UAS-Based LiDAR Mapping

Video F-II

Purdue University

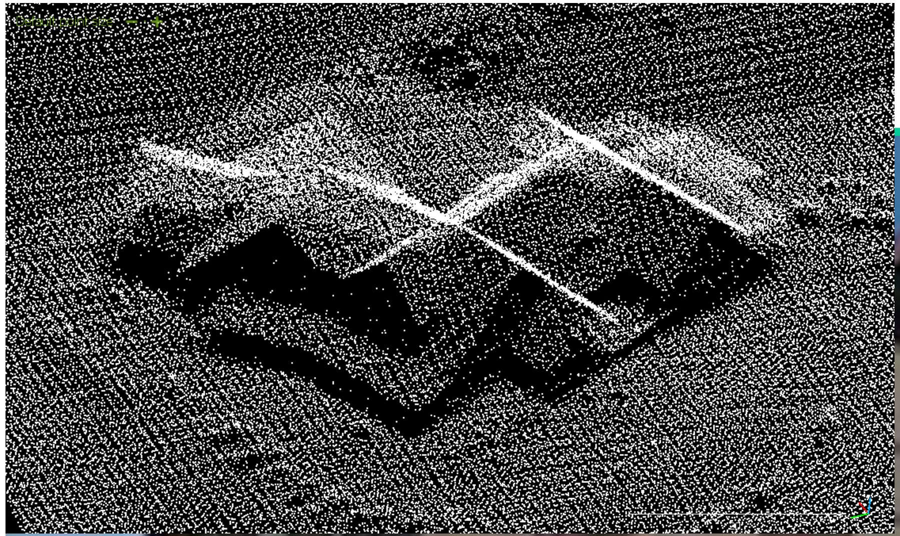
LiDAR Data Characterization

Local Point Density Estimation

Overview

- **LiDAR Data Characterization**
  - Local Point Density (LPD) Estimation
  - Local neighborhood classification

LiDAR Mapping: Ultimate Goal



Airborne scan

Terrestrial scan

Combined and segmented scans

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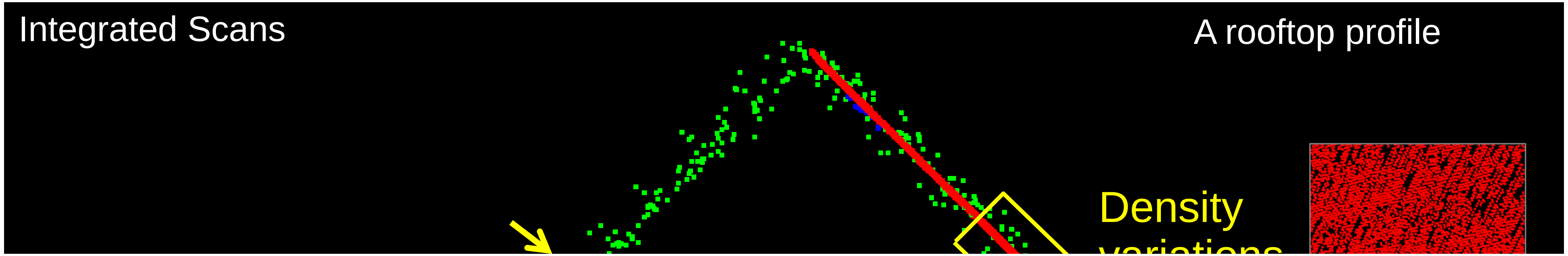
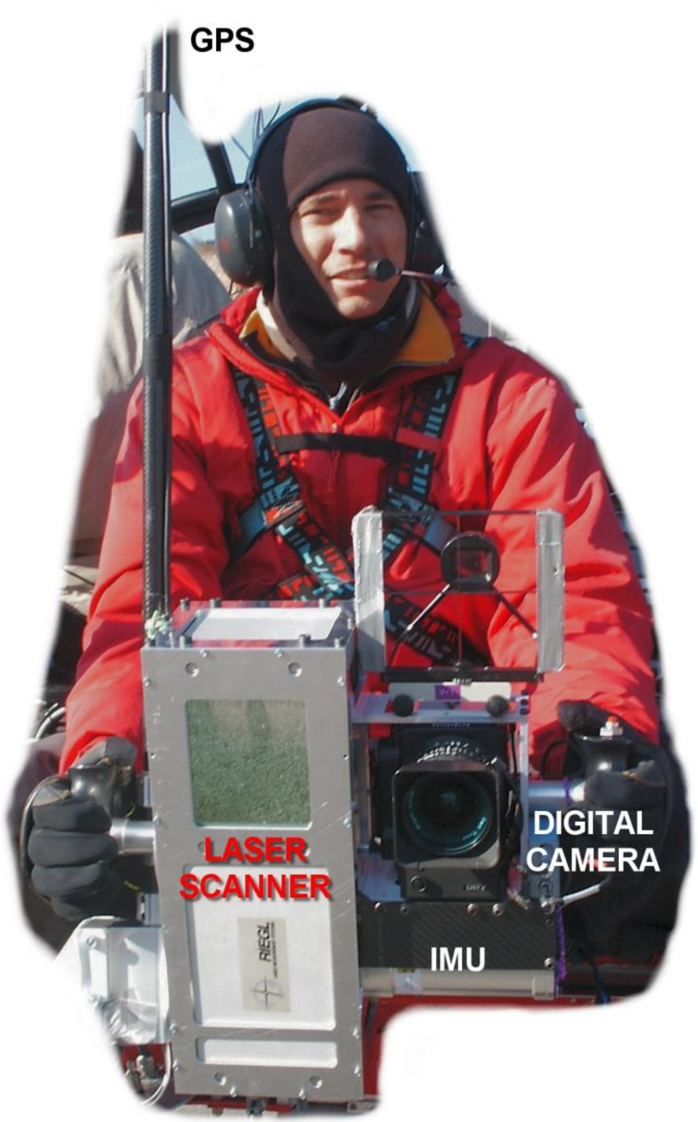
LiDAR Mapping: Ultimate Goal



We need a data characterization step to take into account the varying nature of the input point clouds.

LiDAR Data Characterization

Local Point Density Estimation



Source: http://www.isprs.org/publications/related/semana_geomatica05/front/abstracts/Dimecres9/F01.pdf

