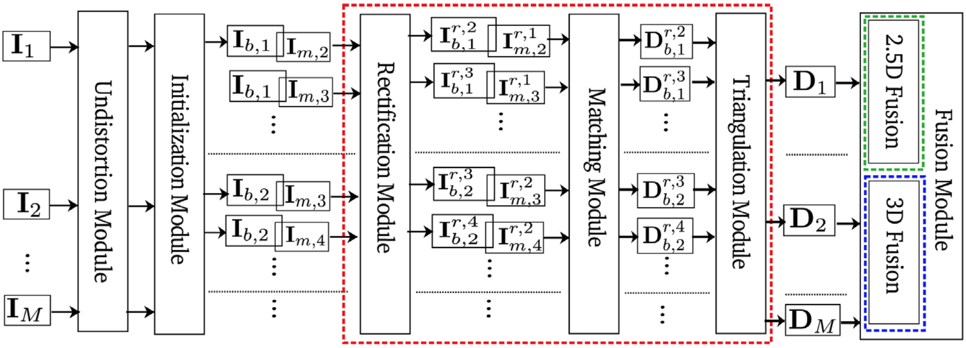
DIM@SURE, 5.5 Mio points
GSD 0.5mm

3.1 SURE History– SUrface REconstruction

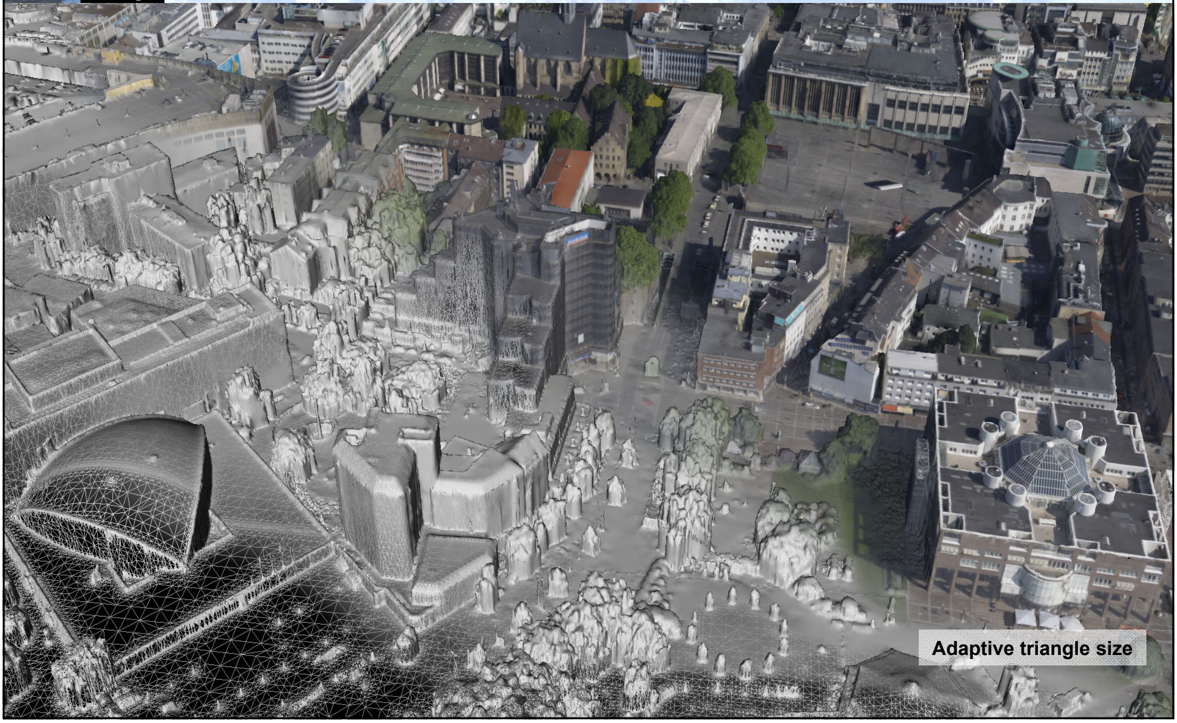
- 08/2011-03/2012: Feasibility study “Dense Image Matching for A3 Imagery” for VisionMap, Tel Aviv.
- 03-06/2012: Feasibility study for IGI with Oblique Imagery
- 05/2012-10/2012: Merger of two DIM software packages to one: SURE
- 12/2012: Publication *Rothermel, R., Wenzel, K., Fritsch, D.& Haala, N. “SURE: Photogrammetric Surface Reconstruction from Imagery, Proceedings LC3D Workshop, Berlin.*
- 06/2013: Decision to outsource further developments of SURE to nFrames, a TGU within the incubator TTI GmbH, Stuttgart
- 01/2015: All rights of SURE to nFrames GmbH, Stuttgart

