A Comparison of Artificial Neural Network and Homotopy Continuation in 3D Interior Building Modelling

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Introduction

- People spend almost 90% of their life in indoor building environment (Klepeis et al. 2001; Li and Lee 2010).
- Indoor building navigation is therefore necessary for moving objects like human to navigate.
- A construction model depends on complex calculations which need to manage a large number of measured points.

Problem Statement

- Indoor building navigation modelling has different challenging issues such as suitability of 3D building models, indoor navigation networks, vertical and horizontal connectivity, which are required to be addressed.
- Indoor surveying for indoor building data collection

TLS? Total station? Photogrammetry?

- 3D Data structure

(Topological vs Geometrical?) DHE?

- 3D Data model

CityGML? BIM? CAD?

- 3D network models
  - GNM? IndoorGML?

Research Workflow

Data Collection

- Trimble LaserAce 1000
- Trimble M3
- Leica C10
- Leica 307 TCR
- Faro Photon 120/20

3D Data Modelling

- Boundary Representation

Uncertainty Modelling

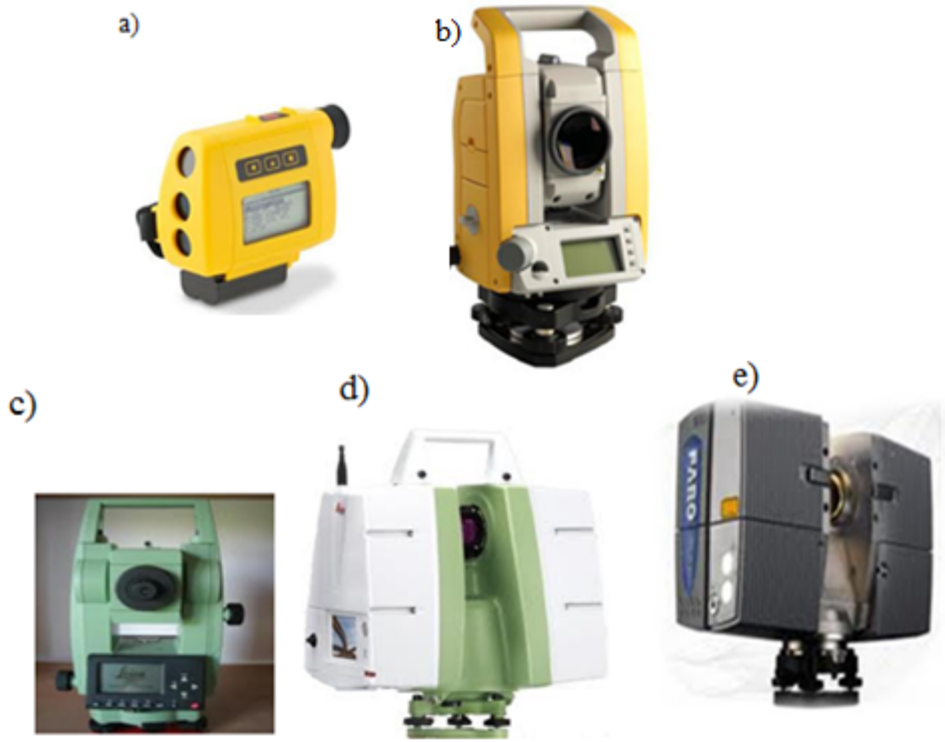
- Least Square Adjustment
- Polynomial Kernel
- Interval Analysis
- **Homotopy Continuation**
- **Artificial Neural Network**

