UAS-Based LiDAR Mapping

Video H

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Digital Terrain Model Generation

LiDAR Classification: Introduction

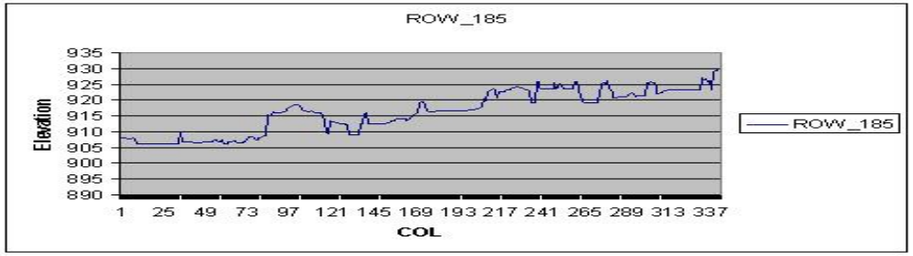
- **LiDAR data includes ground/terrain and non-ground/off-terrain points.**
  - Knowledge of the terrain is useful for deriving contour lines, road network planning, and flood monitoring.
  - Knowledge of the off-terrain points is useful for DBM detection, DBM reconstruction, 3D city modeling, and 3D visualization.
  - Knowledge of terrain and off-terrain points is useful for change detection applications.

LiDAR Classification: Introduction

- **Definition of ground/non-ground (Sithole & Vosselman, 2003)**
  - Ground: Topsoil or any thin layering (asphalt, pavement, etc.) covering it
  - Non-ground: Vegetation and artificial features
- **How to distinguish ground points from non-ground points in LiDAR data?**

Ground Profile

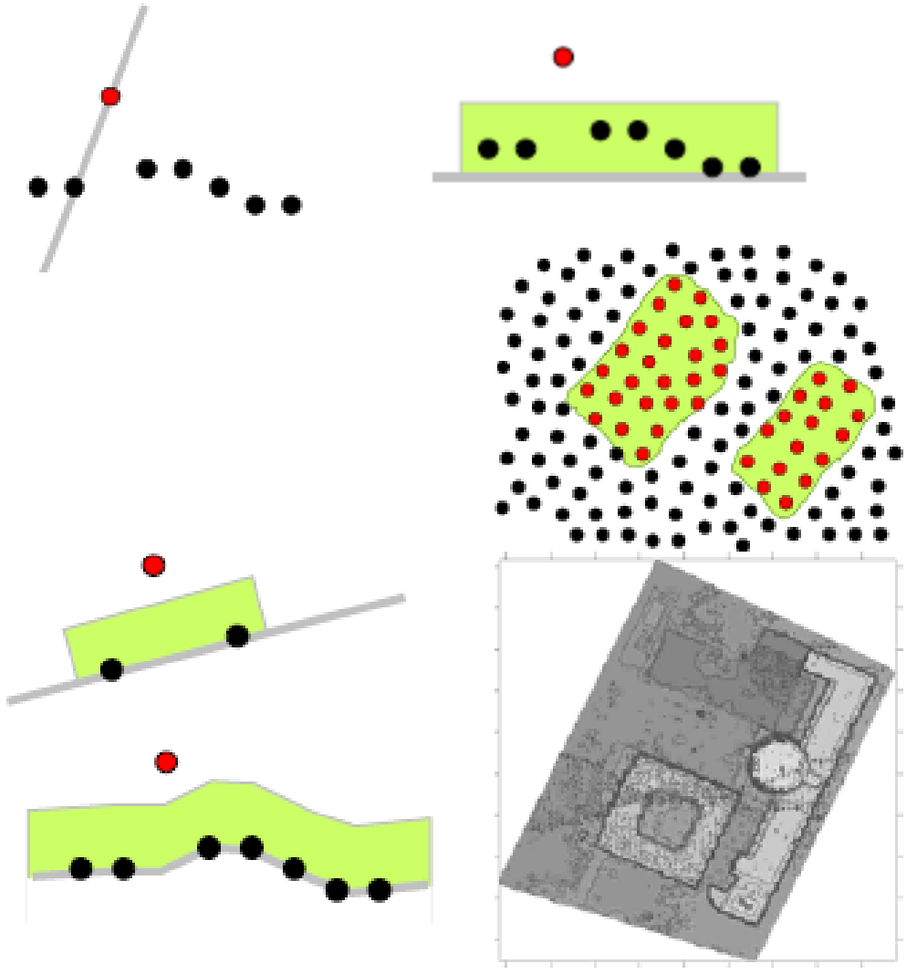
Non-Ground Profile



LiDAR Profile

LiDAR Classification: Existing Approaches

- **Categories (Sithole & Vosselman 2003):**
  - **Slope-based**
  - **Block-minimum**
  - **Surface-based**
  - **Clustering/segmentation**



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LiDAR Classification: Existing Approaches

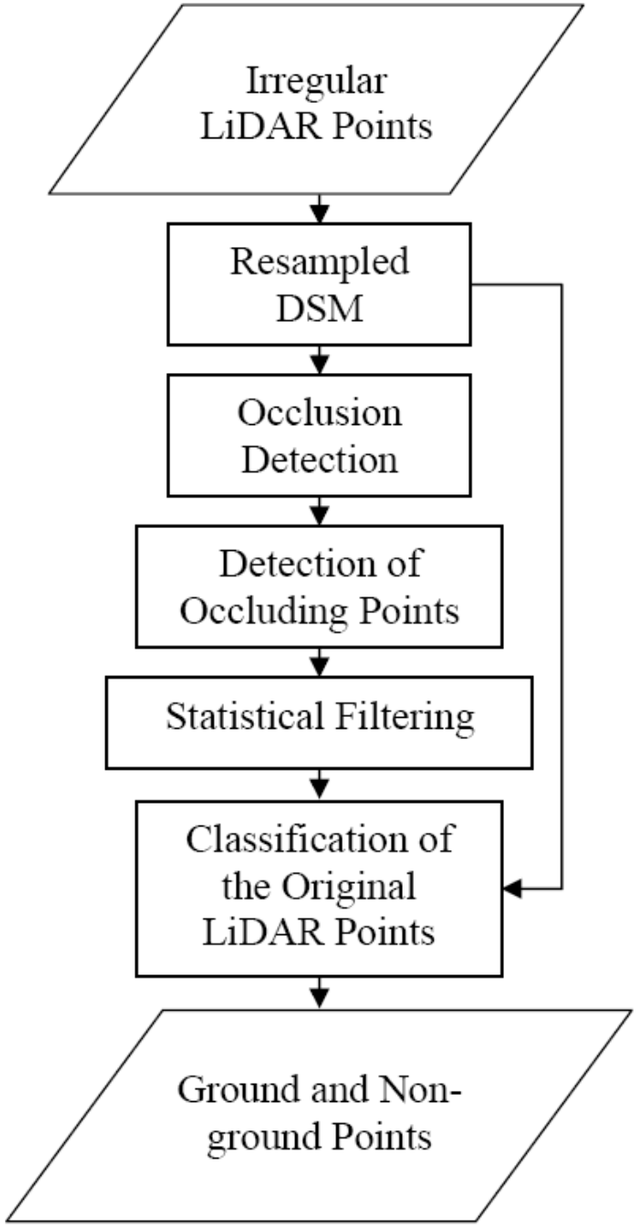
- Modified Block Minimum (Wack and Wimmer, 2002)
- Modified Slope-based Filter (Vosselman, 2000)
- Morphological Filter (Zhang et al., 2003)
- Active Contour (Elmqvist et al., 2001)
- Progressive TIN Densification (Axelsson, 2000)
- Robust Interpolation (Pfeifer et al., 2001)
- Spline Interpolation (Brovelli et al., 2002)