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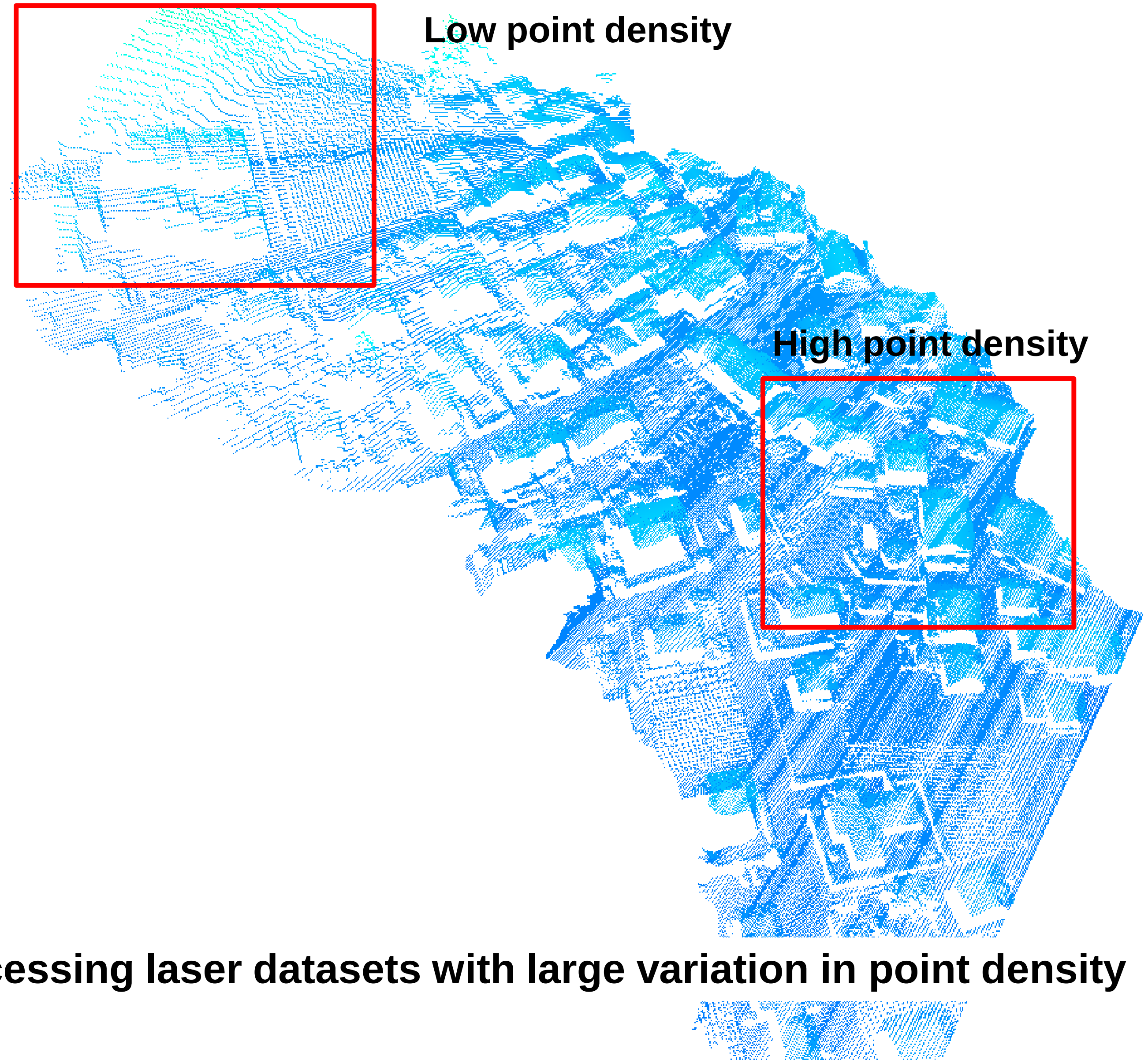
LiDAR Data Characterization

Local Point Density Estimation



Objective: Processing laser datasets with large variation in point density

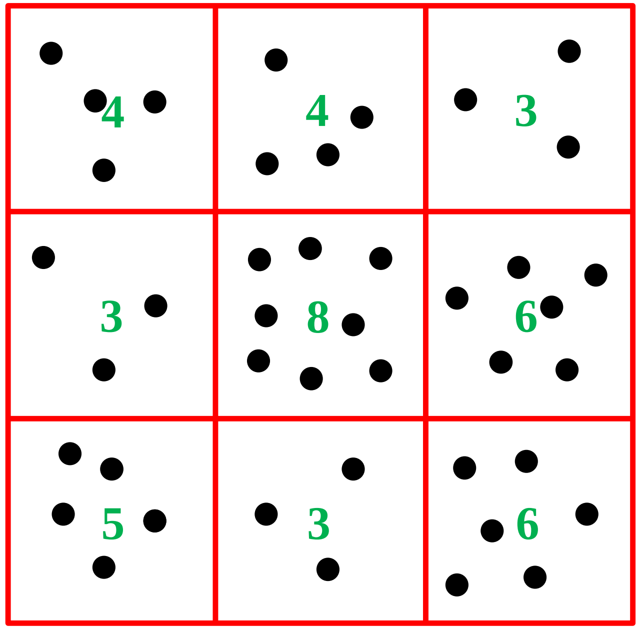
LiDAR Data Characterization

- **Local Point Density Estimation:**
- **A measure of the average inter-point spacing along the surface it belongs to**

- **Local point density variations are caused by:**
  - Change in the topography/elevation
  - Type of platform: terrestrial vs. airborne
  - Irregular movements of the acquisition platform
  - Number of overlapping strips
  - Scattering properties of the mapped surface

LPD Estimation: Box Counting Approach

- **Box-counting method (County, 2003): Derived the point density by a "box counting", where the area of the rectangle is associated with the total number of LiDAR points inside the rectangle.**



- The derived value for the local point density depends on the size and placement of the boxes. There is no standard for the determination of the box size and its placement within an area.

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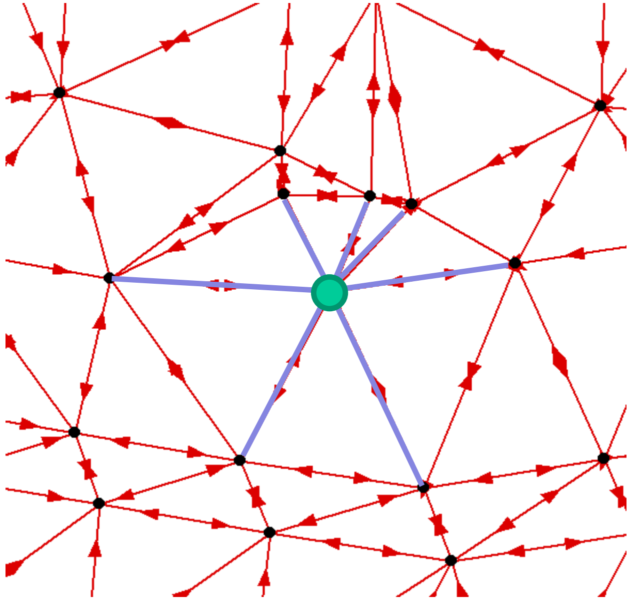
LPD Estimation: TIN-based Approach

- **TIN-based point density determination (Shih and Huang, 2006)**
  - **Local point spacing determination:**
    - I. Construct a Delaunay triangulation
    - II. Calculate the 2D length of every edge connecting the point in question to its neighbors
    - III. Calculate the average of the edges' lengths and record it as the local point spacing



Delaunay triangulated edges for actual LiDAR points are shown in red.