3D Topological Navigation Network Modelling

- Delaunay Triangulation
- Polygonization Method

Data Collection

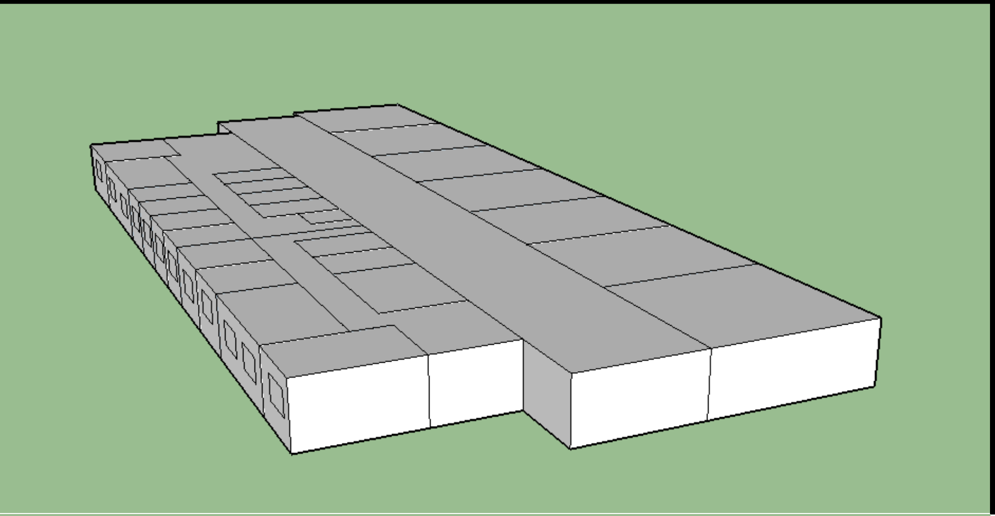
Indoor Building Surveying

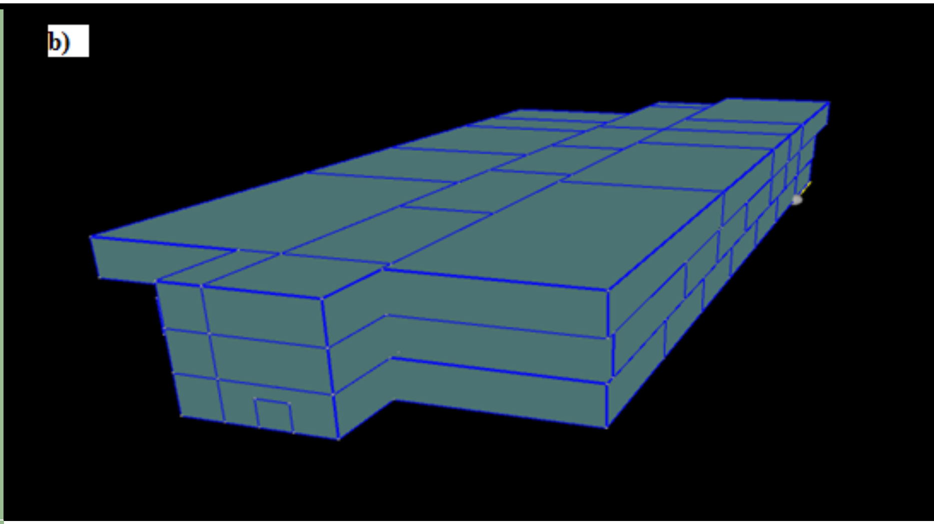


Surveying devices: a) Trimble LaserAce 1000; b) Trimble Total station M3; c) Leica 307 TCR; d) Leica ScanStation C10; e) Faro Photon 120/20.

3D Data Modelling

3D Building Modelling





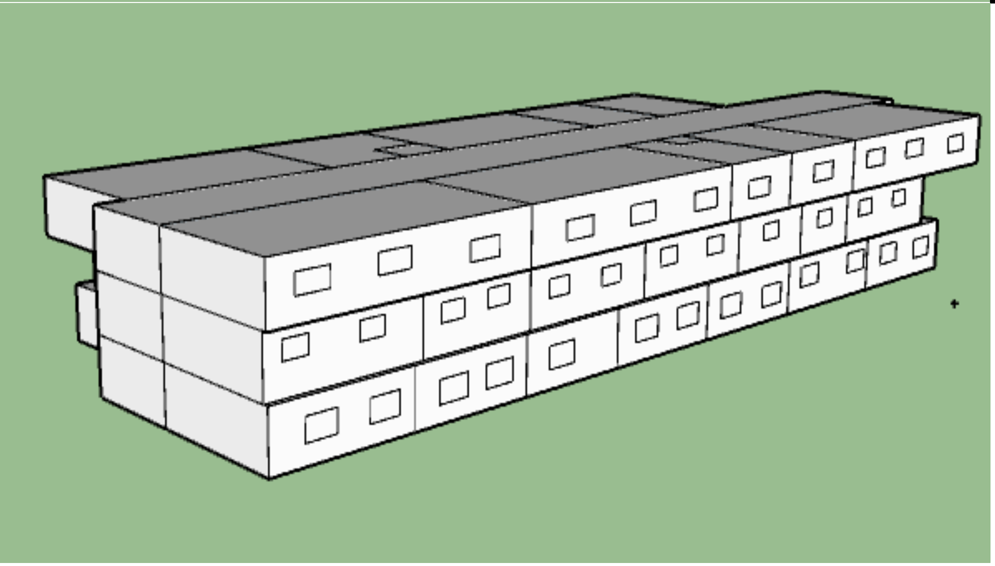


Figure 7: 3D Building Modelling (Trimble M3)

Uncertainty Modelling

Trimble LaserAce 1000 Accuracy

Surveying Equipment	Distance Accuracy	Horizontal Angle Accuracy	Vertical Angle Accuracy
Leica scanstation C10	±4 mm	12”	12”
Trimble LaserAce 1000	±100 mm	7200”	720”

Uncertainty Modelling

- Artificial neural network, interval analysis and homotopy continuation methods provide mathematical or statistical models of the inaccuracies of the measurements by the magnetometer.

- Since the highest measurement uncertainties are those of the horizontal angles measured by the magnetometer of the rangefinder, the researcher focuses on the calibration of these magnetometer measurements.

Interval Analysis and Homotopy Continuation

- Interval analysis is a well-known method for computing the bounds of a function, these being given bounds on the variables of that function (E. Ramon Moore and Cloud, 2009).

- The uncertainty of each measure can be represented using an interval defined either by a lower bound and a higher bound or by a midpoint value and a radius.

- Interval analysis is used to model the uncertainty of each measurement of the horizontal angle and horizontal distance made by the rangefinder.

Interval Analysis and Homotopy Continuation

- For distances observed from a position of the rangefinder, the possible position of the surveyed point by two concentric circles centred on the position of the rangefinder and of radii, the measured distance plus and minus the uncertainty on the distance .

Interval Analysis and Homotopy Continuation

- For horizontal angles observed from a position of the rangefinder, the possible position of the surveyed point by two rays emanating from the position of the rangefinder and whose angles with respect to a given point or the north are the measured angle plus and minus the uncertainty on the horizontal angle.

- Therefore, the surveyed point must be within a region bounded by these four loci: in between two concentric circles and two rays.