Angle-based Approach for LiDAR Data Classification

- **Assumption: Non-ground objects produce occlusions in synthesized perspective views.**
- **Search for occlusions → Non-ground objects can be detected as those causing occlusions.**

Perspective Projection

Angle-based Approach for LiDAR Data Classification



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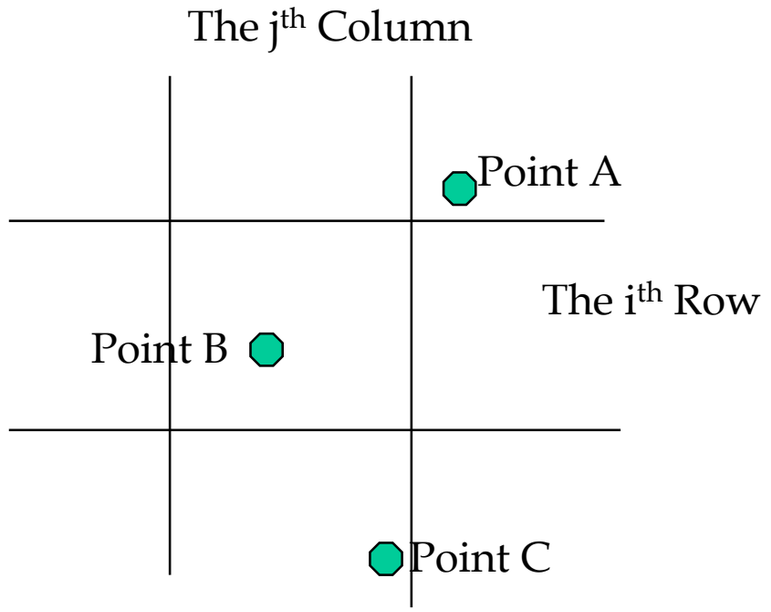
DSM Generation

- **LiDAR data is irregularly distributed.**
- **We start by interpolating the LiDAR data.**
  - The average point density is used to estimate the optimum GSD for resampling.
  - We use the **nearest neighbor interpolation** to avoid blurring the height discontinuities.



DSM(i , j) = Height of Point B

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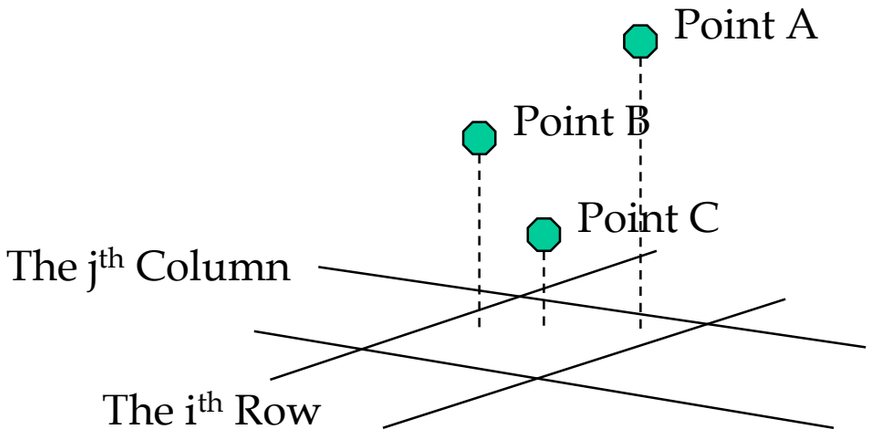
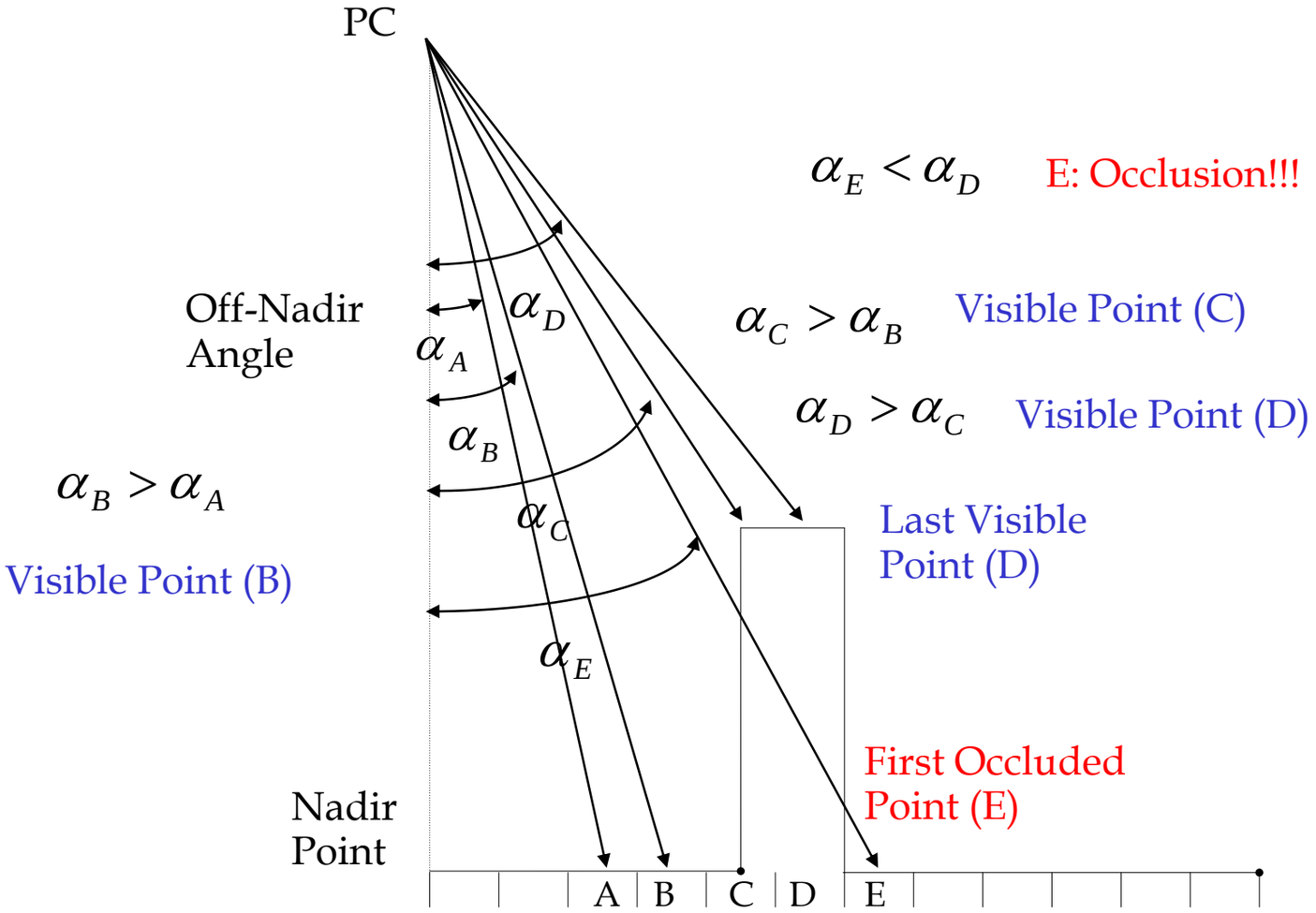
DSM Generation

