“Demystifying Least Square Adjustment Using Android Smartphone and Graphic Calculator”

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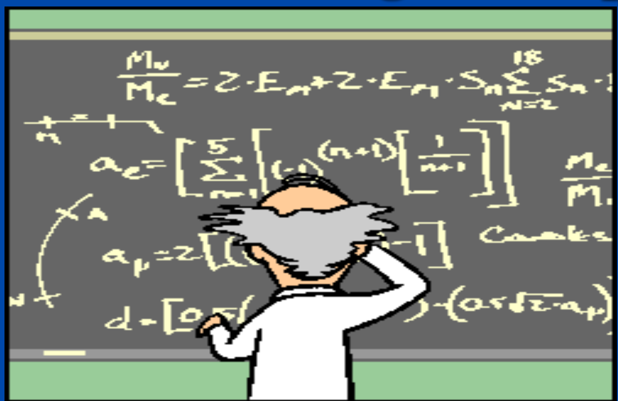
OUTLINE

1. Overview of Least Square Adjustment
2. Errors in Survey Observations and Accepted Practices
3. Comparison to Traditional adjustments methodology
4. The Least Square Principle
5. Equations used in Least Square Adjustments
6. Using BigLine Android app to solve matrix problems
6. Using Graphic Calculator to solve practical examples
7. Using BigshotsGE to solved LSA surveying problems
8. Future developments and Applications
9. Conclusions and Challenges

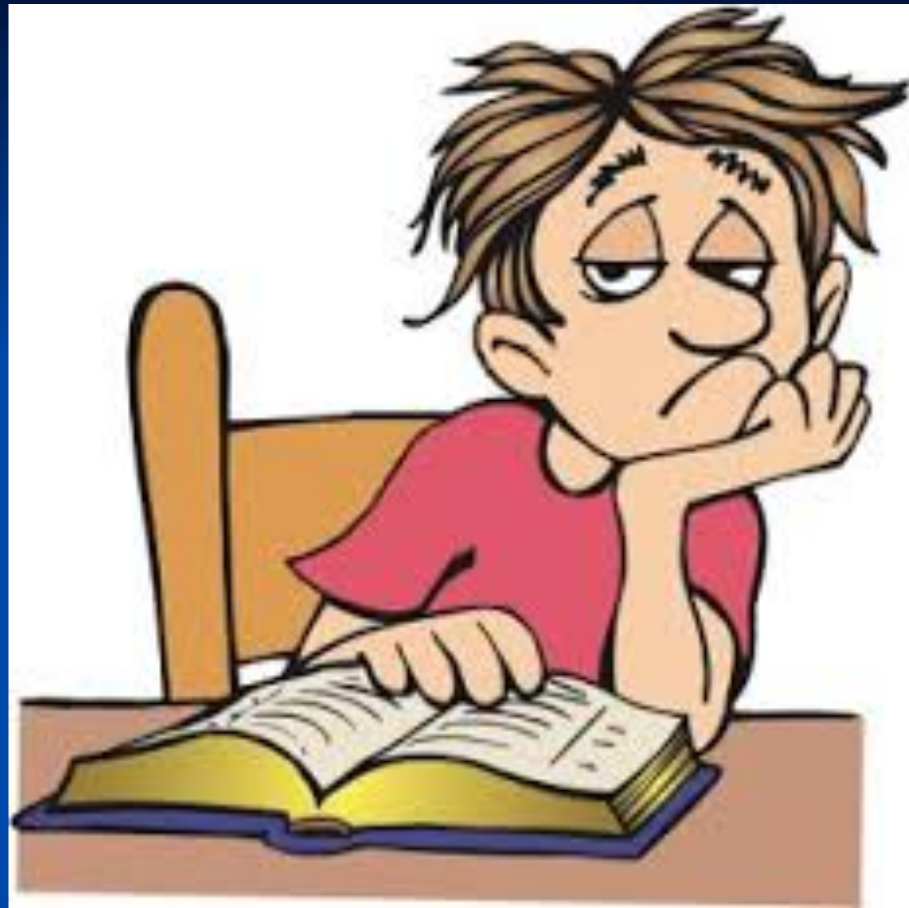
Least Square Principle

"The most probable system of values of the quantities ... will be that in which the sum of the squares of the differences between the actually observed and computed values multiplied by numbers that measure the degree of precision, is a minimum."



Karl Freidrich Gauss

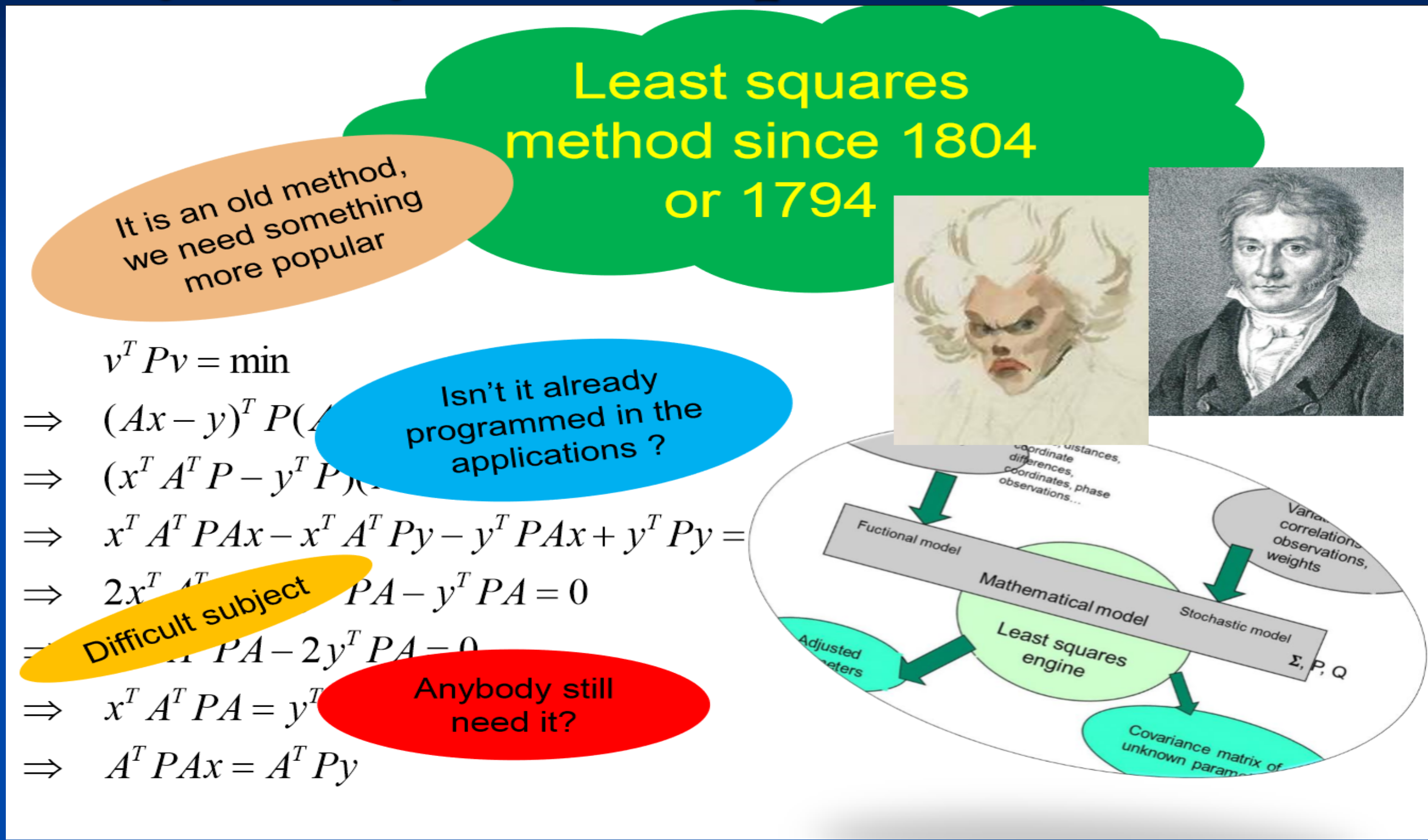

pxleyes.com



Least Square in Surveyors Language

"Least Square is a method of computing the minimum correction to be applied to survey observations so that the best simultaneous adjustments conforms to the truthfulness of known positions by giving more weight to reliable instruments/sources used."

Why study Least Square Adjustments?



