

The Open Source Software Package UNIT&D

Controlling, Measuring and Analysing



Metrology...

- Interdisciplinary area of expertise e.g. physicists, mechanical or surveying engineers
- Different approaches and principles of operation
- Collaboration and exchange of knowledge required
 - Consistent terminology
 - Established working practice
- Guide to the expression of uncertainty in measurement
 - Supplement 1: Propagation of distributions using Monte Carlo method
 - Supplement 2: Extension to any number of output quantities

Software...

- Most of (commercial) software packages do not support GUM
- Implemented algorithms are black-boxes and often undocumented
- Key parameters are missing
- Uncertainties are derived in a non-traceable way

- Conclusion of external comparisons of metrology software packages
 - Radomi & Schlösser (2010): *“There are significant differences in the results.”*
 - Hermann et al. (2015): *“The reason for the differences [...] could not be distinguished clearly.”*

ISO-25000: *“It is important that any quality feature of a software product is determined and evaluated whenever possible using validated or generally accepted measures.”*

UNITED...

Milestones

- Sensor communication (e.g. Lösler et al. 2013)
- Prototype for 6-DOF bundle adjustment (e.g. Lösler & Eschelbach 2012)
- Toolbox for analysing geometric primitives (e.g. Lösler & Nitschke 2010)

Combining components → UNITED

- Smart software solution for metrology and engineering
- Customised for survey engineers
- Restricted to essential components to ensure intuitive operation and handling
- Rigorous analysis using e.g. errors-in-variables model
- Focused on GUM to estimate traceable uncertainties
- Extending scope of operation e.g. congruence analysis

Sensors...

Metrology sensors

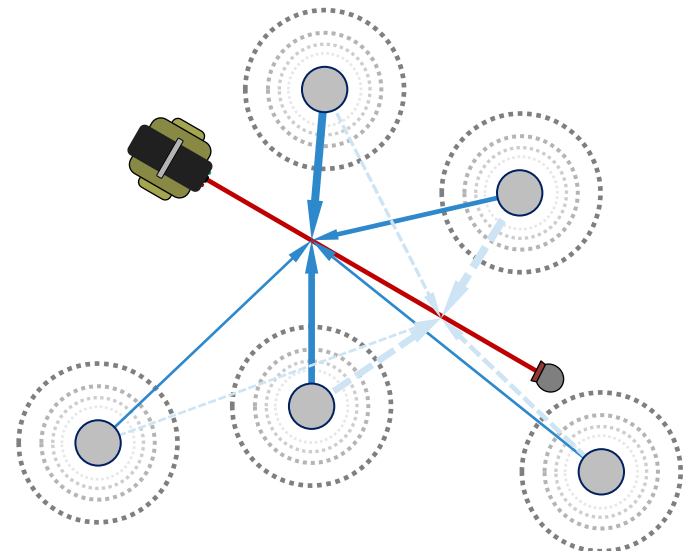
- Total stations via GeoCOM (Leica)
- Laser tracker AT40x (Leica) and Omnitrac 2 (API)

Meteorology sensors

- Wireless sensor network (TSYS01, SHT21, BMP280)
- Meteorological station GFTB100
- Data logger MSR145

First velocity correction (Ciddor 2002)

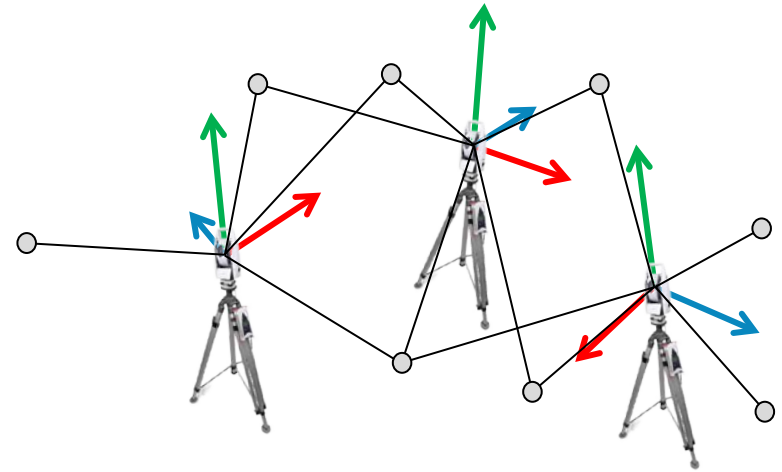
- Inverse distance weighting
- Piecewise correction of electronic distance measurement unit



Bundle Adjustment...