- **If there is more than 1 point located in a given cell, we pick the one with the lowest height and assign its height to that cell.**



DSM(i , j) = Height of Point C

Occlusion Detection (Angle-based Approach)

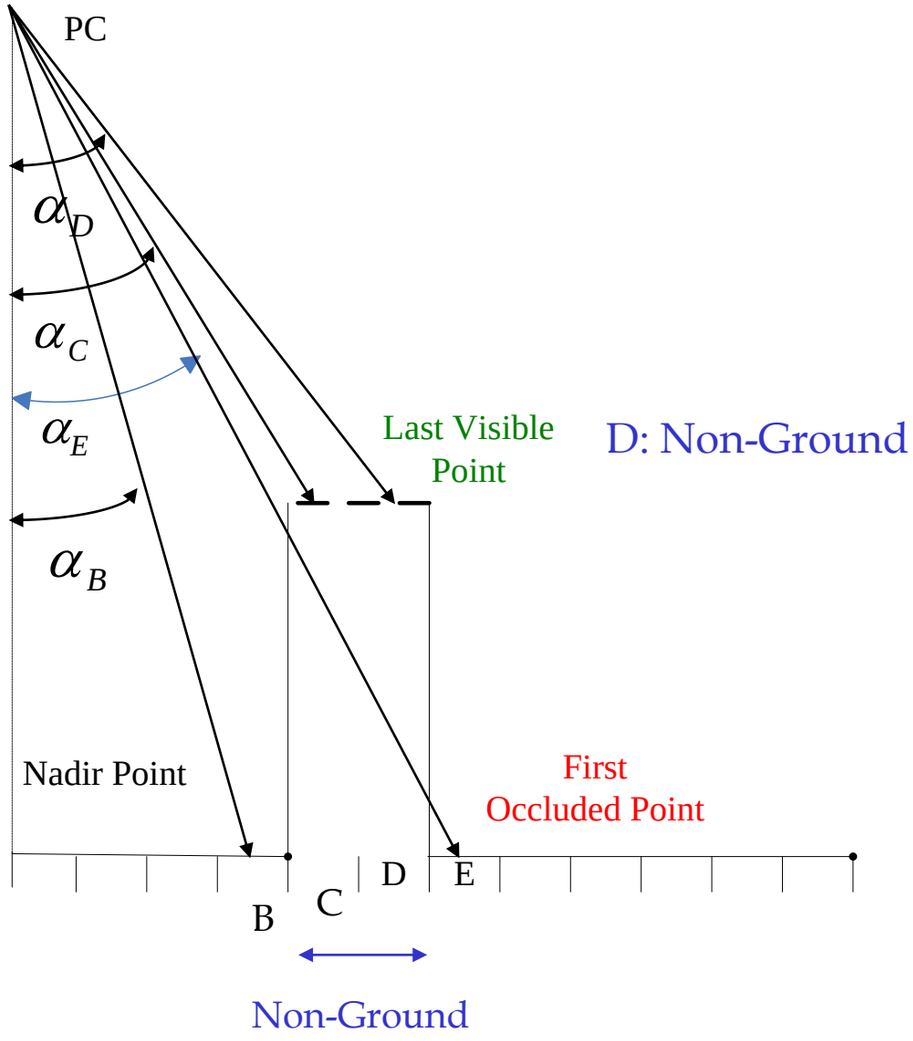


Occlusion Detection (Angle-based Approach)