3.2 SURE Update - Processing Pipeline Overview

- Structure of the dense matching pipeline



3.2 SURE Update – DSM Mesh



Adaptive triangle size

3.2 SURE Update – True Ortho Generation

Sharp edges

3. SURE Update – True Orthophotos

DSM edge refinement

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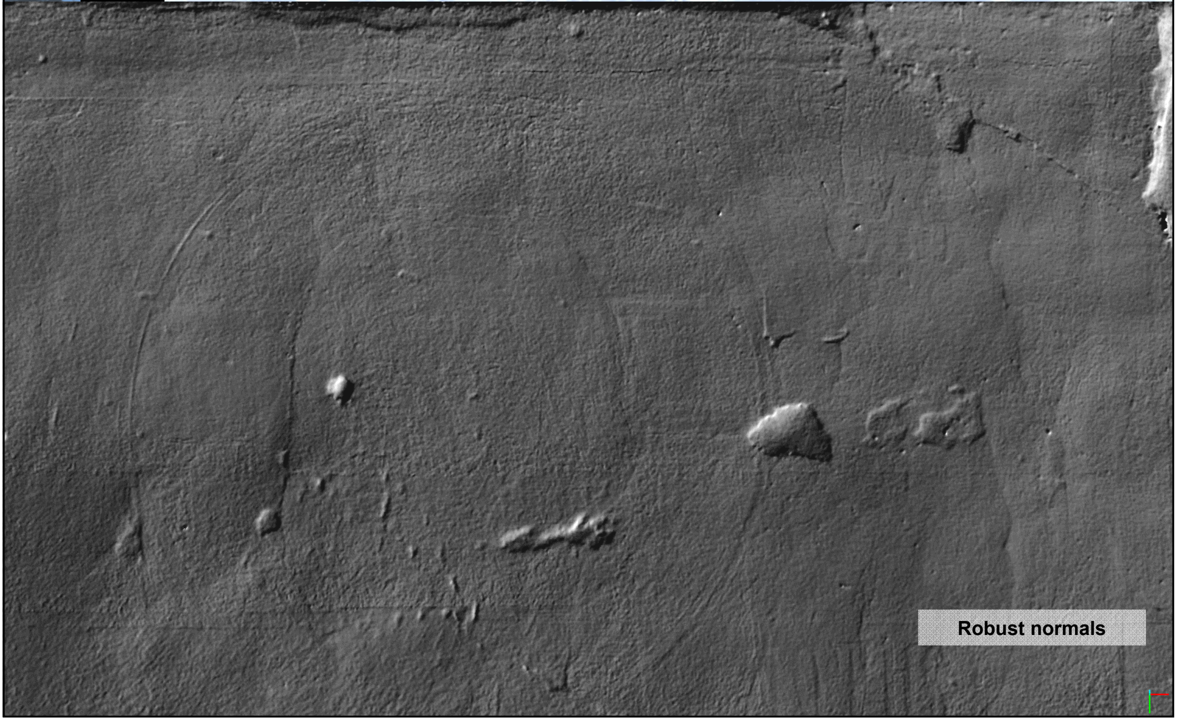
3. SURE Update – DSM Mesh

Automatic seam leveling

3.2 SURE Update – 3D Mesh, Icon Cyprus

Icon, Cyprus

3.2 SURE Update – 3D Mesh, Icon Cyprus



Robust normals

3.2 SURE Update – 3D Mesh

3.2 SURE Update - Mesh Texturing

- Each face is seen in multiple views, how to select texture?
  - Blending texture from multiple views
    - Visible seams due to inaccurate orientation
    - Differences in image scale: blurred textures
  - Select texture from best view
    - Criterion for best view, for example nearest non-blurred view
    - To avoid seams: neighboring faces should be textured from the same image
- Cast as global optimization problem

$$E(l) = \sum_{F_i \in \text{Faces}} E_{\text{data}}(F_i, l_i) + \sum_{(F_i, F_j) \in \text{Edges}} E_{\text{smooth}}(F_i, F_j, l_i, l_j)$$

