Airborne Altimetric LiDAR Simulator: An Education Tool

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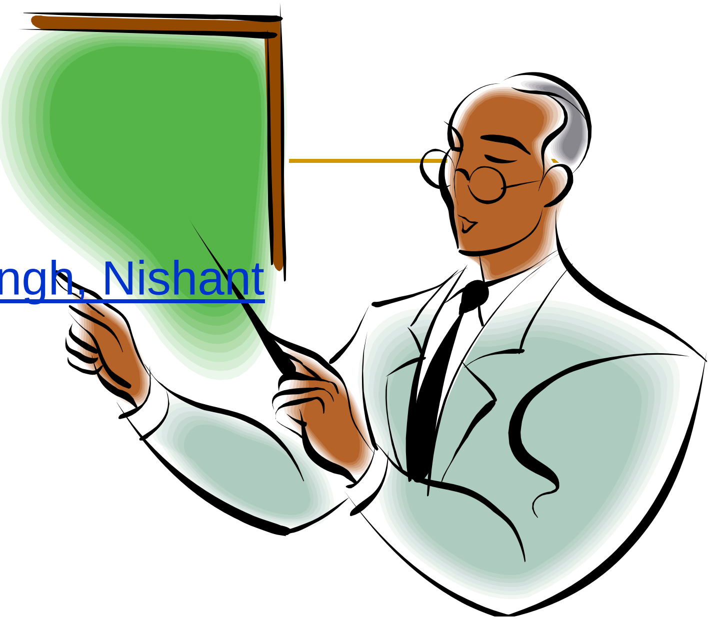
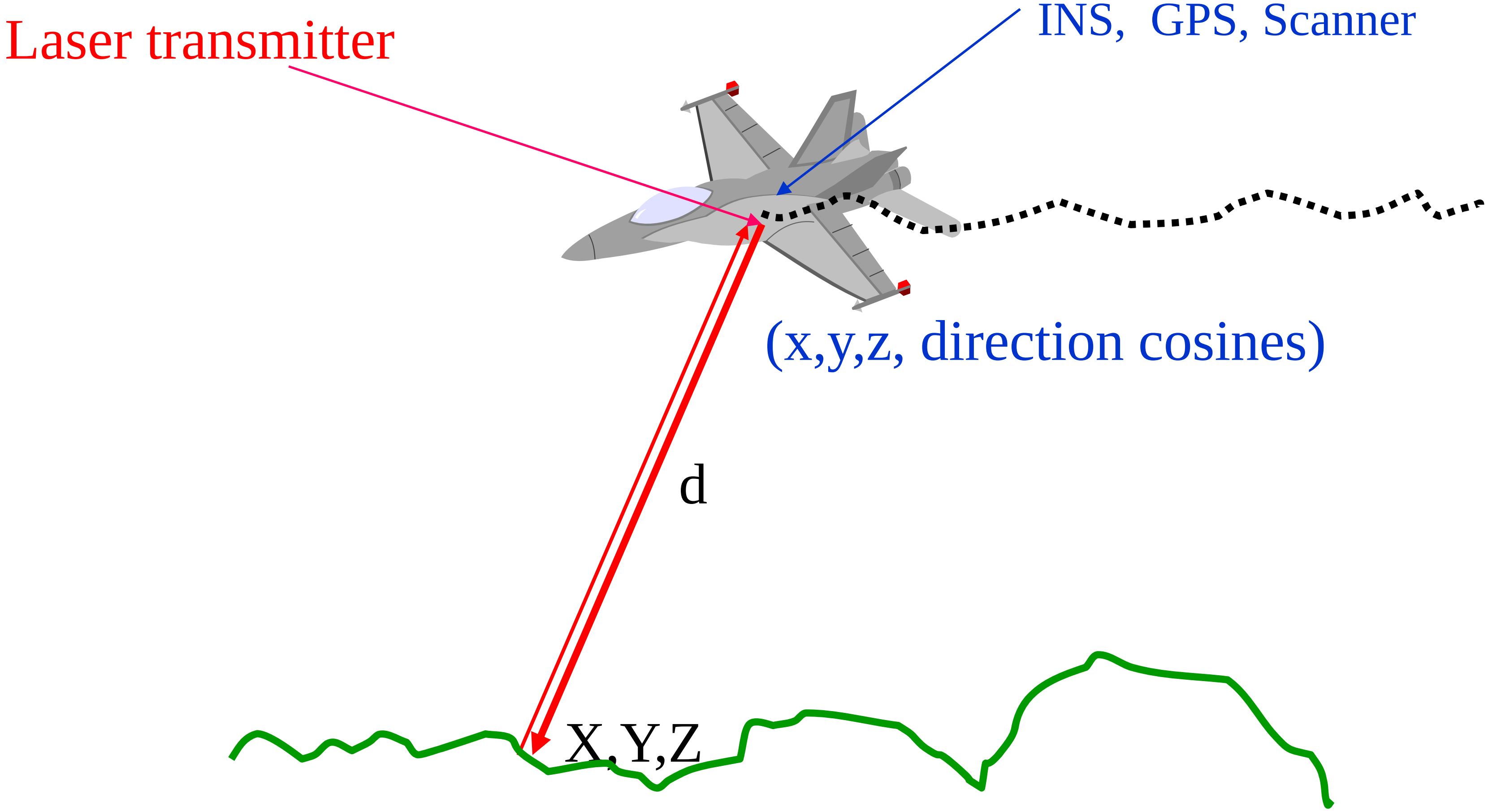


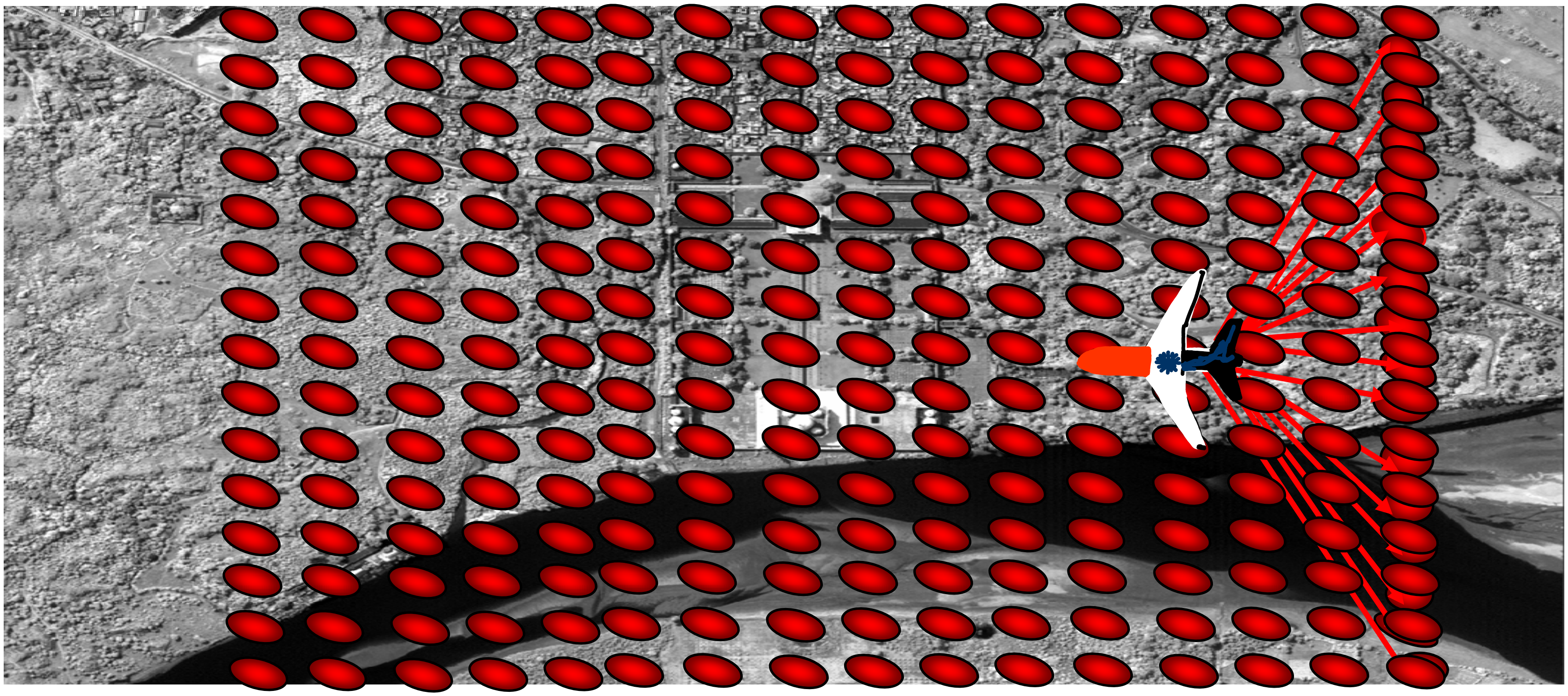
Are data available?

Outline

- What is Airborne Altimetic LiDAR Simulator?
- What should an ideal simulator do?
- Development of simulator
- Simulated data and results
- Applications of simulator

Principle of LiDAR



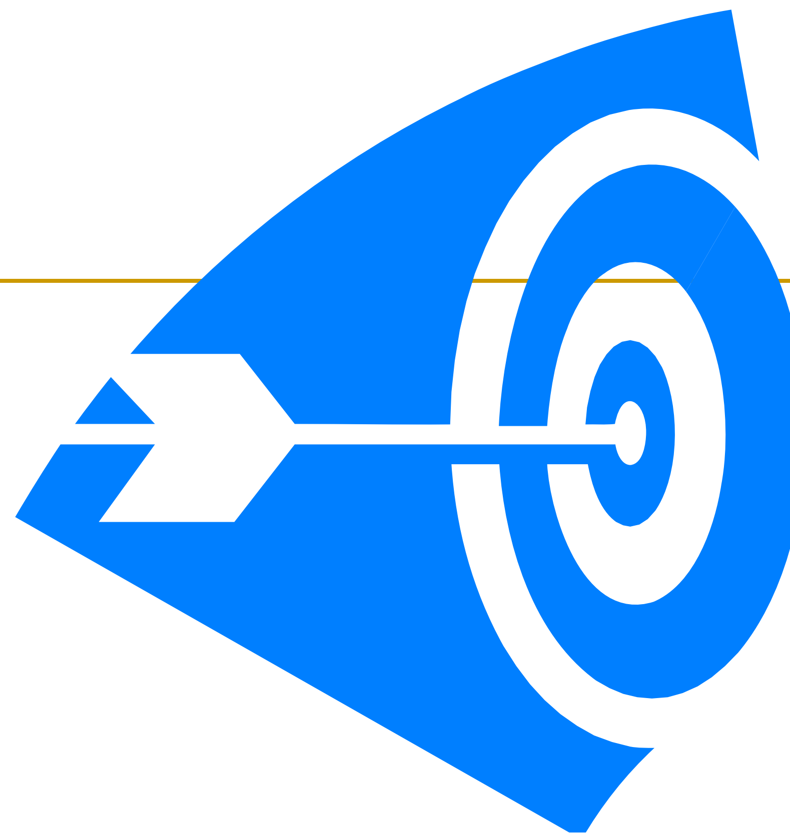


Credit space Imaging for background image

What is an airborne altimetric simulator?

- Definition:
  - A computer based system which generates LiDAR data similar to an actual sensor for user specified sensor and trajectory over a given terrain.
  - Based on mathematical models, algorithms and programming language.

Design consideration for simulator



Should be . . .

- User friendly
- Wider distribution
- Help or tutorial

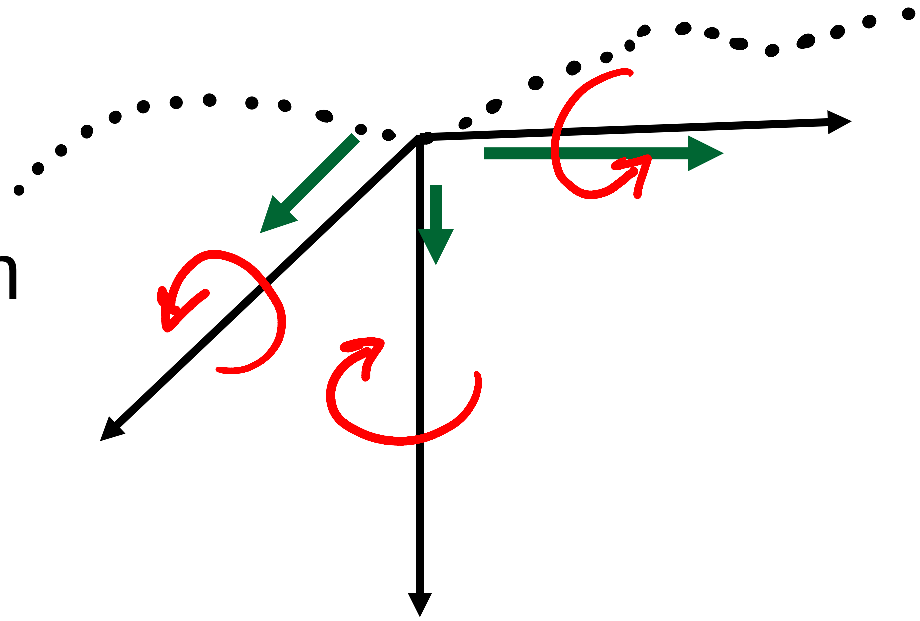
Can simulate . . .

- Generic sensor

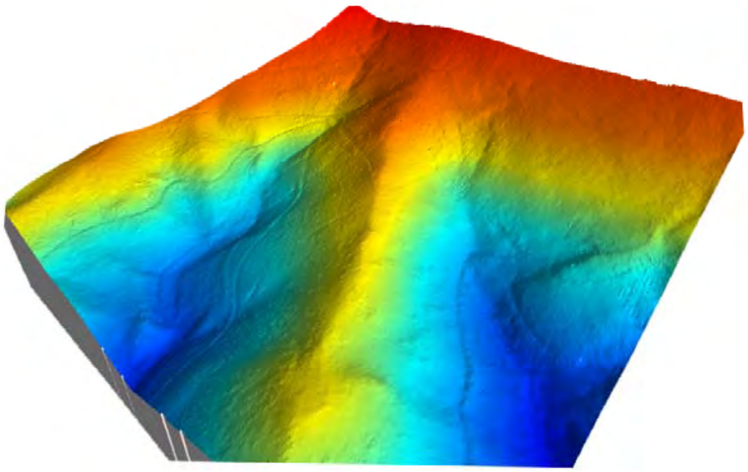
- Specific sensors
  - ALTM
  - ALS
  - And others…

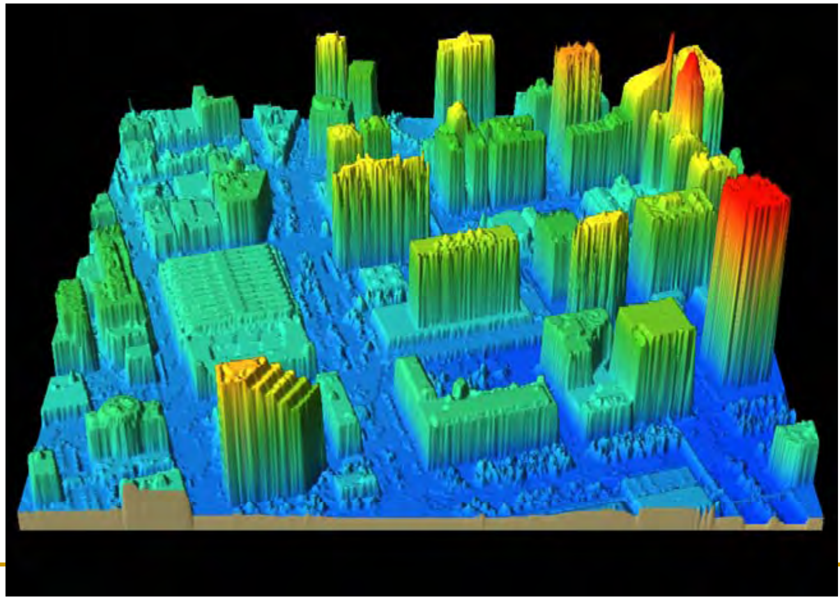
Should simulate trajectory as in a normal flight

- 6 degrees of freedom



Should simulate earthlike surfaces





Source: Optech Inc.

Also…

- Possibility of error introduction

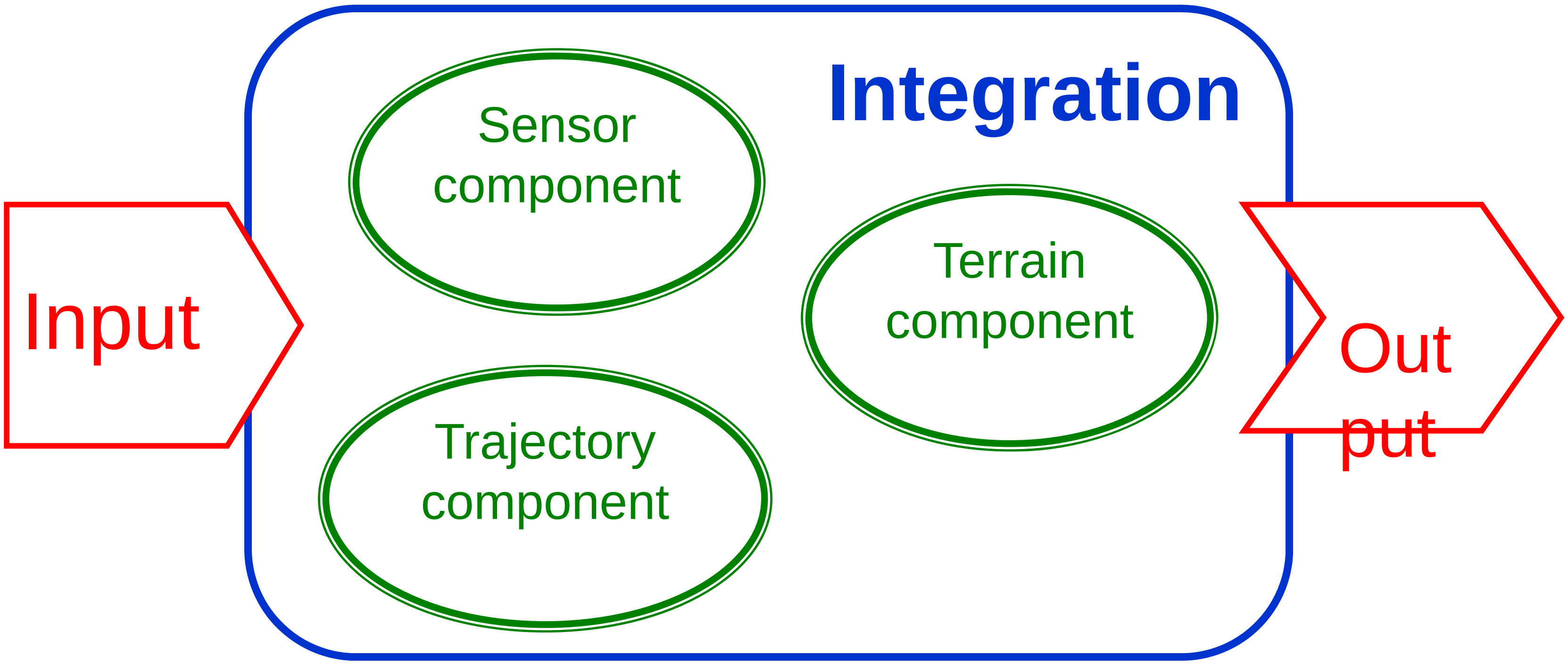
- Output data in common formats

Development of simulator

Programming language

- JAVA
  - GUI
  - Graphical and numerical programming
  - Platform independent

System components



Trajectory component

- Location
- Attitude

Location

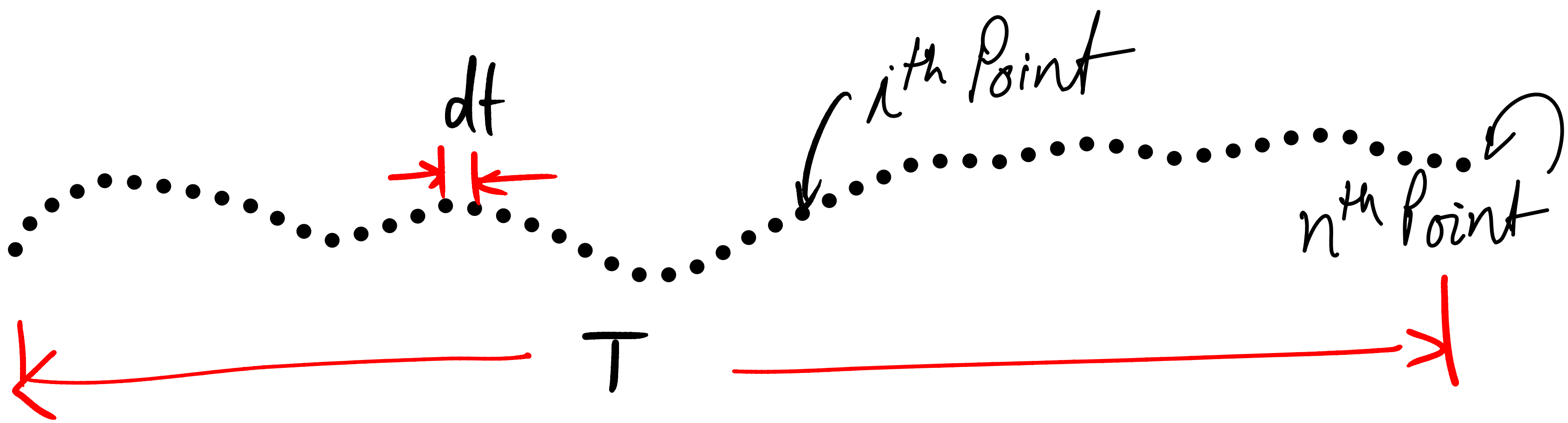
- Location: coordinates of laser head at each firing of pulse