Unbiased LiDAR Data Measurement, Ty Naus, Fugro Horizons, Inc

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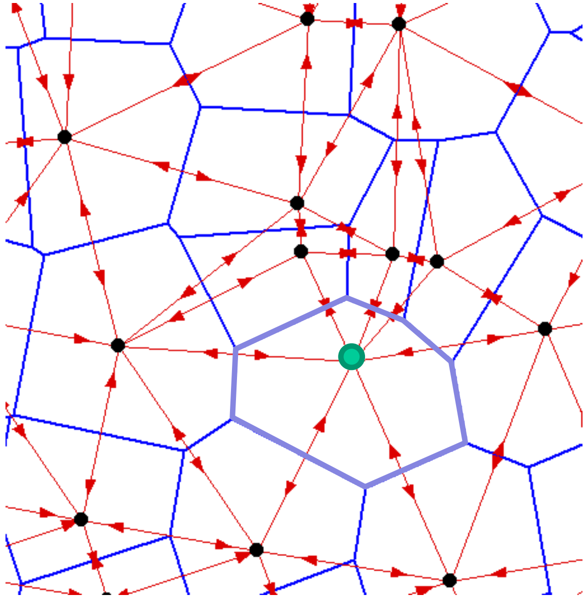
LPD Estimation: TIN-based Approach

- **TIN-based point density determination (Shih and Huang, 2006)**
  - **Local point density determination:**
    I. Construct a Voronoi diagram using constructed TIN structure
    II. Calculate the area of the Voronoi polygon for each point
    III. Assign the inverse of area value, or density in terms of points per unit squared, to the point



Unbiased LiDAR Data Measurement, Ty Naus, Fugro Horizons, Inc

$$Area_{Voronoi\ Polygon} = \frac{1}{2}\sum_{i=0}^{n-1}(x_i y_{i+1} - x_{i+1} y_i)$$

$$Local\ Pnt\ Density = \frac{1}{Local\ Voronoi\ Polygon\ Area}$$

Voronoi polygons shown in blue for actual LiDAR points – the triangulation edges are shown in red.

LPD Estimation: Box/TIN-based approaches

- **Drawbacks:**
  - They are based on the 2D neighborhood of individual points.
  - These techniques are not applicable for both airborne and terrestrial laser data (they are mainly suited for airborne data over flat/horizontal terrain).
  - For the box counting technique, the derived value for the local point density depends on the size and placement of the boxes.
    - There is no standard for the determination of the cell size and its placement within an area.

LPD Estimation: Local Neighborhood Analysis

- **Objectives:**
  - The local point density should be estimated while considering the 3D relationship among the points and the physical properties **(planarity)** of the surfaces enclosing individual points.
  - In order to derive a meaningful estimate of the point density, we introduce three approaches for deciding whether the point of interest belongs to a planar surface or not:
    - Eigen value analysis of the dispersion of the points in a spherical neighborhood relative to their centroid
    - Eigen value analysis of the dispersion of the points in a spherical neighborhood relative to the point in question/point of interest (POI)
    - Adaptive cylinder approach

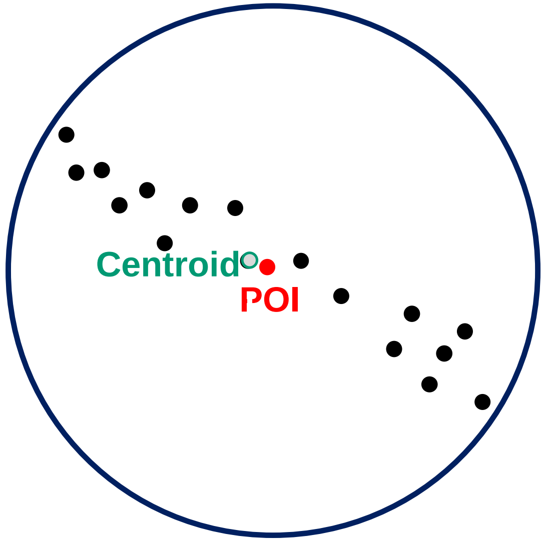
LPD Estimation: Local Neighborhood Analysis (1)

- **Classification using Eigen value analysis of the dispersion of 3D neighboring points relative to their centroid:**
  - Define a spherical neighborhood for the point of interest – the neighborhood includes *n* points (number of points needed for reliable plane definition)
  - Calculate the dispersion matrix of the points in the spherical neighborhood relative to the centroid point

$$\boldsymbol{C_{3\times 3} = \frac{1}{n+1}\sum_{i=1}^{n+1}(\vec{r}_i - \vec{r}_{centroid})(\vec{r}_i - \vec{r}_{centroid})^T}$$

$$\boldsymbol{\vec{r}_i = [X_i \quad Y_i \quad Z_i]^T}$$

$$\boldsymbol{\vec{r}_{centroid} = \frac{1}{n+1}\sum_{i}^{n+1}\vec{r}_i}$$



  - Eigen value decomposition of the dispersion matrix

$$C = W\Lambda W^T = [\vec{e}_1 \quad \vec{e}_2 \quad \vec{e}_3]\begin{bmatrix}\lambda_1 & 0 & 0\\ 0 & \lambda_2 & 0\\ 0 & 0 & \lambda_3\end{bmatrix}\begin{bmatrix}\vec{e}_1^T\\ \vec{e}_2^T\\ \vec{e}_3^T\end{bmatrix}$$

  - If $\lambda_1\ (\approx 0) \ll \lambda_2, \lambda_3$ the point of interest (POI) is considered to belong to a planar surface.

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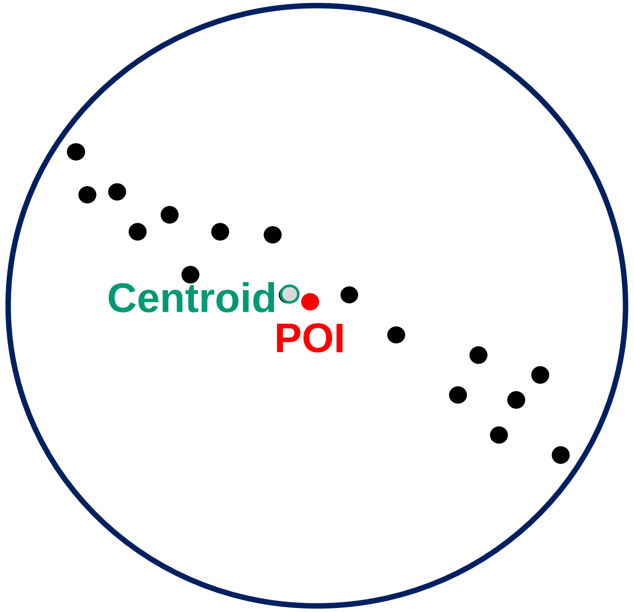
LPD Estimation: Local Neighborhood Analysis (1)

- **Classification using Eigen value analysis of the dispersion of 3D neighboring points relative to their centroid:**
  - Once the planarity of the established neighborhood is checked using the Eigen value analysis, the local point density index is calculated as follows:

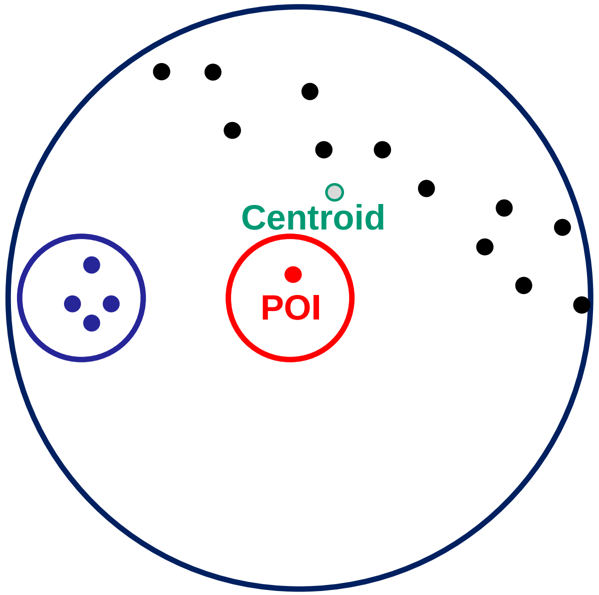
$$LPD = \frac{n+1}{\pi \, r_n^{\ 2}}$$

n+1	Number of points within the spherical neighborhood
r_n	The distance between the POI and its n^{th}-farthest neighbor