Waechter, M., Moehrle, N., Goesele, M. 2014. Let There Be Color! Large-Scale Texturing of 3D Reconstruction. Computer Vision–ECCV 2014. Pages 836--850

3.2 SURE – Texture Mapping

Example Nadir Flight (80/80, 10cm GSD)

3.3 Summary

Key features SURE

- Scalability to large data sets - e.g. city scale projects
- Completely automatic and configurable
- Supports all frame cameras in nadir or oblique configuration
- 8 Bit and 16 Bit multispectral imagery support
- Generation of georeferenced DSM tiles
- Automatic True Ortho generation and refinement
- Automatic 2.5D and 3D texturized meshes
- Orientation interfaces for Match-AT, VSFM, Photoscan, Pix4D and many more
- Multi-core implementation & graphics card support
- Distributed processing
- Multiple interfaces – graphical, command line or APIs

3.4 References SURE (2012 only)

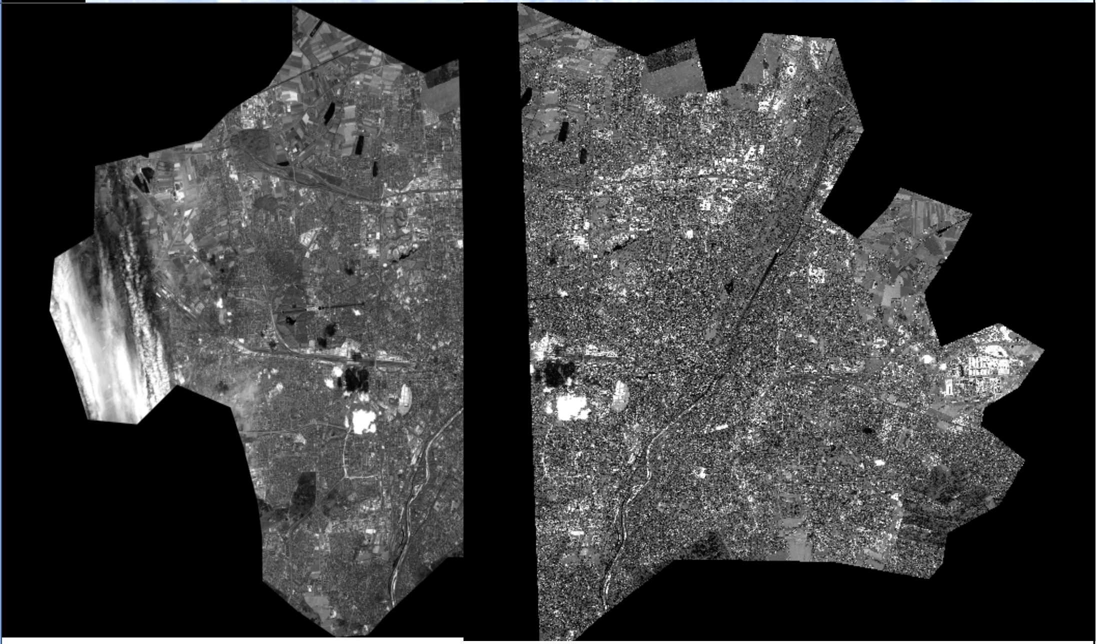
- Abel-Wahab, M., Wenzel, K., & Fritsch, D., 2012a: Efficient Reconstruction of Large Unordered Image Datasets for High Accuracy Photogrammetric Applications. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, I/P3, ISPRS Congress, Melbourne, Australia.
- Abdel-Wahab, M., Wenzel, K., & Fritsch, D., 2012b: Automated and Accurate Orientation of Large Unordered Image Datasets for Close Range Cultural Heritage Data Recording. Photogrammetrie-Fernerkundung-Geoinformation (PFG), 6/2012.
- Cramer, M.&Haala, N., 2012: Genauigkeitspotential der photogrammetrischen Bildauswertung für Daten unbemannter Luftfahrzeuge. DGPF-Jahrestagung, Potsdam.
- Fritsch, D., Kremer, J&Grimm, A., 2012: A Case Study of Dense Image Matching Using Oblique Imagery – Towards All-in-One Photogrammetry. GIM International, 4/2012.
- Fritsch, D., Adel-Wahab, M., Cefalu, A.&Wenzel, K. (2012): Photogrammetric point Cloud Collection with Multi-Camera Systems. In: Progress in Cultural heritage Preservation, Eds. M. Ioannides, D. Fritsch, J. leissner, R. Davies, F. Remondino, R. Caffo, LNCS, Springer, Berlin.
- Rothermel, M., Wenzel, K., Fritsch, D. & Haala, N. (2012): SURE: Photogrammetric Surface Reconstruction fro Imagery. Proceed. Workshop Low Cost 3D (LC3D), Berlin.

