



Surveyor's Applications for Least Squares Adjustment

An Open Source Geodetic Least Squares Adjustment Software Suite



Stephen Johnson¹, J. Clark Hughes¹, Corwin Olson¹, Jae-Ho Song¹, Brian Tolman¹, Don Tucker¹, Bradley Beal²
¹Applied Research Laboratories, The University of Texas at Austin, ²National Geospatial-Intelligence Agency

Download: <https://www.arlut.utexas.edu/salsa>



Motivation / Objective

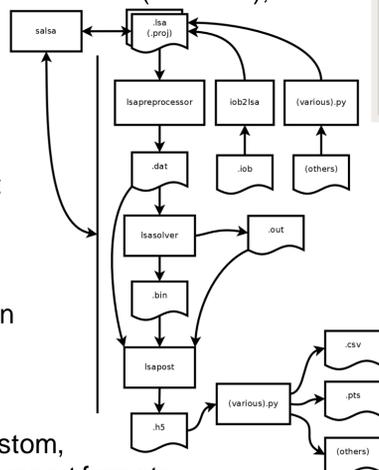
- Motivation:** user-friendly, high performance 3D (versus 2D+1) weighted least squares (WLS) adjustment program for survey applications that is also rigorous and transparent (open source)
- Objective:** optimally combine dissimilar spatial measurements to minimize survey network measurement residuals, yield optimal estimates of surveyed point positions to desired precision with desired confidence and redundancy (and no blunders)

Software

- Free and open source: GNU General Public License (GPLv3)
- C++ (user interface and processing engine)
- Open source libraries employed: ARL:UT GPS Toolkit, Eigen, Marble, Qt, others
- Supports Microsoft Windows and Linux

Processing Engine

- Three Command Line Interface Programs:** prep, solver, post
- Two methods for 3D iterative linearized WLS Adjustment:**
 - Square Root Information Filter
 - Conjugate Gradient Method (Eigen)
- Frame:** WGS 84 geodetic frame (Cartesian ECEF)
- Gravity models included:** EGM08, EGM96
- Geoid undulations:** global or user-specified geoid models
- Accepts all common geodetic survey measurement types:** Distances; Direction Sets; Horizontal and Vertical Angles; Height Differences; GNSS-Derived: 3D Vectors (Diff Proc), Absolute Positions (PPP)
- A priori computations (as needed):**
 - Delta Addition
 - Azimuth Vector Addition
 - Horizontal Angle Vector Addition
 - Triangulation
 - Two Azimuth Lines
 - Resection (3-point Resection Problem)
 - Ranging
 - Leveling Loop Formation
 - Side shot handling
 - Center of Mass
- Derived Points:** 1) 3D Offset 2) Mean (all cross covariance info mapped)
- Constraints:** constrain positions in East, North, and/or Up directions
- Import / Export Scripts:** including custom, converters for input measurements, report formats
- Reduced Dimension:** 1D (Leveling) and 2D adjustments



User Interface

Main UI: **Resizable & Dockable** Widgets

Project Navigator

Record	Summary	Scale	Details
PROJECT	/home/rmlburn/Desktop/example01/example01.proj		
INCLUDE	Auto-Generated Initial Coordinates	1.000	
INCLUDE	ctrl_sites.lsa	1.000	
INCLUDE	gpsMeasurements.lsa	4.000	
UNCR	UNCR_DXYZ_STATIC at: 0 from: 0.001 to: 0.001 m ppm: 0 sigma: 0 m		
VSCA	vscadXYZ		
DXYZ	P513, TP1	4.000	32695.187 m
DXYZ	P513, TP2	4.000	32594.319 m
DXYZ	P513, TP3	4.000	32668.376 m
DXYZ	VNDP, TP1	4.000	19473.638 m
DXYZ	VNDP, TP2	4.000	19755.231 m
DXYZ	VNDP, TP3	4.000	19945.888 m
INCLUDE	conventional.lsa	1.000	
UNCR	UNCR_HDIR at: 0 from: 0.001 to: 0.001 m ppm: 0 sigma: 0 m		
UNCR	UNCR_ZANG at: 0 from: 0.001 to: 0.001 m ppm: 0 sigma: 10 soa		
UNCR	UNCR_DIST_IR at: 0 from: 0.001 to: 0.001 m ppm: 0 sigma: 0 m		
UNCR	UNCR_DIST_RED at: 0 from: 0.001 to: 0.001 m ppm: 0 sigma: 0 m		
HGHT	HGHT_TP1		1.616 m
HGHT	HGHT_TP2		1.577 m
HGHT	HGHT_TP3		1.615 m
DGRP	DGRP_1, TP1	1.000	
DGRP	DGRP_2, TP2	1.000	
DGRP	DGRP_3, TP3	1.000	

Adjustment Summaries

Meas	From (At)	To	Raw	Rel
DXYZ.X	VNDP	TP1	0.004	0.53
DXYZ.X	P513	TP1	0.003	0.46
HDIR	TP2	POLE	0.553	0.16
DXYZ.Y	VNDP	TP2	0.015	0.44
DIST	TP1	TP2	0.000	0.24
DXYZ.Z	VNDP	TP1	0.000	0.34

Status Window

Processing Time (sec): 0.008
 Num Observations: 44
 Num Unknowns: 15
 Degrees of Freedom: 29
 Min Redundancy: 0.1008 > 0.0100