- **Occlusion Detection (Angle-based)**

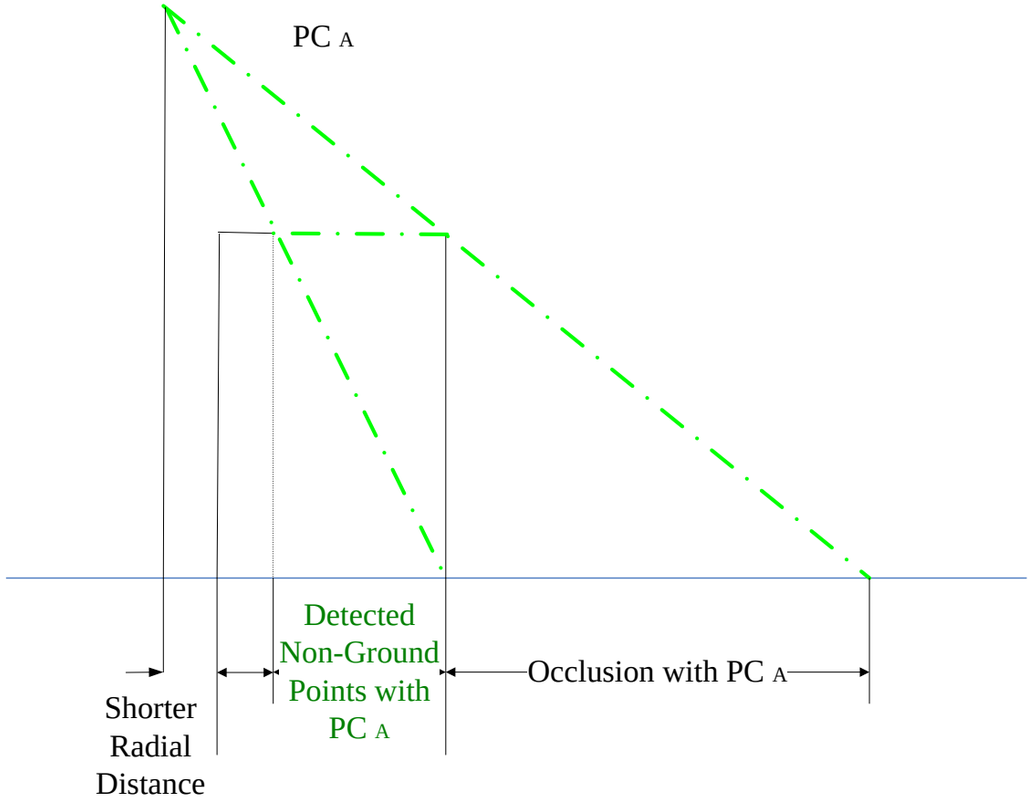
C: Non-Ground $\alpha_C > \alpha_E$

B: Ground $\alpha_B < \alpha_E$



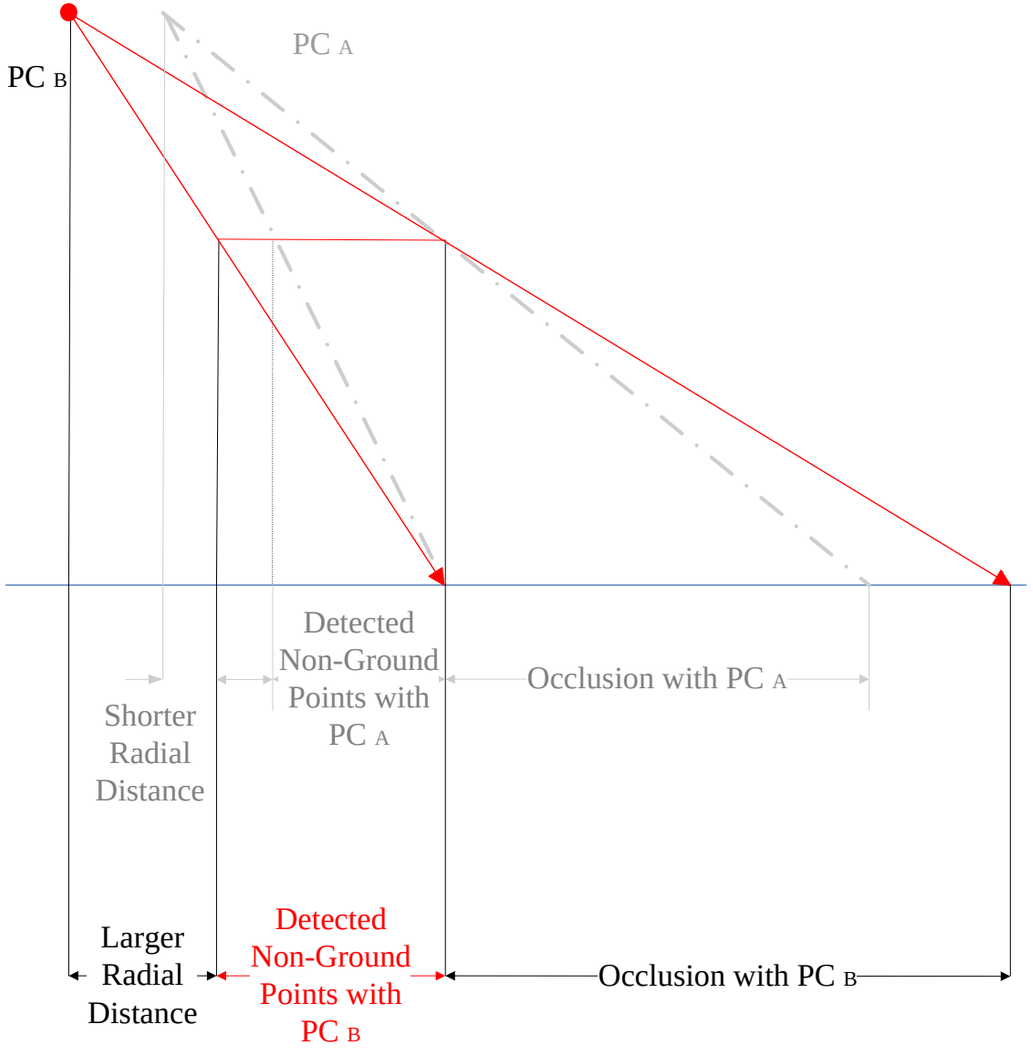
Occlusion Detection (Angle-based Approach)

- **How can we maximize our ability to detect the majority of non-ground objects?**
  - Manipulate the location & number of synthesized projection center(s)



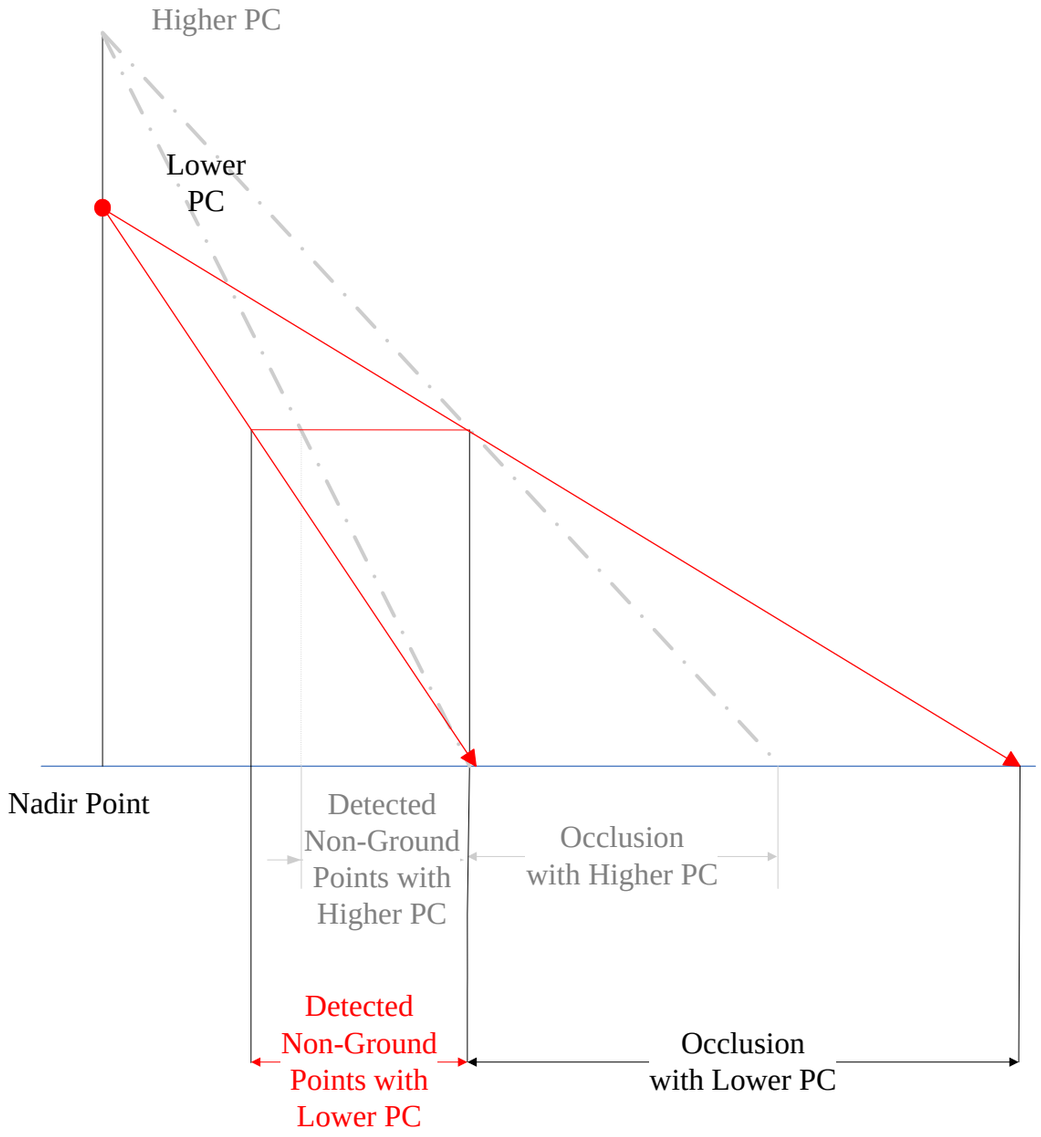
Occlusion Detection (Angle-based Approach)