3.4 References SURE (2012 only)

- Fritsch, D., Pfeifer & Franzen, M, 2012: High Density Image Matching for DSM Computation. EuroSDR Workshop Proceedings.
- Haala, N. & Rothermel, M, 2012a: Dense Multiple Stereo Matching of Highly Overlapping UAV Imagery. Int. Arch. Photogr., Rem. Sens & Spatial Inform. Sci., B1, Comm. I, ISPRS Congress Melbourne, Australia.
- Haala, N. &Rothermel, M., 2012b: Dense Multi-Stereo Matching for High Quality Digital Elevation Models. Photogrammetrie-Fernerkundung-Geoinformation (PFG), 4/2012.
- Khosravani, A., Lingenfelder, M., Wenzel, K. & Fritsch, D., 2012: Co-Registration of Kinect Point Clouds Based on Image and Object Space Observations. Proceed. Low Cost 3D Workshop, Berlin.
- Moussa, W., Abdel-Wahab., M. &Fritsch, D., 2012a: An Automatic Procedure for Combining Digital Images and Laser Scanner Data. Int. Arch. Photogr., Rem. Sens. & Spatial Inform. Sci., B5, ISPRS Congress Melbourne, Australia.
- Moussa, W., Abdel-Wahab, M. &Fritsch, D., 2012b: Automatic Fusion of Digital Images and Laser Scanner Data for Heritage Preservation. In: M. Ioannides et al, LNCS, Springer, Berlin.
- Rothermel, M., Wenzel, K., Fritsch, D. & Haala, N. (2012): SURE: Photogrammetric Surface Reconstruction fro Imagery. Proceed. Workshop Low Cost 3D (LC3D), Berlin.

4.1 Geometric Processing of WorldView-2

The Munich Stereo Images – Example 1



Copyright: DigitalGlobe

4.1 Geometric Processing of WV-2 Imagery

Rational Polynomial Coefficients

- Usually, satellite imagery does not provide the interior and exterior elements, but Rational Polynomial Coefficients (RPCs).

$$y = \frac{Num_L(B,L,H)}{Den_L(B,L,H)}$$

$$x = \frac{Num_S(B,L,H)}{Den_S(B,L,H)}$$

$$\begin{cases} B = \dfrac{lat - lat\_off}{lat\_scale} \\ L = \dfrac{lon - long\_off}{long\_scale} \\ H = \dfrac{h - height\_off}{height\_scale} \\ y = \dfrac{j - line\_off}{line\_scale} \\ x = \dfrac{i - sample\_off}{sample\_scale} \end{cases}$$

- For NumL, DenL, Nums and Dens, each one is a function of normalized latitude, longitude and elevation with 20 coefficients. So 80 coefficients for all.