Interval Analysis and Homotopy Continuation

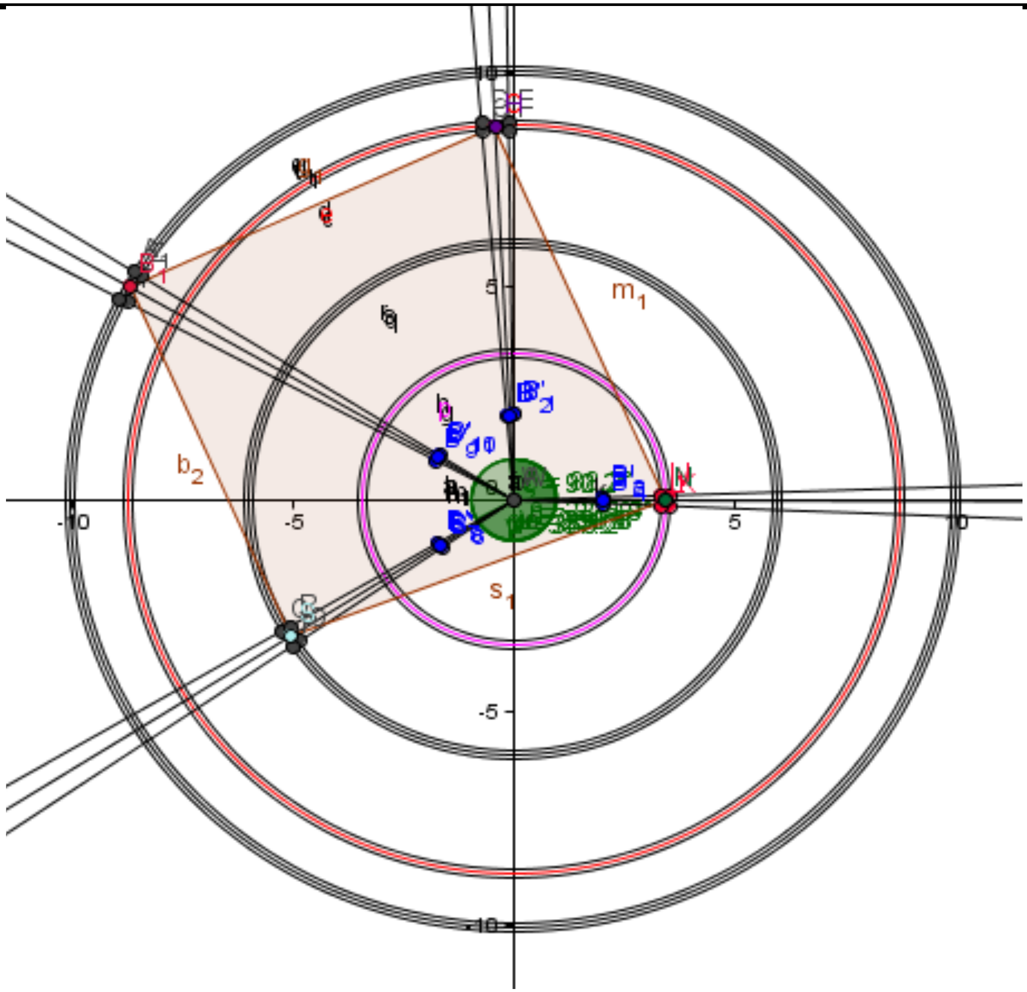


Figure 9: The geometric loci of each corner of a room as a function of all the measurements

Interval Analysis and Homotopy Continuation

- A homotopy is a continuous deformation of geometric figures or paths or more generally, functions: a function (or a path, or a geometric figure) is continuously deformed into another one (Allgower and Georg, 1990).