- **Non-ground points detected from projection centers with different horizontal locations**



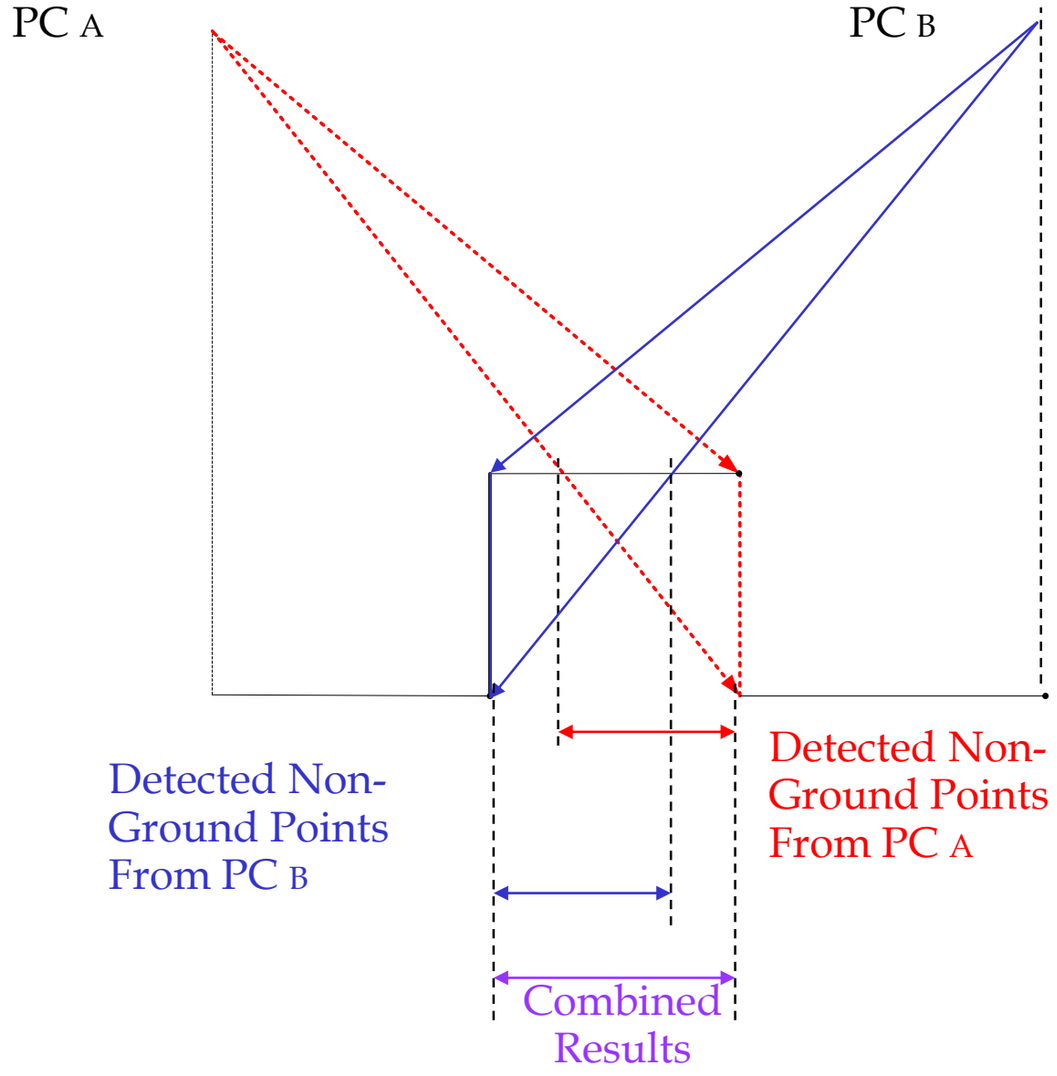
Occlusion Detection (Angle-based Approach)

- **Non-ground points detected from projection centers with different vertical locations**

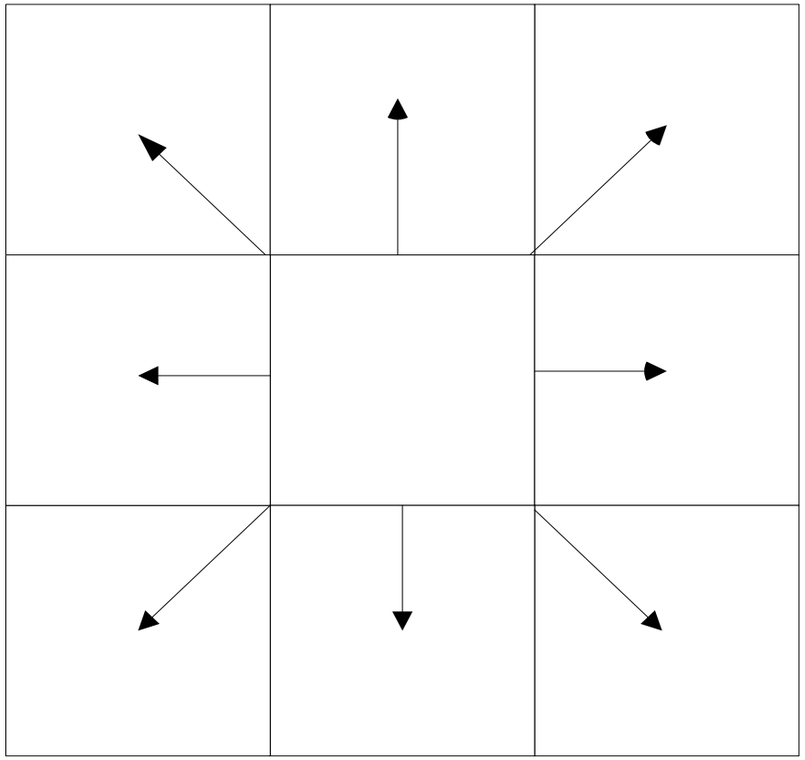


Occlusion Detection (Angle-based Approach)