- Location depends on Instantaneous accelerations

- Instantaneous accelerations should be simulated as in a normal flight: pseudo-random simulation

Acceleration simulation

$$a_X^i = \sum_{j=1}^{J} A_j \sin\left(B_j \left(\frac{2\pi}{T}(id_t)\right)\right) + \sum_{k=1}^{K} C_k \cos\left(D_k \left(\frac{2\pi}{T}(id_t)\right)\right) + m(id_t)$$



$$dt = \frac{1}{F}$$

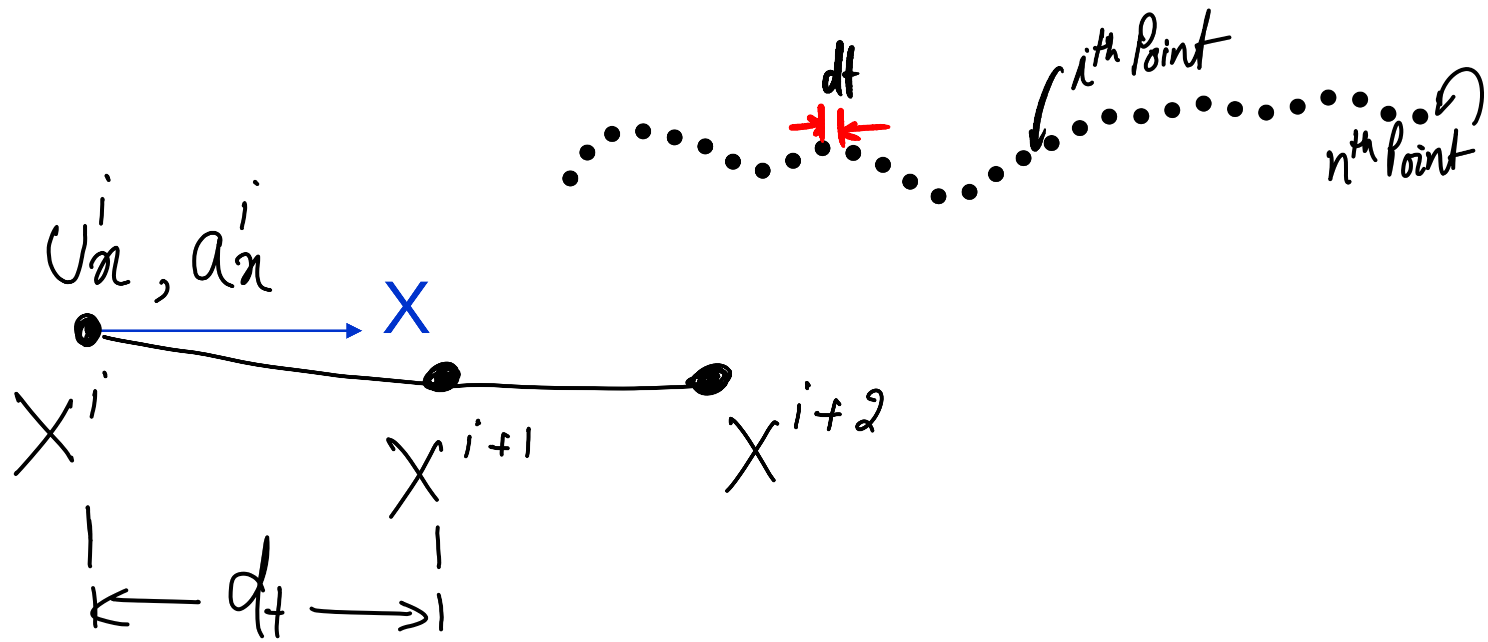
$$T = n \cdot dt$$

F = Firing frequency

J,K,A,B,C,D and m governing parameters

Location simulation

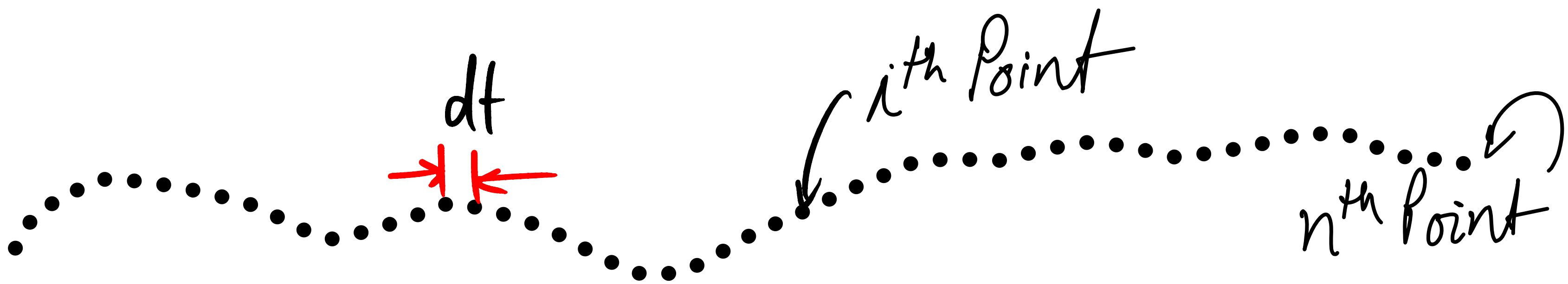
$$X^{i+1} = X^{i} + u_x^i d_t + \frac{1}{2} a_x^i d_t^{\,2}$$



u_x = Velocity in direction flight i.e. X axis

Attitude (Roll, Pitch, Yaw) simulation

$$R^i = \sum_{j=1}^{J} A_j \sin\left(B_j (\frac{2\pi}{T}(id_t)) \right) + \sum_{k=1}^{K} C_k \cos\left(D_k (\frac{2\pi}{T}(id_t)) \right) + m(id_t)$$



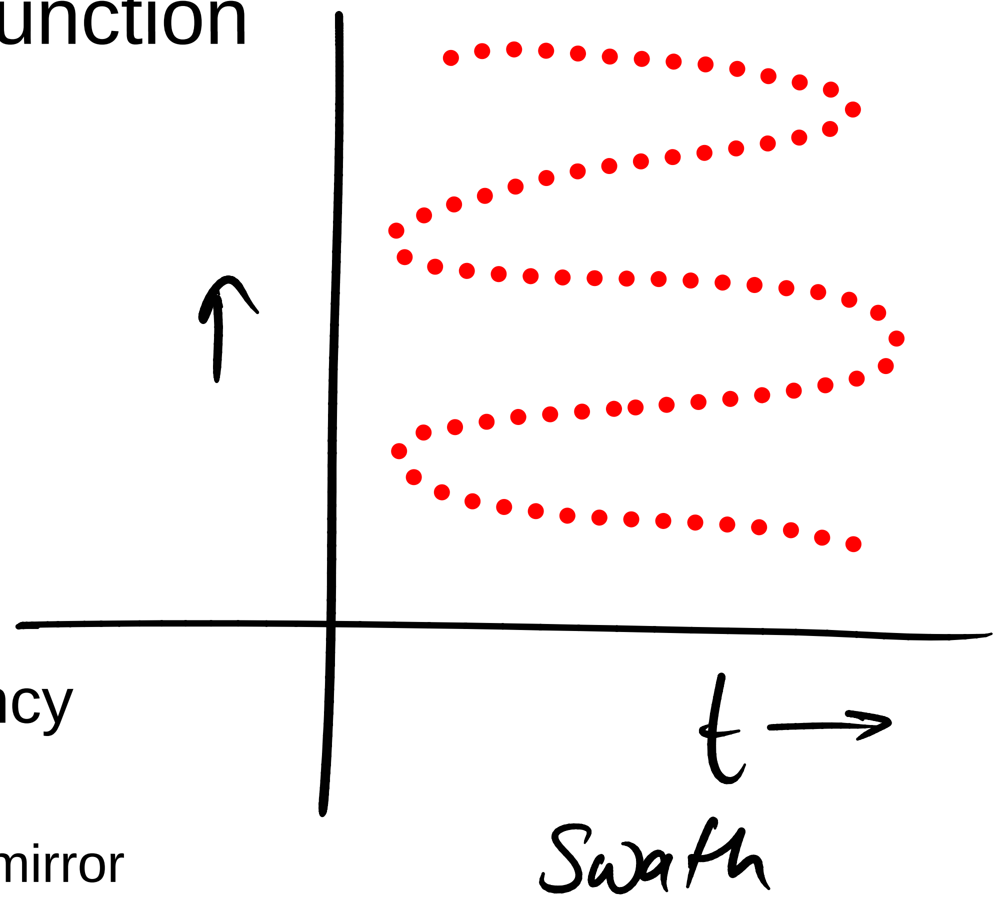
Sensor component

- Replicate sensor function

$$\theta = \frac{\frac{S}{2}\sin(t\sqrt{\frac{k}{R}})}{\sin(\frac{1}{4f}\sqrt{\frac{k}{R}})}$$