LPD Estimation: Local Neighborhood Analysis (1)

- **Classification using Eigen value analysis of the dispersion of 3D neighboring points relative to their centroid:**
  - Disadvantages:
  - ➢ Points that do not belong to the local planar surface (outliers) are considered in LPD estimation.
  - ➢ Does not consider the fact that the point of interest might not belong to the local planar surface



LPD Estimation: Local Neighborhood Analysis (2)

- **Classification using Eigen value analysis of the dispersion of 3D neighboring points relative to the POI:**
  - Define a spherical neighborhood for the point in question which includes at least n (number of points for reliable plane definition) points
  - Calculate the dispersion matrix for the points in spherical neighborhood relative to the point of interest (POI)

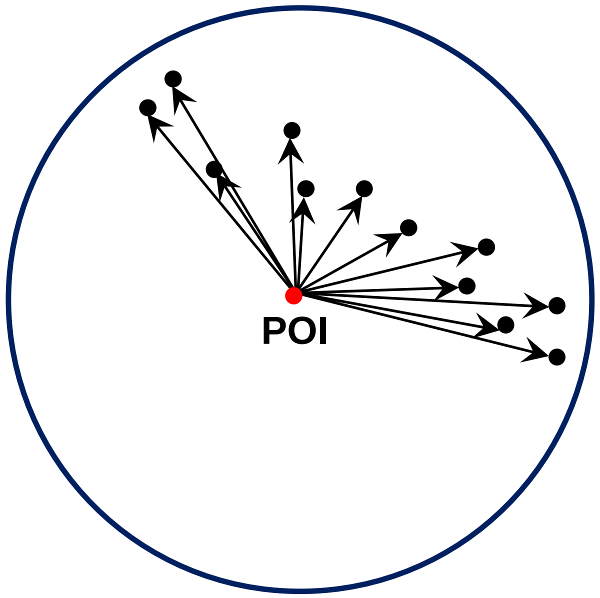
$$\boldsymbol{C_{3\times3} = \frac{1}{n}\sum_{i=1}^{n}(\vec{r}_i - \vec{r}_{POI})(\vec{r}_i - \vec{r}_{POI})^T}$$

$$\boldsymbol{\vec{r}_i = [X_i \quad Y_i \quad Z_i]^T}$$

$$\boldsymbol{\vec{r}_{POI} = [X_{POI} \quad Y_{POI} \quad Z_{POI}]^T}$$

  - Eigen value decomposition of the dispersion matrix

$$C = W\Lambda W^T = [\vec{e}_1 \quad \vec{e}_2 \quad \vec{e}_3]\begin{bmatrix}\lambda_1 & 0 & 0\\ 0 & \lambda_2 & 0\\ 0 & 0 & \lambda_3\end{bmatrix}\begin{bmatrix}\vec{e}_1^T\\ \vec{e}_2^T\\ \vec{e}_3^T\end{bmatrix}$$



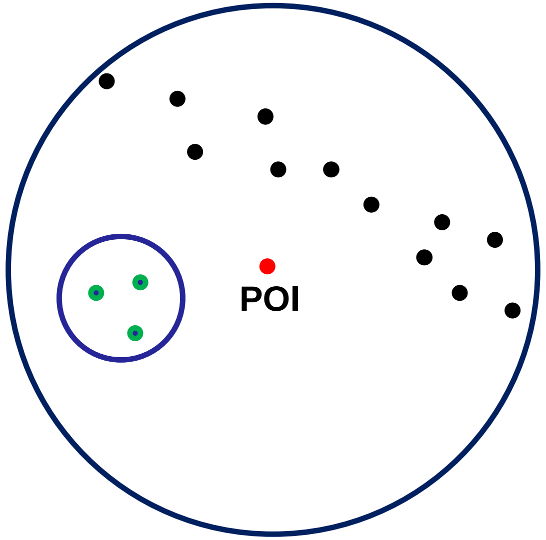
  - If $\boldsymbol{\lambda_1(\approx 0) \ll \lambda_2, \lambda_3}$ the point of interest (POI) is considered to belong to a planar surface.

LPD Estimation: Local Neighborhood Analysis (2)

- **Classification using Eigen value analysis of the dispersion of 3D neighboring points relative to the POI:**

$$LPD = \frac{n+1}{\pi r_n^2}$$

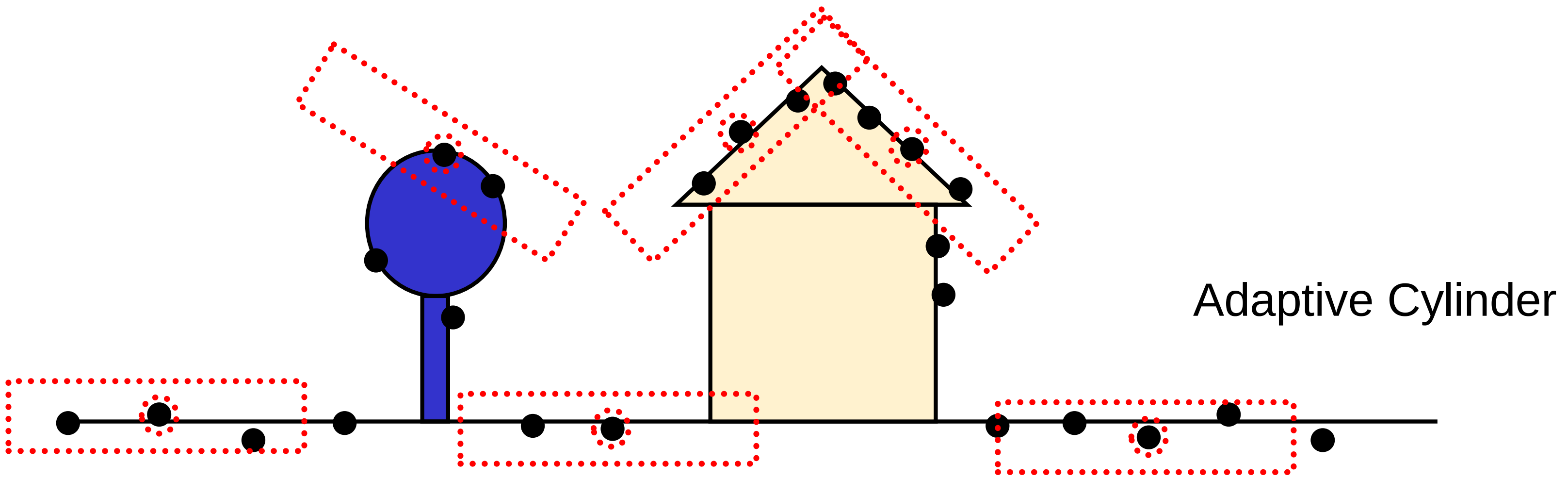
n+1	Number of the points within the spherical neighborhood



- **Disadvantages:**
  - Points that do not belong to the local planar surface (outliers) are considered in LPD estimation

LPD Estimation: Local Neighborhood Analysis (3)

- **Classification using an adaptive cylinder:**
  - This approach is based on defining a cylinder, which changes its orientation with the local planar surface. This cylinder is used to decide whether the point belongs to a planar or rough surface.
- **Advantages:**
  - ➢ Takes into consideration whether the point of interest belongs to the local planar surface or not
  - ➢ Points that do not belong to the local planar surface (outliers) are not considered in local point density estimation.