- **Two opposite projection centers will allow for the detection of a larger non-ground area**

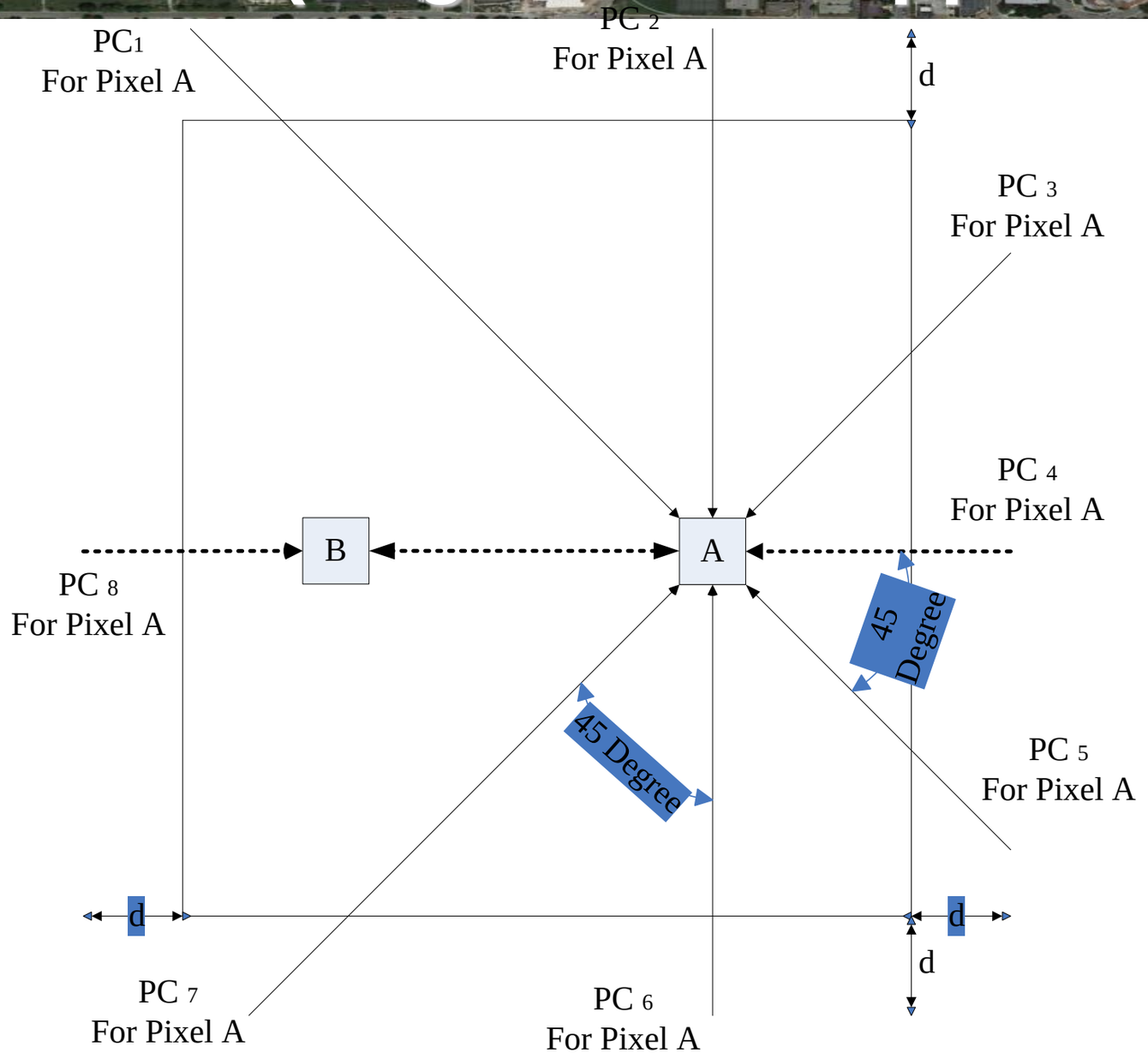


Occlusion Detection (Angle-based Approach)