Source: 25 Years of Teaching Least Square by: Ulla Kallio Finland

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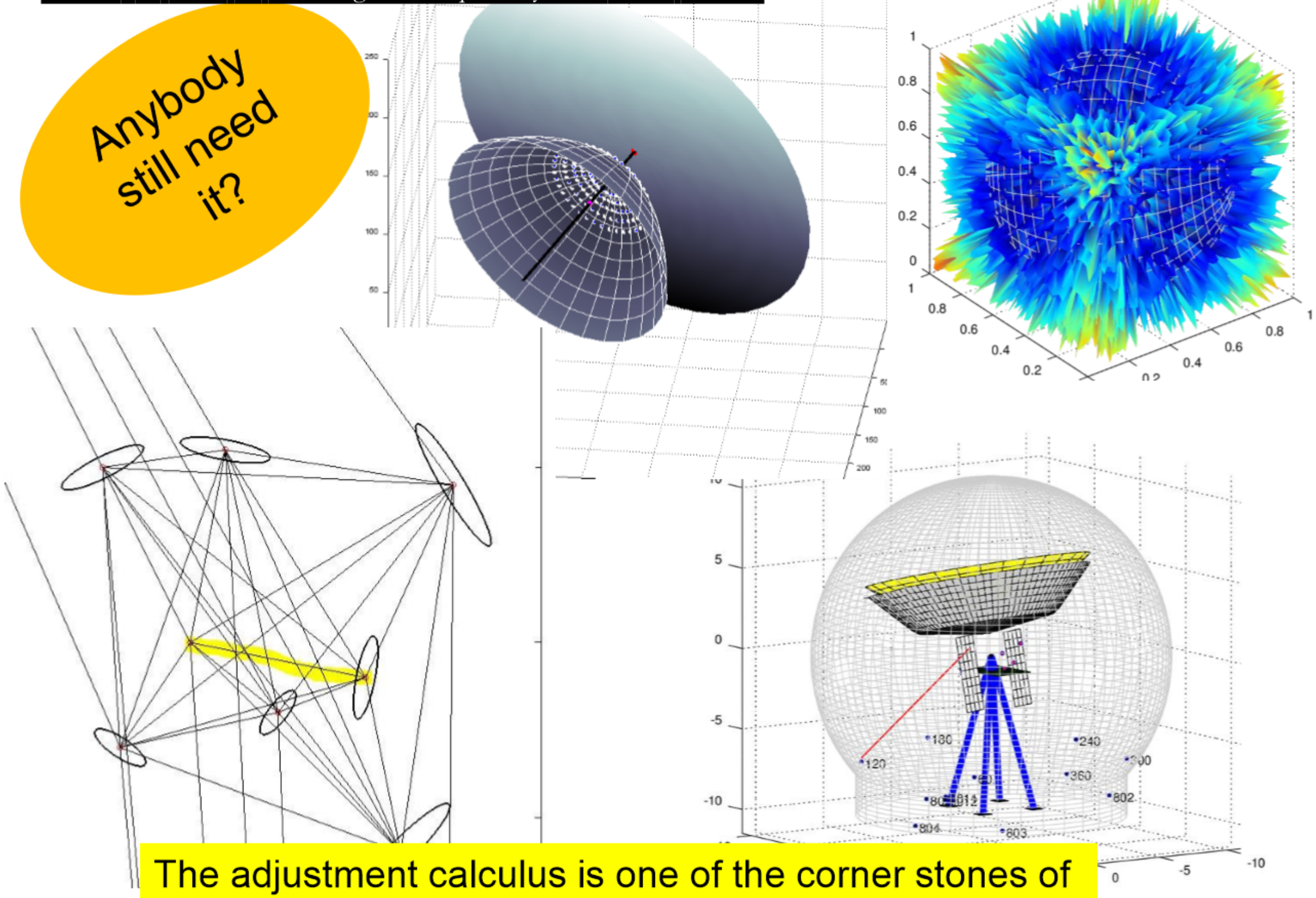


The adjustment calculus is one of the corner stones of the professional knowledge of geodetic surveyors.

Prof. Ulla Kallio on Teaching LSA

- Learning is very much personal process, I believe in learning by doing
- There is no guarantee that learning process of human being follows the Bloom's taxonomy steps
- Teaching the least squares method is still important

Elementary Examples

Ex. 1 Road Measurement

AB = 211.52

BC = 220.10

AC = 431.71

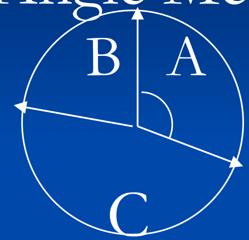
Equation:

$x + y = 431.71$

$x = 211.52$

$y = 220.10$

Ex. 2 Angle Measurements



$A = 134^{o}38' 56''$

$B = 83^{o}17' 35''$

$C = 142^{o} 03' 15''$

$A + B + C = 360$

$(A+v1) + (B+v2)+(C+v3) = 360$

My personal Learning Experience

- Statistics and Algebra in High School
- Introduced to Matrix Arithmetic First Year College
- Analytic Geometry and Calculus in 2nd Year
- Differential Equations 3rd Year
- Used Matrix Method in Structural Analysis
- Mentioned but not discussed in my GE class
- The more I study the more I realize that I know less
- Programming made me better understand the methods

All measurements have errors

- GEs do a lot of field measurements
- There are no perfect measurements, all measurements have errors.
- Errors are inherent in the instrumentation we use.
  - A 5" instrument measures angles to +- 5".
  - An EDM may measures distances to +- 0.01' and 3PPM.

Types of Errors

- There are three classifications of errors:
  - Blunders
  - Systematic Errors
  - Random Errors

Adjustments

- Why do we adjust traverses?
  - All traverses have errors; they do not close exactly on the terminal point.
  - If we do not adjust the traverse, all the error is placed in the last leg of the traverse which is not a valid assumption.
  - Error adjustments are important to future work on a project. Placing all the error in one measurement can prove problematic for both project design and layout.

Source: Goodman, Dean "Network Least Squares Adjustment.ppt"

Traditional Adjustments

- Averaging
- Transit Rule for Traverse
- Compass Rule
- Crandall Method

Averaging

- Averaging is a type of adjustment.
- We average SETS of angles measured in both direct and reverse faces:
- We average distances and zenith angles measured in both faces and in both directions:

Source: Goodman, Dean "Network Least Squares Adjustment.ppt"

Traditional Adjustments

- Prior to the advent of high powered computers, when only calculators or hand calculations were used, there were three popular adjustments:
  - Transit Rule
  - Crandall's Rule
  - Compass Rule

Typically angles were balanced prior to adjusting the traverse with these methods.

Source: Goodman, Dean "Network Least Squares Adjustment.ppt"

Transit Rule

- Transit Rule adjusts both angles and distances but makes the assumption that angles are measured with a higher precision than distances.
- This assumption may have been valid in the past when using a 10" theodolite for angles while pulling a chain for distances, but it is not valid for today's measuring equipment.

Compass Rule

- The Compass Rule assumes both angles and distances are measured with equal precision.
- Of the traditional adjustments, this assumption is most valid for today's measuring equipment.
- The Compass Rule remains a very popular form of adjustment by surveyors but has distinct disadvantages when compared to Least Squares Adjustments.

Source: Goodman, Dean "Network Least Squares Adjustment.ppt"

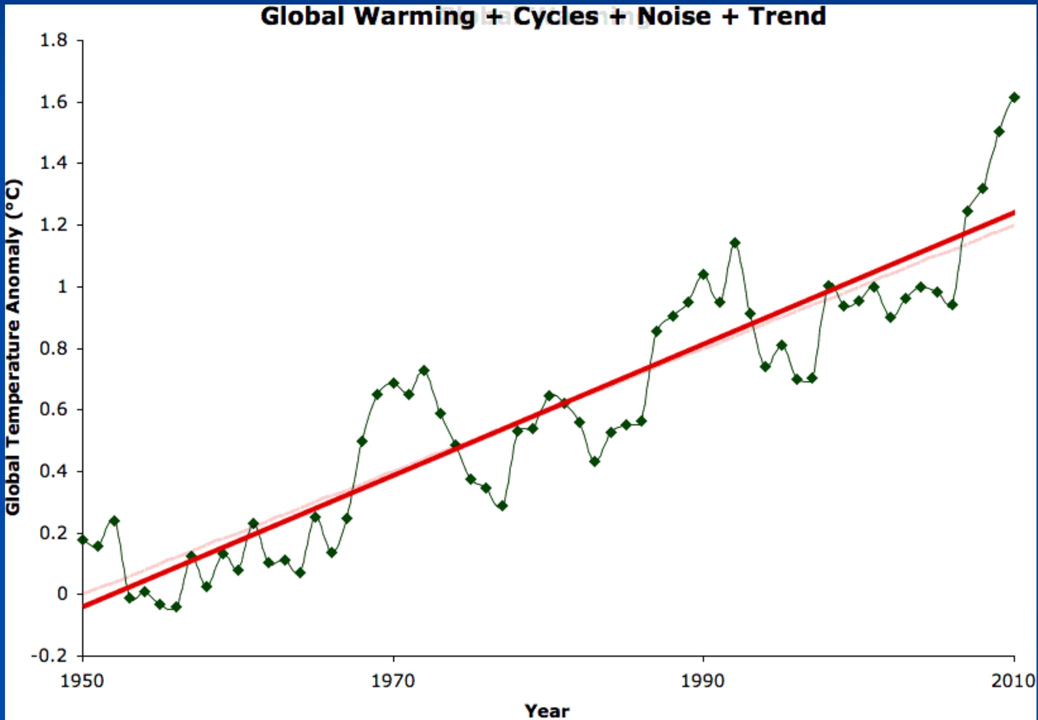
Crandall's Rule

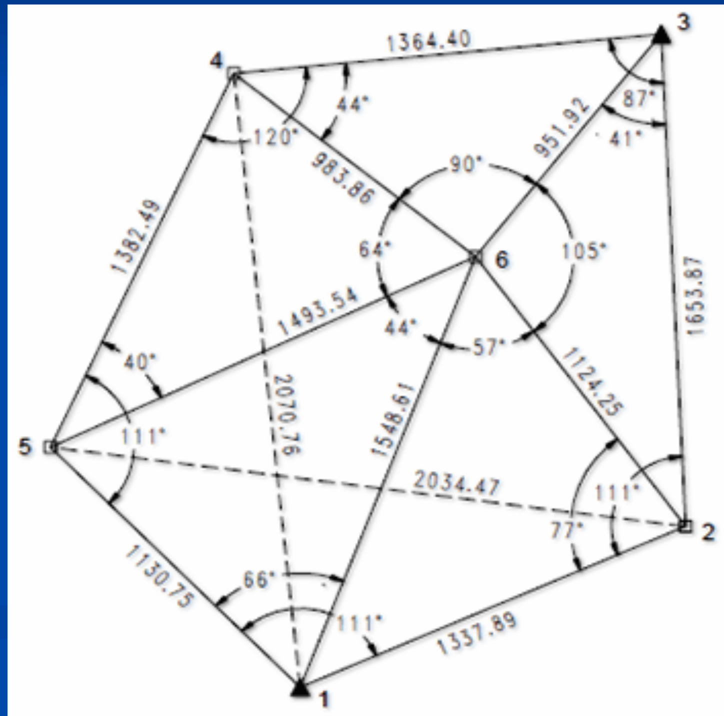
- Crandall' Rule is a "special case" least squares adjustment.
- Crandall's Rule assumes there is NO error in the angles – angles/directions are assigned an infinite weight.
- Therefore, adjustments are made only to distances.
- This adjustment was typically used to match bearings with previous surveys but under certain conditions can give unexpected results.
- The assumption that angles contain no error is not a valid assumption.

Source: Goodman, Dean "Network Least Squares Adjustment.ppt"

What is Least Squares?

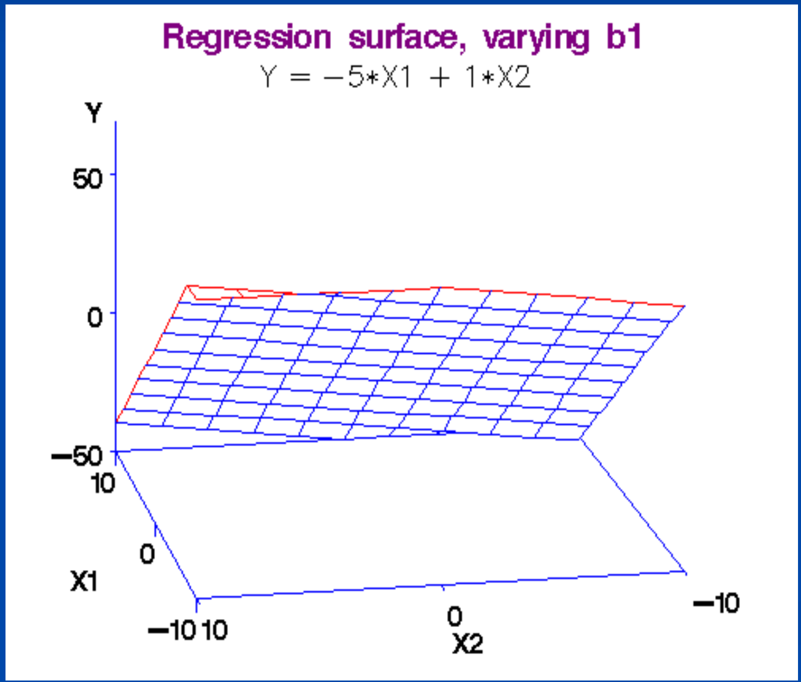
Least squares is a statistical method used to compute a best-fit solution for a mathematical model when there are excess measurements of certain variables making up the mathematical model.

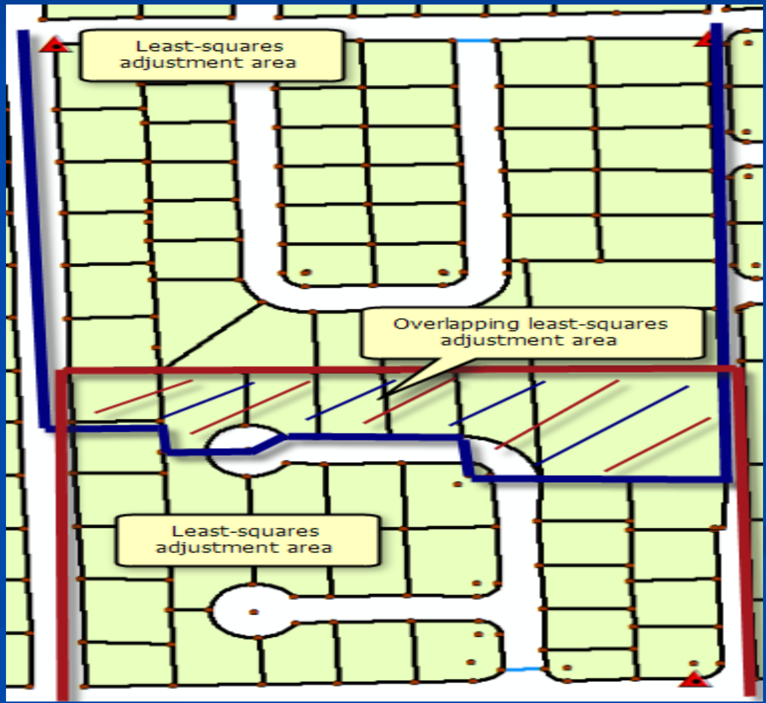




What is Least Squares?

Least squares requires a mathematical model, a system of equations. It requires redundant measurements of one or more variables (the known variables). Lastly it requires variables that are unknown that are being solved for.

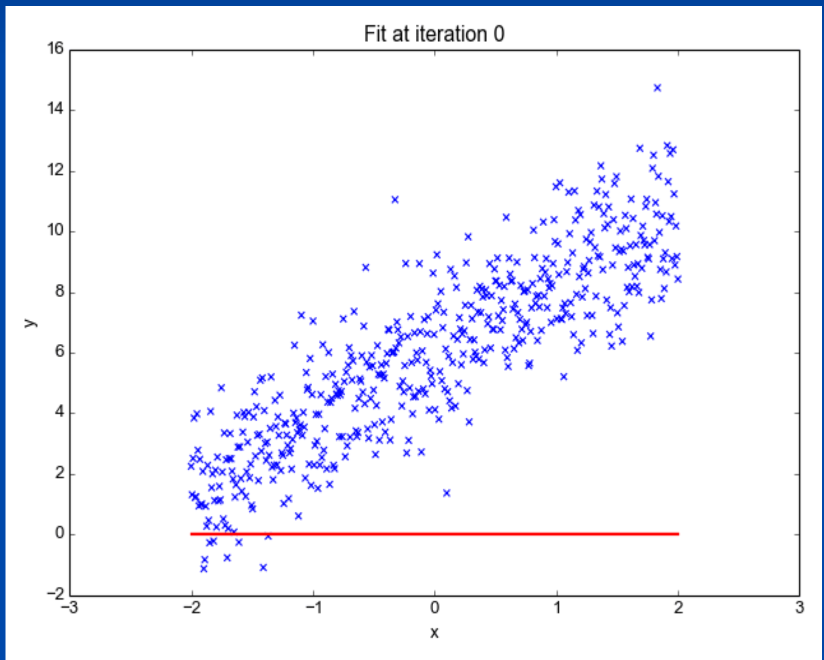


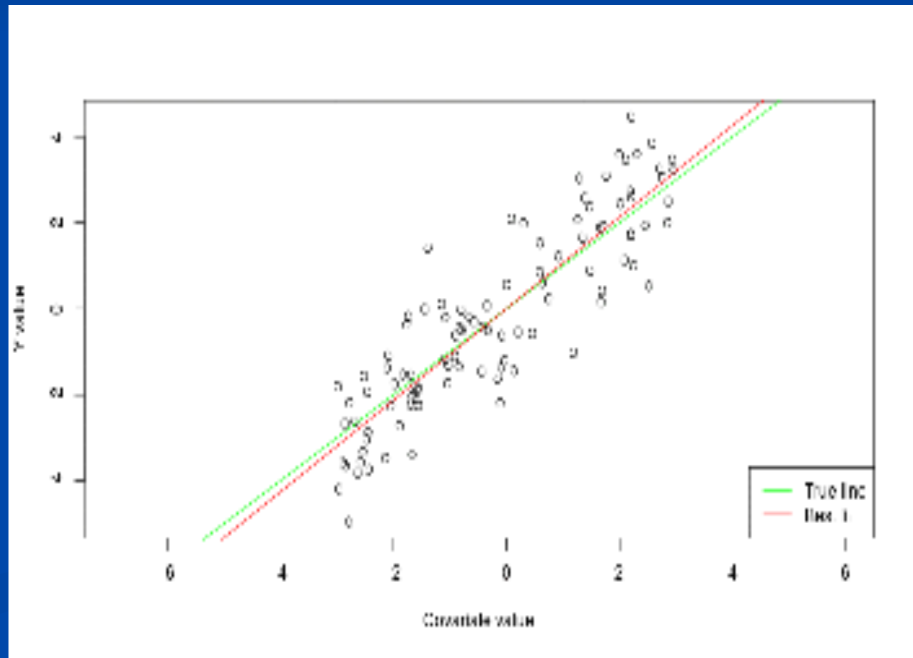


What is Least Squares?

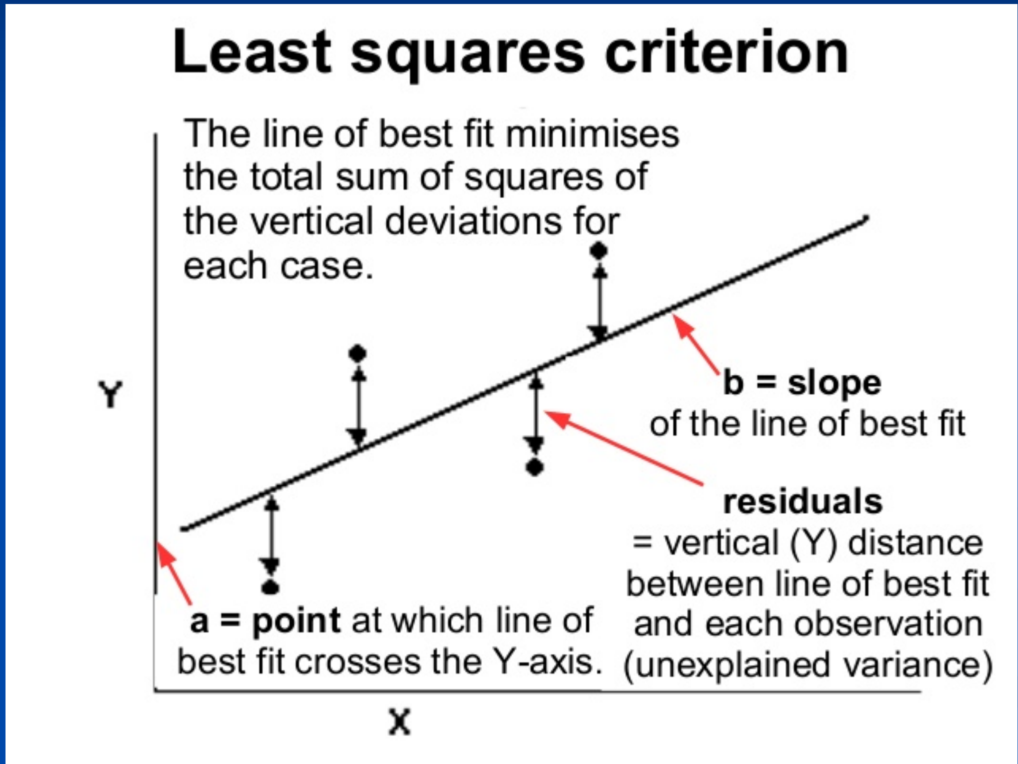
The least squares criteria is reached when the sum of the squares of the residuals have been minimized.

$$v^T P v = \text{minimum}$$





Least Squares Adjustment applies the least possible amount of correction when adjusting the measurements which arguably makes it the best adjustment.



Advantages of LSA

- It allows the simultaneous adjustment of a network of traverses. Traditional adjustments can only adjust one traverse at a time.
- It allows the combined adjustment of traverse data, GPS data and level data – 1D, 2D or 3D adjustments.
- It allows complete control of the adjustment process. Measurements are weighted based on the equipment used and the number of measurements made.

Advantages of LSA

- It allows processing data of different precision – weights can be applied to individual measurements or groups of measurements.
- It allows flexible control. The control points can be anywhere in the traverse, you don't need to start on a known point. Control points do not have to be contiguous and they can be side-shots.
- It can handle resection data (measurements from an unknown point to known points), triangulation (angle-only measurements) and trilateration (distance-only measurements).

Advantages of LSA

- Extensive data analysis provides more information for evaluation of traverse networks.
- Enhanced blunder detection tools.
- Allows flexible field procedures; the data does not have to be in any specific order.

Common misconceptions of LSA

- Least Squares Adjustments are just too complicated.
  - Reports are intuitive and easily understood
  - Flexibility of LSA makes processing of difficult datasets easy.
- Least Squares Adjustments are only necessary for very precise surveys.
  - LSA can and should be used for any type survey.
  - LSA can be used for simple loop traverses as well as complex traverse networks.

Least Square Solution Flow

Error Equation founded on Pythagorean Theorem

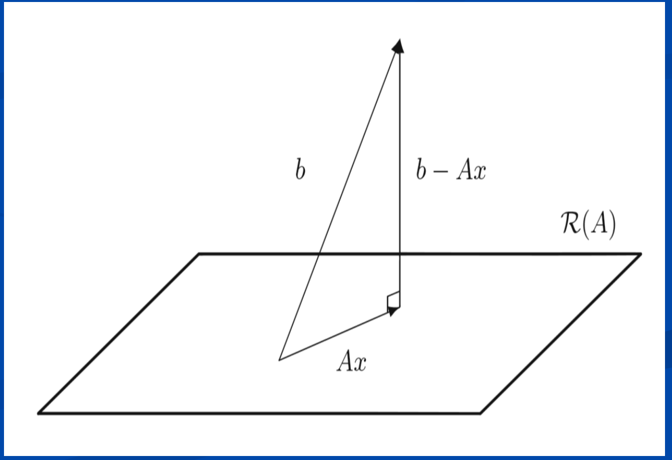
Line and Curve Data Modelled by Analytic geometry

Minimized by Differential Calculus

Simplified by Matrix Algebra

Improved and validated by Statistics

Made Easy by programming



Matrix Method in Least Square Adjustment

Matrix Method is better adapted than algebraic solution and works efficiently with computer programs.

$$A\ X = L + V$$

$$A^T A X = A^T L$$

$$X = (A^T A)^{-1} A^T L$$

For weighted Observations

$$X = (A^T P A)^{-1} A^T P L$$

$$V = AX - L \quad \text{(Residuals)}$$

Sample Distance easurement

Equation:

$$x + y = 431.71$$

$$x = 211.52$$

$$y = 220.10$$

Matrix Form:

$$\begin{matrix} 1 & 1 & = 431.71 \\ 1 & 0 & = 211.52 \\ 0 & 1 & = 220.10 \end{matrix}$$

Gaussian Normal Equation

$$A^TAX = A^TL$$

$$\begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 1 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} 431.71 \\ 211.52 \\ 220.10 \end{bmatrix}$$

by Matrix Arithmetic

$$X = 211.55$$

$$Y = 220.13$$

$$X + Y = 431.68$$

Residuals $v = AX - L$

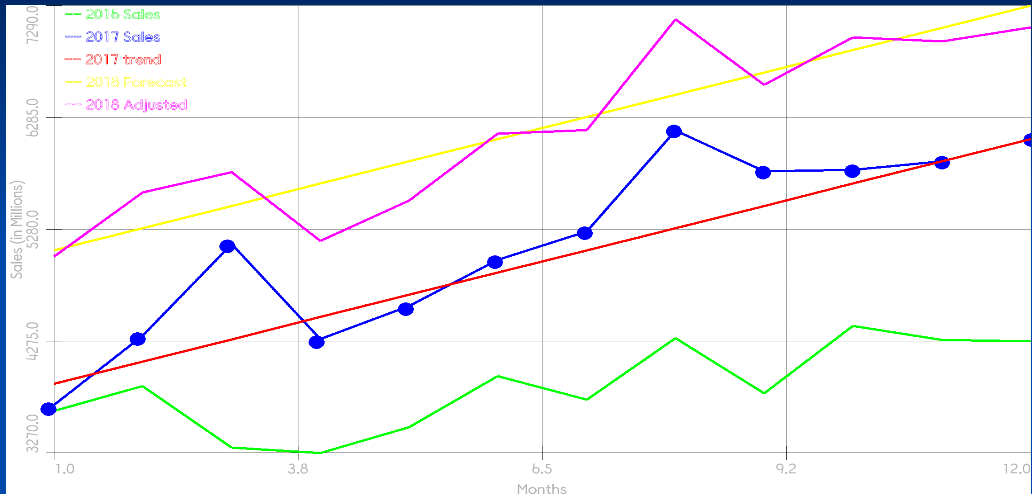
$$v2 = 0.03$$

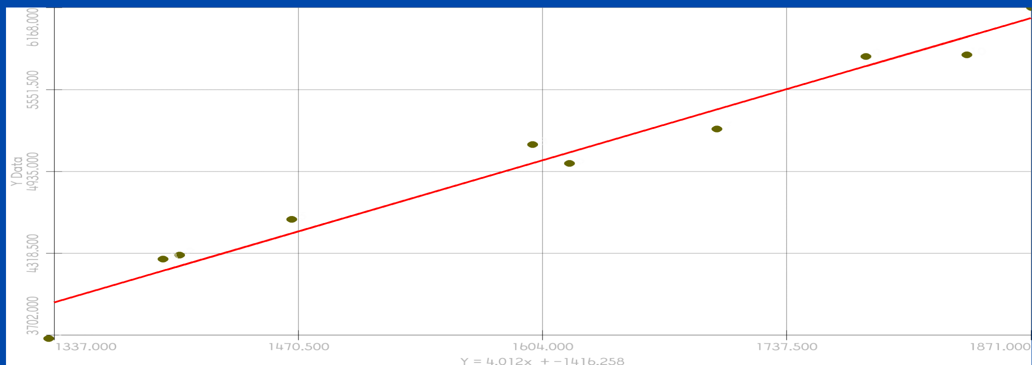
$$v3 = 0.03$$

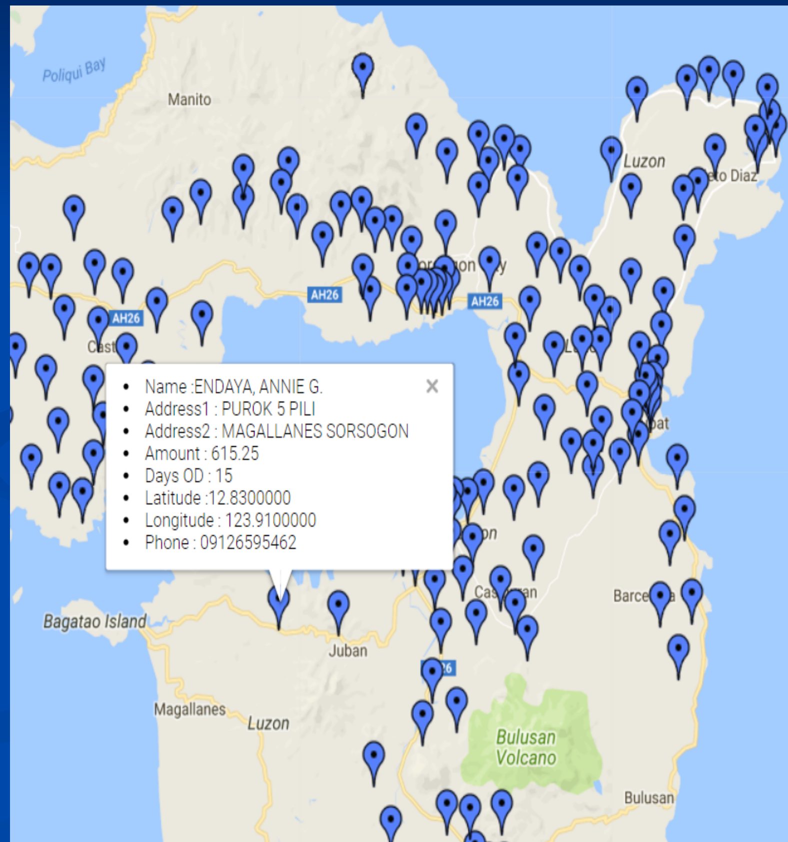
$$v1 = -0.03$$

"The solution is simple but if more observations and equations are added the manual matrix computation becomes tedious and time consuming hence it is designed for computer processing efficiency."

Applying Least Square in my Business







FREE Android Application at

www.bigshotspc.net/BigLine.apk

- New Matrix Entry
- Select File Data Sets
- Matrix Arithmetic
- Matrix Properties
- Ordinary LSQ Solution
- EigenValues EigenVectors
- Cholesky Decomposition
- LU Decomposition
- QR Decomposition
- SV Decomposition
- Weighted Least Square
- Matrix Tutorial
- Download Updates
- Exit

Tutorial on Matrix Algebra

Matrix A

12	4	-3
2	32	2
1	6	-18

Vector B

50
180
-74

Transpose Matrix A'

12	2	1
4	32	6
-3	2	-18

Multiply A' * A

149.0000	118.0000	-50.0000
118.0000	1076.0000	-56.0000
-50.0000	-56.0000	337.0000

MatInverse (A'xA)`

0.0077	-0.0008	0.0010
-0.0008	0.0010	0.0001

Matrix A

12.0000	4.0000	-3.0000
2.0000	32.0000	2.0000
1.0000	6.0000	-18.0000

Matrix Properties

Determinant:	-6844.0000
Ratio of LSQ value:	2.9555
Numeric Rank SVD:	3.0000
Max Column Sum :	42.0000
Max Singular Value:	33.1033
SQR Sum of Squares:	39.5221
Maximum Row Sum :	36.0000
Sum of Diagonals :	26.0000

Transpose Matrix A

12	2	1
4	32	6
-3	2	-18

Inverse of Matrix (A`)

0.085914669784	-0.007890122735	-0.0151957
-0.005552308591	0.031122150789	0.0043834

Entering Data

- Use the built in data entry of the augmented matrix by row
- Import files in csv format
- With built in editing of matrix element
- With capability to backup data
- HTML output of Least Square Solution
- Can be sent as attachment via email

Different Methods of Solving LSQ

Gaussian Normal Exquation

Matrix Multiply A*A'

29	15	-24	-19
15	39	-15	-16
-24	-15	49	27
-19	-16	27	55

Multiply A'x B

8
27
44
57

Matrix Inverse A`

0.217	0.000	0.130	-0.043
0.000	0.140	-0.070	0.093
0.130	-0.070	0.013	0.127
-0.043	0.093	0.127	0.004

A*A` Should BE Identity

1.000	0.000	0.000	0.000
0.000	1.000	0.000	0.000
0.000	0.000	1.000	0.000
0.000	0.000	0.000	1.000

Weighted Least Square

Multiply A'W * A

456.0000	272.0000	48.0000	136.0000
272.0000	804.0000	256.0000	68.0000
48.0000	256.0000	1364.0000	768.0000
136.0000	68.0000	768.0000	1336.0000

Matrix Inverse (A'WA)`

0.0029	-0.0011	0.0003	-0.0004
-0.0011	0.0017	-0.0004	0.0003
0.0003	-0.0004	0.0012	-0.0007
-0.0004	0.0003	-0.0007	0.0012

Multiply A'W * B

5336.0000
8520.0000
17468.0000
17152.0000

Weighted LSQ = (A'WA)` * A'WB

5.0000
6.0000
7.0000
8.0000

Eigenvalue and Eigenvectors

0	-3	2	6
-3	1	6	3

Eigenvalues

Real parts

-5.1219	3.4750	5.4487	10.1982

Imaginary parts

0.0000	0.0000	0.0000	0.0000

Eigenvector Matrix

0.2745	-0.8585	0.1366	-0.4110
-0.3116	0.2147	0.8462	-0.3752
-0.6593	-0.4656	0.1306	0.5757
0.6268	-0.0071	0.4982	0.5991

Block Diagonal Matrix

-5.1219	0.0000	0.0000	0.0000
0.0000	3.4750	0.0000	0.0000
0.0000	0.0000	5.4487	0.0000
0.0000	0.0000	0.0000	10.1982

Submit OK

Alternative Methods of Solving Least Square

Cholesky Decomposition

Transpose Matrix A'

20	4	0	2
4	16	2	0
0	2	16	6
2	0	6	24

Cholesky Decomposition

Triangular Factor X

4.4721	0.0000	0.0000	0.0000
0.8944	3.8987	0.0000	0.0000
0.0000	0.5130	3.9670	0.0000
0.4472	-0.1026	1.5258	4.6327

Matrix is symmetric and positive definite

Solve LSQ A*X = B

5.0000
6.0000
7.0000
8.0000

Submit OK

LU Decomposition

LU Decomposition

Determinant	102672.0000

Pivot Permutation Vector

0.0000	1.0000	2.0000	3.0000

Lower Triangular Factor L

1.0000	0.0000	0.0000	0.0000
0.2000	1.0000	0.0000	0.0000
0.0000	0.1316	1.0000	0.0000
0.1000	-0.0263	0.3846	1.0000

Upper Triangular Factor U

20.0000	4.0000	0.0000	2.0000
0.0000	15.2000	2.0000	-0.4000
0.0000	0.0000	15.7368	6.0526
0.0000	0.0000	0.0000	21.4615

Solve Matrix Least Square

5.0000
6.0000
7.0000
8.0000

QR Decomposition

Orthogonal (Q) and Triangular (R) Matrix Decomposition

20	4	0	2
4	16	2	0
0	2	16	6
2	0	6	24

Householder vector H

1.9759	0.0000	0.0000	0.0000
0.1952	1.9905	0.0000	0.0000
0.0000	0.1329	1.9324	0.0000
0.0976	-0.0362	0.3615	2.0000

Orthogonal factors Q

-0.9759	0.1898	0.0138	0.1068
-0.1952	-0.9717	0.1122	-0.0712
0.0000	-0.1329	-0.9250	0.3560
-0.0976	0.0455	-0.3628	-0.9256

Upper Triangular Factor R

-20.4939	-7.0265	-0.9759	-4.2940
0.0000	-15.0542	-3.7958	0.6757
0.0000	0.0000	-16.7523	-14.2293
0.0000	0.0000	0.0000	19.8653

Singular Value Decomposition

Singular Value Decomposition (SVD)

Condition Number	2.5110
SVD Rank	4.0000
SVD Norm	27.9408

Singular Values

27.9408	21.7455	15.1864	11.1273

Left Singular Vectors (U)

0.2958	-0.7943	0.4158	0.3296
0.1736	-0.5013	-0.6467	-0.5480
0.4448	0.1485	-0.5685	0.6759
0.8273	0.3093	0.2927	-0.3663

Right Singular Vectors (V)

0.2958	-0.7943	0.4158	0.3296
0.1736	-0.5013	-0.6467	-0.5480
0.4448	0.1485	-0.5685	0.6759
0.8273	0.3093	0.2927	-0.3663

Diagonal Matrix Singular Values (S)

27.9408	0.0000	0.0000	0.0000
0.0000	21.7455	0.0000	0.0000

”One of the most beautiful and useful results from linear algebra, known as the **singular value decomposition** of a matrix”

Diagonal Matrix Singular Values (S)

80.5865	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	16.3033	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	15.2340	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	14.4960	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	12.2162	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	11.7935	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	10.6885	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	10.0867	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	8.4523	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	7.0018
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Arriving at the same values

Gaussian Normal Equation

Multiply A' * A

420.0000	144.0000	20.0000	88.0000
144.0000	276.0000	64.0000	20.0000
20.0000	64.0000	296.0000	240.0000
88.0000	20.0000	240.0000	616.0000

MatInverse (A'xA)`

0.0031	-0.0017	0.0007	-0.0007
-0.0017	0.0048	-0.0015	0.0007
0.0007	-0.0015	0.0054	-0.0022
-0.0007	0.0007	-0.0022	0.0025

Multiply A' * B

3808.0000
2984.0000
4476.0000
7168.0000

Ordinary LSQ = (A'A)` * A'B

5.0000
6.0000
7.0000
8.0000

Cholesky Decomposition

Transpose Matrix A'

20	4	0	2
4	16	2	0
0	2	16	6
2	0	6	24

Cholesky Decomposition

Triangular Factor X

4.4721	0.0000	0.0000	0.0000
0.8944	3.8987	0.0000	0.0000
0.0000	0.5130	3.9670	0.0000
0.4472	-0.1026	1.5258	4.6327

Matrix is symmetric and positive definite

Solve LSQ A*X = B

5.0000
6.0000
7.0000
8.0000

Submit OK

QR Decomposition

Orthogonal factors Q

-0.7428	0.0123	-0.6145	-0.2656
-0.3714	-0.7095	0.1890	0.5683
0.0000	0.5367	-0.3257	0.7784
0.5571	-0.4565	-0.6933	0.0247

Upper Triangular Factor R

-5.3852	-2.7854	4.4567	3.5282
0.0000	-5.5894	0.4627	1.1043
0.0000	0.0000	-5.3781	-2.0016
0.0000	0.0000	0.0000	6.1095

Least Square R`Q'B

5.0000
6.0000
7.0000
8.0000

Residuals V= AX - L

0.0000
0.0000
0.0000
0.0000

Singular Value Decomposition

Left Singular Vectors (U)

0.2958	-0.7943	0.4158	0.3296
0.1736	-0.5013	-0.6467	-0.5480
0.4448	0.1485	-0.5685	0.6759
0.8273	0.3093	0.2927	-0.3663

Right Singular Vectors (V)

0.2958	-0.7943	0.4158	0.3296
0.1736	-0.5013	-0.6467	-0.5480
0.4448	0.1485	-0.5685	0.6759
0.8273	0.3093	0.2927	-0.3663

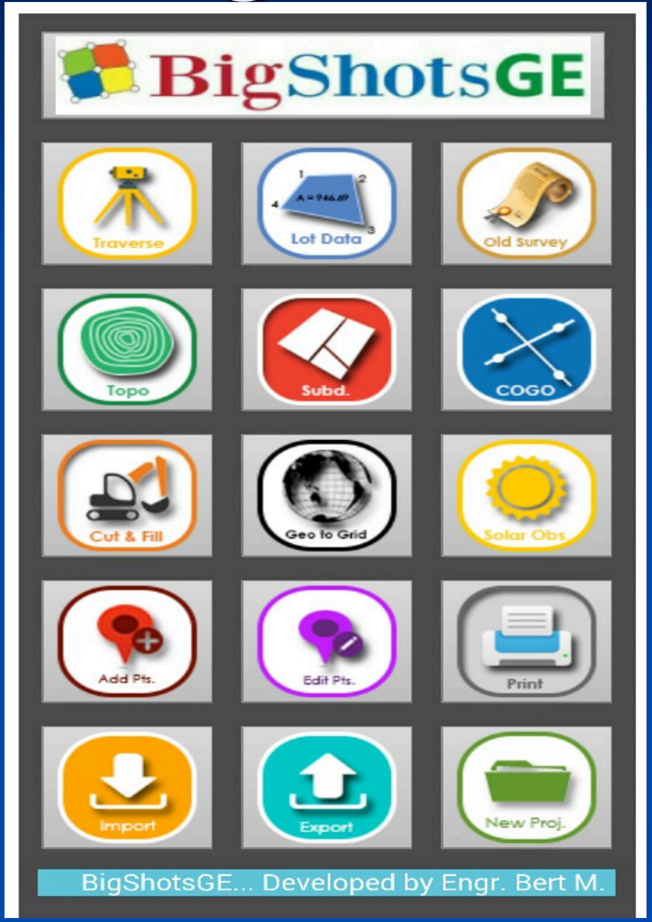
Diagonal Matrix Singular Values (S)

27.9408	0.0000	0.0000	0.0000
0.0000	21.7455	0.0000	0.0000
0.0000	0.0000	15.1864	0.0000
0.0000	0.0000	0.0000	11.1273

Least square X=VS`U'*B

5.0000
6.0000
7.0000
8.0000

Using Android Apps BigShotsGE*



Least square method of adjustment is embedded as selection choice in Traverse Computation, Resection, Intersection, Coordinate Transformation and others.

*Soon to be Released

Applying LSQ in Graphic Calculator

FREE UPDATE

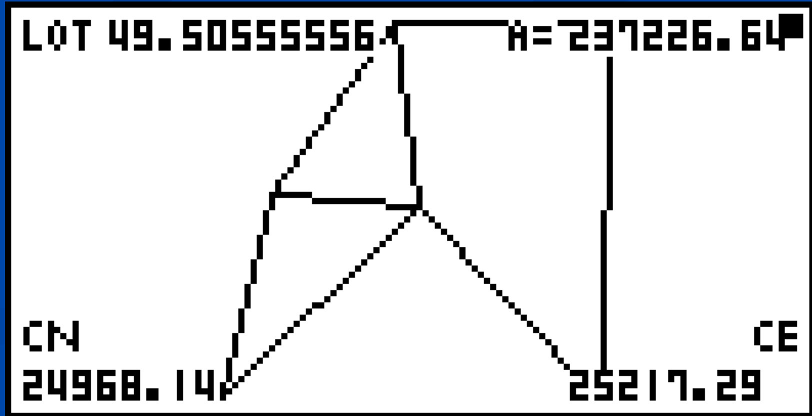
Latest Operating system of Casio fx-9860G models contain matrix and vector computation functions as well as Statistics functions which can be used in Least Square Adjustments or any Linear Algebra problems.

Sample Problem in Resection Compuation

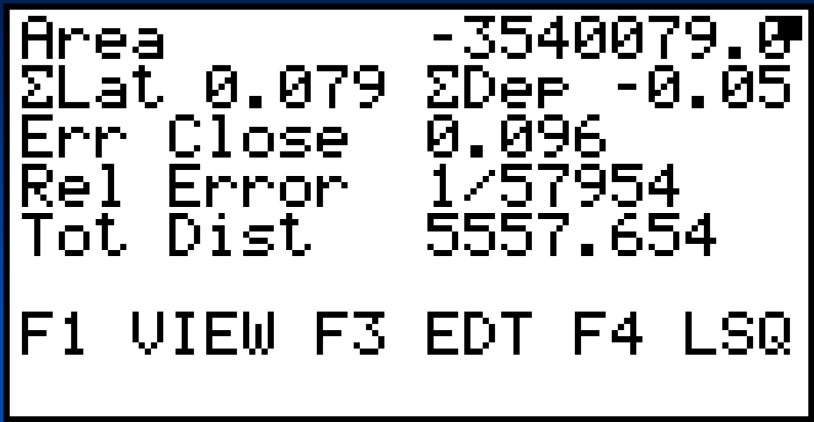
```
Northg Pt Aa?
24680.20
Ea?
24917.12
Brg A?
0
```

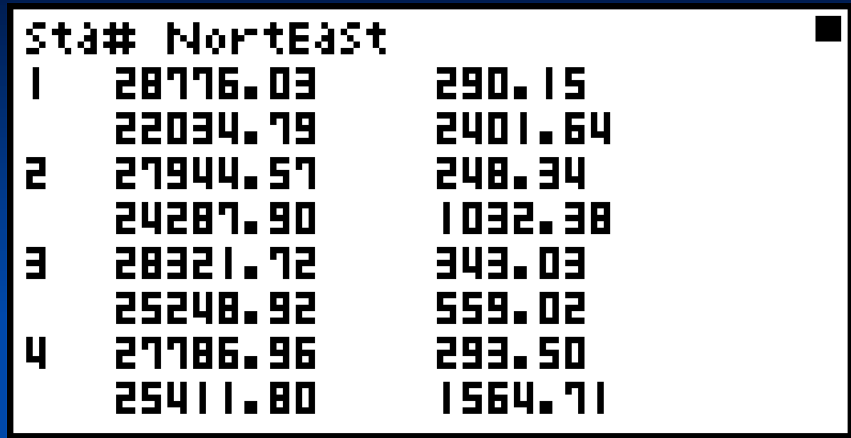
```
NP=          24976.71
EP=          25227.76
           - Disp -
```

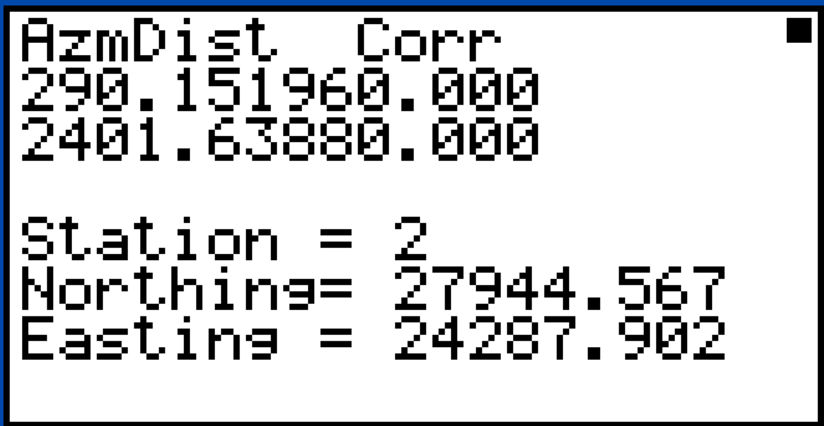
```
North Pt.  B?
25267.06
Eb?
25186.98
Brg B?
125.4021
```

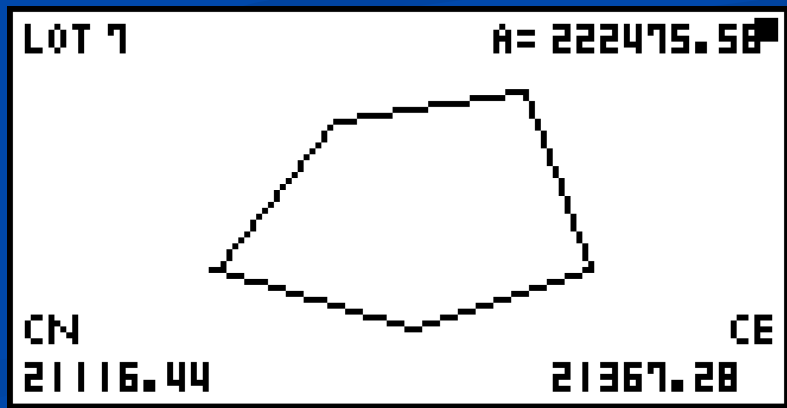


Traverse Adjustments using LSA









Coordinate Transformation using Matrix

```
Press 0-4 to select
 1 Geog  to Grid
 2 Grid  to Geog
 3 Local to Grid
 4 WGS84 to PRS92
 5 PRS92 to WGS84
 0 Exit
```

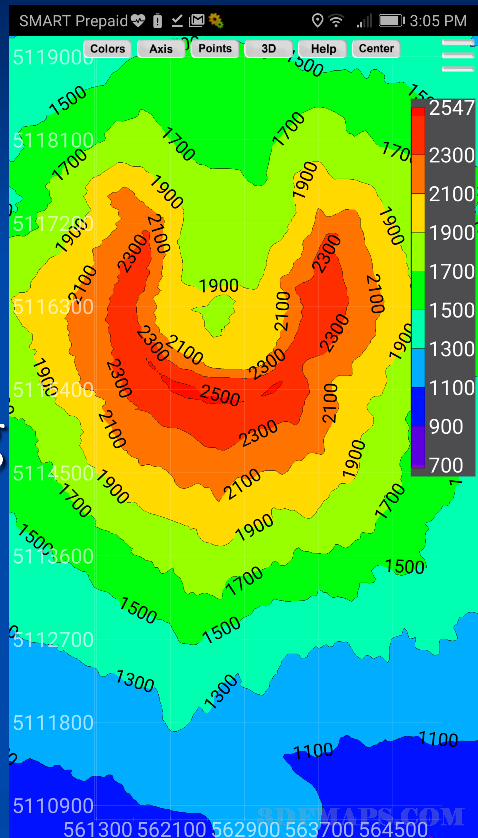
```
123.241832
El Ht?
56.2208
          123°24'23.4"
           12°15'26.1"
           112.0001527
             - Disp -
```

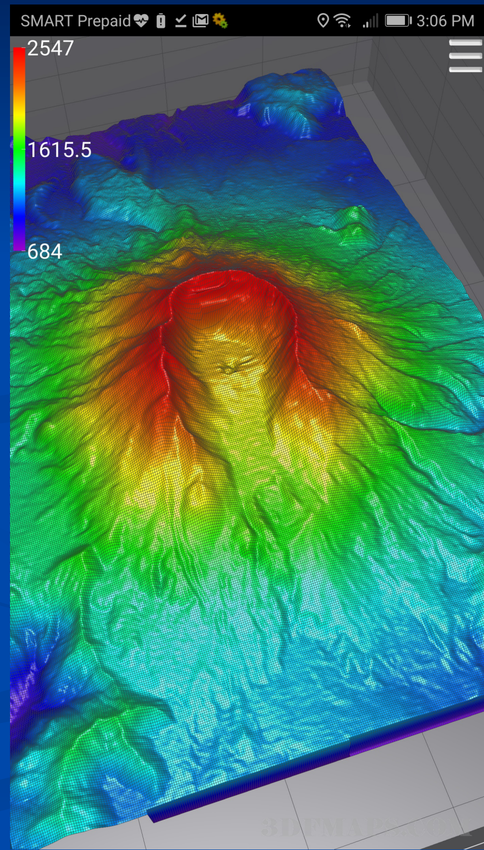
```
12.153076
Long?
123.241832
El Ht?
56.2208
          123°24'23.4"
             - Disp -
```

```
123.24234
El Ht?
112
         123°24'18.32"
          12°15'30.76"
           56.22084493
             - Disp -
```

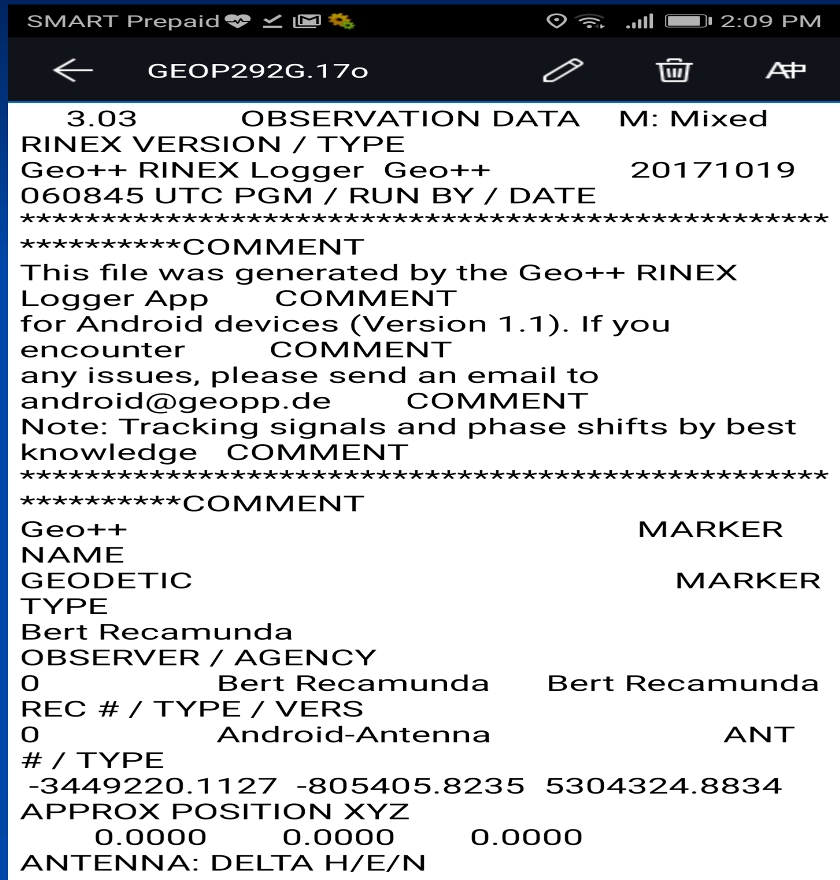
Future Developments

- Constrained Adjustments
- Contouring
- GNSS Raw Data Processing
- Kalman Filtering