S is full scan angle
f is the scanning frequency

k is driving acceleration
R is radius of the scanning mirror



Terrain component

- Modeling surfaces: earthlike
  - Vector approach

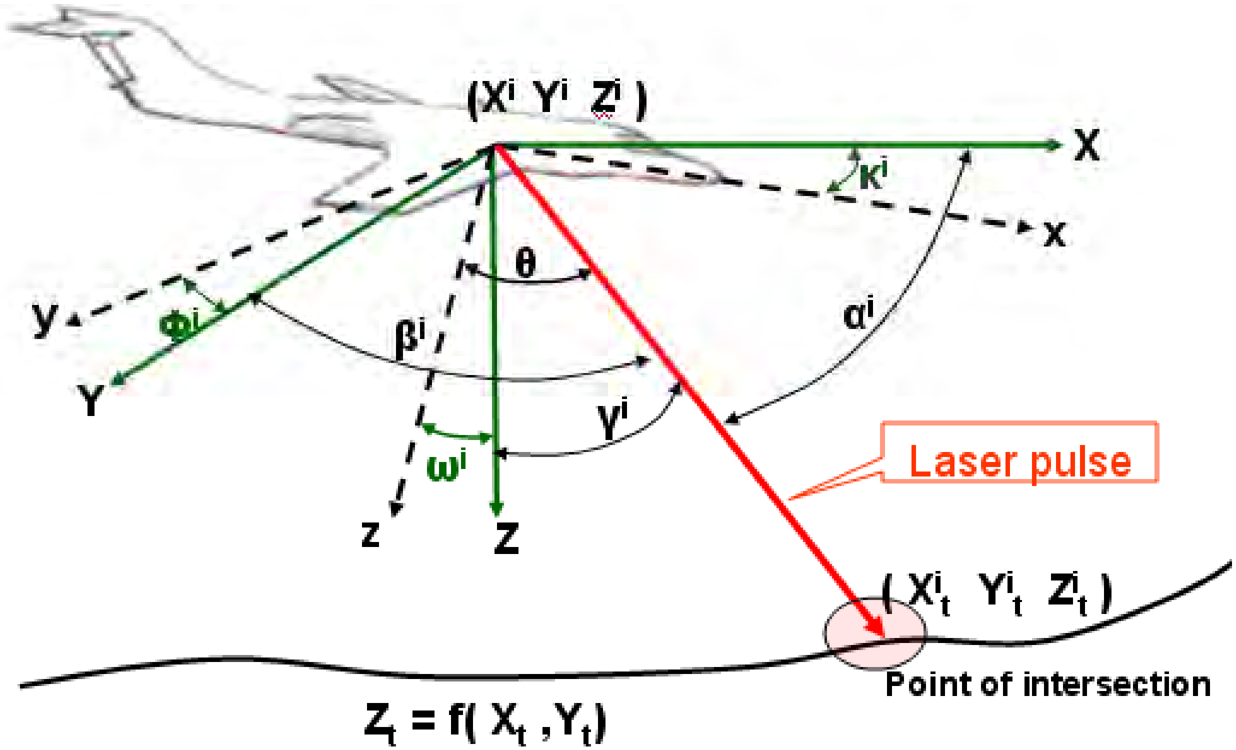
$$Z = AX + BY + C$$

$$Z = A[\sin(X / B) - \sin(XY / C)] + D$$

$$Z = A[\sin(X / Y) - \sin(XY / B)] + C$$

  - Raster approach

Integration of components



Laser vector $\frac{X - X^i}{a^i} = \frac{Y - Y^i}{b^i} = \frac{Z - Z^i}{c^i}$

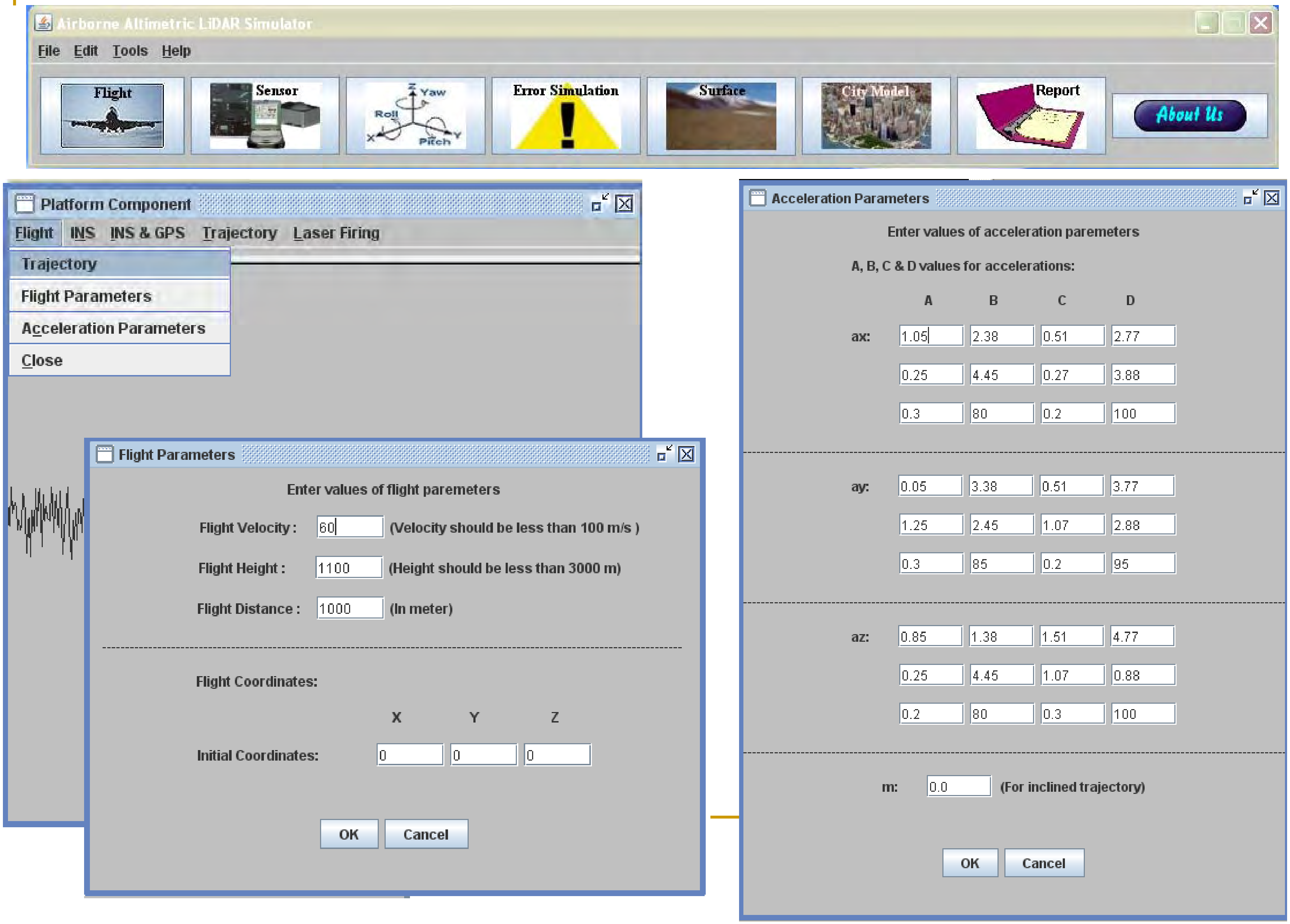
Solving the intersection

Error introduction in simulated data

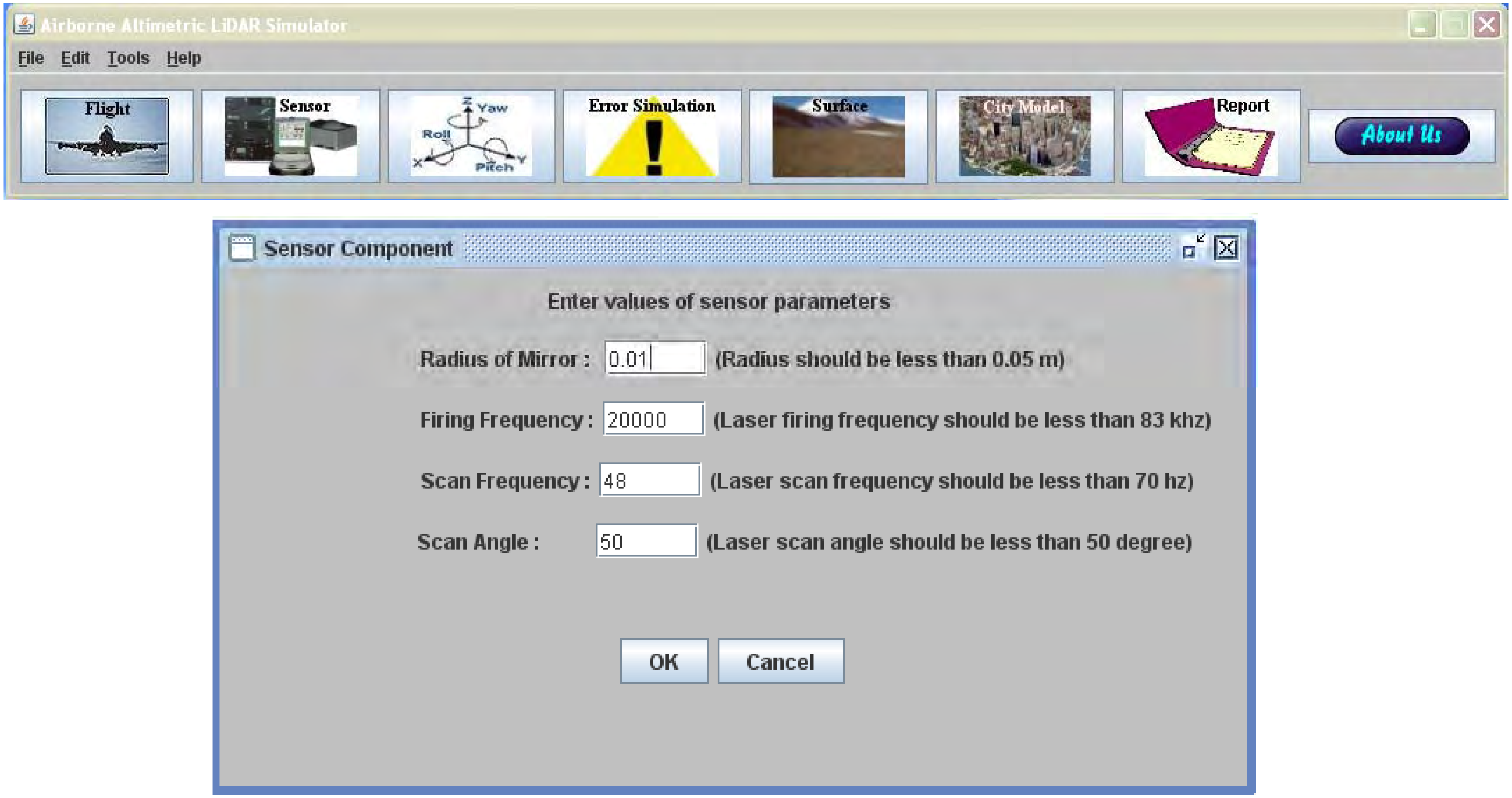
$$X_T^i = X_t^i + N(\mu_X, \sigma_X{}^2)$$

Known from field

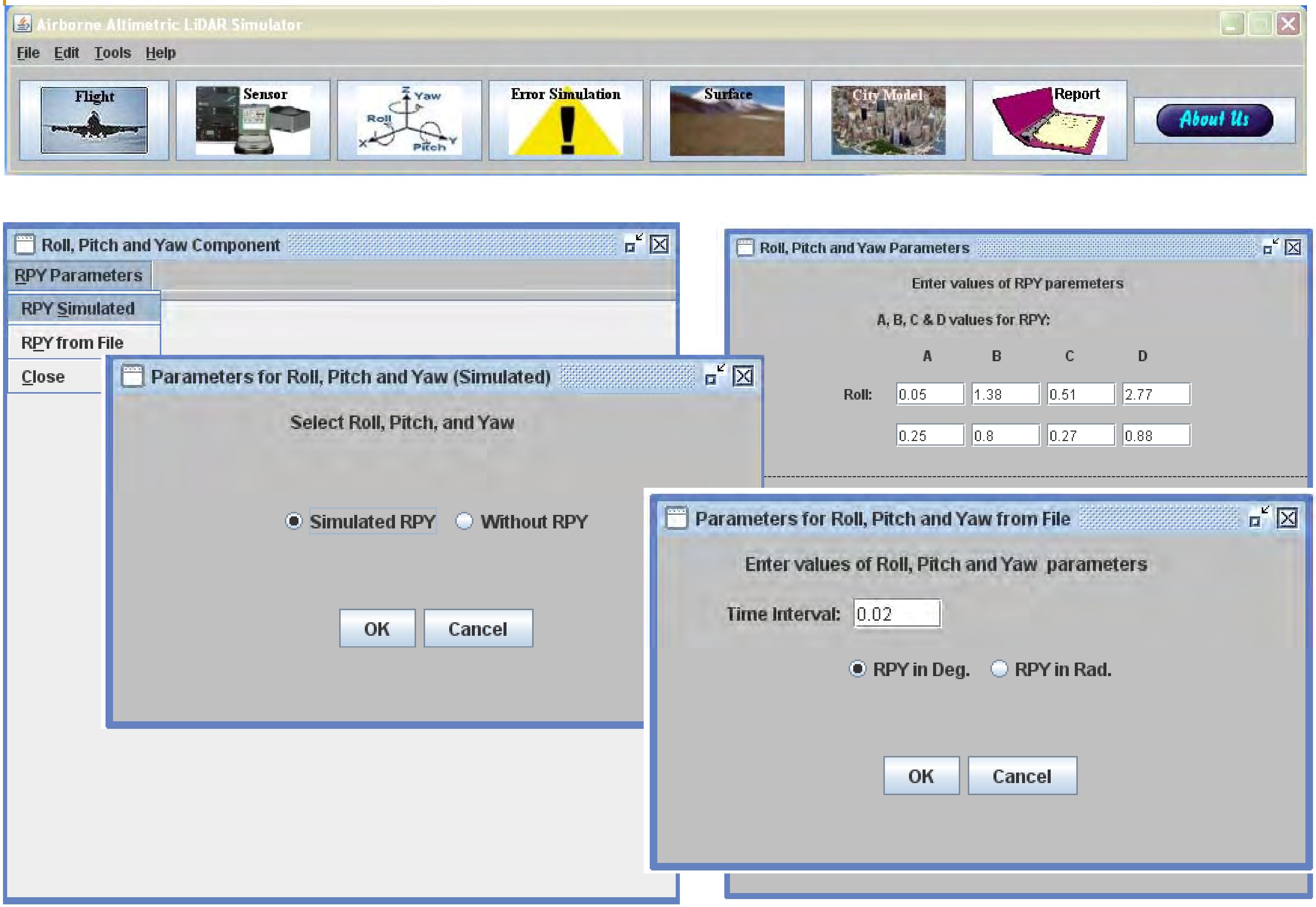
Software development


Airborne Altimetric LiDAR Simulator
File Edit Tools Help
Flight
Sensor
Yaw
Roll
Pitch
Error Simulation
Surface
City Model
Report
About Us
Platform Component
Flight INS INS & GPS Trajectory Laser Firing
Trajectory
Flight Parameters
Acceleration Parameters
Close
Flight Parameters
Enter values of flight paremeters
Flight Velocity : 60 (Velocity should be less than 100 m/s)
Flight Height : 1100 (Height should be less than 3000 m)
Flight Distance : 1000 (In meter)
Flight Coordinates:
X Y Z
Initial Coordinates: 0 0 0
OK Cancel
Acceleration Parameters
Enter values of acceleration paremeters
A, B, C & D values for accelerations:
A B C D
ax: 1.05 2.38 0.51 2.77
0.25 4.45 0.27 3.88
0.3 80 0.2 100
ay: 0.05 3.38 0.51 3.77
1.25 2.45 1.07 2.88
0.3 85 0.2 95
az: 0.85 1.38 1.51 4.77
0.25 4.45 1.07 0.88
0.2 80 0.3 100
m: 0.0 (For inclined trajectory)
OK Cancel

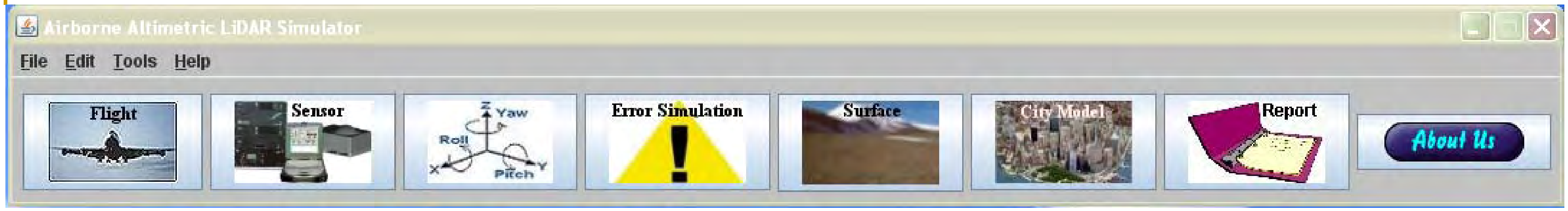
Sensor component.

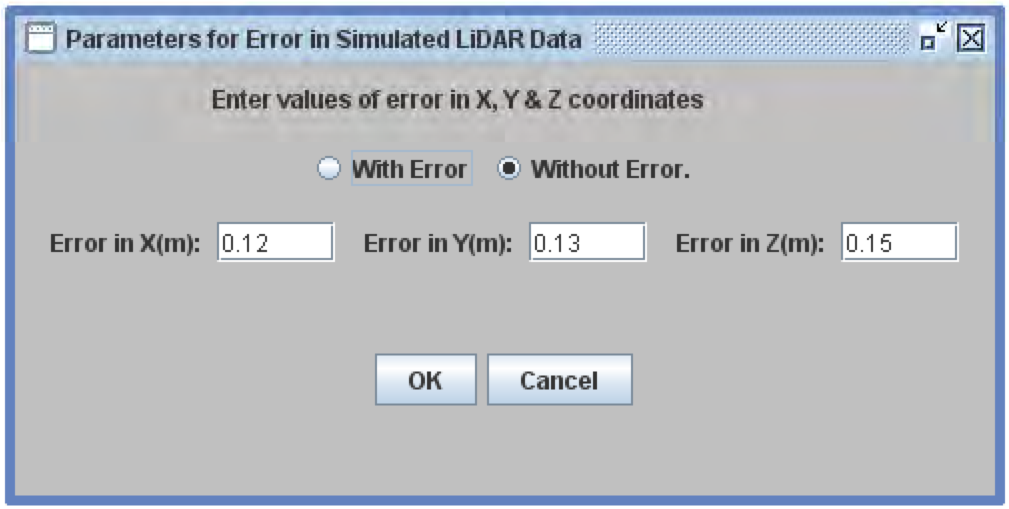


Simulation of Roll, Pitch and Yaw.

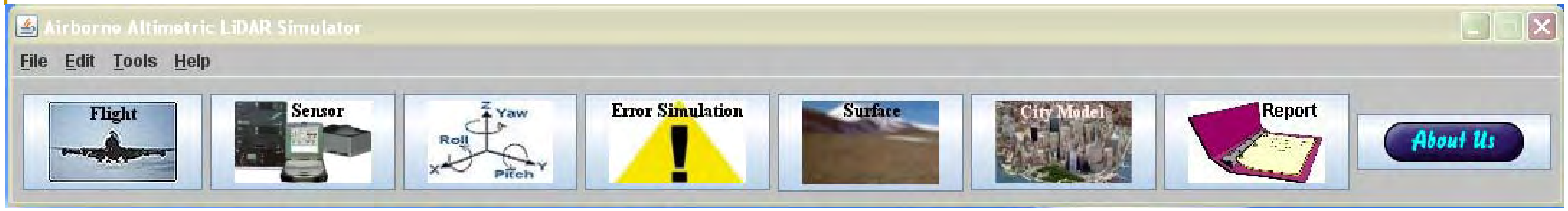


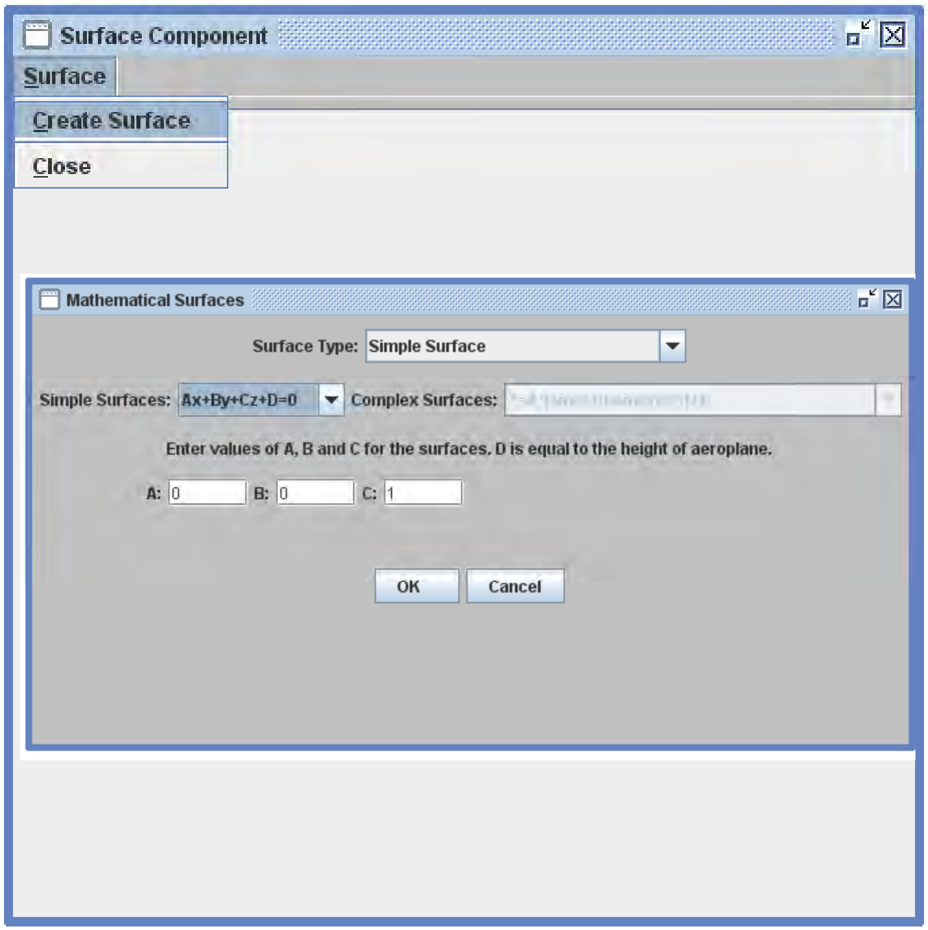
Error Simulation.

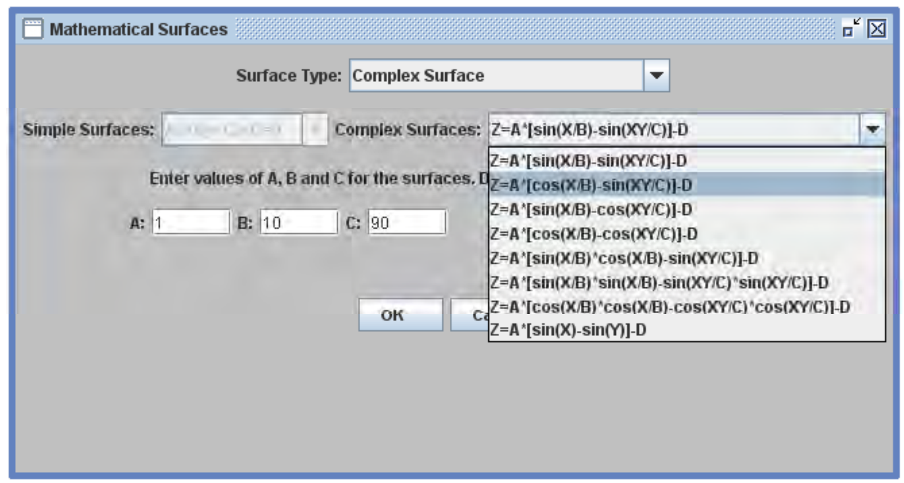




Surface component.