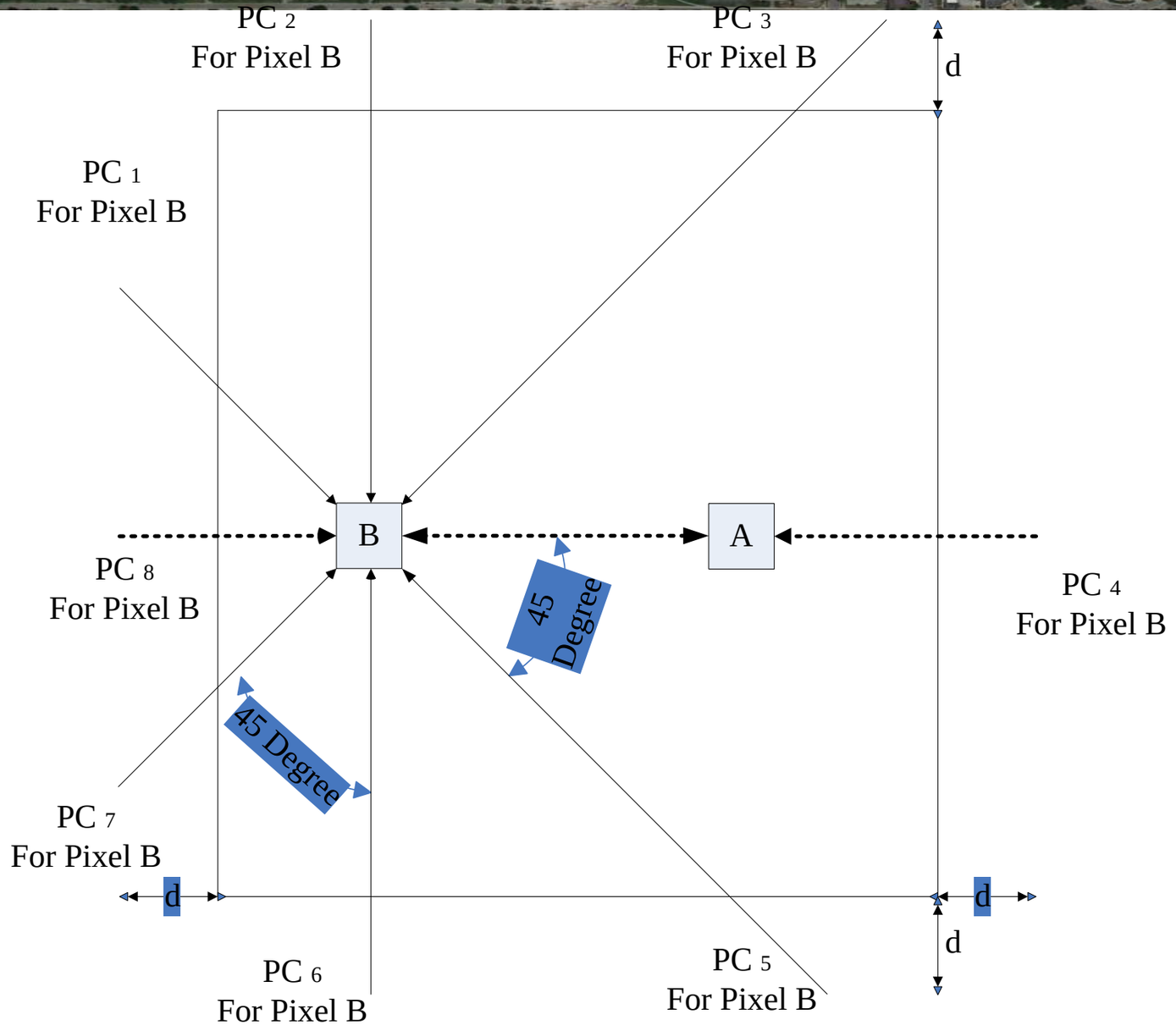


The eight neighbors of any given pixel are checked to see if they are occluded by that pixel or not.

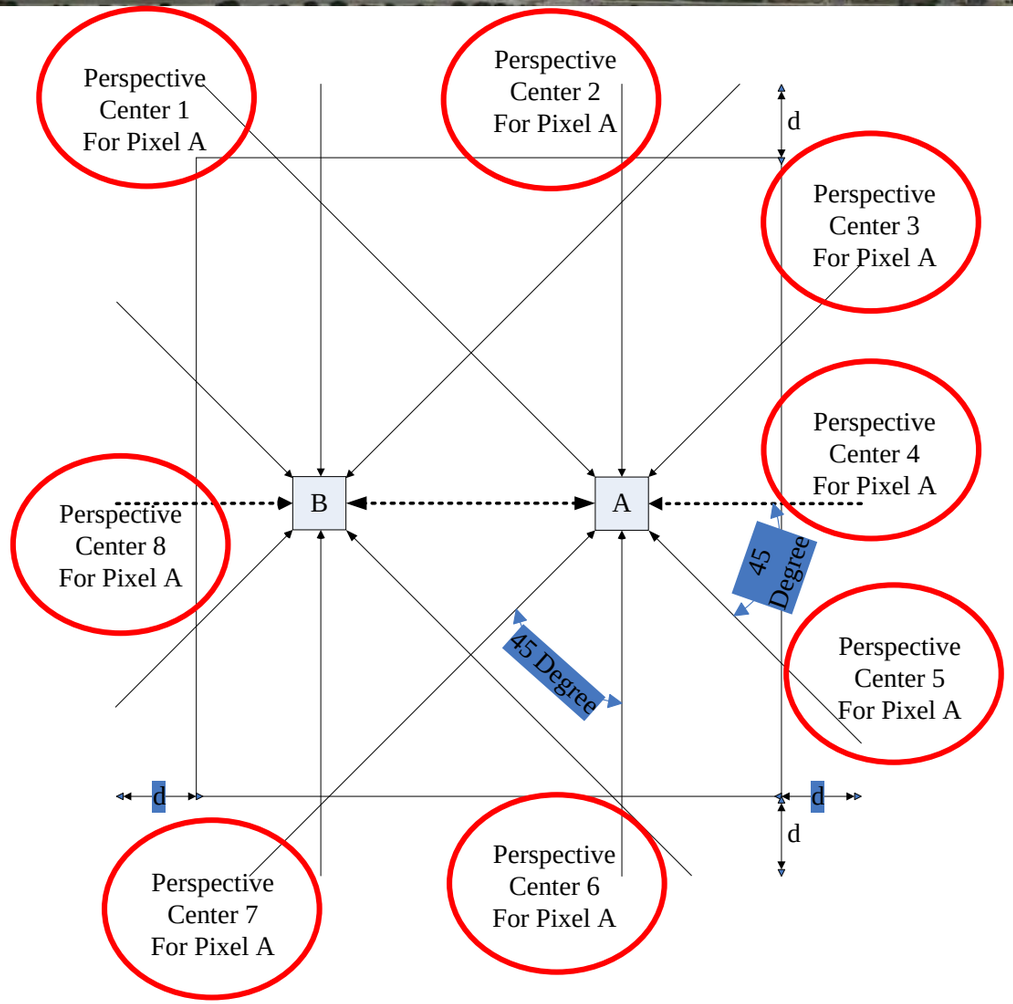
Occlusion Detection (Angle-based Approach)



Occlusion Detection (Angle-based Approach)



Occlusion Detection (Angle-based Approach)

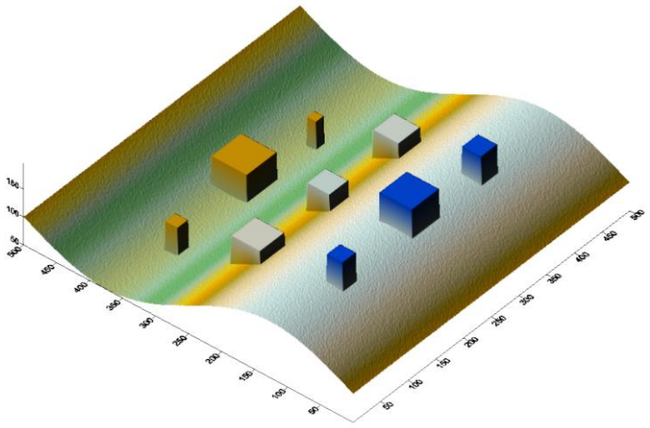


The eight neighbors of any given pixel are checked to see if they are occluded by that pixel or not.

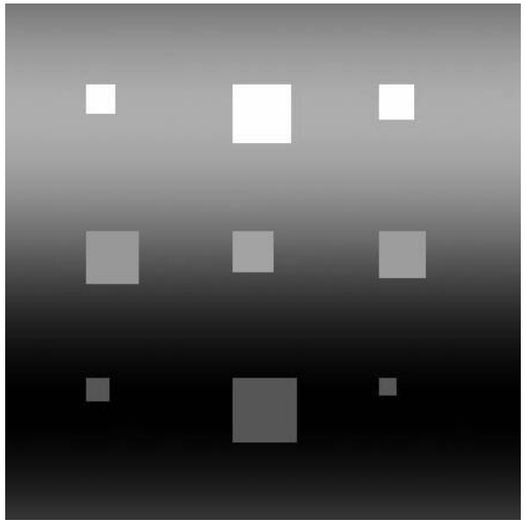
Occlusion Detection (Angle-based Approach)