LPD Estimation: Local Neighborhood Analysis (3)

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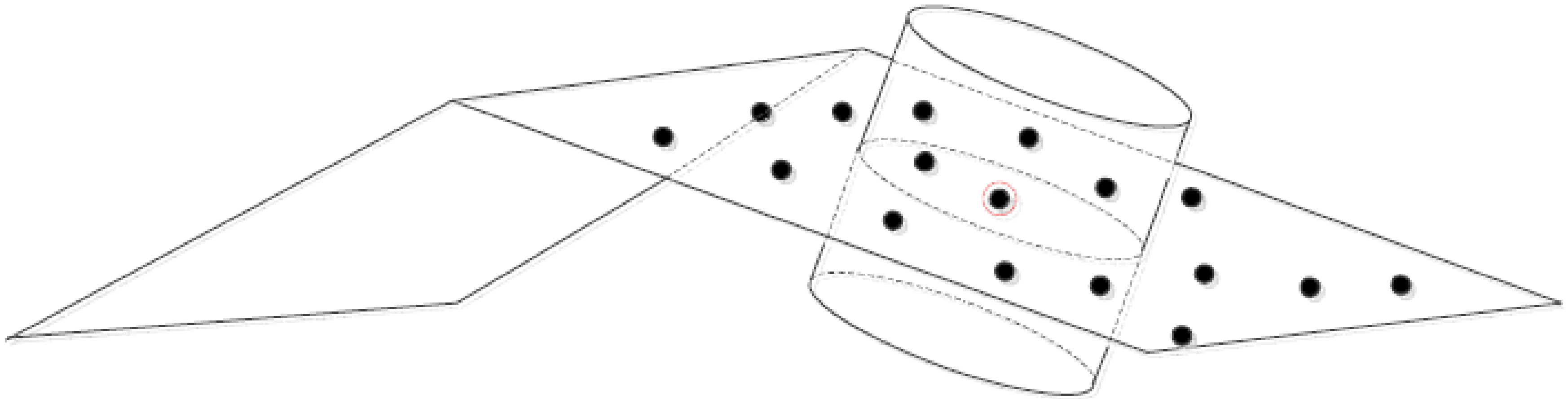
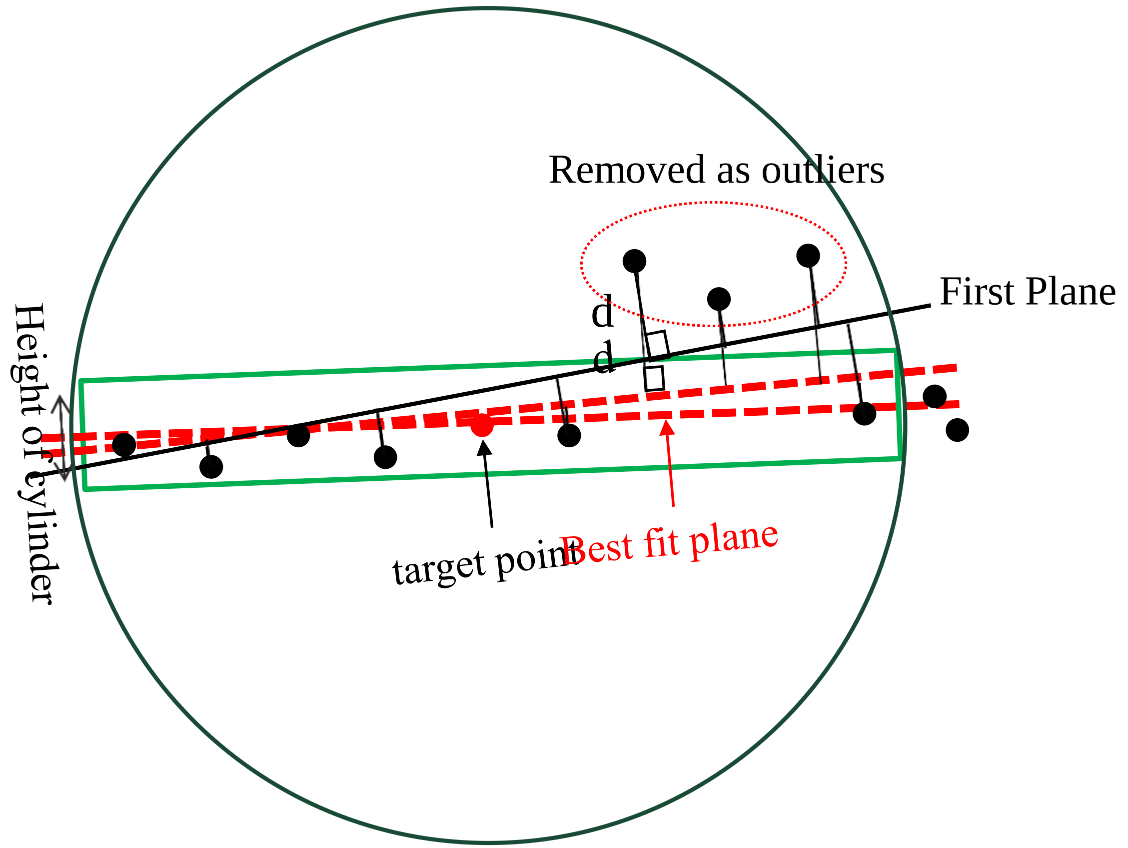


LPD Estimation: Local Neighborhood Analysis (3)