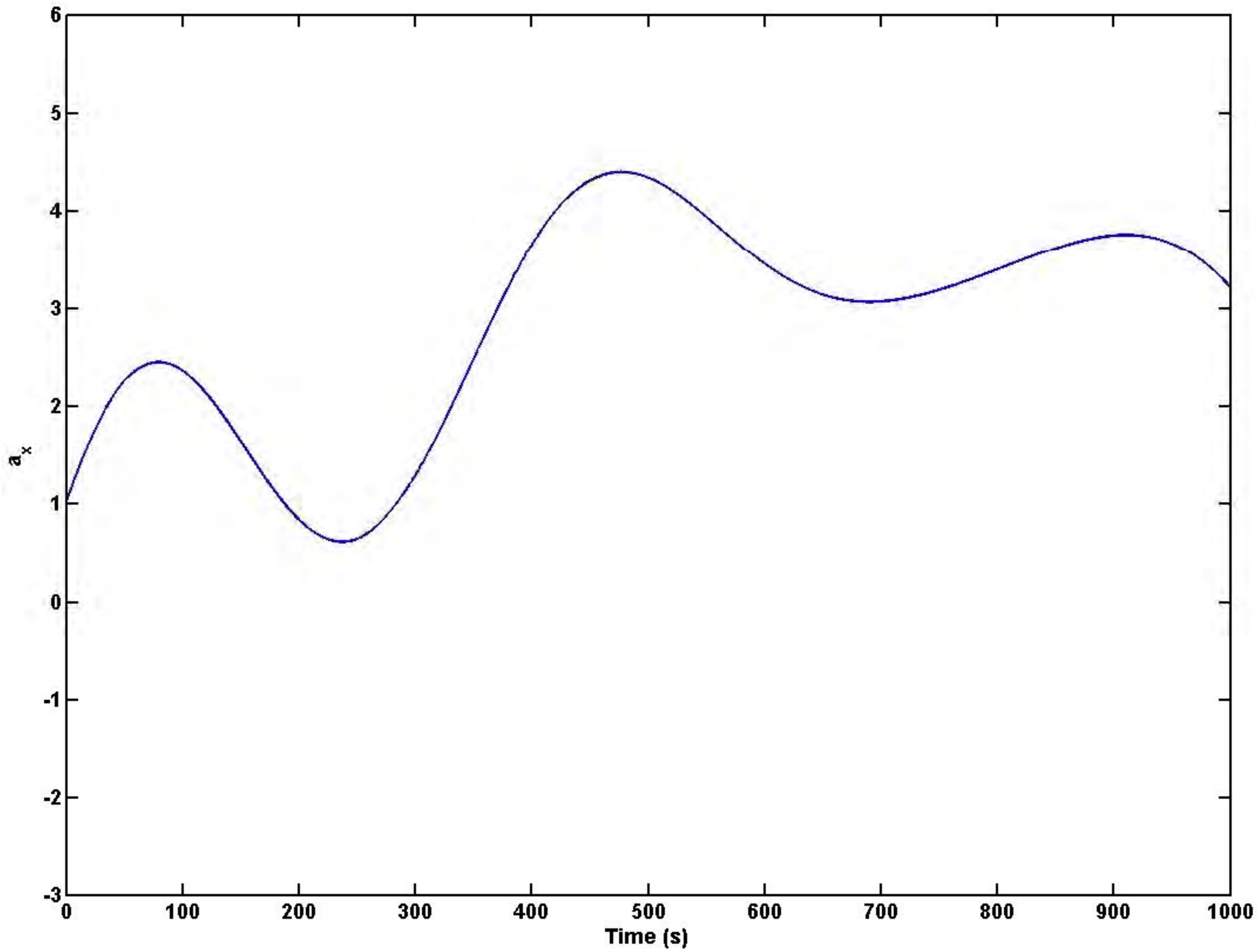






Simulated data and results

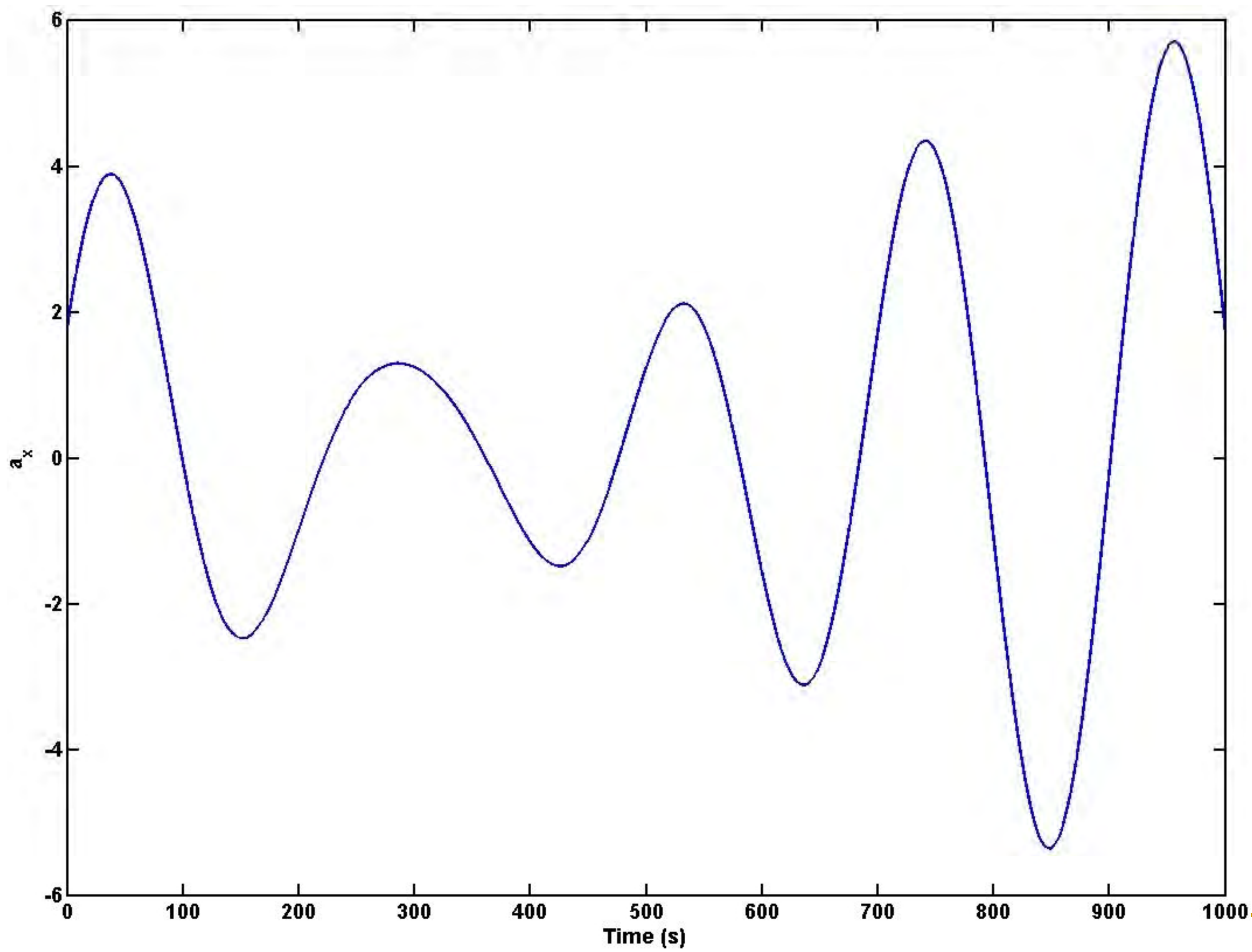
$$a_X^i = \sum_{j=1}^{J} A_j \sin\left(B_j \left(\frac{2\Pi}{T}(id_t)\right)\right) + \sum_{k=1}^{K} C_k \cos\left(D_k \left(\frac{2\Pi}{T}(id_t)\right)\right) + m(id_t)$$



j=2, k=2

A_1	3.54
A_2	1.65
B_1	0.38
B_2	2.45
C_1	0.51
C_2	3.77
D_1	2.77
D_2	0.88
m	0.0
dt	0.001
T	1000

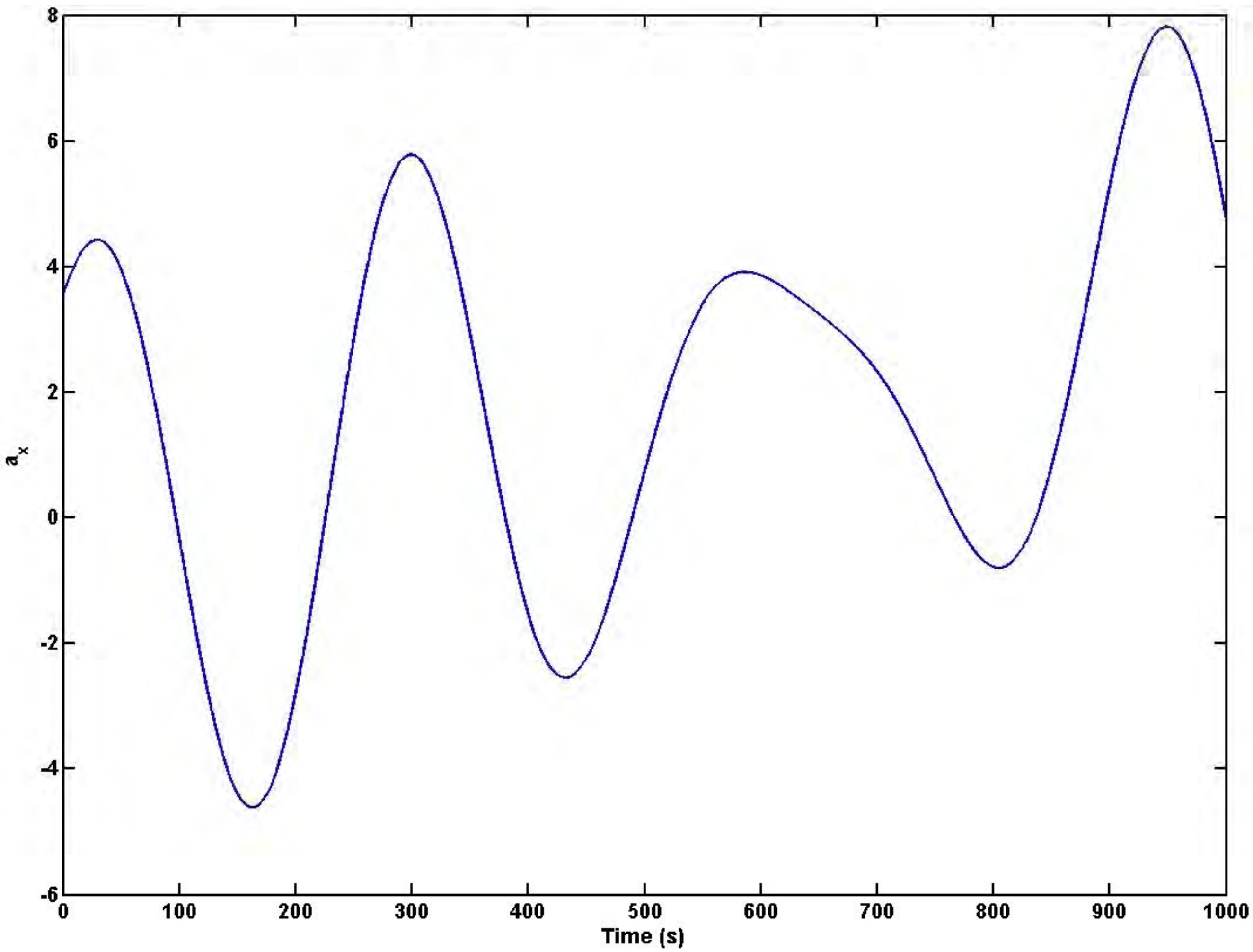
$$a_X^i = \sum_{j=1}^{J} A_j \sin\left(B_j (\frac{2\Pi}{T}(id_t)) \right) + \sum_{k=1}^{K} C_k \cos\left(D_k (\frac{2\Pi}{T}(id_t)) \right) + m(id_t)$$



j=2, k=2

A_1	0.68
A_2	3.25
B_1	3.38
B_2	4.45
C_1	0.89
C_2	2.54
D_1	5.23
D_2	1.34
m	0.0
dt	0.001
T	1000

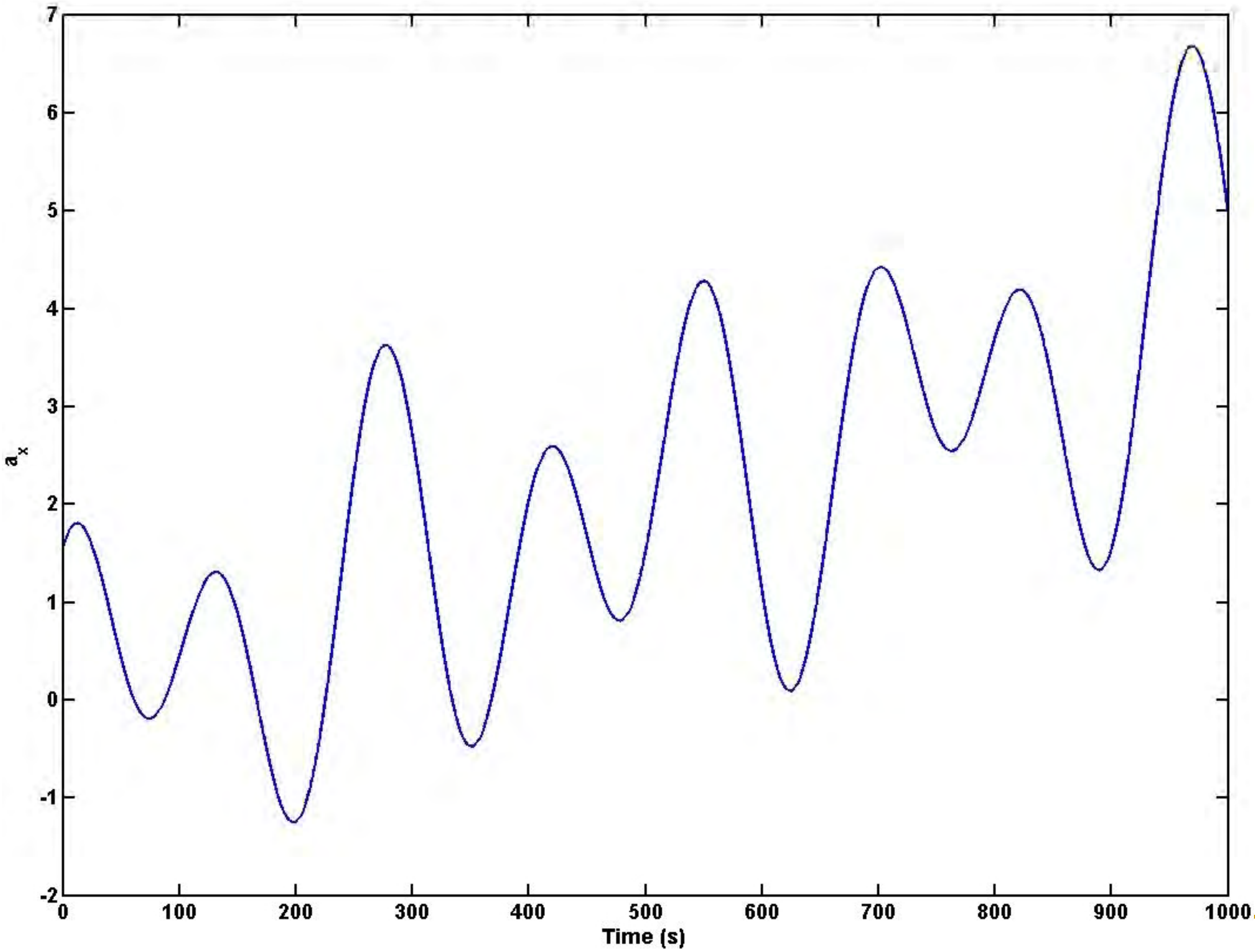
$$a_X^i = \sum_{j=1}^{J} A_j \sin\left(B_j \left(\frac{2\Pi}{T}(id_t)\right)\right) + \sum_{k=1}^{K} C_k \cos\left(D_k \left(\frac{2\Pi}{T}(id_t)\right)\right) + m(id_t)$$



j=2, k=2

A_1	1.78
A_2	0.25
B_1	4.38
B_2	2.45
C_1	1.78
C_2	1.24
D_1	3.23
D_2	2.34
m	0.003
dt	0.001
T	1000

$$a_X^i = \sum_{j=1}^{J} A_j \sin\left(B_j \left(\frac{2\Pi}{T}(id_t)\right)\right) + \sum_{k=1}^{K} C_k \cos\left(D_k \left(\frac{2\Pi}{T}(id_t)\right)\right) + m(id_t)$$

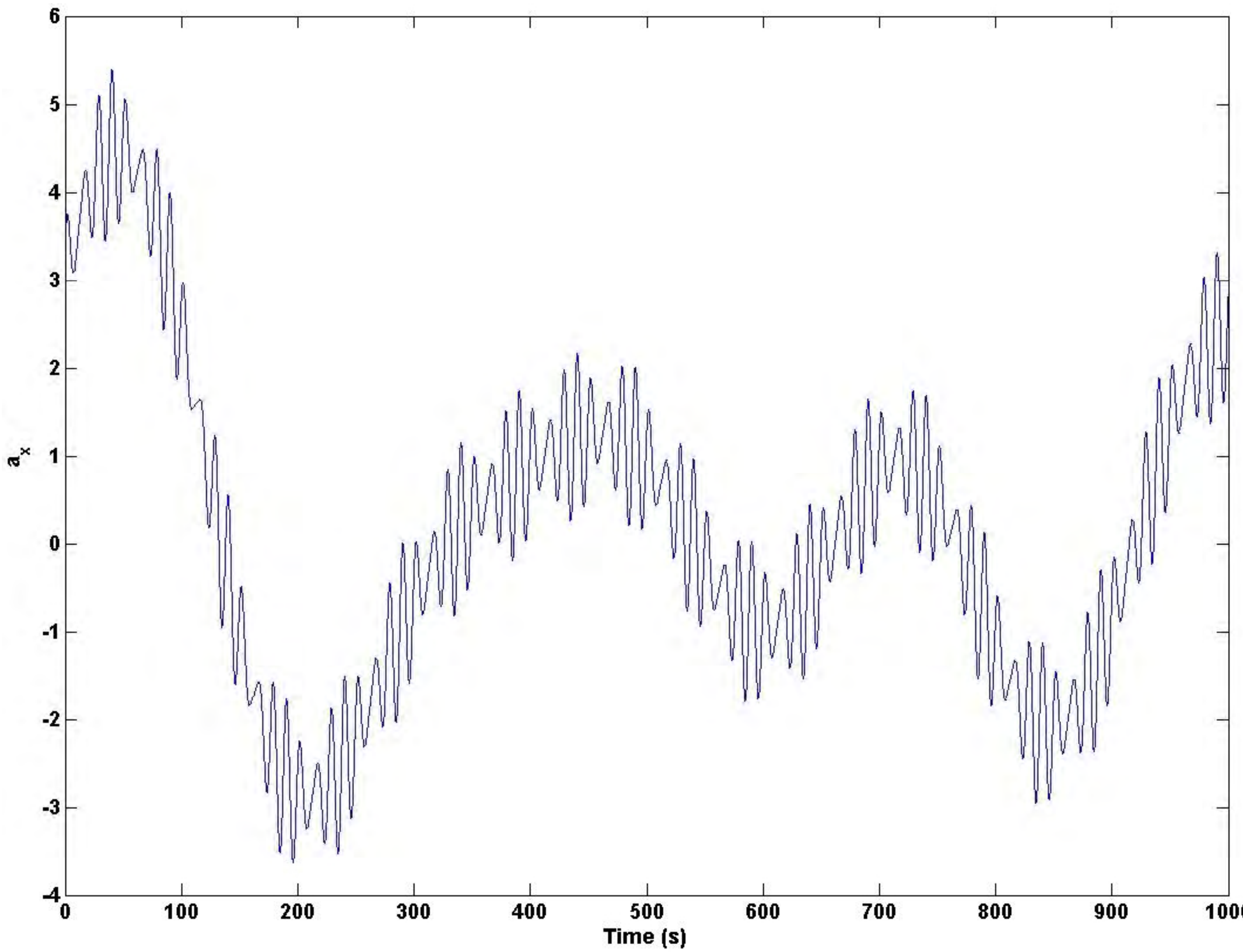


j=2, k=2

A_1	1.0
A_2	0.25
B_1	4.38
B_2	5.45
C_1	0.78
C_2	1.24
D_1	7.23
D_2	4.34
m	0.004
dt	0.001
T	1000