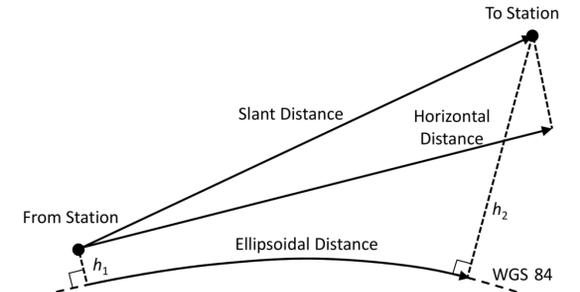
Convergence Test: **PASS**
 Convergence (m): 1.29e-06
 Conv Limit (m): 1.00e-05
 Iterations: 4
 Max Iterations: --

Chi-Squared Test: **PASS**
 Chi-Squared/nDOF (APV): 1.279
 Chi-Squared: 0.611 < 1.279 < 1.467
 Confidence Level: 95.0%

Degrees of freedom = 29; Std dev of unit weight = 1.13090; APV = 1.27894 (Final)
 RMS post-fit raw residual (angles) (Final) = 2.9e-05 rad = 6.0e+00 soa.
 RMS post-fit raw residual (length) (Final) = 1.19639e-02 m.
 Two-sided Chi-squared test (0.825, 0.975): 0.553 < 1.279 < 1.577 pass
 lsasolver timing: 0.008 seconds. (0.000 sec)
 13:53:08.716 lsapost starting... COMPLETED
 13:53:09.046 h5ReportGenerator.py starting... COMPLETED
 --- Mon Oct 28 13:53:10 2019

Definitions

- Convergence Metric:** RMS of adjustment (state update) vector
- Raw Residuals:** Postfit Measurement Residuals, R_{raw}
- Relative Residuals:** $R_{rel} = \sqrt{MCov}^{-1} R_{raw}$ ($\sqrt{MCov} \sqrt{MCov}^T = MCov$)
- Chi-Squared Metric:** $\chi^2 = (RMS(R_{rel}))^2 N_{obs}$
- Redundancy:** $Q_{RR} = MCov - H Cov H^T$
 $Rd = [Q_{RR,11} MCov^{-1}_{11} \quad Q_{RR,22} MCov^{-1}_{22} \quad \dots]^T$
- Degrees of Freedom (Observables Redundancy):** $N_{DOF} = N_{obs} - N_{Unknowns}$
- A posteriori variance (APV):** $APV = \chi^2 / N_{DOF}$ (Scale Covariance by APV)
- Standard Residuals:** $R_{rel} = [R_{rel,1} / \sqrt{APV \cdot Rd_1} \quad R_{rel,2} / \sqrt{APV \cdot Rd_2} \quad \dots]^T$



Station Inverse Dialog

Station Selected Pair: From: TP1, To: VNDP

Station Inverse Pairs:

From Station	To Station
1 P513	POLE
2 TP1	VNDP
3 TP2	VNDP
4 TP3	POLE

Relative Geodetic (WGS84) Data:

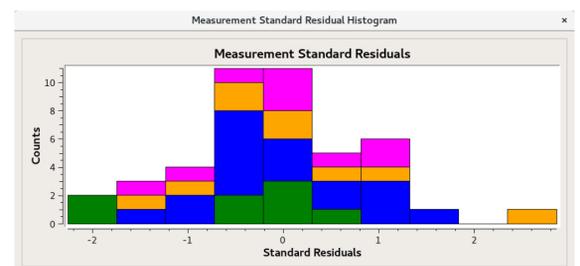
Measurement	Value	Uncertainty
Slant Distance	294.003 m	0.001 m
Horizontal Distance	294.003 m	0.001 m
Vertical Angle	-0.5045 dms	5.0 soa
Height Difference	-0.5045 m	0.0072 m
DY	31.509 m	1.48e-05 m
DZ	196.787 m	2.06e-05 m

Final Positions

Percent Confidence: 95
 Geoid File: /home/colson/projects/lsa/data/geoid/egm2008_2.5m.und
 Number of Points: Adjusted(4) + Fixed/Unused(2) + Derived(0) = 6

Label	Lat	Lon	Eht(m)	Sig N(m)	Sig E(m)	Sig U(m)	AdjN(m)	AdjE(m)	AdjU(m)	Adj (m)
P513	N 34 54 26.14901	W 120 39 0.63210	284.6066	320.2764	0.0000	0.0000	0.0000	0.0000	0.0000	0
POLE	N 34 39 56.75966	W 120 26 41.59363	20.9402	56.8159	0.0053	0.0061	0.0078	2.5888	-0.4700	30.8692
TP1	N 34 39 50.09287	W 120 26 55.31484	-9.2065	26.6702	0.0037	0.0033	0.0066	0.0015	-0.0003	-0.0009
TP2	N 34 39 57.86848	W 120 26 48.62328	-9.7110	26.1654	0.0031	0.0028	0.0063	-0.0017	-0.0017	-0.0099
TP3	N 34 39 59.51670	W 120 26 40.68734	-10.6372	25.2384	0.0039	0.0029	0.0066	0.0019	0.0021	-0.0040
VNDP	N 34 33 22.72740	W 120 36 59.23622	-11.4937	24.7197	0.0000	0.0000	0.0000	0.0000	0.0000	0

Subject to least squares adjustment, **Pass-through (fixed, unused, or derived)**



Plotted Types St. Dev.

AZIN	1.11
DXYZ	0.88
HANG	1.22
HDIR	1.22
PPP	0.89
VANG	0.89
ZANG	0.89

Plotted Files:

Filename	St. Dev.
example1	0.99
gpsMeasurements.lsa	0.88
conventional.lsa	1.07
conventional_TP.lsa	0.57
conventional_tgtpole.lsa	1.82

Acknowledgements

Funding and support provided by the National Geospatial-Intelligence Agency
 Approved for Public Release #20-165