Functional model

- Rigorous combination of observations of k instrument locations
- Quaternion algebra for bilinear equations
- Gauß-Markov model with restrictions

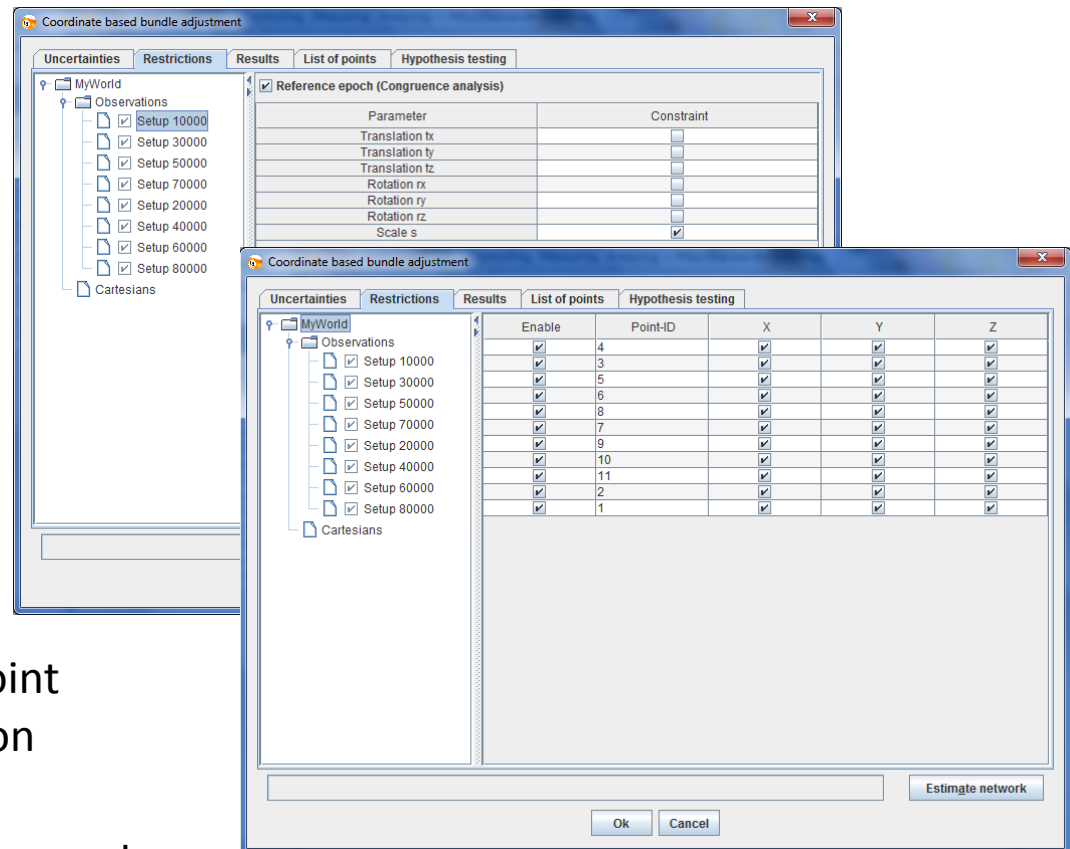


$$\begin{bmatrix} \mathbf{A}_{\tilde{\mathbf{p}},1} & \mathbf{A}_{\mathbf{T},1} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{A}_{\tilde{\mathbf{p}},2} & \mathbf{0} & \mathbf{A}_{\mathbf{T},2} & \cdots & \mathbf{0} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}_{\tilde{\mathbf{p}},k} & \mathbf{0} & \mathbf{0} & \cdots & \mathbf{A}_{\mathbf{T},k} \end{bmatrix} \begin{bmatrix} \mathbf{x}_{\tilde{\mathbf{p}}} \\ \mathbf{x}_{\mathbf{T}_1} \\ \mathbf{x}_{\mathbf{T}_2} \\ \vdots \\ \mathbf{x}_{\mathbf{T}_k} \end{bmatrix} = \begin{bmatrix} \mathbf{l}_{\mathbf{p},1} \\ \mathbf{l}_{\mathbf{p},2} \\ \vdots \\ \mathbf{l}_{\mathbf{p},k} \end{bmatrix} + \begin{bmatrix} \mathbf{v}_{\mathbf{p},1} \\ \mathbf{v}_{\mathbf{p},2} \\ \vdots \\ \mathbf{v}_{\mathbf{p},k} \end{bmatrix}$$

Bundle Adjustment...

Restrictions in functional model

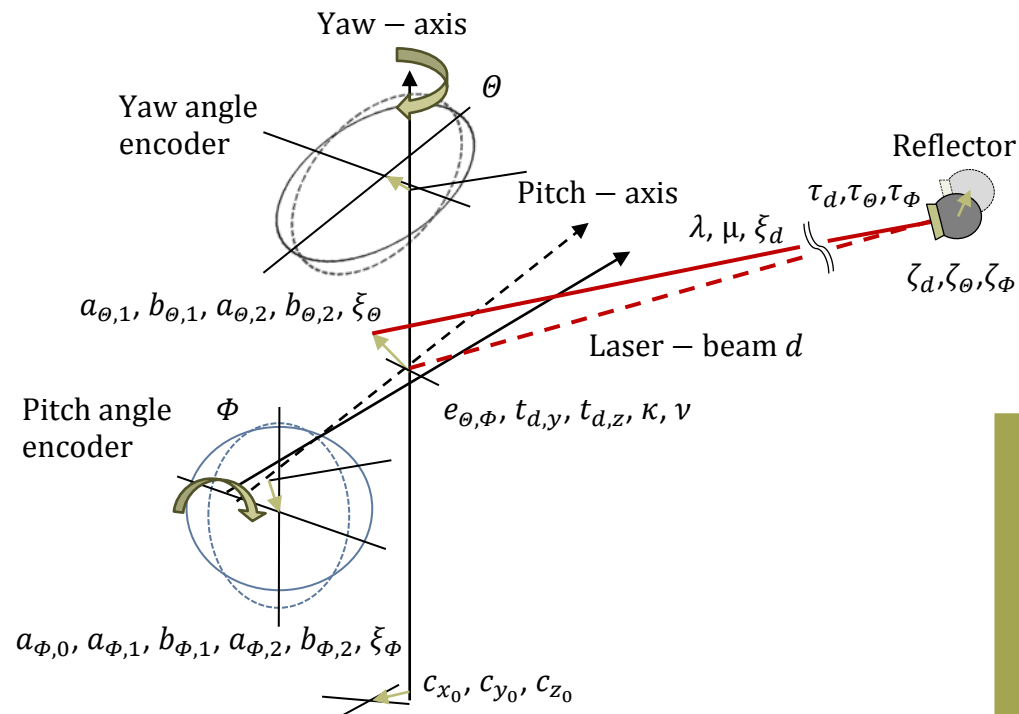
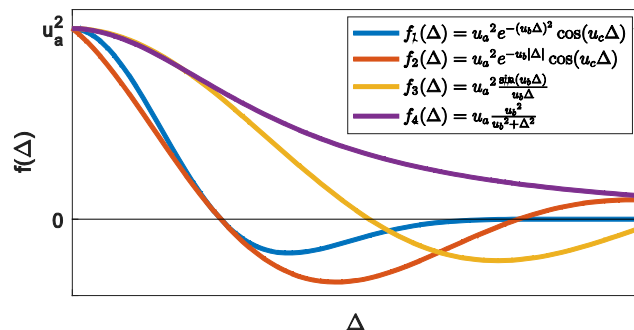
- Constraining the number of integration parameters e.g. fixing scale parameter
- Datum restrictions to solve the rank deficiency of normal equation
- Free choice of definition of geodetic datum, i.e. defining point components for datum definition
- Note: Non-datum points are also used to combine local instrument frames



Bundle Adjustment...