- **Classification using an adaptive cylinder:**

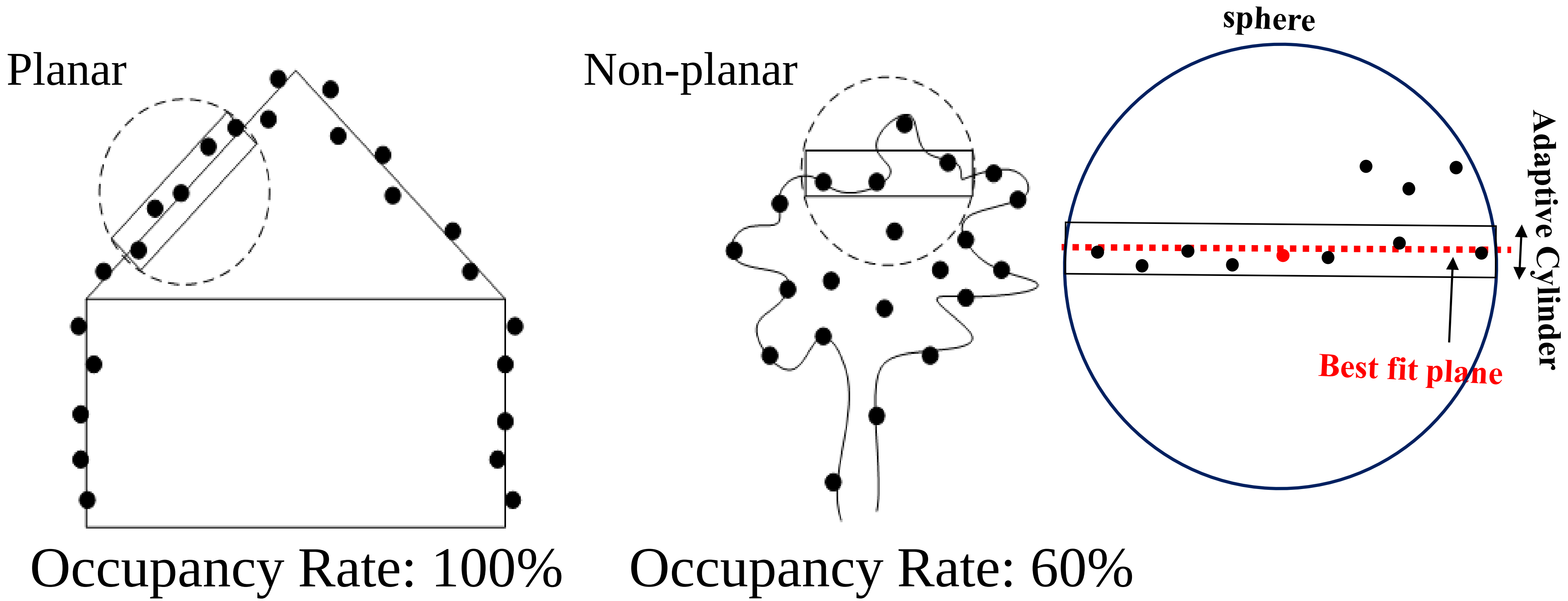
Derivation of the Adaptive Cylinder



If the iterative plane fitting procedure **<u>does not converge</u>** within a pre-specified number of iterations, the point of interest is classified as a **<u>non-planar point</u>** and we will not estimate the local point density index for this point.

LPD Estimation: Local Neighborhood Analysis (3)

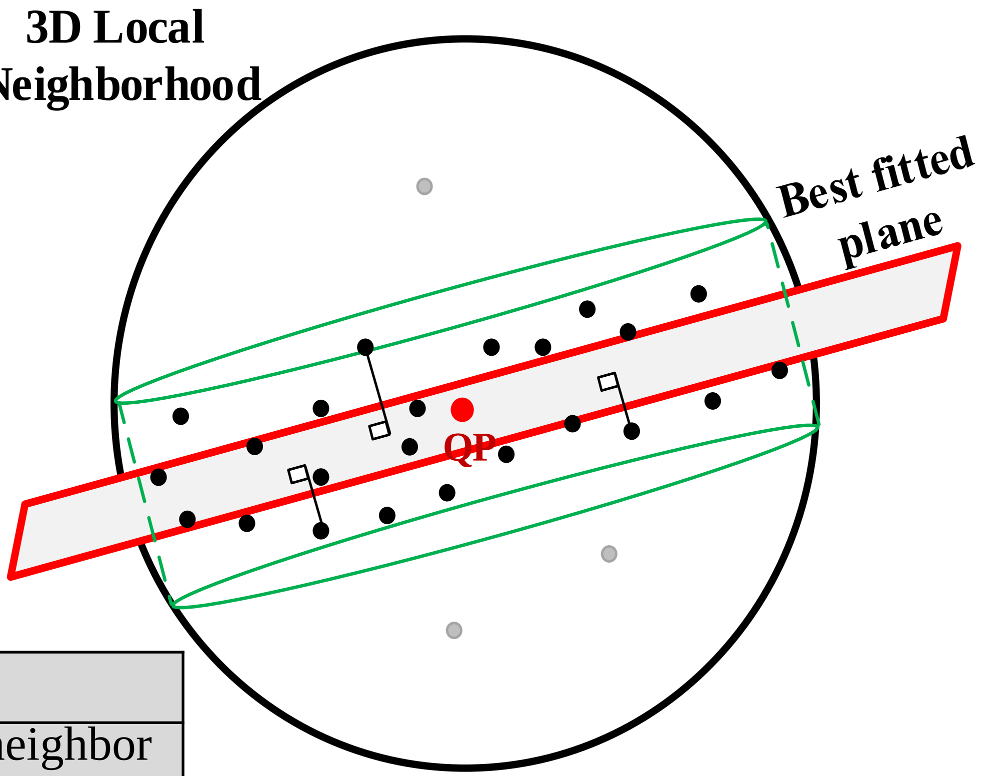
- **Classification using an adaptive cylinder:**
  - The point of interest should be within the adaptive cylinder, and
  - The majority of the points within the spherical neighborhood should be inside the adaptive cylinder.



LPD Estimation: Local Neighborhood Analysis (3)

- **Classification using an adaptive cylinder:**
  - Once the planarity of the established neighborhood is checked using the adaptive cylinder, the local point density index is calculated as follows:

$$LPD = \frac{k}{\pi\ r_n^{\ 2}}$$



k	Number of points within the adaptive cylinder
r_n	The distance between the POI and its n^{th}-farthest neighbor

$$k\,(number\ of\ \ pnts\ in\ adaptive\ cylinder) \le n\,(number\ of\ \ pnts\ in\ sphere)$$

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LPD Estimation: Local Neighborhood Analysis

- **Eigen value analysis of the dispersion matrix of the points in a spherical neighborhood relative to their centroid (Drawbacks):**

  1. This approach classifies the neighborhood without considering the fact that the point in question might not belong to the planar neighborhood.
  2. Non-coplanar points are considered in LPD estimation.

- **Eigen value analysis of the dispersion matrix of the points in a spherical neighborhood relative to the POI (Drawback):**

  1. Non-coplanar points are considered in LPD estimation.

- **Adaptive cylinder (Advantage):**

  − Only the points that belong to the planar neighborhood are taken into consideration during the local point density computation while making sure that the query point belongs to the planar neighborhood.

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Experimental Results (Airborne Data)

- **Location: University of Calgary campus**
- **Average point density: 1 pnts/m^2**