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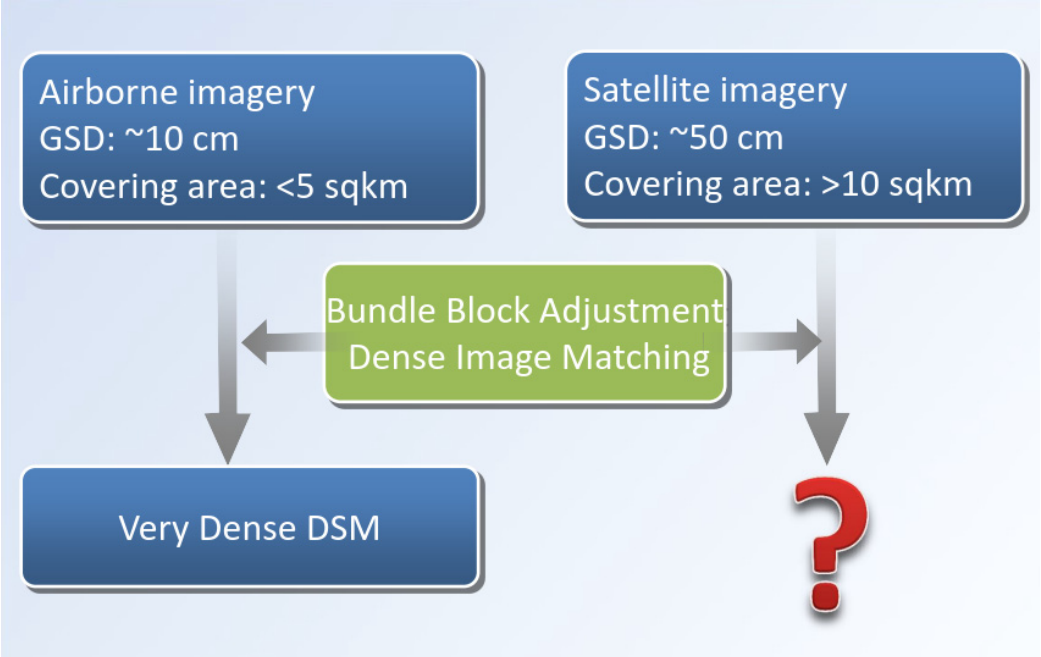
Part II – Research Projects

4.1 Geometric processing of WV-2 Imagery

Challenges



Airborne imagery
GSD: ~10 cm
Covering area: <5 sqkm

Satellite imagery
GSD: ~50 cm
Covering area: >10 sqkm

Bundle Block Adjustment
Dense Image Matching

Very Dense DSM

?

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4.2 Geometric Processing of WV-2 Imagery

Bias-Compensation

- With RPCs a bundle block adjustment can be done, but the accuracy of RPCs provided by satellite data provider is low. Therefore, often an affine model is used to compensate the bias.

$$\Delta p^{(j)} = a_0^{(j)} + a_S^{(j)} * \overline{sample_i}^{(j)} + a_L^{(j)} * \overline{line_i}^{(j)}$$

$$\Delta r^{(j)} = b_0^{(j)} + b_S^{(j)} * \overline{sample_i}^{(j)} + b_L^{(j)} * \overline{line_i}^{(j)}$$

- For each point i on image j the RPC bundle block adjustment observation equations are:

$$F_{Li} = -line_i^{(j)} + p^{(j)}(\phi_k, \lambda_k, h_k) + \varepsilon_{Li} + \underline{\Delta p^{(j)}} = 0$$

$$F_{Si} = -sample_i^{(j)} + r^{(j)}(\phi_k, \lambda_k, h_k) + \varepsilon_{Si} + \underline{\Delta r^{(j)}} = 0$$

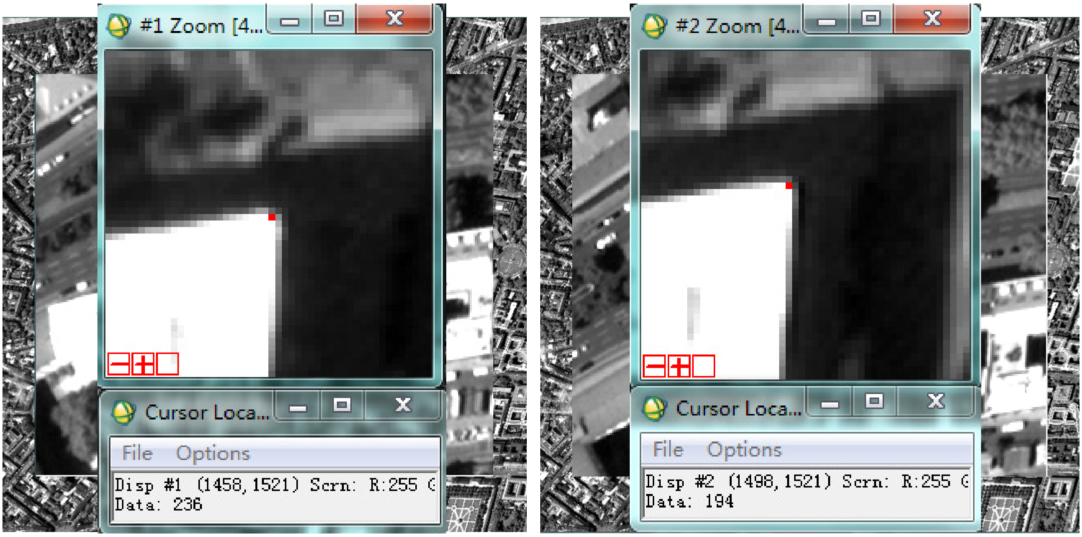
4.3 Geometric Processing of WV-2 Imagery

Epipolar Image Generation

- Epipolar images are images without any vertical parallax or disparity.
- For traditional frame imagery, the perspective centre is fixed, the epipolar line is the intersection between the epipolar plane and the image plane.
- For push-broom sensors, the perspective centre is changing (as a function of time).
- How to solve the problem? With the projection trajectory method based on RPCs.

4.2 Geometric Processing of WorldView-2

Epipolar Image

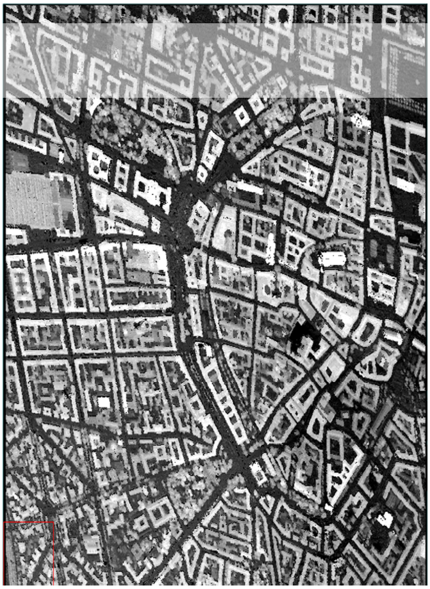


```
Disp #1 (1458,1521) Scrn: R:255
Data: 236
```

```
Disp #2 (1498,1521) Scrn: R:255
Data: 194
```

4.3 Geometric processing of WV-2 Imagery

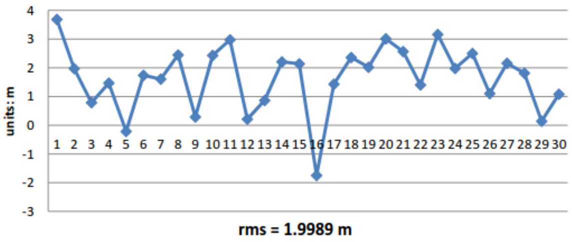
Disparity Image and DSM

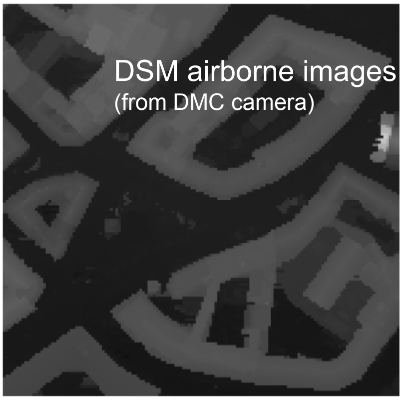


4.3 Geometric Processing of WV-2 Imagery

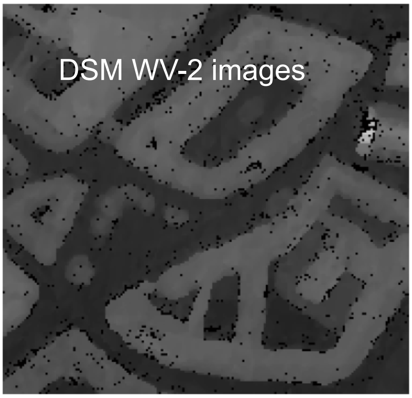
DSM Results

Vertical difference at check points from airborne LiDAR





DSM airborne images
(from DMC camera)