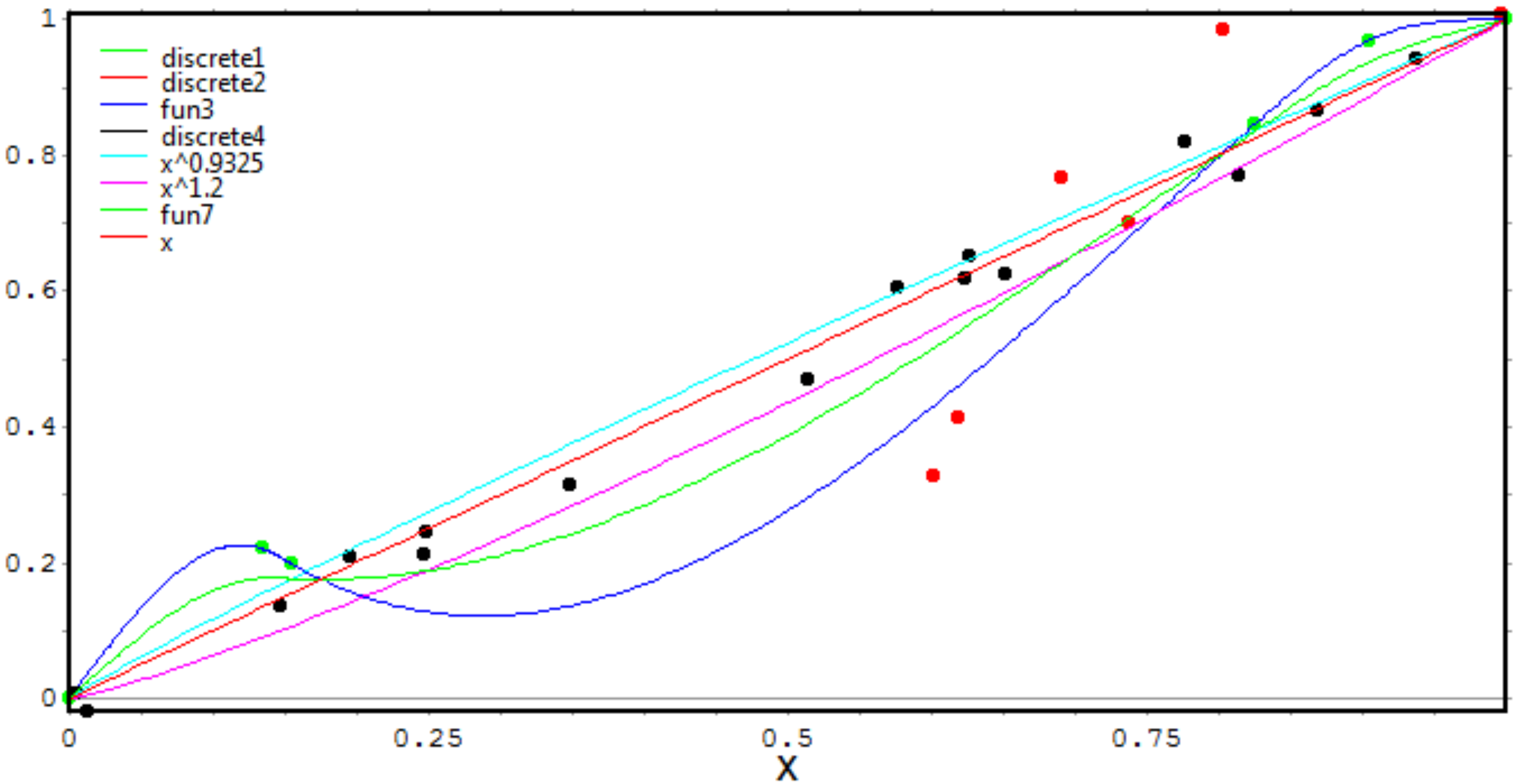
- homotopy is used to calibrate the rangefinder. The main idea is that the 360 degrees compass of the magnetometer is subject to continuous deformations, which do not induce any cut of any single part of this compass, nor any gluing of different parts of this compass.

Interval Analysis and Homotopy Continuation

- One can therefore think that the 360 degrees compass of the magnetometer is made of a highly deformable material like plastic, while the 360 degrees compass of the theodolite component of a total station is made of a very non-deformable material like temperature-invariant metal.

- This homotopy calibration can be visualized as the continuous deformation of each sector (defined by the rangefinder horizontal angle intervals of room 1) of a plastic disk (corresponding to the old-time theodolite graduated disk) to the corresponding sector of the total station's theodolite graduated disk.

Interval Analysis and Homotopy Continuation



Interval Analysis and Homotopy Continuation

cspline=(2.835277541322018*x-65.91303193139909*x^3)*charfun2(x,-inf,0.135214008)+(36.95438765091345*x^3-110.8631629527404*x^2+110.8472201502744*x-35.93844484844747)*charfun2(x,0.904669261,inf)+(-42.13985472016081*x^3+103.7992264328436*x^2-83.35124501967609*x+22.6233491424303)*charfun2(x,0.825306122,0.904669261)+(-2.820265996590805*x^3+6.447134568590096*x^2-3.005967614601302*x+0.5201993703648098)*charfun2(x,0.155102041,0.825306122)+(534.1896340799024*x^3-243.4268600486203*x^2+35.74999894335104*x-1.483510467657241)*charfun2(x,0.135214008,0.155102041)

0.25*cspline+0.75*lambda(x)^0.9325

Interval Analysis and Homotopy Continuation

Calibration of the horizontal angle measurements of the rangefinder using theodolite horizontal angle measurements

Point	Horizontal angle rangefinder (decimal degrees)	Horizontal angle first reading theodolite (degrees min sec)	Horizontal angle 2nd reading theodolite (degrees min sec)	Average Difference horizontal angle theodolite (decimal degrees)	Calibrated rangefinder horizontal angle	Difference between consecutive calibrated horizontal angles
1	268.9	163 19 18	343 19 51	67.745139	268.9	67.745139
2	336.0	231 04 54	51 03 40	122.85028	336.645139	122.85028
3	99.6	353 55 21	173 55 15	65.881667	99.495417	65.881667
4	166.1	59 50 03	239 46 21	294.264583	165.377083	294.264583
5	98.5	354 04 30	174 03 39	169.258333	99.641667	169.258333

Neural Network

- An artificial neural network is designed by several interconnected nodes which are called neurons.
- To train the artificial neural network, data is required to be divided into three datasets as training, validation and test data. Input data are the rangefinder measurements and target data are Total Station data.

Neural Network

- Our training algorithm is Levenberg-Marquardt (Levenberg, 1944; Marquardt, 1963; Moré, 1978; Lourakis, 2005).

- Levenberg-Marquardt algorithm is an iterative technique that determines the minimum of a multivariate function that is presented as the sum of squares of non-linear real-valued functions.

- It is a standard technique for non-linear least-squares problems (Lourakis, 2005).