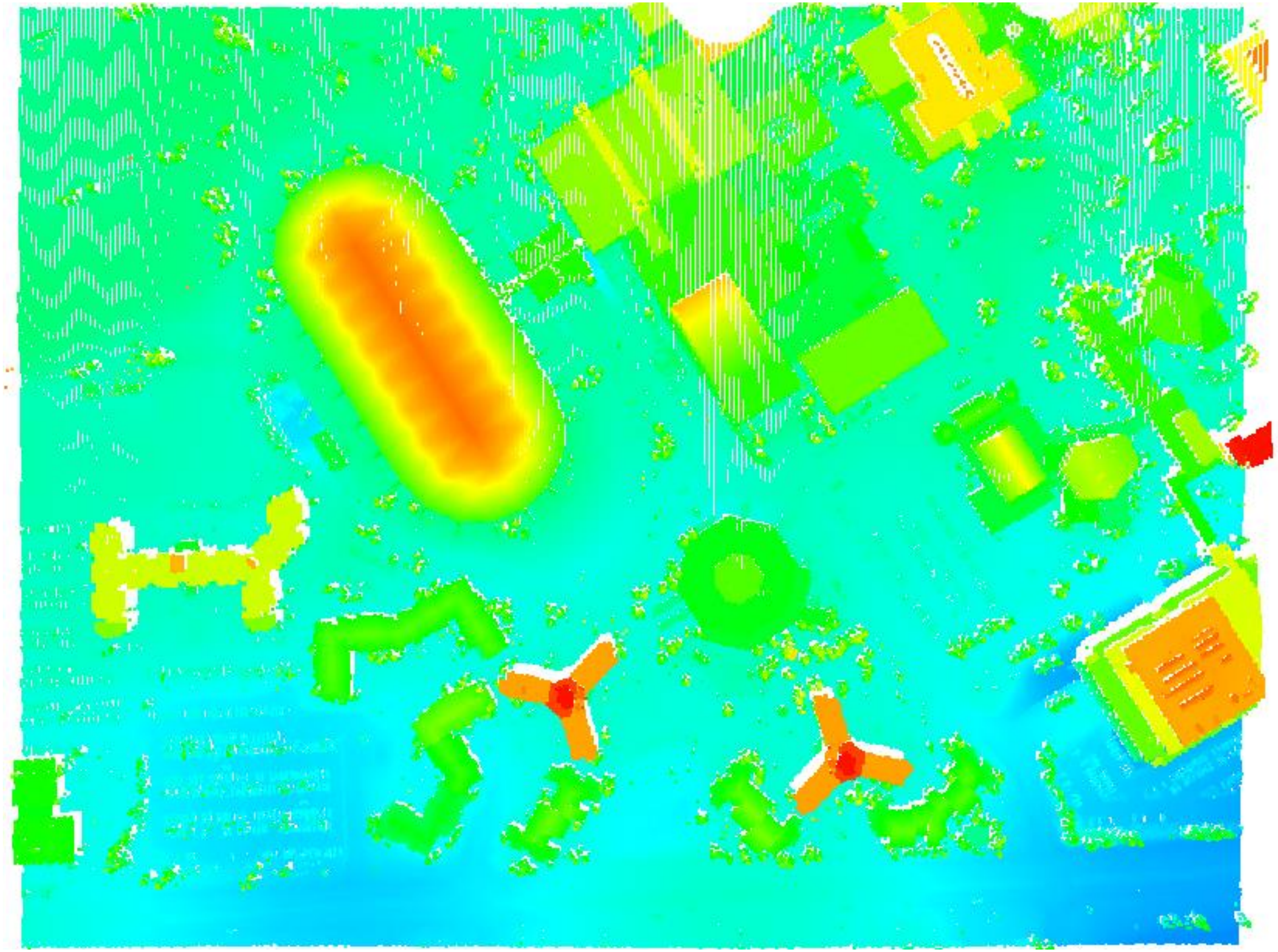
Threshold	Value
No. of neighboring points for Eigen-values calculation	12
No. of neighboring points for best fit plane definition	12
Height of cylinder	0.8 m
Planarity ratio	95%

Experimental Results (Airborne Data)

- Orthophoto over the test area:

Experimental Results (Airborne Data)

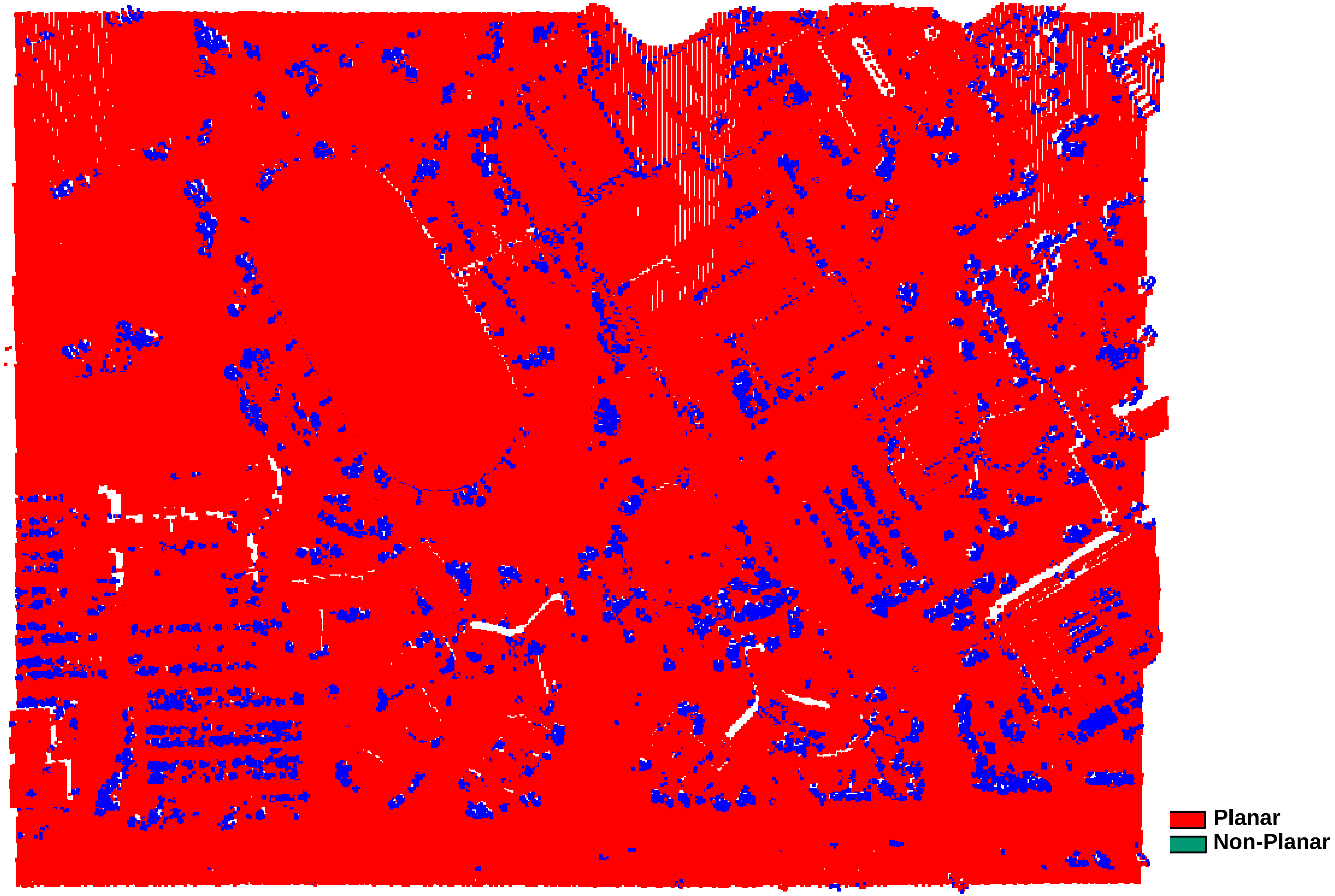
- Original LiDAR data:



Experimental Results (Airborne Data)