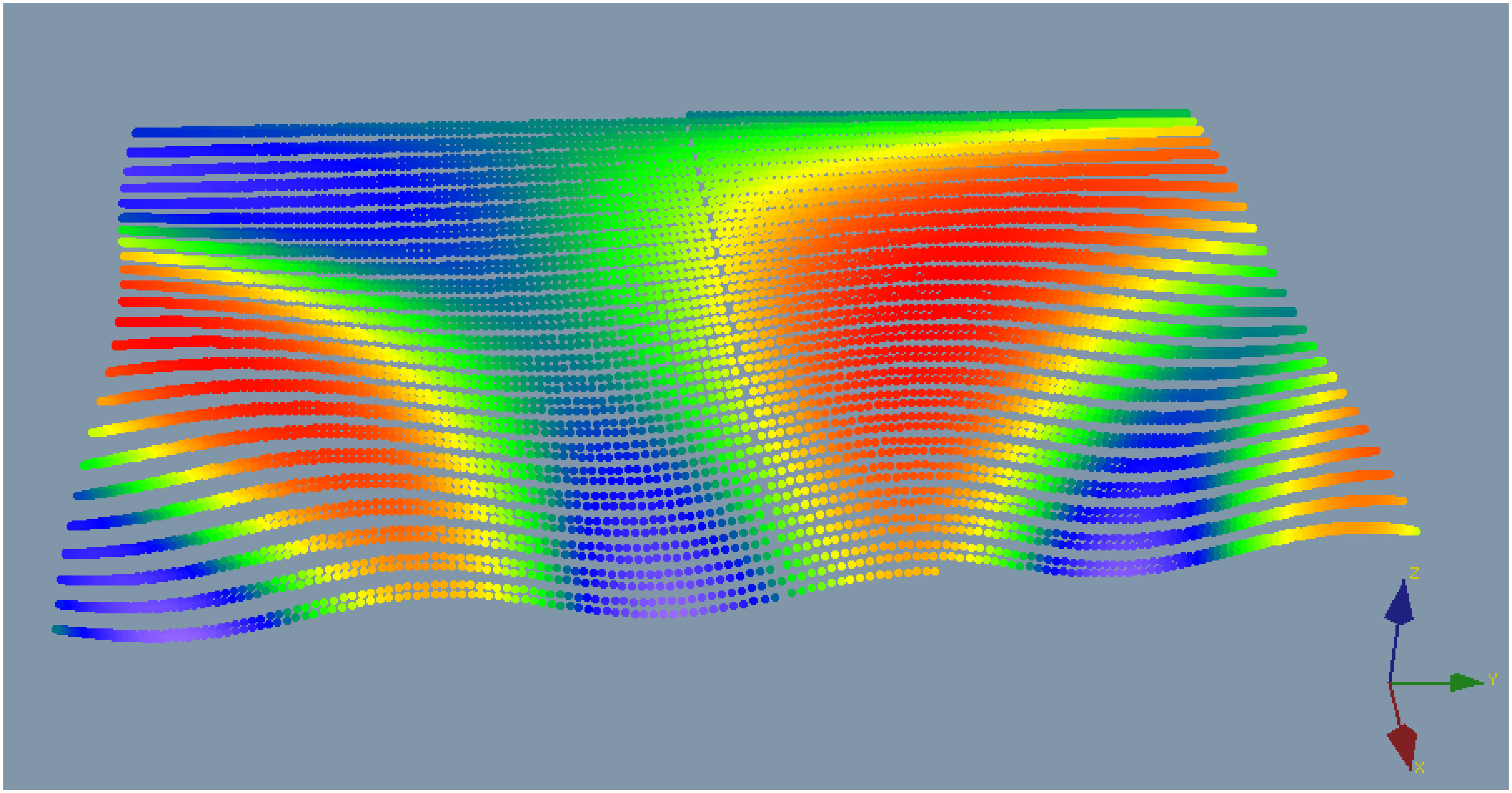
$$a_X^i = \sum_{j=1}^{J} A_j \sin\left(B_j \left(\frac{2\Pi}{T}(id_t)\right)\right) + \sum_{k=1}^{K} C_k \cos\left(D_k \left(\frac{2\Pi}{T}(id_t)\right)\right) + m(id_t)$$

j=3, k=3



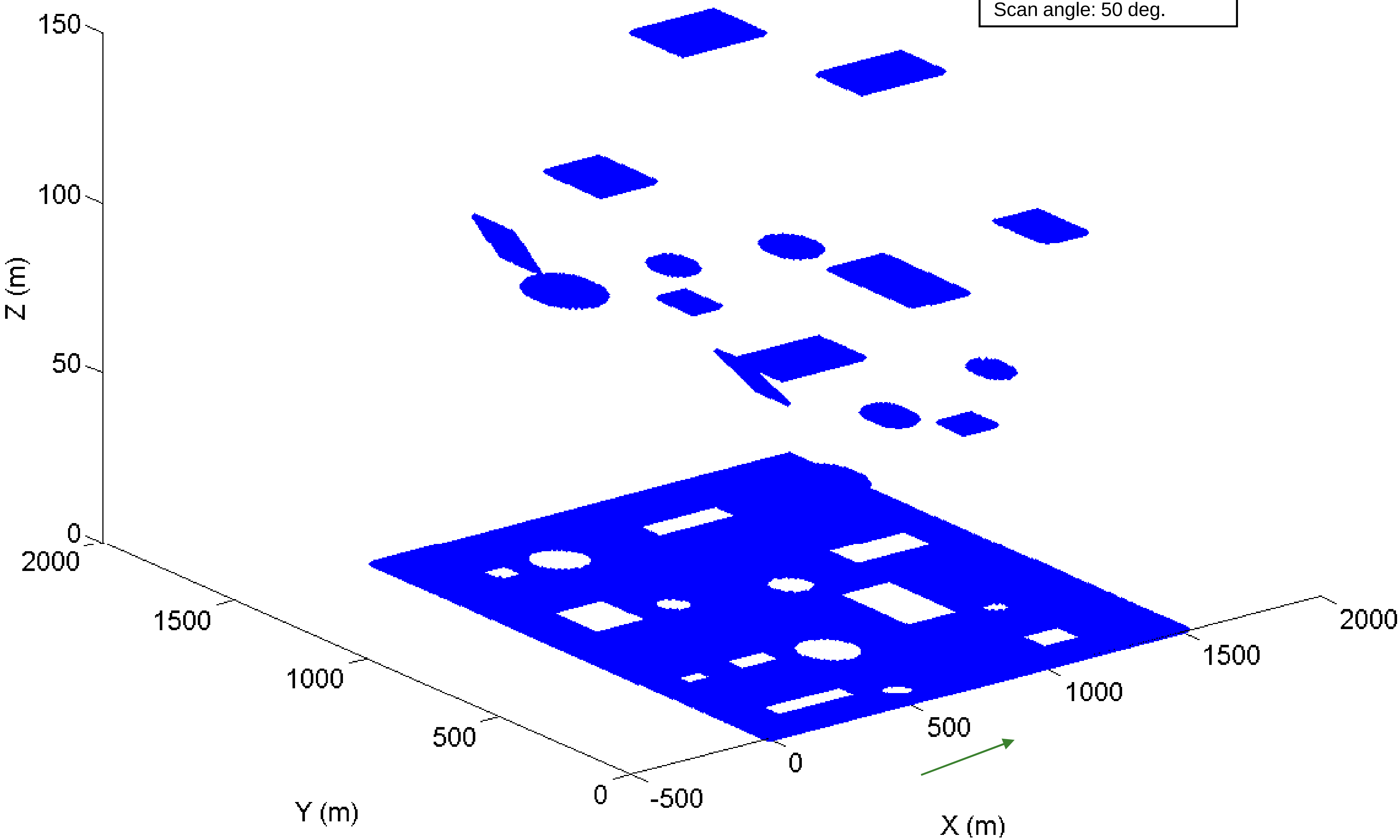
A_1	2.75
A_2	0.65
A_3	0.6
B_1	2.38
B_2	4.45
B_3	80
C_1	1.51
C_2	1.77
C_3	0.35
D_1	2.77
D_2	3.38
D_3	100
m	0.0
dt	0.006
T	1000

Point cloud for complex surface

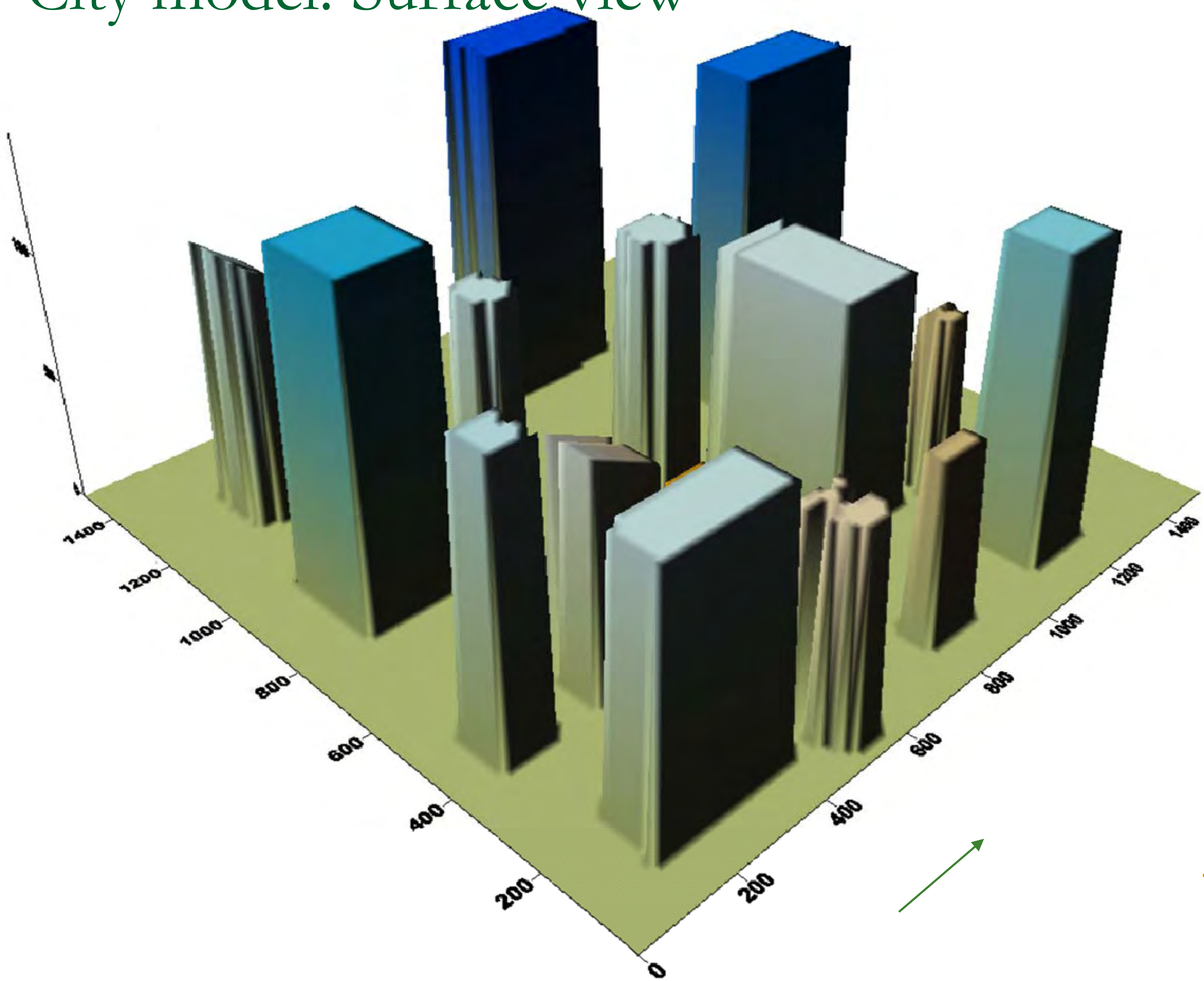


Point cloud for city model

Flight velocity: 60 m/s.
Flight height: 1610 m.
Distance: 1500 m.
Firing frequency: 20000 Hz.
Scan frequency: 48 Hz.
Scan angle: 50 deg.

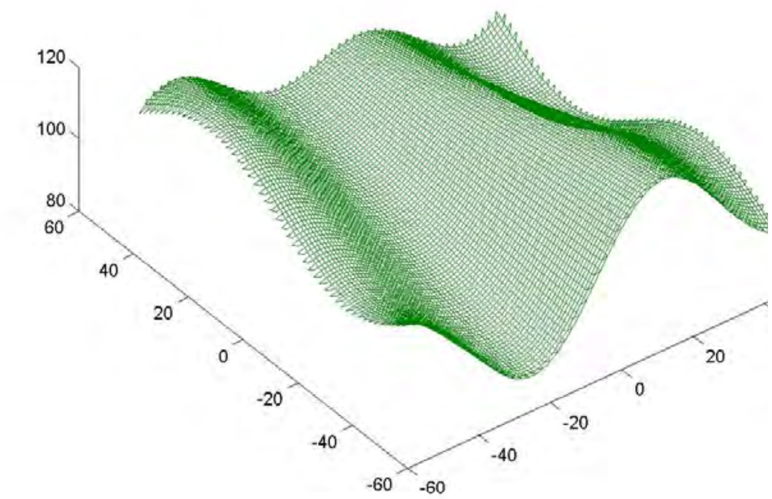


City model: Surface view

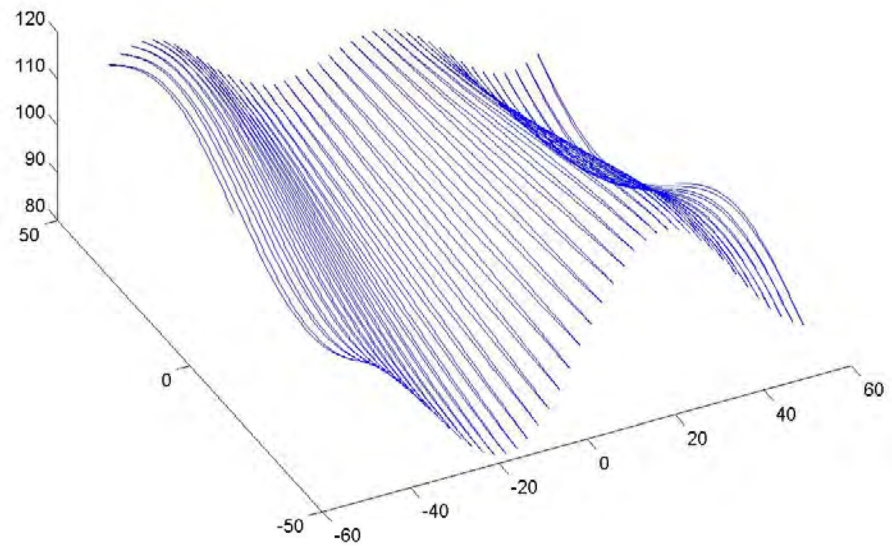


Complex surfaces

$$Z = 10[\sin(X/10) - \sin(XY/800)] + 100$$



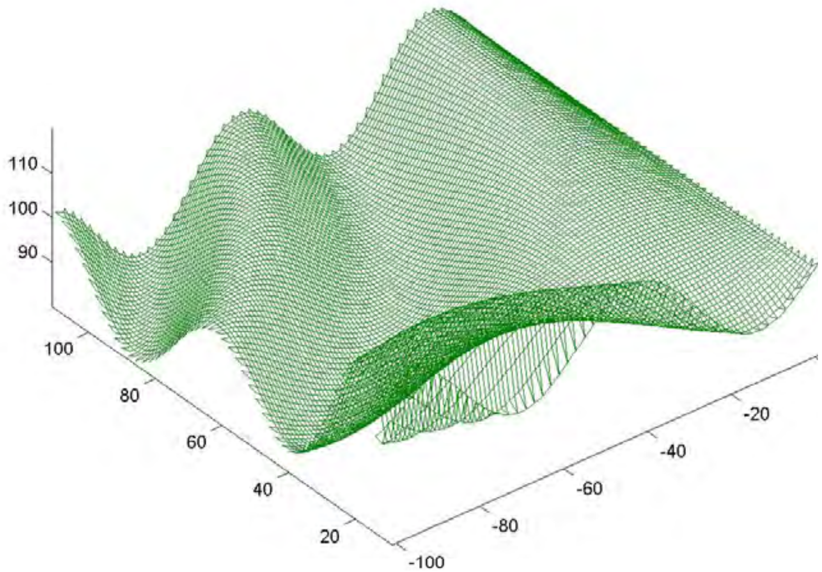
Generated in MATLAB



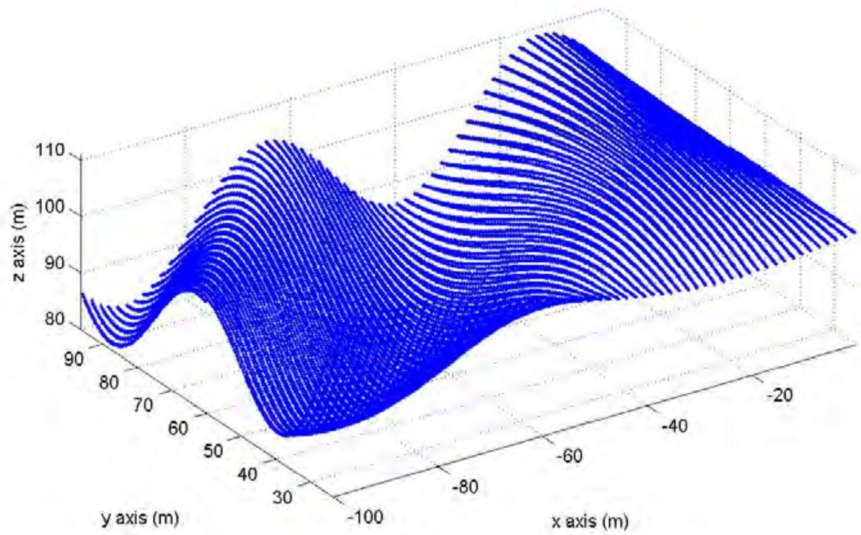
Generated in simulator

Complex surfaces

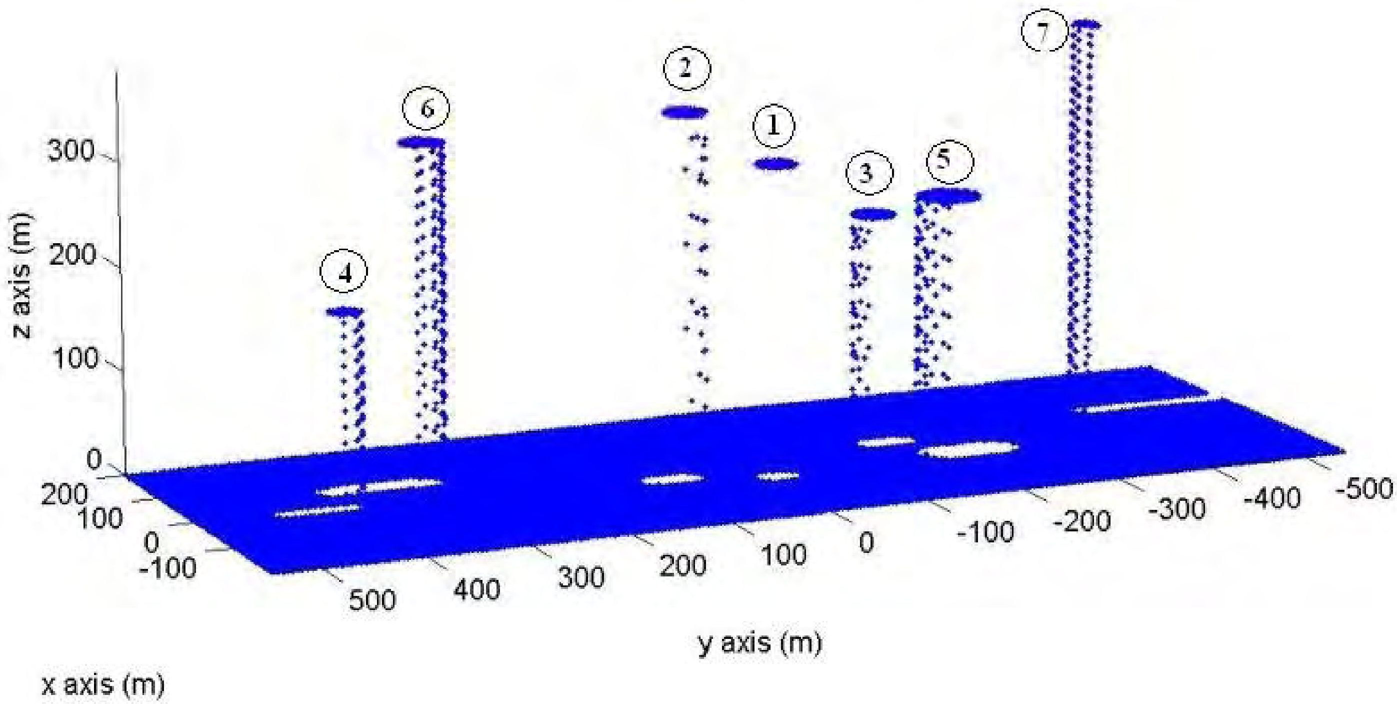
$$Z = 10[\sin(X/Y) - \sin(XY/800)] + 100$$

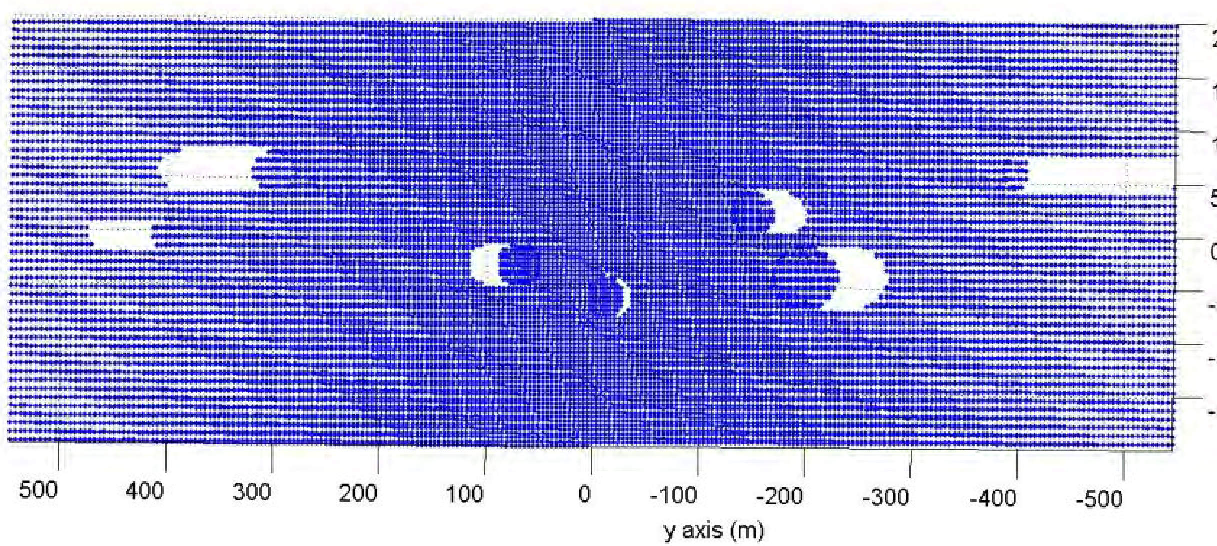


Generated in MATLAB

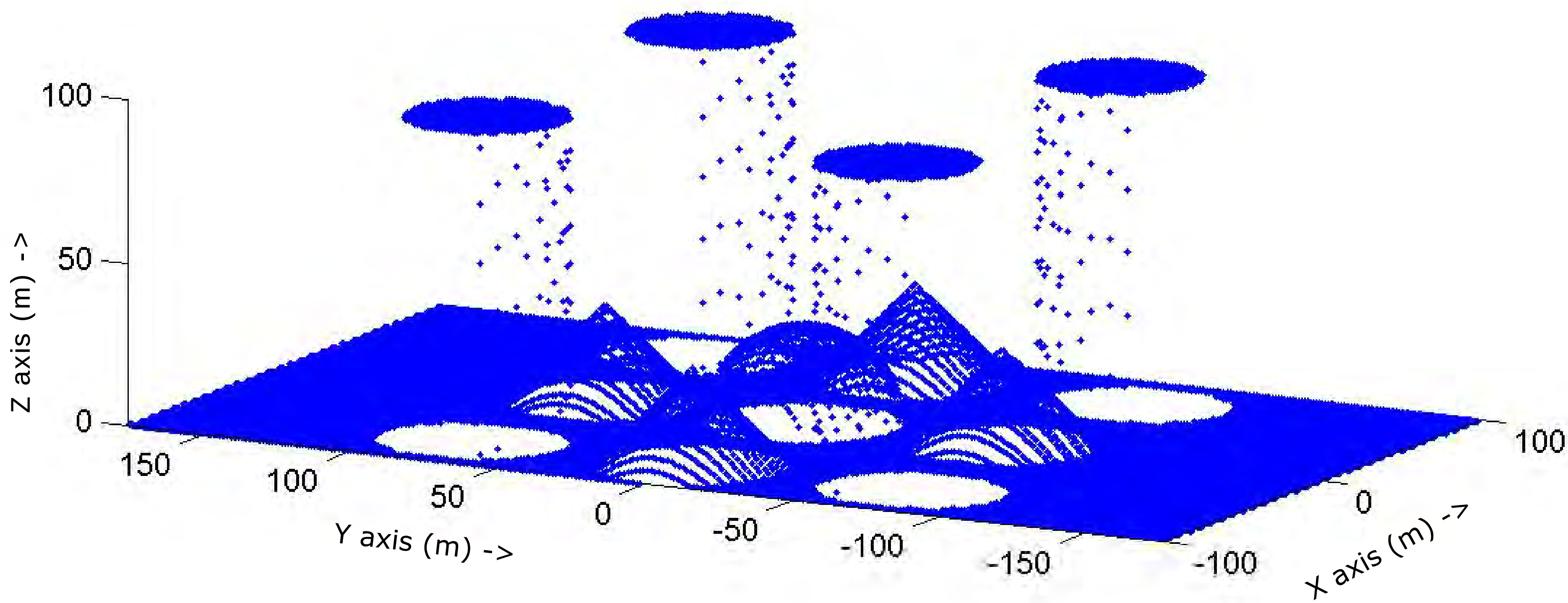


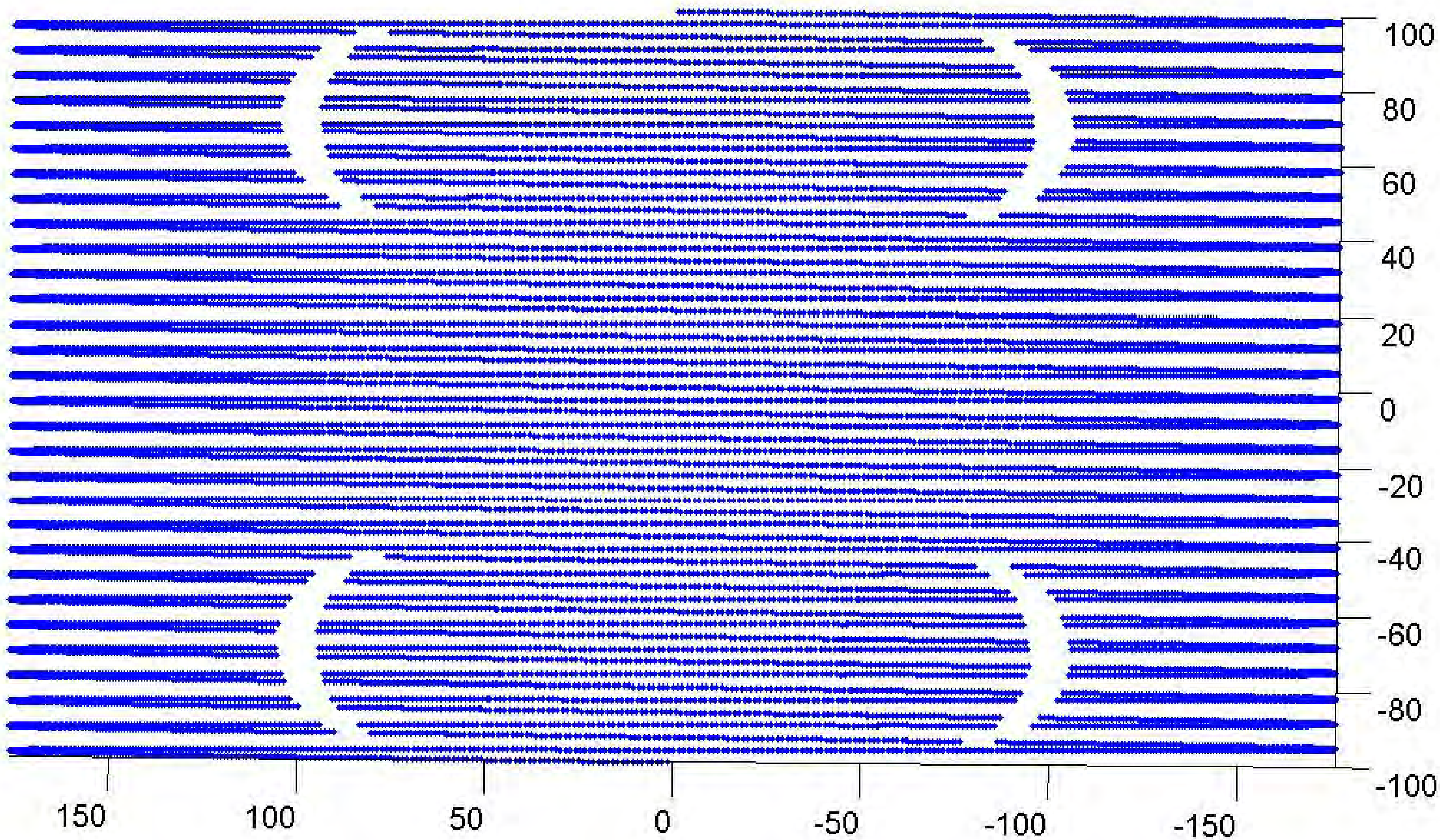
Generated in simulator



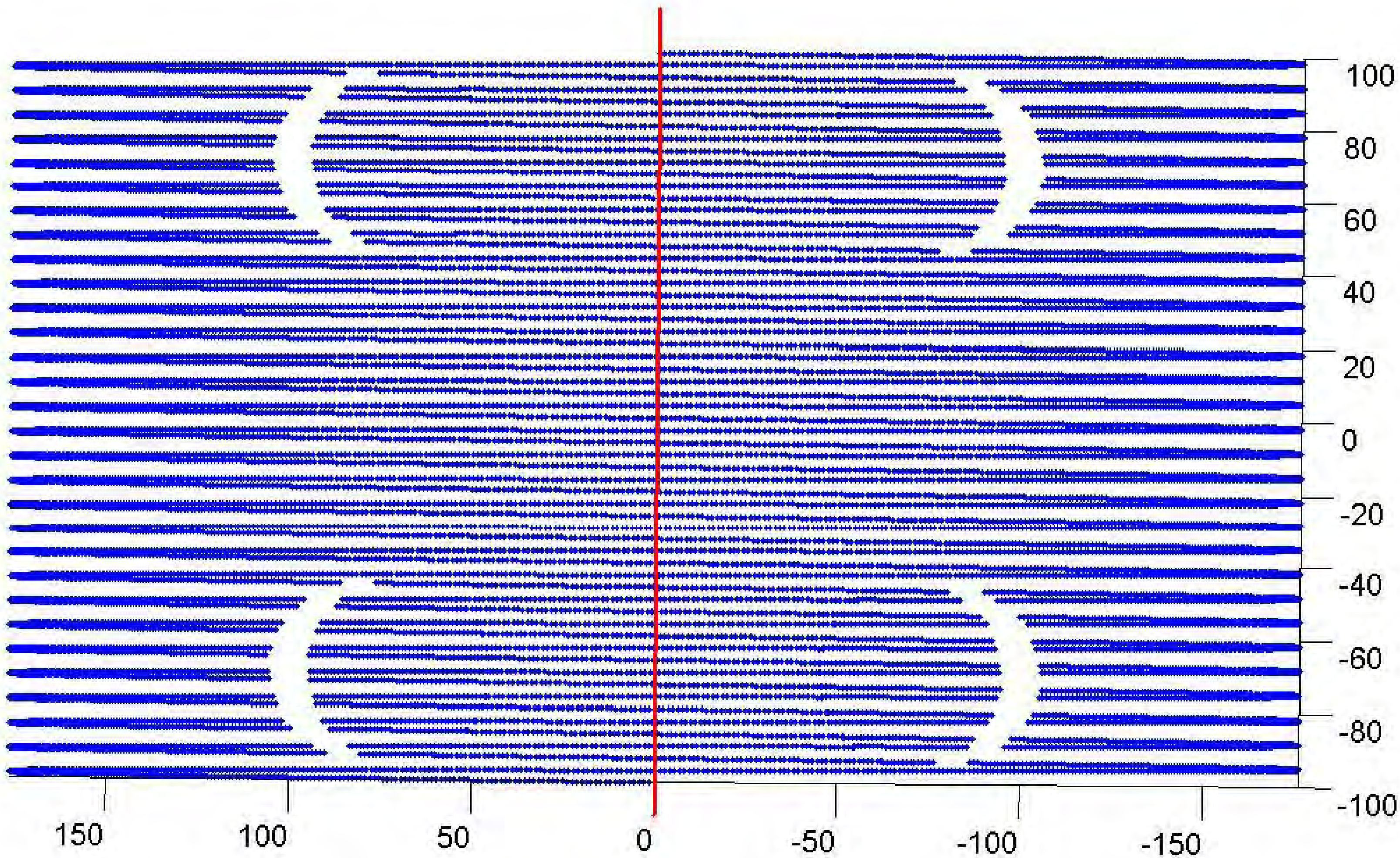


Top view (shadow effect)

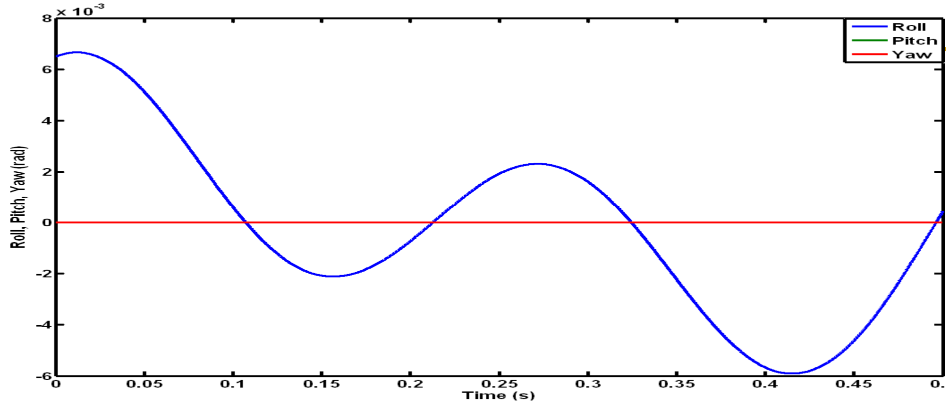

100
50
0
Z axis (m) ->
150
100
50
0
-50
-100
-150
Y axis (m) ->
100
0
-100
X axis (m) ->



100
80
60
40
20
0
-20
-40
-60
-80
-100
150
100
50
0
-50
-100
-150

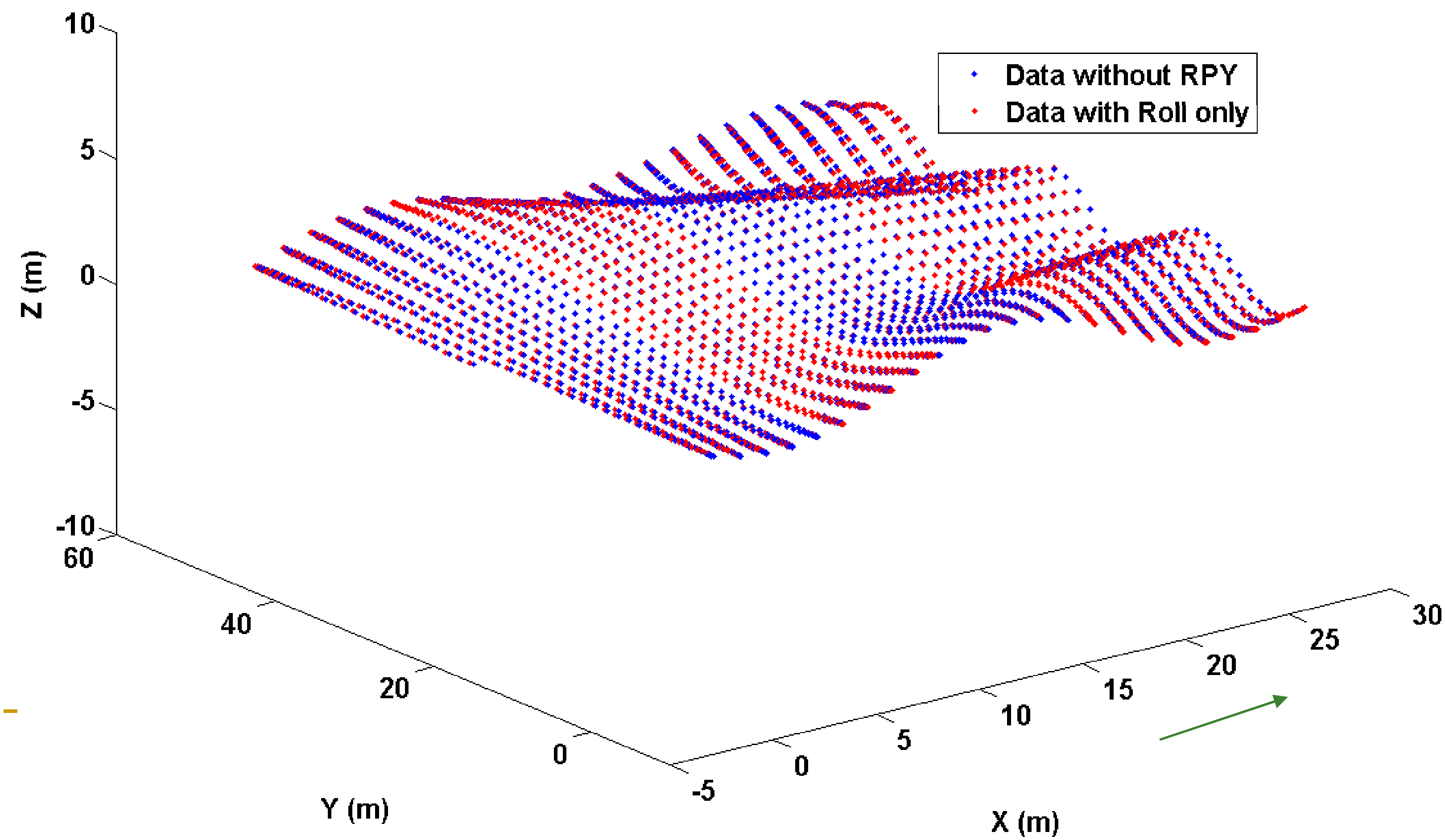


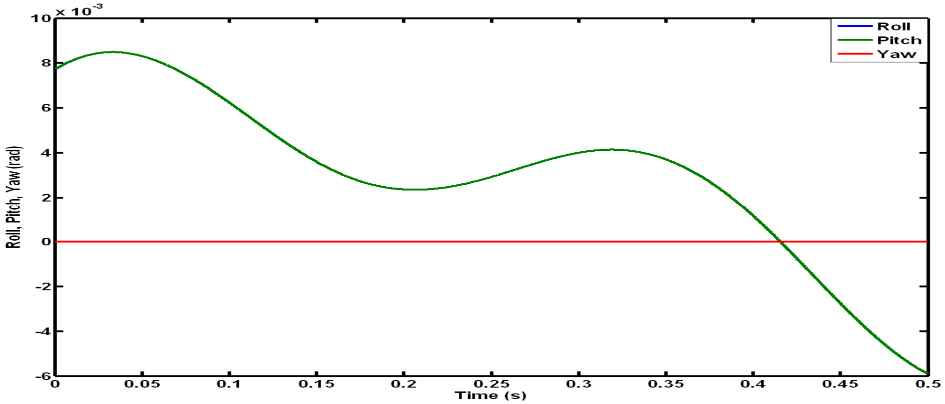
100
80
60
40
20
0
-20
-40
-60
-80
-100
150
100
50
0
-50
-100
-150



Comparison of data sets without RPY and with Roll only.