Neural Network

$$w_{K+1} = w_K - \left(J_K^T J_k + \mu I\right)^{-1} J_k e_k$$

Where μ is always positive, called combination coefficient;

k is the index of iterations;

w is the weight vector;

e is error vector;

J is the Jacobian matrix that contains first derivatives of the network errors with respect to the weights and biases;

And I is the identity matrix.

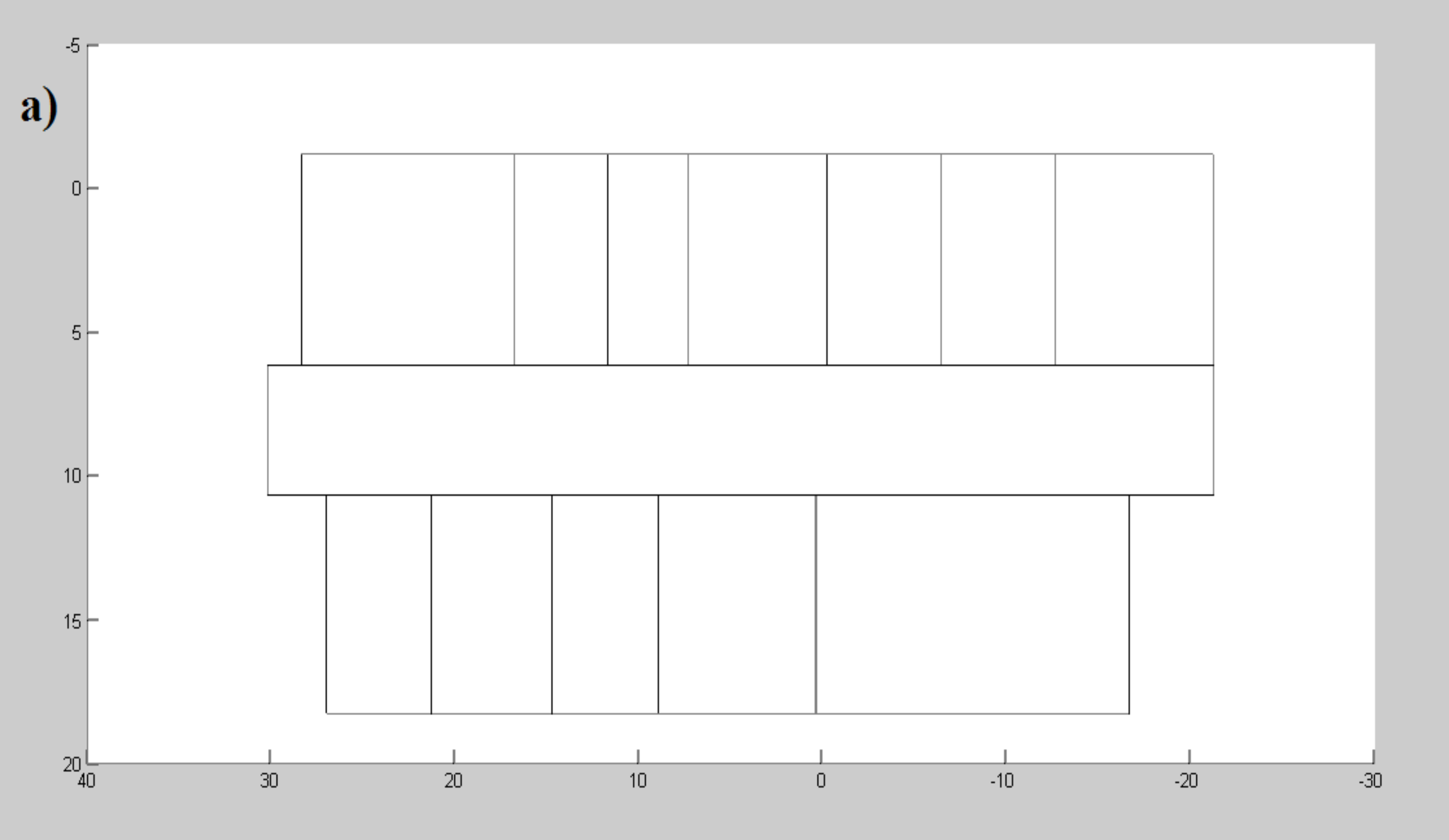
Neural Network vs Homotopy Continuation

Point	Horizontal angle rangefinder	Horizontal angle total station	Calibrated rangefinder horizontal angle (homotopy)	Calibrated rangefinder horizontal angle (neural network)
Δ2-1	95.9	95.3	95.3	96.08
Δ3-2	82.1	79.55	79.55	82.07
Δ4-3	102.9	109.07	109.07	100.57
Δ1-4	79.1	76.08	76.08	81.27

3D Feature Merge

- Residual errors of our building model collected by the rangefinder have been minimized using least square adjustment, polynomial kernel, interval analysis and homotopy continuation.
- Then we glue geometrical features such as rooms and corridors to model a precise geometrical model.
- we defined six topological relationships between two building features.