Stochastic model

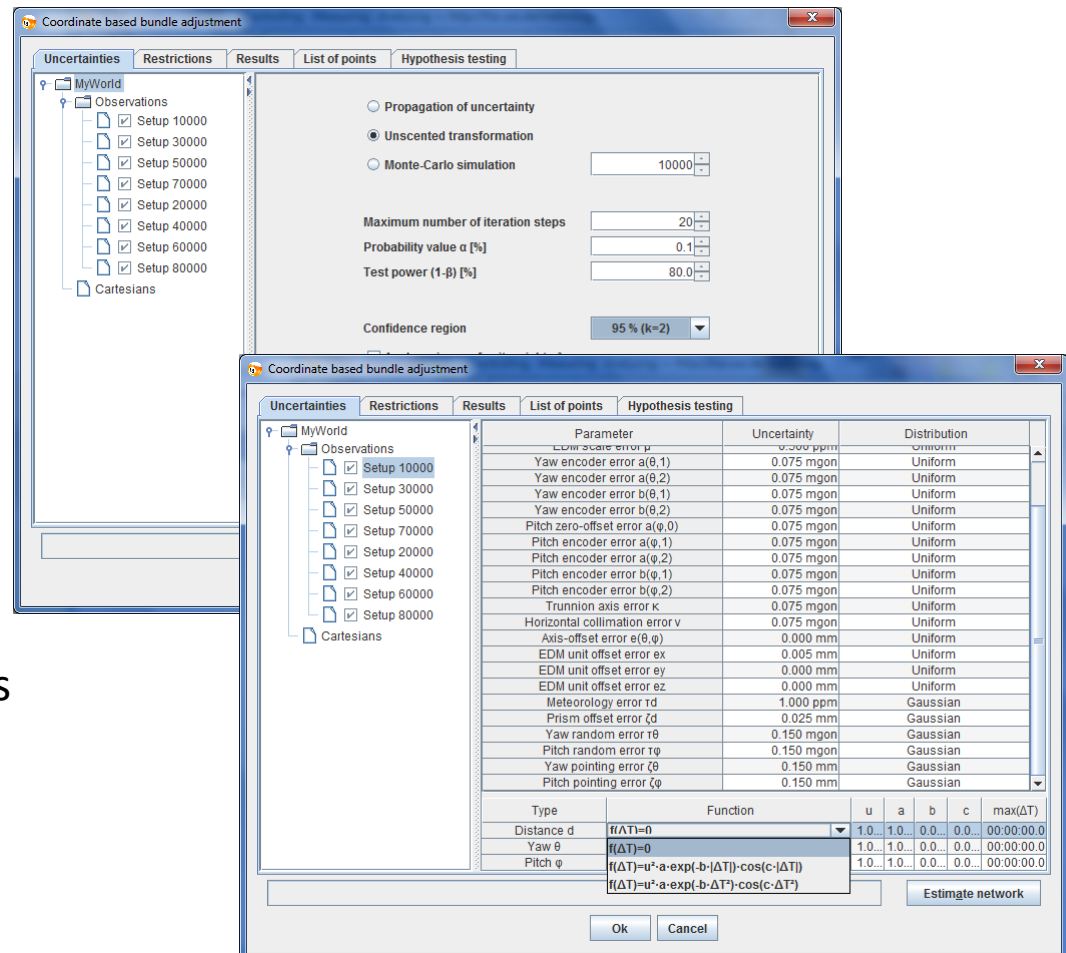
- Extended version of Hughes et al. (2011) compensation model, cf. Lösler et al. (2016)
- Converting polar observations to Cartesian coordinates
- Considering correlation functions for time-dependent covariances
- Fully populated variance-covariance matrix per instrument frame



Bundle Adjustment...

Stochastic model

- Propagation of uncertainty
- Unscented transformation (2nd order Taylor expansion)
- Monte-Carlo simulation
- 25 uncertainty-parameters per instrument frame
- Two correlation functions for time-dependent covariances



Further analyses components...