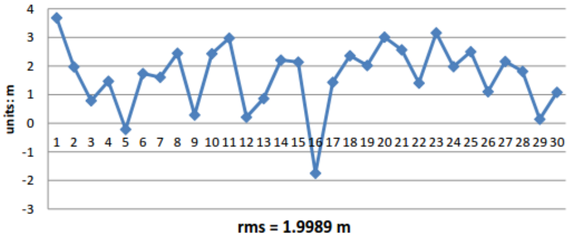


DSM WV-2 images

4.3 Geometric Processing of WV-2 Imagery

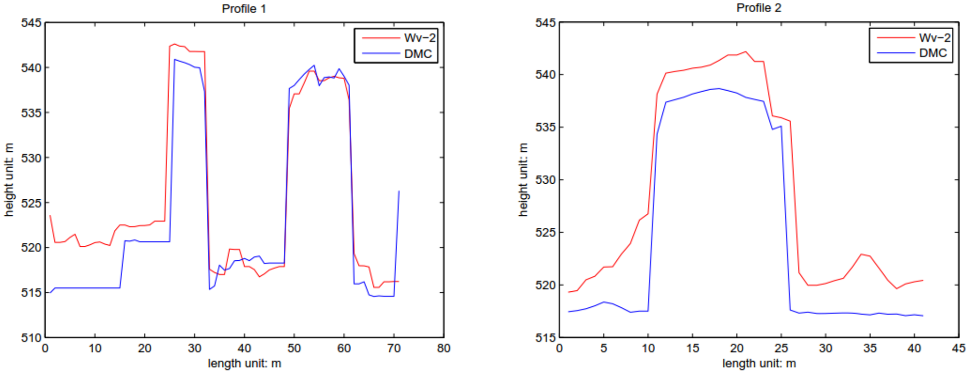
DSM Accuracy Analysis

Vertical difference at check points from airborne LiDAR



- P1: 20 ChP DMC vs WV-2: RMS 1.41m
- P2: 20 ChP DMC vs WV-2: RMS 2,09m

Vertical profiles DSM from DMC versus DSM from WV-2



4.4 Summary

- QuickBird and WV-2 images have been processed using an affine distortion model.
- Epipolar image generation using RCP trajectories
- Dense Image Matching with SURE delivers reasonable results: along roofs 1.4m RMS, along terrain 2.1m RMS
- Not yet all optimizations explored, we just started!
- Will continue with WV-3 imagery

5. Conclusions

- The Institute for Photogrammetry of the University of Stuttgart continued with the tradition to make an impact to R&D in photogrammetry, remote sensing and geoinformatics.
- Excellent staff members contributed to these developments in the last 5 decades
- **Remember the date: April 8, 2016 – 50th Anniversary of ifp, Stuttgart**
- Teaching is video-casted since 2006 – worldwide recognition!
- Exports of Teaching to GUC, Cairo and Berlin
- Exports of Teaching to SUSTECH, Khartoum, Sudan
- The Photogrammetric Week Series got a new profile in 2003 – open for all participants, open for Open PhoWo Partners!

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6. Staff Members Institute for Photogrammetry, Univ. Stuttgart (1992-2015)

Martina Kroma, Werner Schneider, Markus Englich, Dr. Eberhard Stark,
Prof Norbert Haala, Dr. Volker Walter, Dr. Michael Cramer, Prof. Ralf Bill,
Prof. Michael Hahn, Prof. Ulrike Klein, Dr. Michael Glemser, Dr. Babak Ameri,
Dieter Schmidt, Dieter Kraus, Prof. Monika Sester, Prof. Claus Brenner,
Prof. Jan Böhm, Prof. Timo Balz, Prof. Martin Kada, Prof. George Vosselman,
Prof. Yahya Alshawabkeh, Dr. Susanne Becker, Prof. Karl-Heinrich Anders,
Martin Bofinger, Reinhold Burger, Dr. Jens Gühring, Beate Haala, Prof. Ralf Reulke,
Jürgen Hefele, Dr. Heiner Hild, Dr. Michael Kiefner, Johannes Kilian,
Darko Klinec, Daud Nwir, Dr. Michael Peter, Berthold Plietker,
Antje Quednau, Esther Hinz, Dirk Stallmann, Dr. Holger Schade,
Thomas Schürle, Sarah Schuhmacher, Dr. Carola Stauch, Christian Stätter,
Alessandro Cefalu, Konrad Wenzel, Mathias Rothermel, Dr. Vassilis Tsingas,
Franz Schneider, Chien-Tzung Tschiang, Yinyin Tun, Patrick Tutzauer,
Dr. Steffen Volz, Heike Weippert, Marianne Wind, Dr. Wassim Moussa, Dr. Fen Luo
Ali Khosravani, Dr. Wolfgang Schmid, Mohammed Othman, Dr. Hainan Chen,
Dr. Alexander Fietz, Dr. Yevgeniya Filippovska, Dr. Silke Rossipal, Dr. Rongfu Tang

Thank you all for your strong support – you made an impact!

Thank you for Participating the 55th Photogrammetric Week.

… when it started at the 44th Photogrammetric Week 1993

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