3D Feature Merge



3D Feature Merge

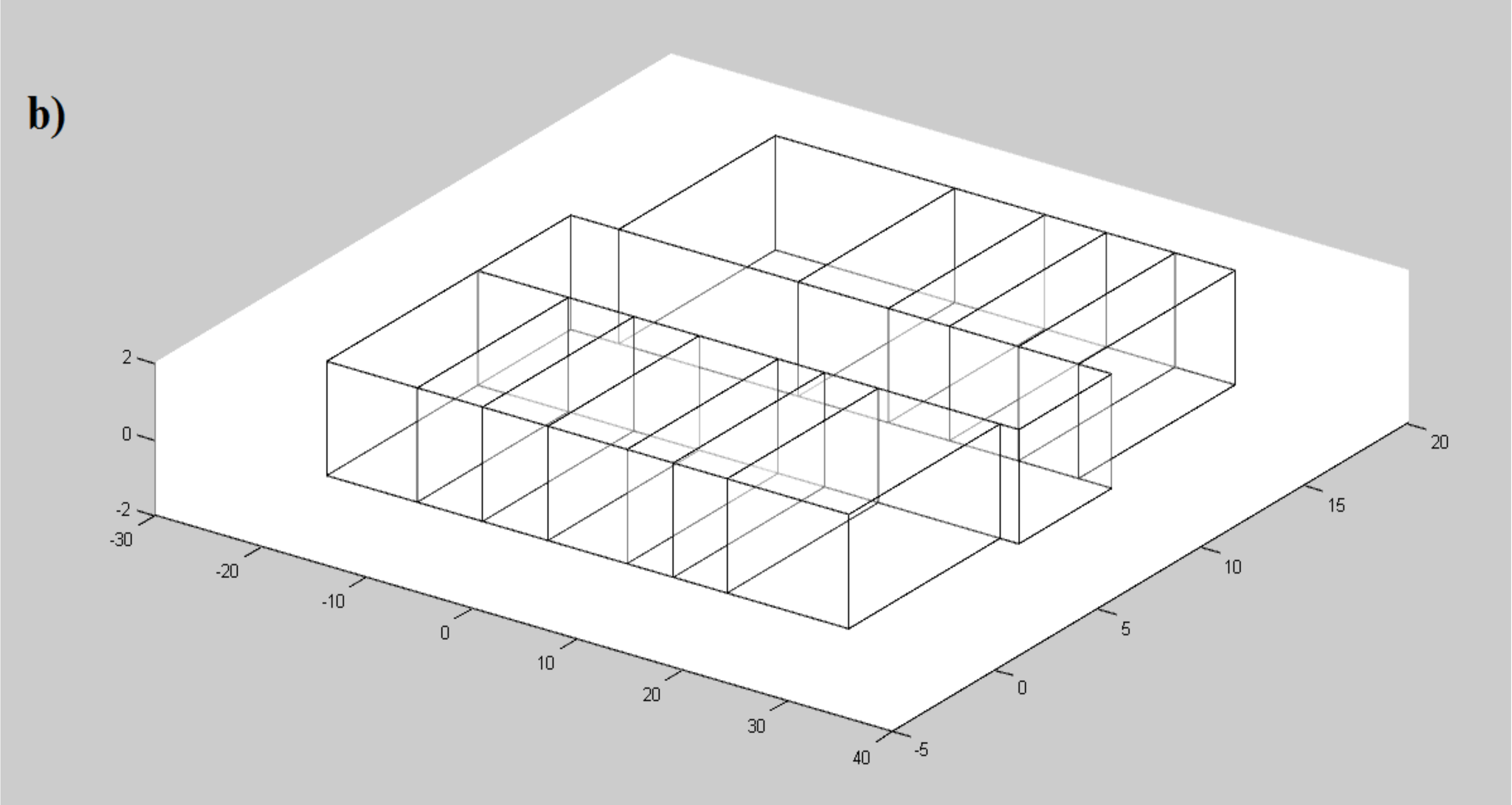


Figure 11: A precise geometrical model of a) 2D floor plan b) 3D floor collected by the rangefinder.