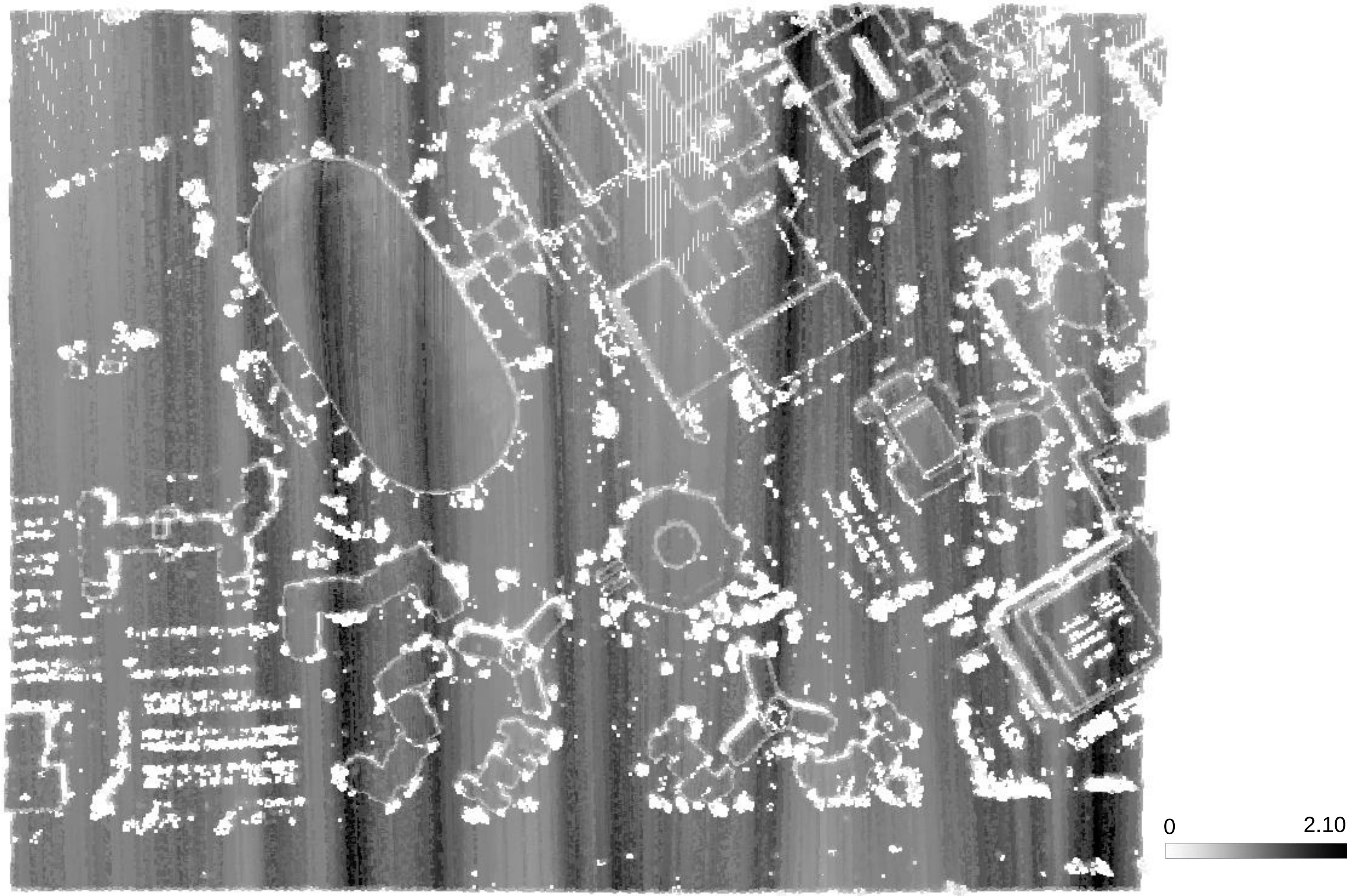
- Dispersion of the point’s 3D neighbors relative to their centroid:

Classification Results



Experimental Results (Airborne Data)

- Dispersion of the point's 3D neighbors relative to their centroid:



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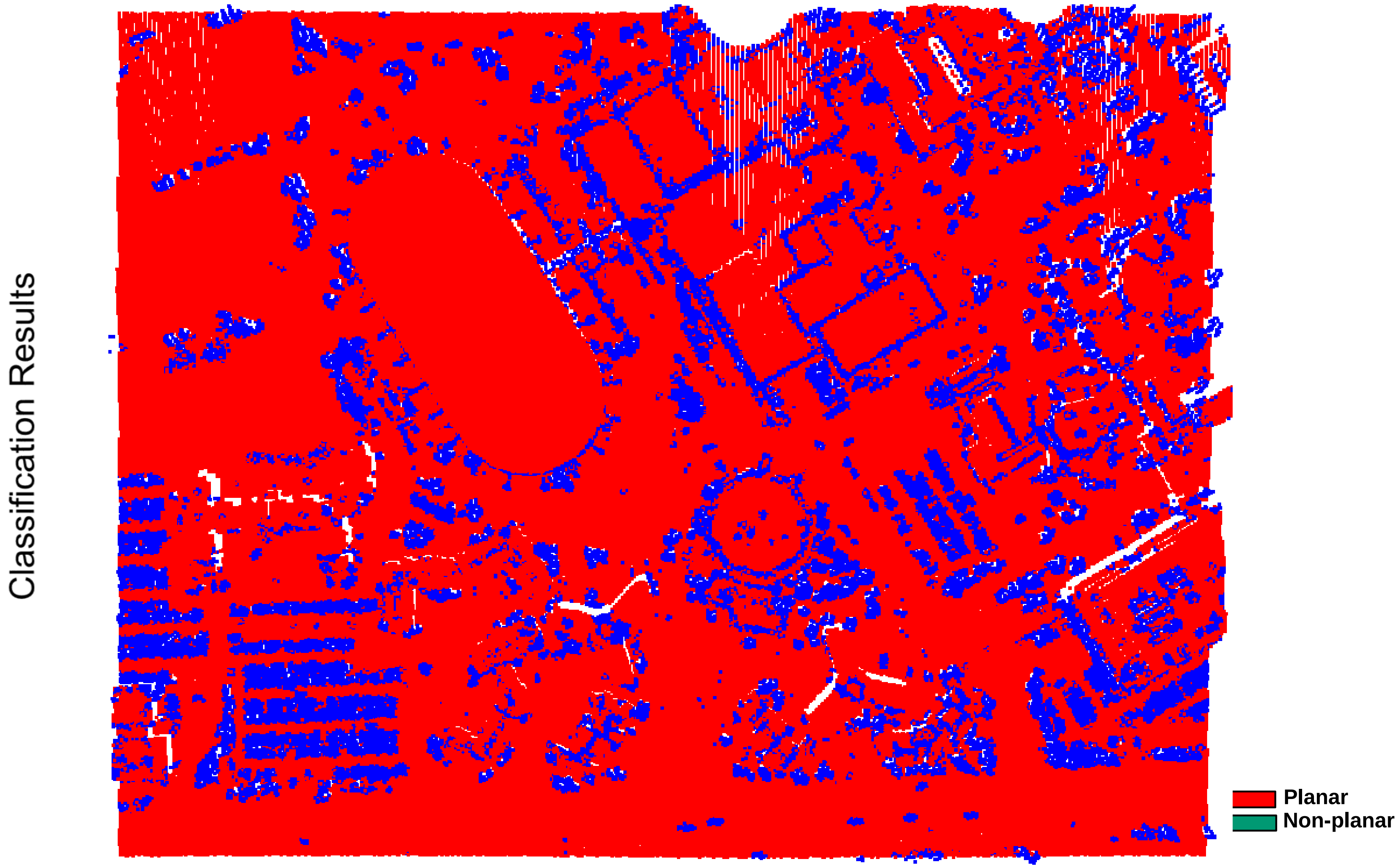
Experimental Results (Airborne Data)

- Adaptive cylinder:



Experimental Results (Airborne Data)

- Adaptive cylinder: