Generating LiDAR data in laboratory: LiDAR Simulator

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Motivation…

Are LiDAR data available?

* LiDAR data NOT available in majority of countries
  - Lack of awareness
  - Security issues
  - Cost

Are LiDAR data available?

* LiDAR data NOT available for teaching purposes
  - Readily available data
  - Data with as-desired specifications
  - Data with ground truth

Are LiDAR data available?

* LiDAR data NOT available for research
  - Data with a wide range of desired specifications
  - Data with complete and 100% accurate ground truth

Solution lies in LiDAR simulator…

* User creates a terrain
* User chooses the flight parameters
* **LiDAR data are generated for created terrain as if the actual LiDAR sensor had flown the terrain**
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

Also . . .
- Possibility of error introduction
- Output data available in common formats
Development of simulator

System components

Integration

Sensor component

Terrain component

Trajectory component

Input

Output

Trajectory component

Flight direction
Location
Attitude

Acceleration simulation

\[ \dddot{x_i} = \sum_{j=1}^{J} A_j \sin \left( B_j \left( \frac{2\pi}{T_j} (id_j) \right) \right) + \sum_{i=1}^{C} C_i \cos \left( D_i \left( \frac{2\pi}{T} (id_i) \right) \right) + m \ddot{d}_i \]

Location simulation

\[ X^{i+1} = X^i + u^i d_i + \frac{1}{2} a^i d_i^2 \]

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

\[ d_j = \frac{1}{F} \]

\[ T = n \ dt \]

F = Firing frequency
J,K,A,B,C,D and m governing parameters

\[ u_c = \text{Velocity in direction flight i.e. } X \text{ axis} \]
Attitude (Roll, Pitch, Yaw) simulation

\[
R' = \sum_{i=1}^{n} A_i \sin \left( B_i \left( \frac{2\pi}{T} i \right) \right) + \sum_{i=1}^{n} C_i \cos \left( D_i \left( \frac{2\pi}{T} i \right) \right) + m(i) 
\]

Sensor components

- Sinusoidal scan pattern
- Zig-zag scan pattern

Sinusoidal scan pattern

- Let time taken to complete 1/4th of a scan is \( T \).
- \( P \) is the numbers of points in 1/4th of a scan.
- The maximum scan angle is \( \theta_{max} \).

\[
\theta_i = \theta_{max} \sin \left( \frac{\pi}{T} i \right)
\]

where, \( t_i = \frac{T}{P} i \)

Zig-zag scan pattern

\[
\theta = \frac{\theta_{max}}{P} i
\]

Terrain component

Modeling surfaces: earthlike

- Vector approach: mathematical surfaces
- Raster approach with over ground objects
- Fractal terrain

Simple Surface

\[\mathbf{AX} + \mathbf{BY} + \mathbf{CZ} + \mathbf{D} = 0\]

Example of a simple surface: \( 2X + 5Y + 10Z - 100 = 0 \) (displayed in surfer)
Vector approach: Mathematical surfaces

Complex Surface

\[ Z = A \sin(X/B) + \sin(XY/BC) + D \]

Example of a complex surface: \( Z = 10 \sin(X/25) + \sin(XY/(25\times50)) - 300 \) (displayed in surface)

Raster surfaces

Fractal surfaces

Integration of components

Integration of components

Error introduction in simulated data

\[ X'_i = X'_i + N(\mu_X, \sigma_X^2) \]

Known from field
Concept implementation

Optimal flight lines given by system
User defined flight lines

Simulated data and results
3D raster terrain (displayed in Surfer)

Altitude=210m
Overlap=4%
Velocity=60m/s
Sensor-ALS-50
Firing frequency=20KHz
Scan frequency=48Hz
Scan angle=40°
Flight area=430m × 430m

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Profile A-A without error

Profile A-A with error

Profile B-B w. r. t. flight lines

LiDAR data without error

LiDAR data with error
Data with no attitude variation

Data with attitude variation

Fractal data displayed in surfer

Terrain with objects
LiDAR data of terrain with objects

Effect of data density

Profile view of buildings

Effect of different altitude
Effect of different scan angle

Effect of different flight direction

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

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

- Multiple return implementation
- Error introduction in individual parameters

Final touches...in next three months