3D Topological Navigation Network Modelling

3D Indoor Navigation Network Modelling

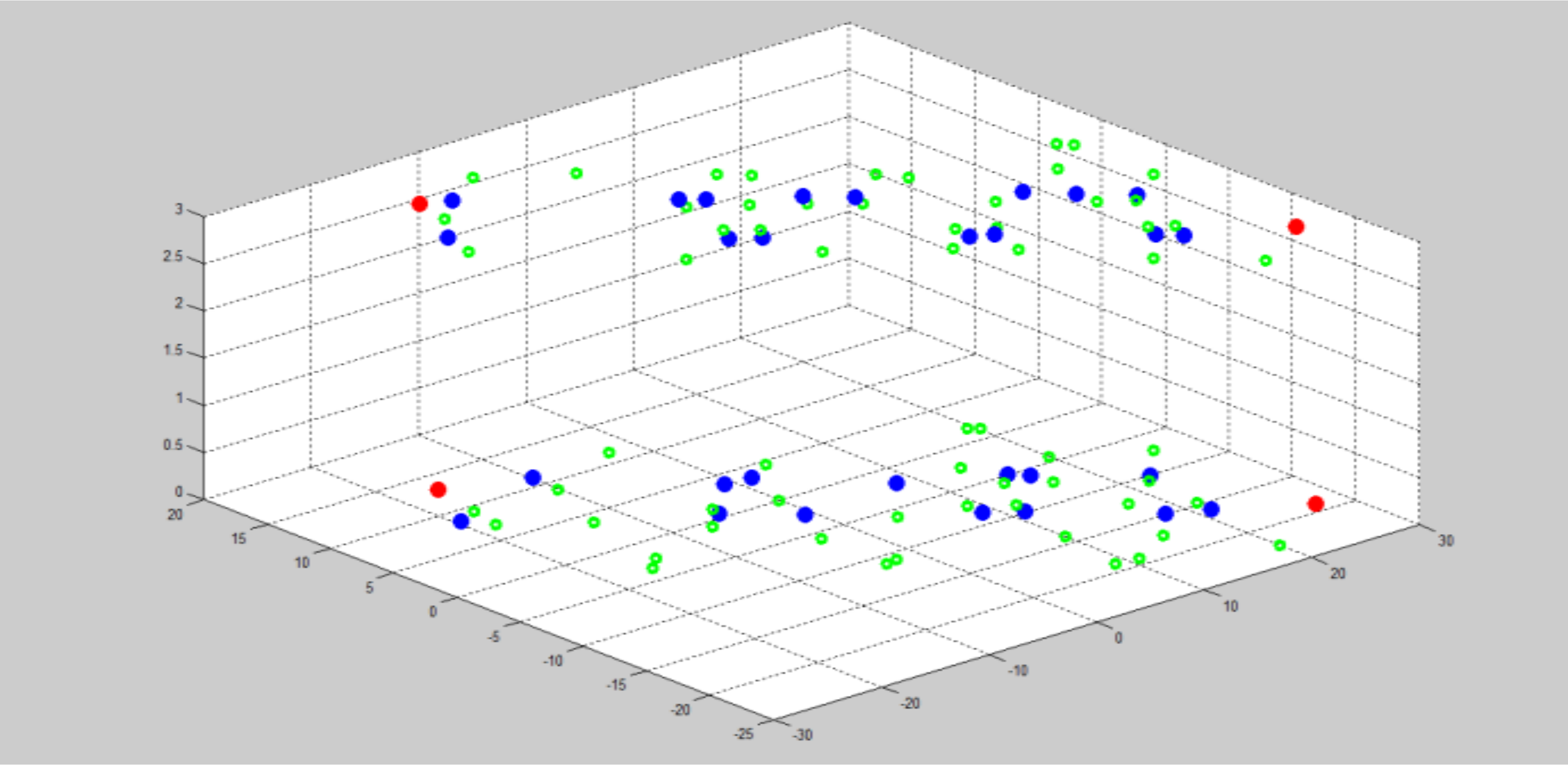


Figure 12: Surveying control points as dual nodes: doors are represented as blue points, elevators as red points, room and corridor control points as green points.

3D Indoor Navigation Network Modelling (precise geometry)