- Congruence analysis based on original observations
- Stability check of reference point group
- Consideration of inter-epochal correlations
- Fitting of geometric primitives, e.g. spatial ellipse, elliptic cylinder etc.
- Errors-in-variables model
- Taking fully populated variance-covariance matrix of bundle adjustment into account
- Applying offset correction during adjustment process

Coordinate based bundle adjustment

Uncertainties Restrictions Results List of points Hypothesis testing

MyWorld
Observations
Cartesians

Parameters Uncertainties Confidences Redundancy Gross error Test statistic

Enable	Point-ID	uX [mm]s	uY [mm]s	uZ [mm]s	∇X [mm]	∇Y [mm]	∇Z [mm]	$\ \nabla\ $ [mm]	T	T > 5.42
<input checked="" type="checkbox"/>	1	0.306	0.311	0.300	-1.537	0.111	-0.297	1.569	8.98	<input checked="" type="checkbox"/>
<input checked="" type="checkbox"/>	6	0.234	0.236	0.232	0.668	0.086	0.098	0.681	4.00	<input type="checkbox"/>
<input checked="" type="checkbox"/>	5	0.248	0.244	0.244	-0.646	-0.052	-0.013	0.648	3.00	<input type="checkbox"/>
<input checked="" type="checkbox"/>	2	0.259	0.260	0.263	0.314	-0.129	-0.033	0.341	0.81	<input type="checkbox"/>
<input checked="" type="checkbox"/>	9	0.231	0.236	0.240	0.148	-0.010	0.097	0.178	0.25	<input type="checkbox"/>
<input checked="" type="checkbox"/>	3	0.321	0.241	0.333	0.114	0.082	0.135	0.195	0.13	<input type="checkbox"/>
<input checked="" type="checkbox"/>	7	0.273	0.261	0.272	0.034	-0.111	0.055	0.129	0.10	<input type="checkbox"/>
<input checked="" type="checkbox"/>	8	0.225	0.235	0.225	0.039	-0.079	-0.010	0.089	0.07	<input type="checkbox"/>
<input checked="" type="checkbox"/>	10	0.224	0.235	0.223	0.002	-0.004	-0.094	0.094	0.07	<input type="checkbox"/>
<input checked="" type="checkbox"/>	4	0.230	0.235	0.241	0.025	-0.040	0.066	0.081	0.04	<input type="checkbox"/>
<input checked="" type="checkbox"/>	11	0.233	0.233	0.227	-0.001	0.050	-0.020	0.054	0.03	<input type="checkbox"/>

Surface fitting

Spatial ellipse

Maximum number of iteration steps: 20
Probability value α [%]: 0.1
Test power (1- β) [%]: 80.0
Levenberg-Marquardt parameter μ : 0.0
Confidence region: 95 % (k=2)
Planar offset ϵ [mm]: -19.050
Radial offset δ [mm]: -19.050
 Apply variance of unit weight σ^2

$\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$ $\begin{pmatrix} u^2 & 0 & 0 \\ 0 & u^2 & 0 \\ 0 & 0 & u^2 \end{pmatrix}$ $\begin{pmatrix} u^2 & \times & \times \\ \times & u^2 & \times \\ \times & \times & u^2 \end{pmatrix}$

Type	Value	uss
tx	99.81793 m	0.055 mm
ty	209.44946 m	0.118 mm
tz	59.66392 m	0.186 mm
a	0.02645 m	0.090 mm
b	0.02618 m	0.110 mm
nx	-0.9998270 m	0.026 ppm
ny	0.0175778 m	1.388 ppm
nz	-0.0060851 m	1.848 ppm