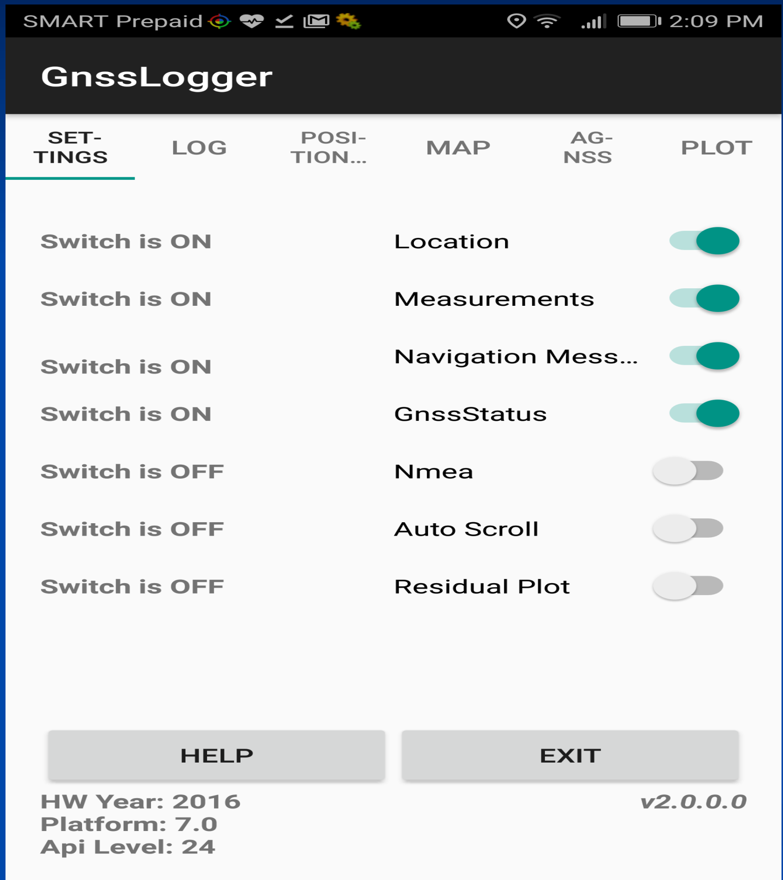




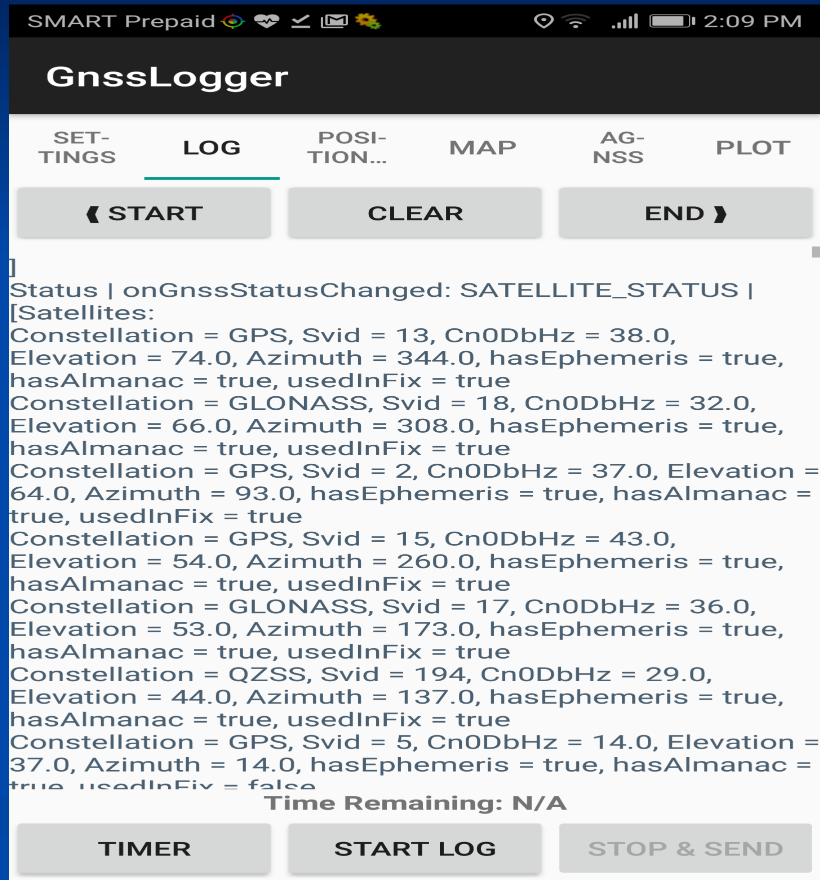
Capturing RAW GNSS Data from Android



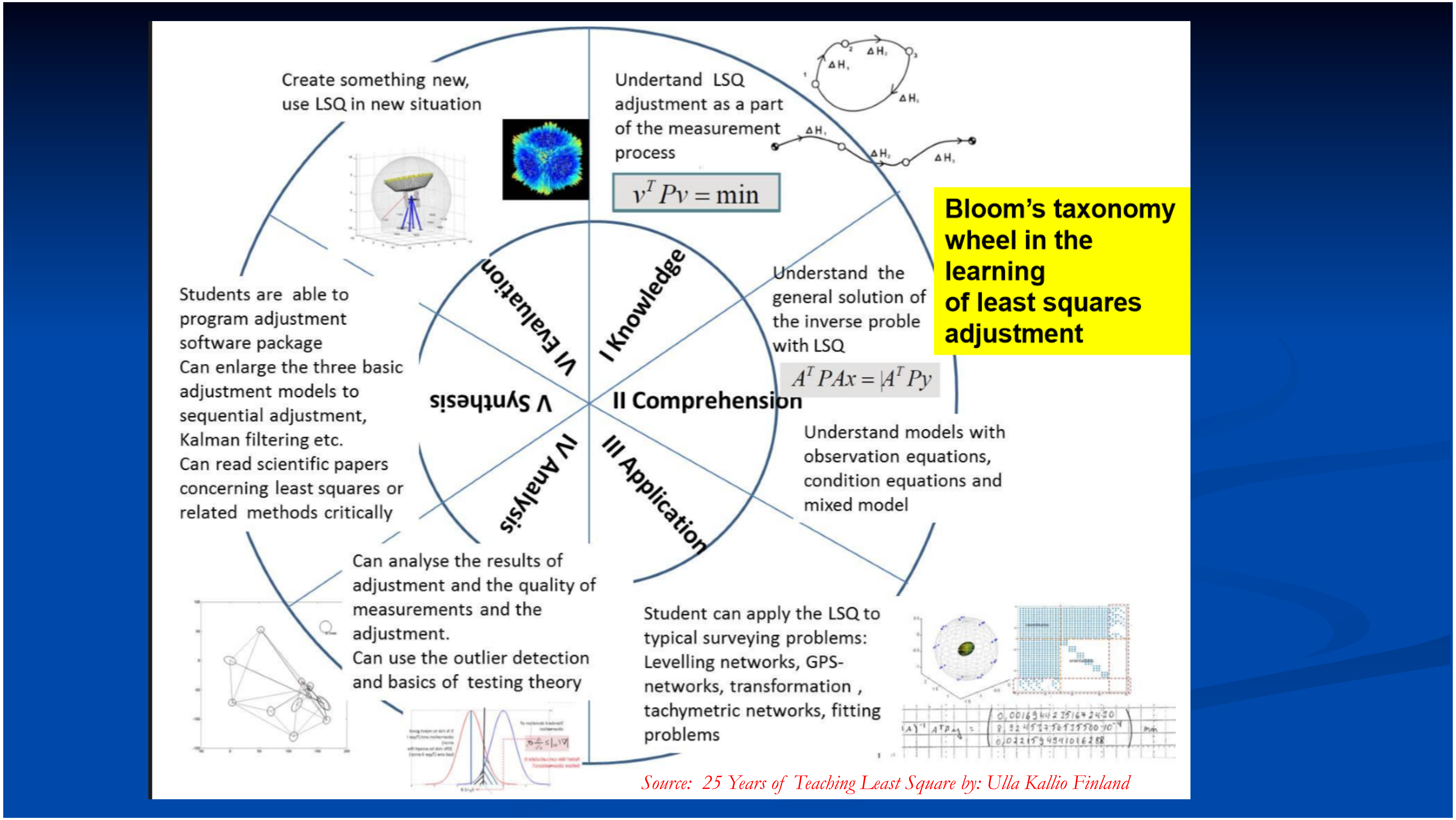
GNSS Logger



SMART Prepaid
2:09 PM
GnssLogger
SET-TINGS
LOG
POSI-TION...
MAP
AG-NSS
PLOT
Switch is ON Location
Switch is ON Measurements
Switch is ON Navigation Mess...
Switch is ON GnssStatus
Switch is OFF Nmea
Switch is OFF Auto Scroll
Switch is OFF Residual Plot
HELP
EXIT
HW Year: 2016
Platform: 7.0
Api Level: 24
v2.0.0.0



SMART Prepaid
2:09 PM
GnssLogger
SET-TINGS
LOG
POSI-TION...
MAP
AG-NSS
PLOT
START
CLEAR
END
]
Status | onGnssStatusChanged: SATELLITE_STATUS |
[Satellites:
Constellation = GPS, Svid = 13, Cn0DbHz = 38.0,
Elevation = 74.0, Azimuth = 344.0, hasEphemeris = true,
hasAlmanac = true, usedInFix = true
Constellation = GLONASS, Svid = 18, Cn0DbHz = 32.0,
Elevation = 66.0, Azimuth = 308.0, hasEphemeris = true,
hasAlmanac = true, usedInFix = true
Constellation = GPS, Svid = 2, Cn0DbHz = 37.0, Elevation =
64.0, Azimuth = 93.0, hasEphemeris = true, hasAlmanac =
true, usedInFix = true
Constellation = GPS, Svid = 15, Cn0DbHz = 43.0,
Elevation = 54.0, Azimuth = 260.0, hasEphemeris = true,
hasAlmanac = true, usedInFix = true
Constellation = GLONASS, Svid = 17, Cn0DbHz = 36.0,
Elevation = 53.0, Azimuth = 173.0, hasEphemeris = true,
hasAlmanac = true, usedInFix = true
Constellation = QZSS, Svid = 194, Cn0DbHz = 29.0,
Elevation = 44.0, Azimuth = 137.0, hasEphemeris = true,
hasAlmanac = true, usedInFix = true
Constellation = GPS, Svid = 5, Cn0DbHz = 14.0, Elevation =
37.0, Azimuth = 14.0, hasEphemeris = true, hasAlmanac =
Time Remaining: N/A
TIMER
START LOG
STOP & SEND


Create something new,
use LSQ in new situation
Undertand LSQ
adjustment as a part
of the measurement
process
$v^T Pv = \min$
Bloom's taxonomy
wheel in the
learning
of least squares
adjustment
Understand the
general solution of
the inverse proble
with LSQ
$A^T PAx = A^T Py$
I Knowledge
II Comprehension
III Application
IV Analysis
V Synthesis
VI Evaluation
Students are able to
program adjustment
software package
Can enlarge the three basic
adjustment models to
sequential adjustment,
Kalman filtering etc.
Can read scientific papers
concerning least squares or
related methods critically
Understand models with
observation equations,
condition equations and
mixed model
Can analyse the results of
adjustment and the quality of
measurements and the
adjustment.
Can use the outlier detection
and basics of testing theory
Student can apply the LSQ to
typical surveying problems:
Levelling networks, GPS-
networks, transformation ,
tachymetric networks, fitting
problems
Source: 25 Years of Teaching Least Square by: Ulla Kallio Finland

Conclusions and Challenges

- Using formulas in Least Square as applied to Android Applications and Casio Graphic Calculators lead to the same results in reference examples.
- Students should devote more time to Numerical Methods for Solving Measurement Adjustments
- Redundant Field measurements must always be practiced as mobile solution apps are readily available.
- Capability building for offices verifying survey submissions.
- Further research and development to improve the apps

References

- Andersen,JM & Mikhail E.M., 2002, “Surveying Theory and Practice”
- Brinker, R.C. & Minnick, R. , 1987, “The Surveying Handbook”
- Mikhail, E.M., 1976, “Observations and Least Squares”, IEP—A Dun-Donnelley Publisher, New York.
- Deakin R.M, 1999 “A Review Of Least Squares Theory Applied To Traverse Adjustment”
- Wikipedia, https://en.wikipedia.org/wiki/Least_squares, Accessed 9/08/2017
- Wolfe, P.R.,1980, Survey Measurements Adjustment by Least Squares
- Goodman, Dean, “Network Least Square Adjustment”, Powerpoint

Websites for Further Readings

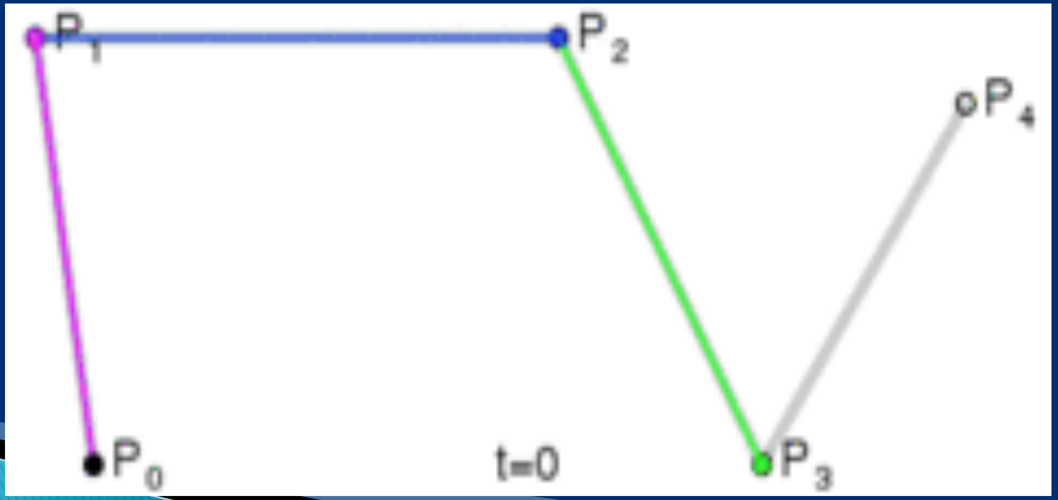
- http://www.mygeodesy.id.au/least-squares/
- https://en.wikipedia.org/wiki/Least_squares
- https://www.google.com/search?q=least+square (for images used in this presentation)

Baby Shark

- We need to be child like to be able to Learn LSqA
- We need motherly teachers to guide us in the learning path
- We need fatherly discipline to mentor us in its application
- We need grandparents legacy of sharing and caring for future generations
- We can swim and adventure with confidence
- We are safe from attacks/questions because we use LSQ

"Computers are invented and broken;
Programming languages may come and go but,
Mathematics is for eternity"

Engr. Roberto M. Recamunda



Thank You