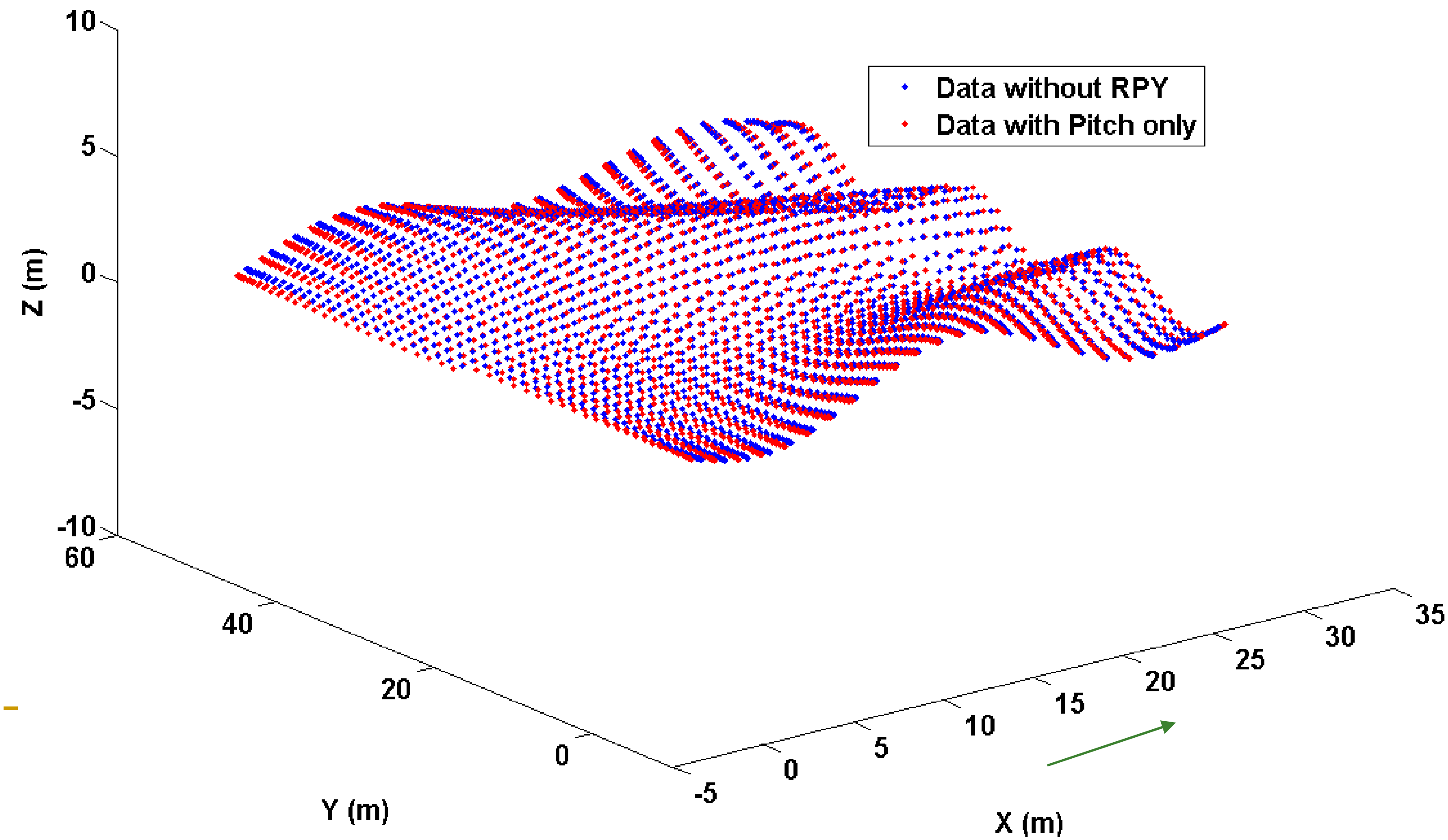
Equation of the surface: Z=sin(X/10)-sin(XY/90)-60.
Flight velocity: 60 m/s.
Flight height: 60 m.
Distance: 30 m.
Firing frequency: 5000 Hz.
Scan frequency: 48 Hz.
Scan angle: 50 deg.



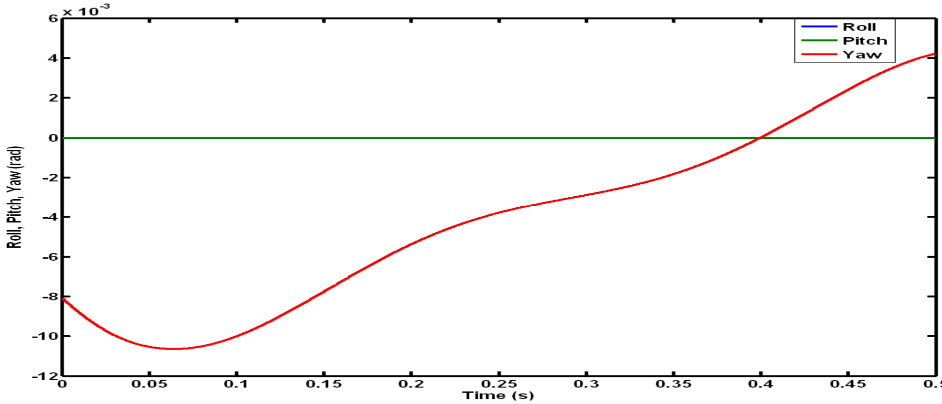


Comparison of data sets without RPY and with Pitch only

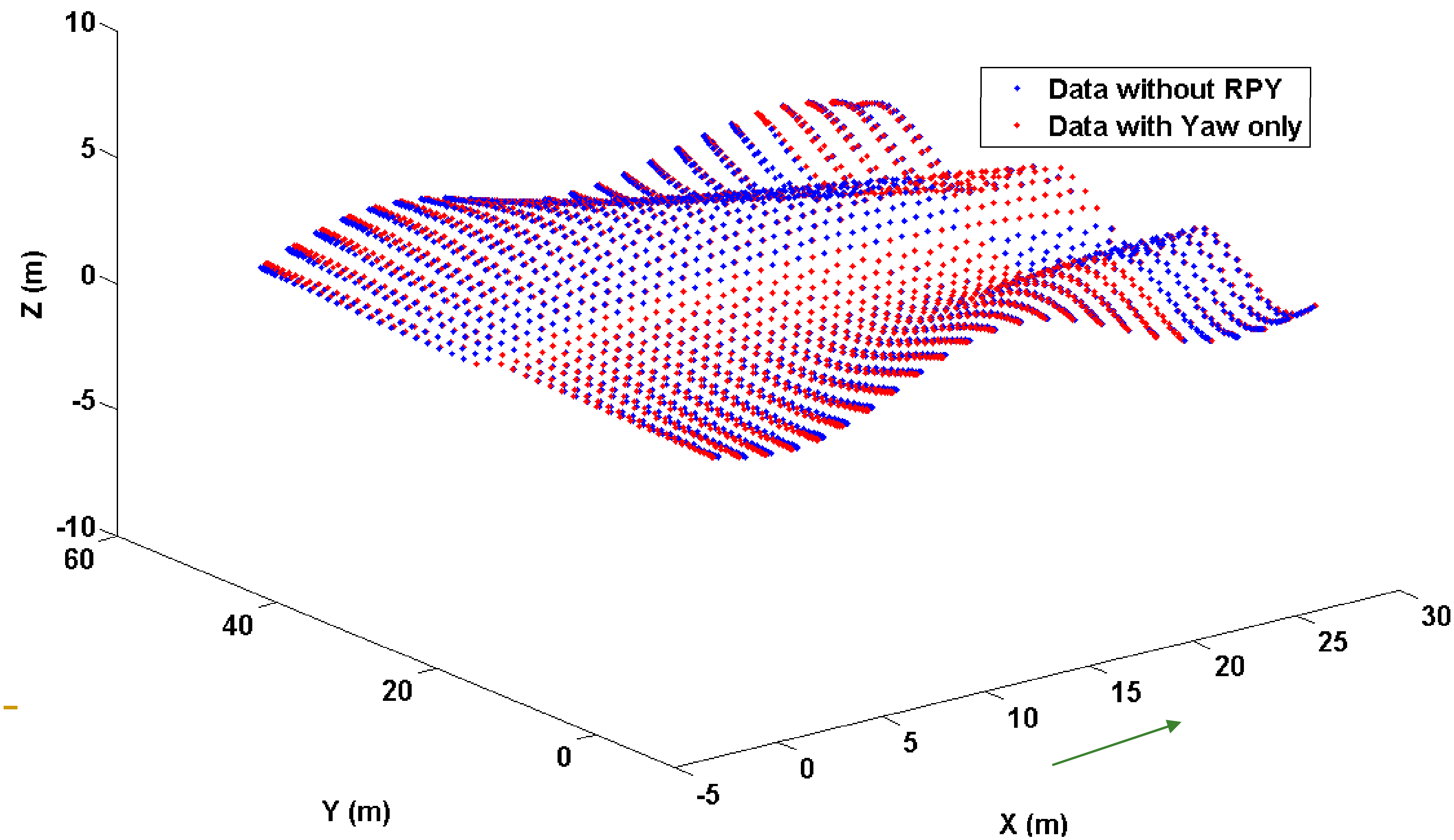
Equation of the surface: Z=sin(X/10)-sin(XY/90)-60.
Flight velocity: 60 m/s.
Flight height: 60 m.
Distance: 30 m.
Firing frequency: 5000 Hz.
Scan frequency: 48 Hz.
Scan angle: 50 deg.

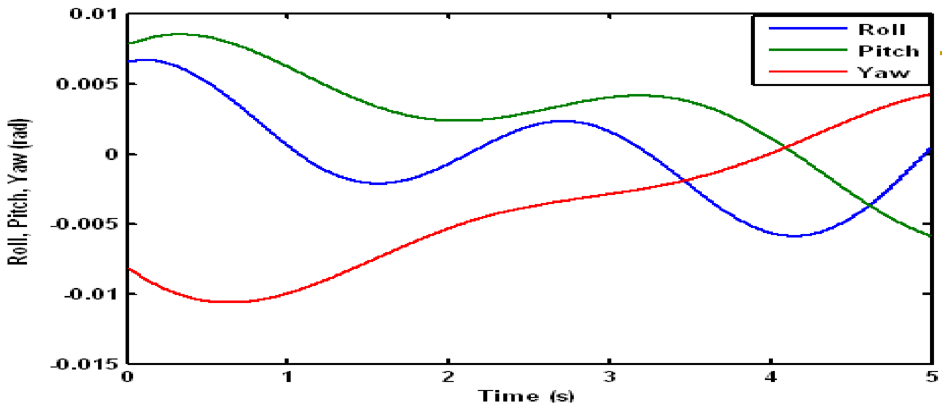


Comparison of data sets without RPY and with Yaw only



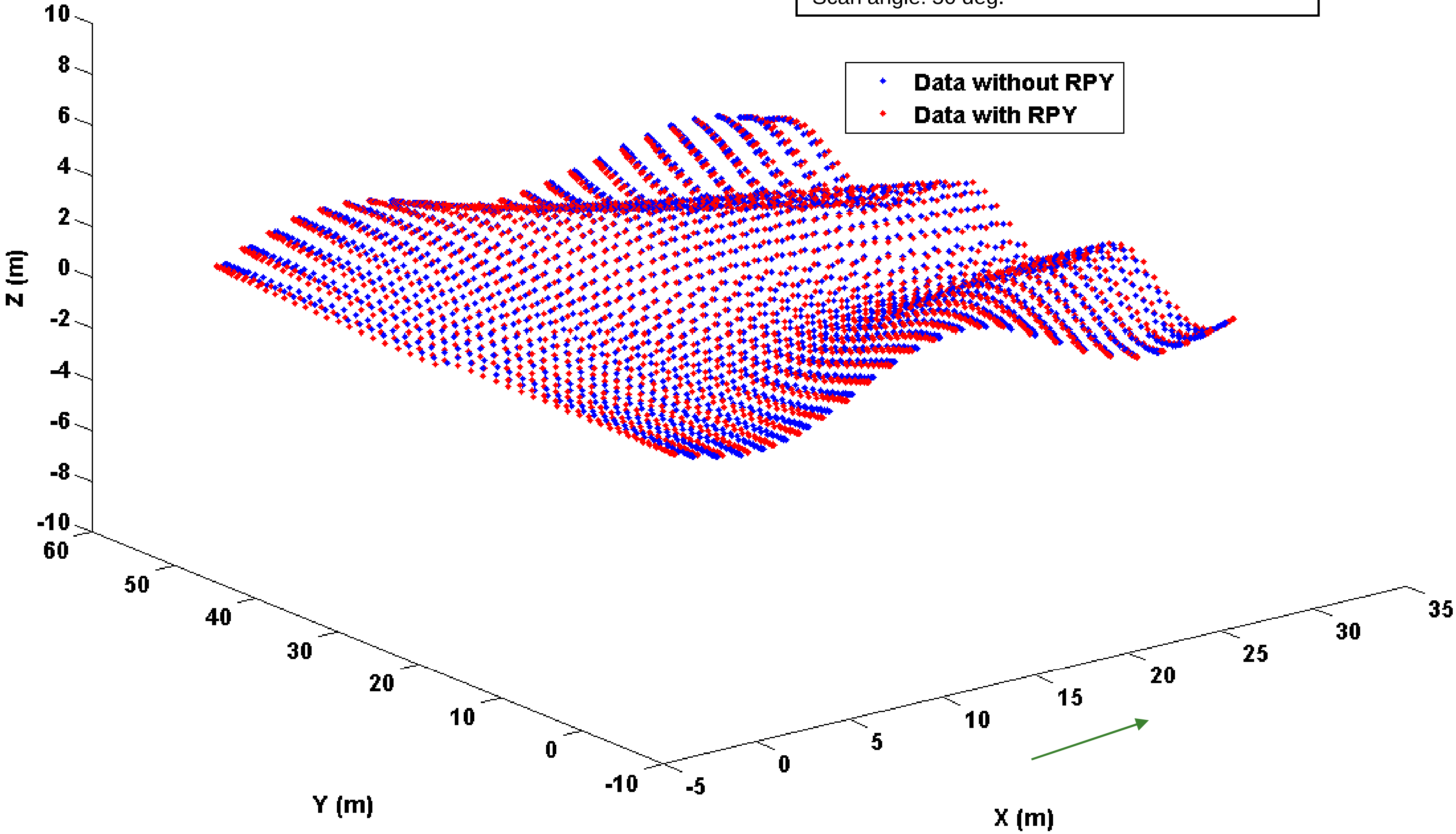
Equation of the surface: Z=sin(X/10)-sin(XY/90)-60.
Flight velocity: 60 m/s.
Flight height: 60 m.
Distance: 30 m.
Firing frequency: 5000 Hz.
Scan frequency: 48 Hz.
Scan angle: 50 deg.



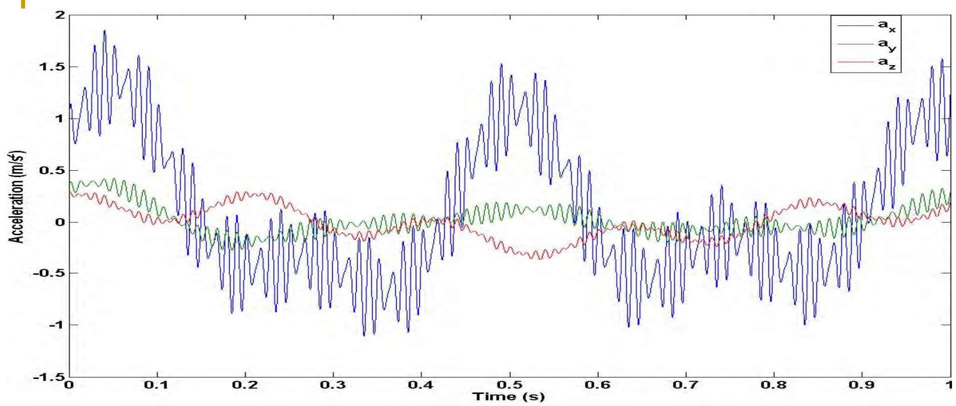


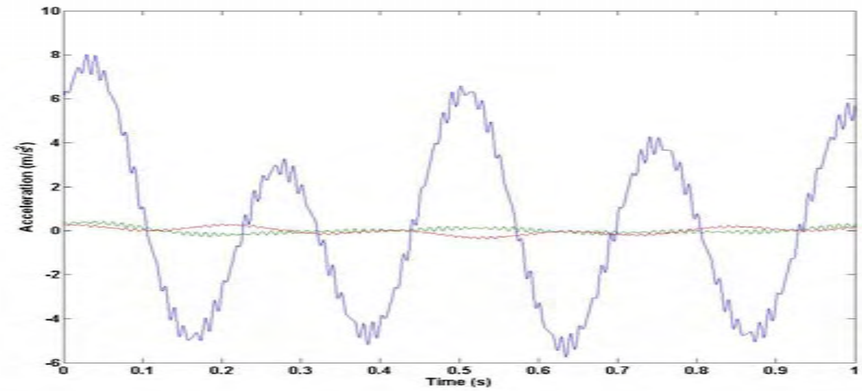
Comparison of data sets with and without RPY

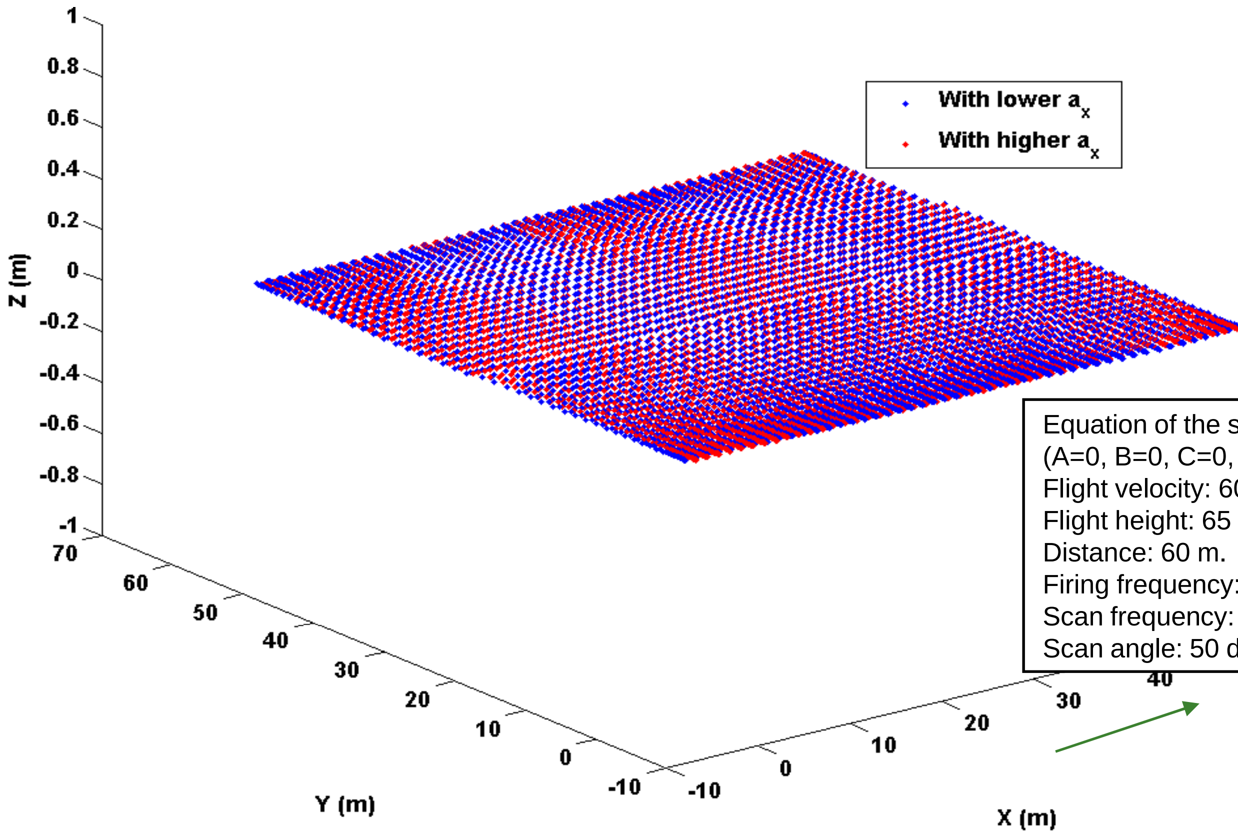
Equation of the surface: Z=sin(X/10)-sin(XY/90)-60.
Flight velocity: 60 m/s.
Flight height: 60 m.
Distance: 30 m.
Firing frequency: 5000 Hz.
Scan frequency: 48 Hz.
Scan angle: 50 deg.



Comparison of data sets with lower and higher ax



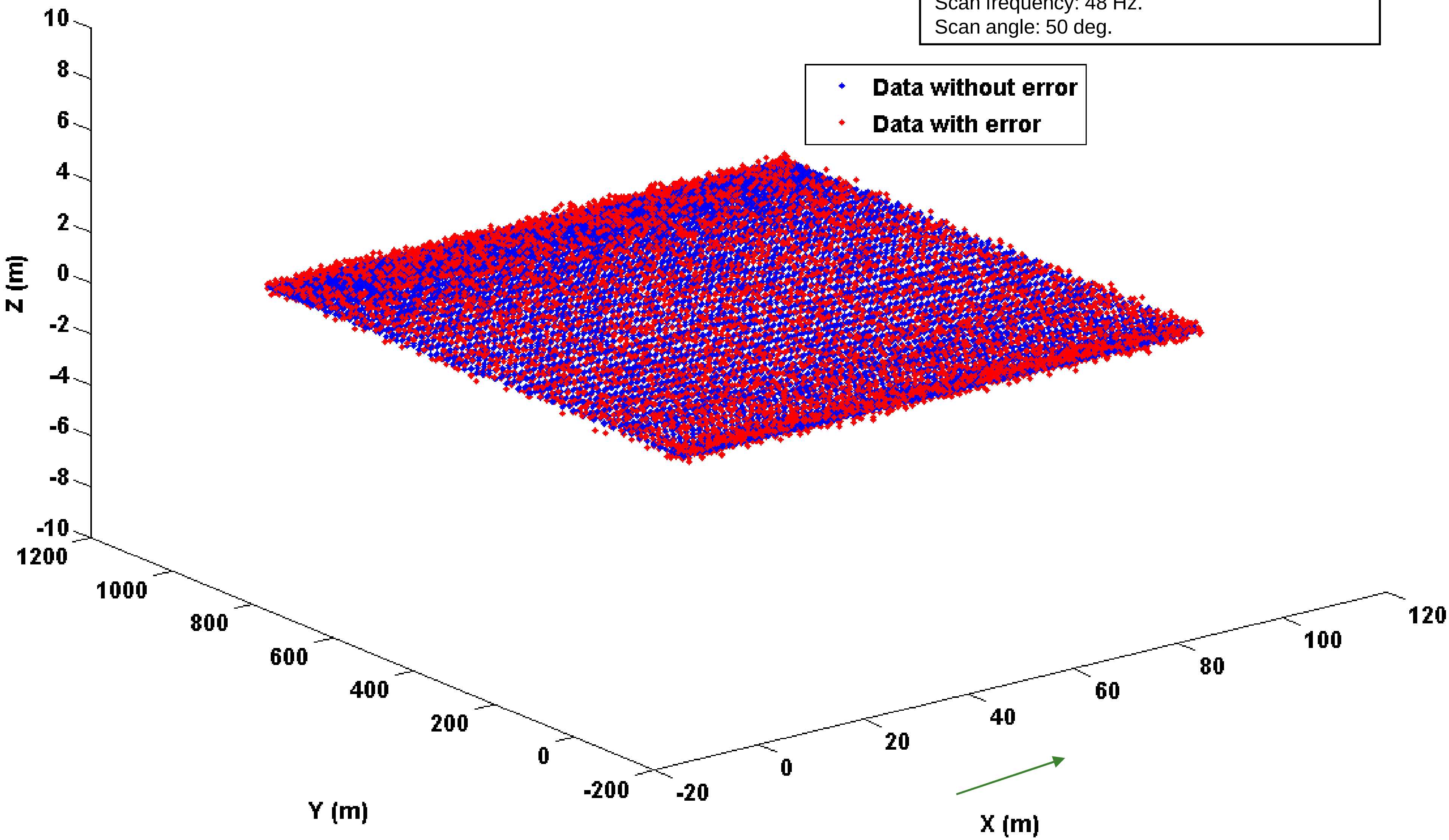




Equation of the surface: AX+By+CZ+D=0.
(A=0, B=0, C=0, D= -65)
Flight velocity: 60 m/s.
Flight height: 65 m.
Distance: 60 m.
Firing frequency: 5000 Hz.
Scan frequency: 48 Hz.
Scan angle: 50 deg.

Comparison of data sets with and without normal error.

Equation of the surface: AX+By+CZ+D=0.
(A=0, B=0, C=0, D= -1100)
Flight velocity: 60 m/s.
Flight height: 1100 m.
Distance: 100 m.
Firing frequency: 5000 Hz.
Scan frequency: 48 Hz.
Scan angle: 50 deg.



Applications of simulator

Education

- To understand:
  - Process of data generation
  - Effect of change in various parameters on data
  - Effect of errors on data

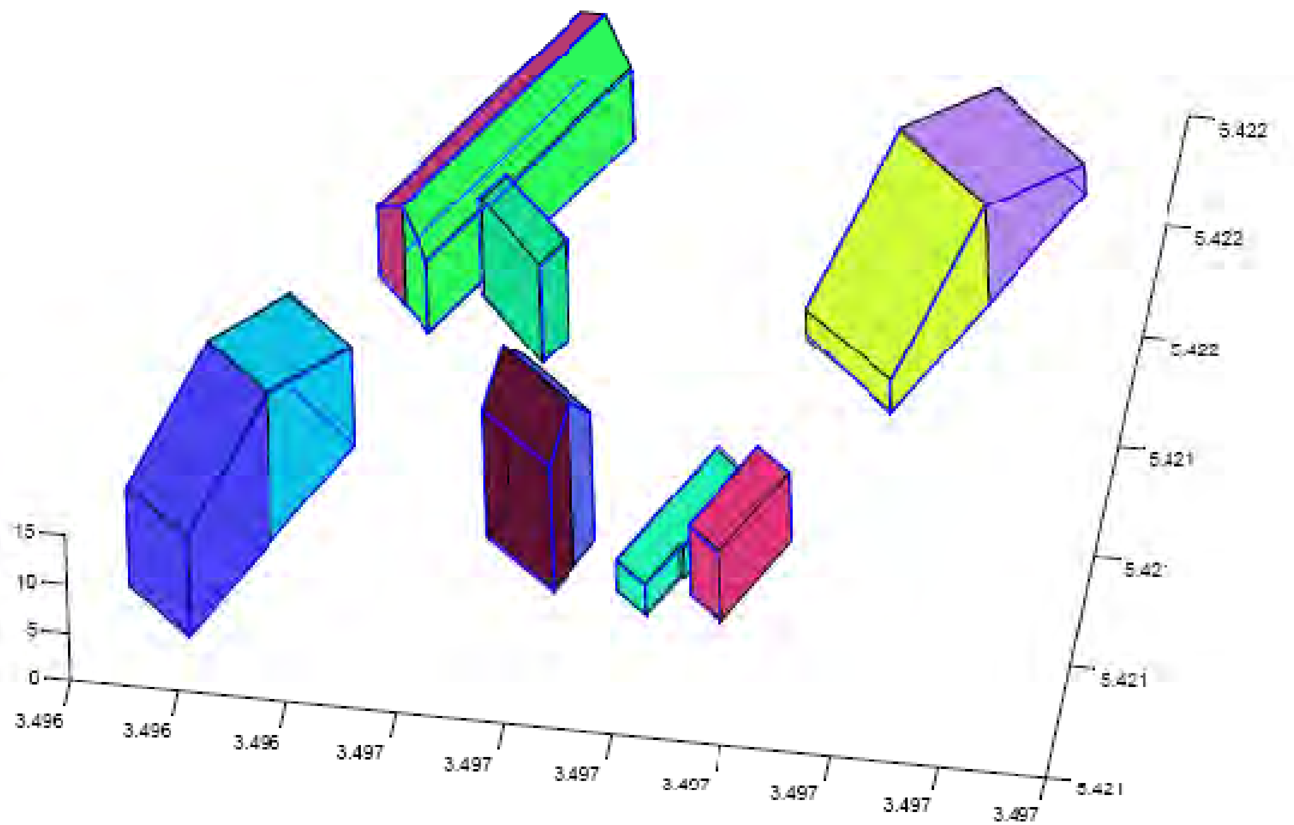
Laboratory exercises

- Data with varied specifications
- Full and accurate ground truth known

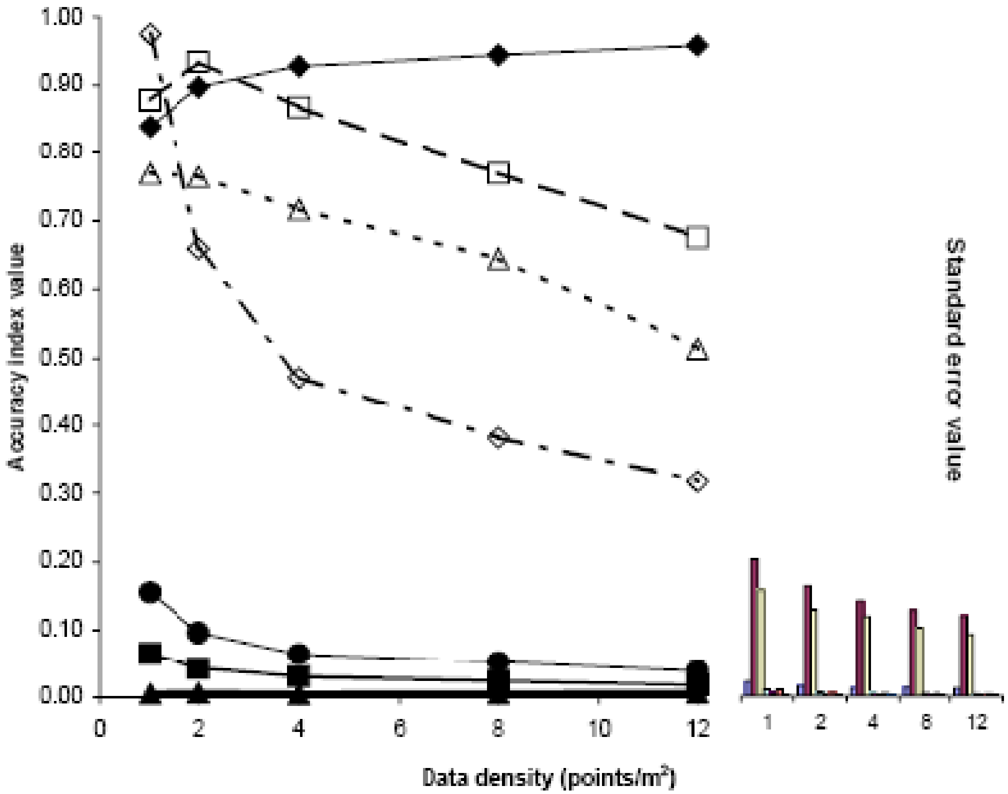
Student research projects

- Evaluation of Information extraction algorithms
- Assessing effect of error on performance of algorithms
- Finding optimal data specifications for an application

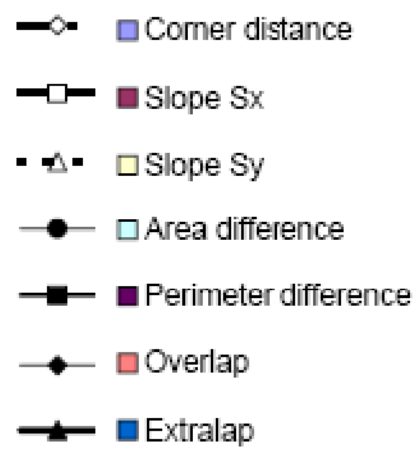
Application in building identification research



Variation of accuracy indices

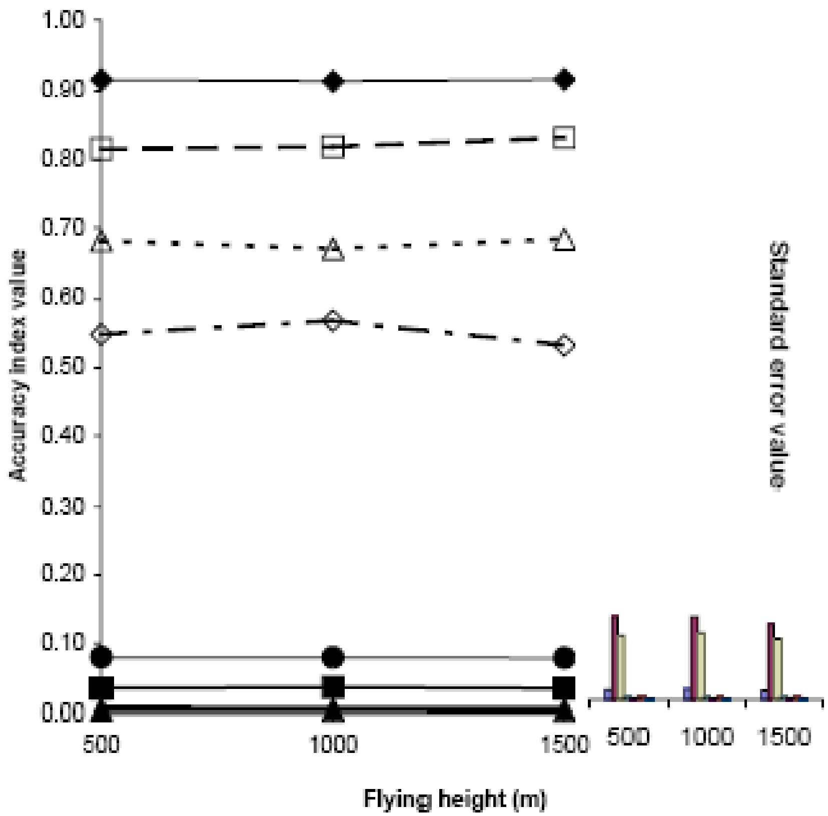


(c) With data density

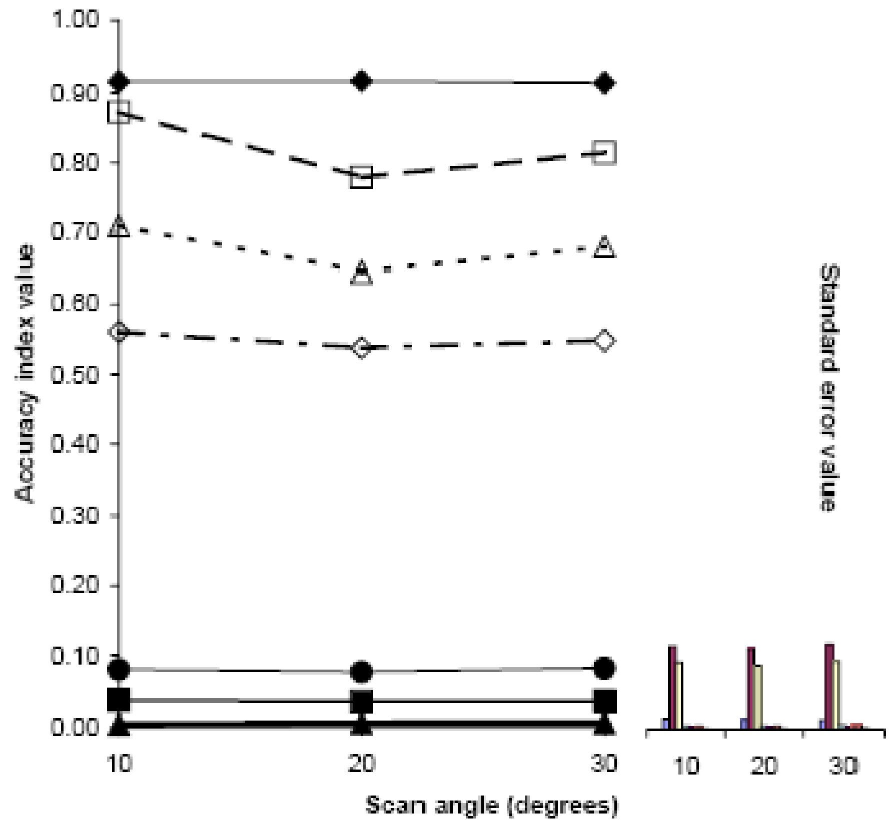


(d) Legend for mean and standard error

Variation of accuracy indices



(a) With flying height



(b) With scan angle

Thanks!