List of points Points on surface Perpendicular points

Parameters Uncertainties Confidences Redundancy Gross error Test statistic

Enable	Point-ID	X [m]	Y [m]	Z [m]	uMax [mm]s	uMid [mm]s	uMin [mm]s
<input checked="" type="checkbox"/>	27651	99.81774	209.44771	59.89015	0.349	0.259	0.069
<input checked="" type="checkbox"/>	27652	99.81747	209.42907	59.88077	0.416	0.191	0.066
<input checked="" type="checkbox"/>	27653	99.81745	209.42316	59.86595	0.457	0.154	0.064
<input checked="" type="checkbox"/>	27654	99.81763	209.42770	59.84930	0.410	0.188	0.066
<input checked="" type="checkbox"/>	27655	99.81805	209.44739	59.83775	0.349	0.258	0.070
<input checked="" type="checkbox"/>	27656	99.81837	209.46822	59.84529	0.409	0.203	0.068
<input checked="" type="checkbox"/>	27657	99.81839	209.47581	59.86370	0.457	0.160	0.066
<input checked="" type="checkbox"/>	27658	99.81812	209.46707	59.88330	0.390	0.211	0.068
<input checked="" type="checkbox"/>	27671	99.81756	209.43674	59.88706	0.278	0.178	0.065
<input checked="" type="checkbox"/>	27672	99.81744	209.42505	59.87408	0.395	0.149	0.063
<input checked="" type="checkbox"/>	27673	99.81753	209.42424	59.85652	0.430	0.152	0.064
<input checked="" type="checkbox"/>	27674	99.81788	209.43858	59.84009	0.280	0.187	0.066
<input checked="" type="checkbox"/>	27675	99.81825	209.45958	59.83957	0.270	0.185	0.066
<input checked="" type="checkbox"/>	27676	99.81841	209.47273	59.85136	0.375	0.156	0.064
<input checked="" type="checkbox"/>	27677	99.81834	209.47496	59.87031	0.439	0.154	0.065
<input checked="" type="checkbox"/>	27678	99.81802	209.46262	59.88655	0.288	0.184	0.065

Estimate surface

Ok Cancel

Thank you for your attention...

If the *kits* are
UNITED

References...

- Ciddor, P. (2002): Refractive index of air: 3. The role of CO₂, H₂O, and refractivity virials. *Appl Opt*, 41, doi:10.1364/AO.41.002292, pp. 2292-2298.
- Herrmann, C.; Lösler, M.; Bähr, H. (2015): Comparison of SpatialAnalyzer and Different Adjustment Programs. In: Kutterer, H.; Seitz, F.; Schmidt, M. (Eds.): Proceedings of the 1st International Workshop on the Quality of Geodetic Observation and Monitoring Systems (QuGOMS'11) International Association of Geodesy Symposia Volume 140, Springer, doi: 10.1007/978-3-319-10828-5_12, pp. 79-84.
- Hughes, B.; Forbes, A.; Lewis, A.; Sun, W.; Veal, D.; Nasr, K. (2011): Laser tracker error determination using a network measurement. *MeasSci Technol*, 22(4), doi:10.1088/0957-0233/22/4/045103, pp. 1-12
- Lösler, M.; Nitschke, M. (2010): Determination of the parameters of a spatial regressions ellipse (in German). *Allgemeine Vermessungs-Nachrichten*, 117(3), pp. 113-117.
- Lösler, M.; Eschelbach, C. (2012): Concept of a Realisation of a Prototype for Adequate Evaluation of Polar Measurements (in German). *Allgemeine Vermessungs-Nachrichten*, 119(7), pp. 249-258.
- Lösler, M.; Haas, R.; Eschelbach, C. (2013): Automated and continual determination of radio telescope reference points with sub-mm accuracy: results from a campaign at the Onsala Space Observatory. *J Geod*, 87(8), doi:10.1007/s00190-013-0647-y, pp. 791-804.
- Lösler, M.; Haas, R.; Eschelbach, C. (2016): Terrestrial monitoring of a radio telescope reference point using comprehensive uncertainty budgeting - Investigations during CONT14 at the Onsala Space Observatory. *J Geod*, 90(5), doi: 10.1007/s00190-016-0887-8, pp. 467-486.
- Radomi, P.; Schlösser, M. (2010): Adjustment with Least Squares Method, two software packages – two results. 11th International Workshop on Accelerator Alignment (IWAA), 13.-17. September 2010, DESY, Hamburg.