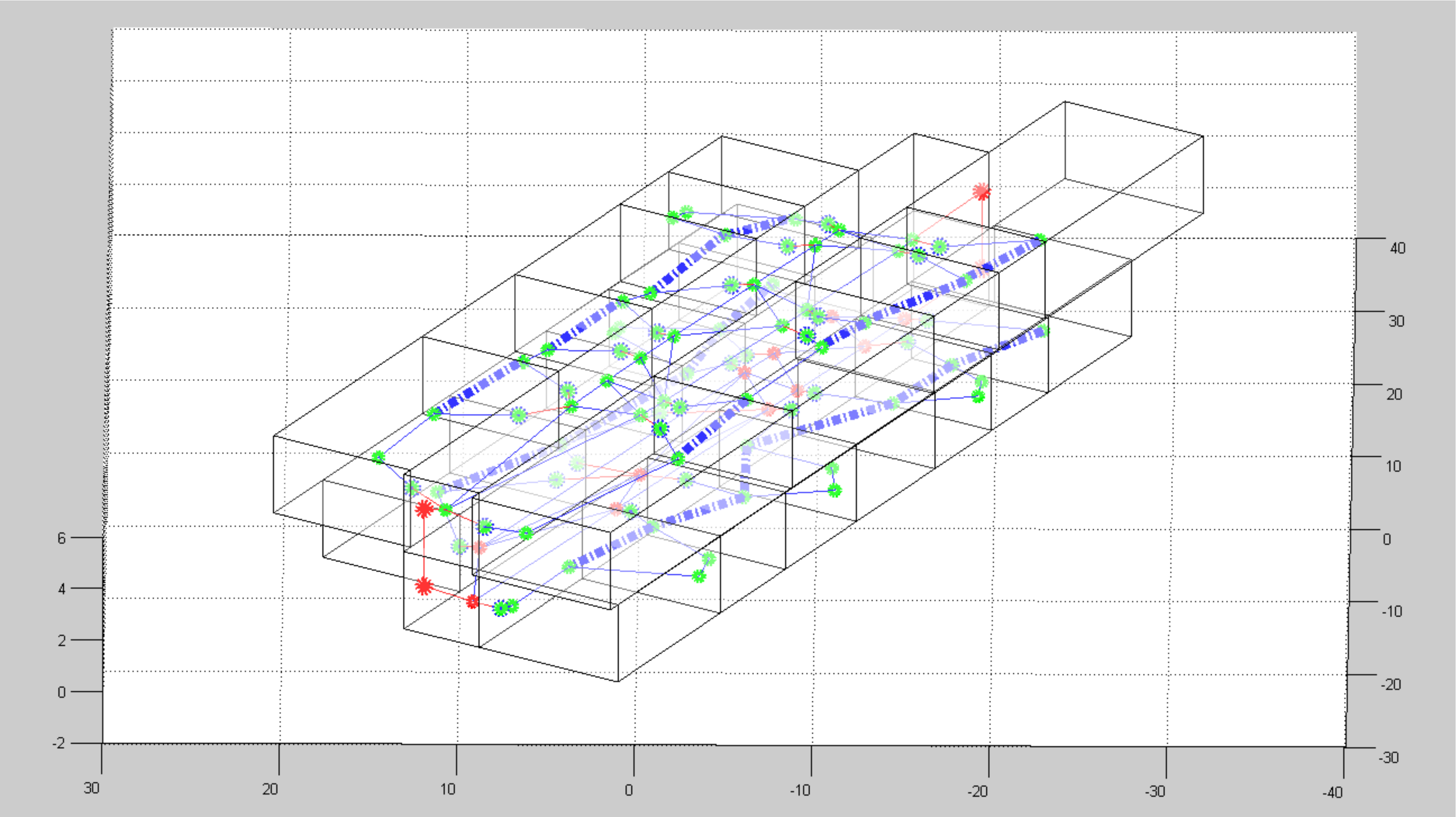


Figure 14: Topological indoor navigation network model.

3D Indoor Navigation Network Modelling

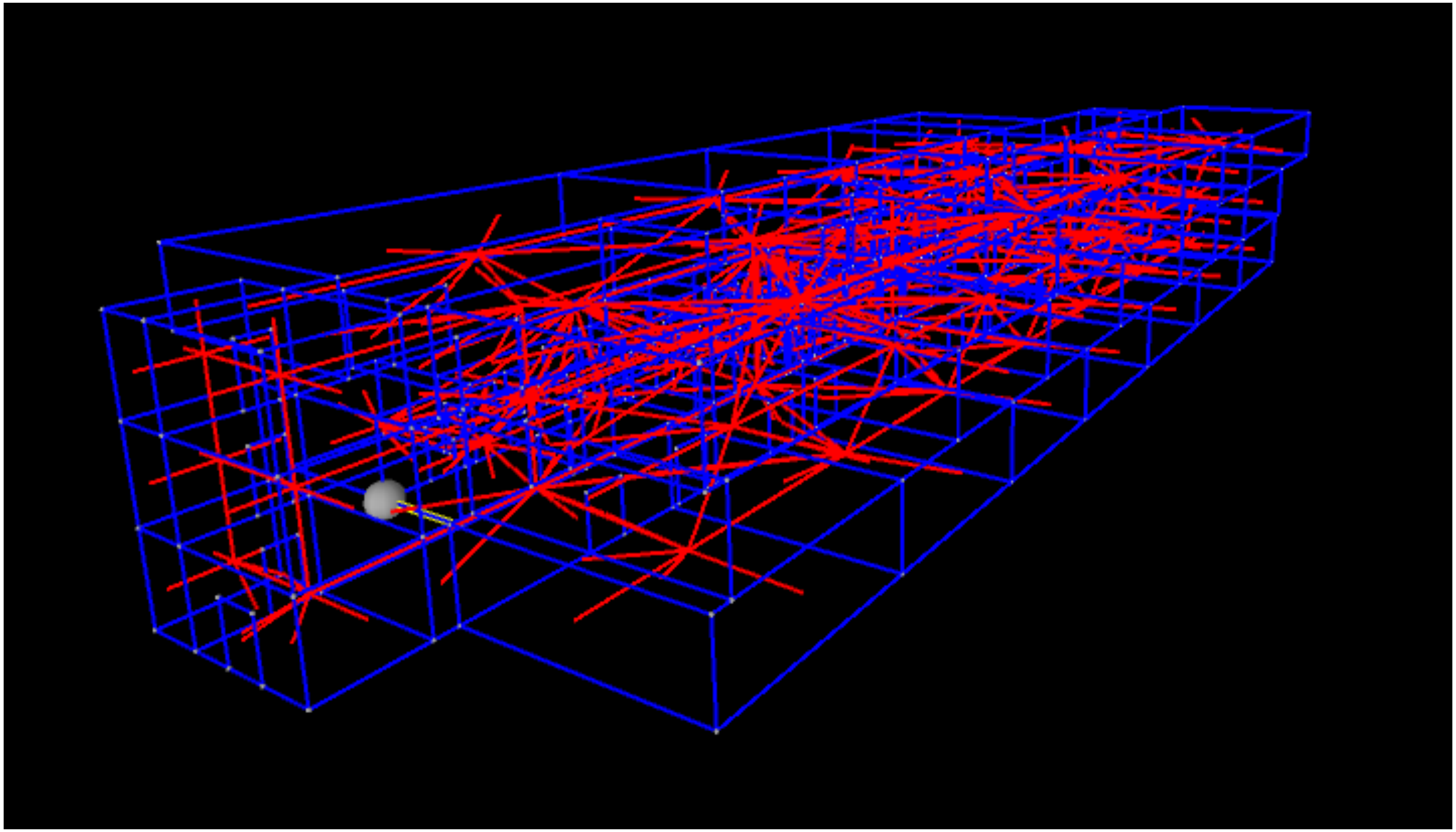


Figure 15: Topological indoor navigation network model generated using DHE data structure.

Demo

movies\model.webm

Conclusion

- A topological mathematical function has been introduced against the popular statistical least square adjustment which is obtained by continuous deformation of the function mapping of the rangefinder measurements to the theodolite measurements.

Conclusion

- We presented the interval valued homotopy model of the measurement of horizontal angles by the magnetometer component of the rangefinder.

- This model blends interval analysis and homotopy continuation. The results prove that homotopies give the best results both in terms of RMSE and the L_∞ metric.

Thank you