Simulated Dataset

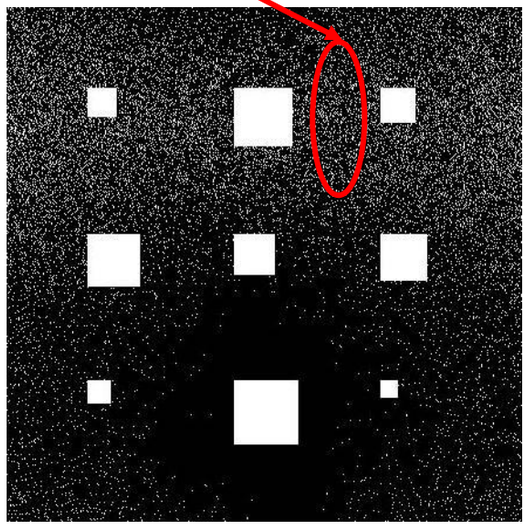
Misclassified ground points



Simulated Dataset



DSM



Identified Occluding Points
(in white)

Occlusion Detection (Angle-based Approach)

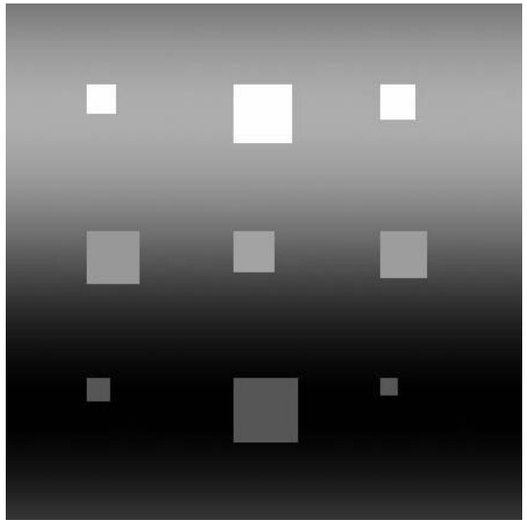
- **Multiple projection centers at pre-specified locations will:**
  - \+ Improve our capability of detecting non-ground points
    - Useful when dealing with large and low buildings
  - − Enhance the noise and high-frequency components of the terrain
    - Will lead to false hypotheses regarding instances of non-ground points
- **Solution: implement a statistical filter to refine the occlusion-based terrain/off-terrain classification procedure**

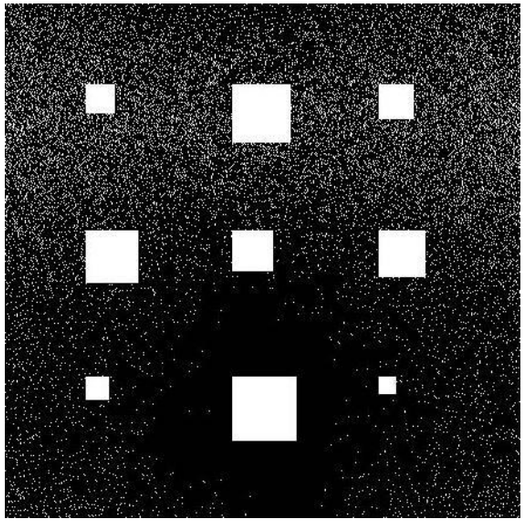
Occlusion Detection (Angle-based Approach)

- **Points producing occlusions (hypothesized off-terrain point):**
  - True non-ground points + false non-ground points
- **Points not producing occlusions (hypothesized terrain point):**
  - True ground points + false ground points

Less probable

DSM

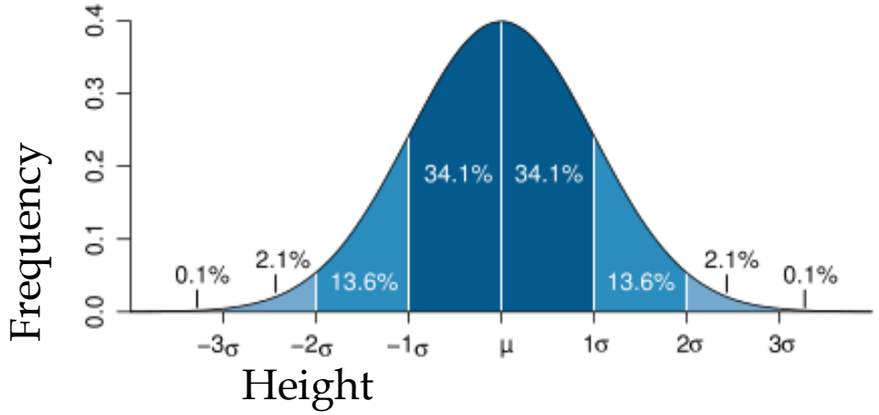




Identified Occluding Points
(in white)

LiDAR Classification: Filtering

- **We can use a statistical filter to remove the effects of terrain roughness (e.g., noise in the LiDAR data and high frequency components of the surface – cliffs).**
- **The elevation "h" of the ground points can be assumed to be normally distributed with a mean "μ" and standard deviation "σ".**



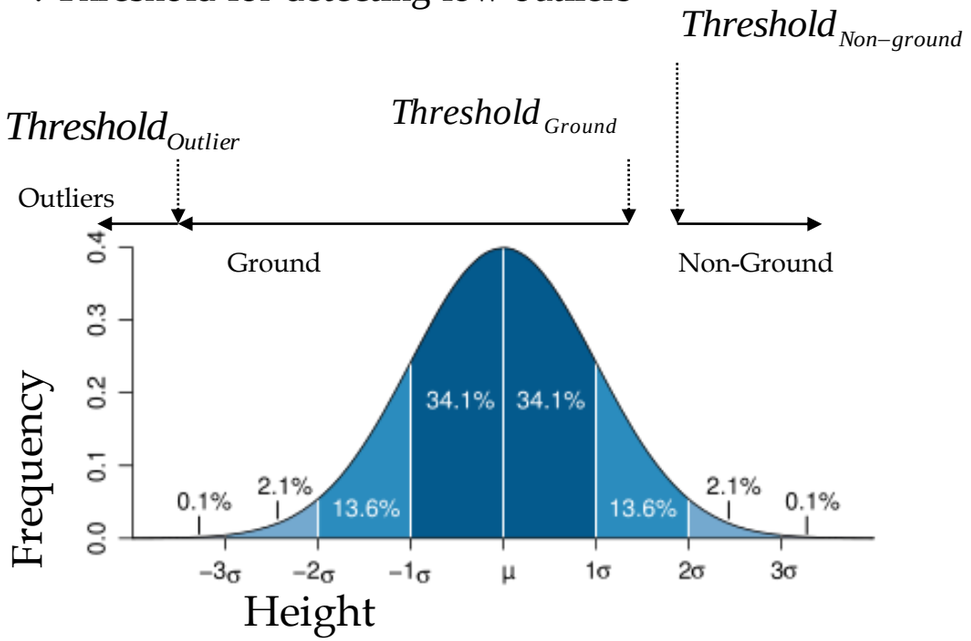
LiDAR Classification: Filtering

- **For each DSM cell, we define a local neighborhood that is adaptively expanded until a pre-defined number of terrain points is located.**
  - Derive a histogram of the terrain point elevations

$Threshold_{Ground}$: Threshold for modifying non-ground points

$Threshold_{Non-ground}$: Threshold for modifying ground points

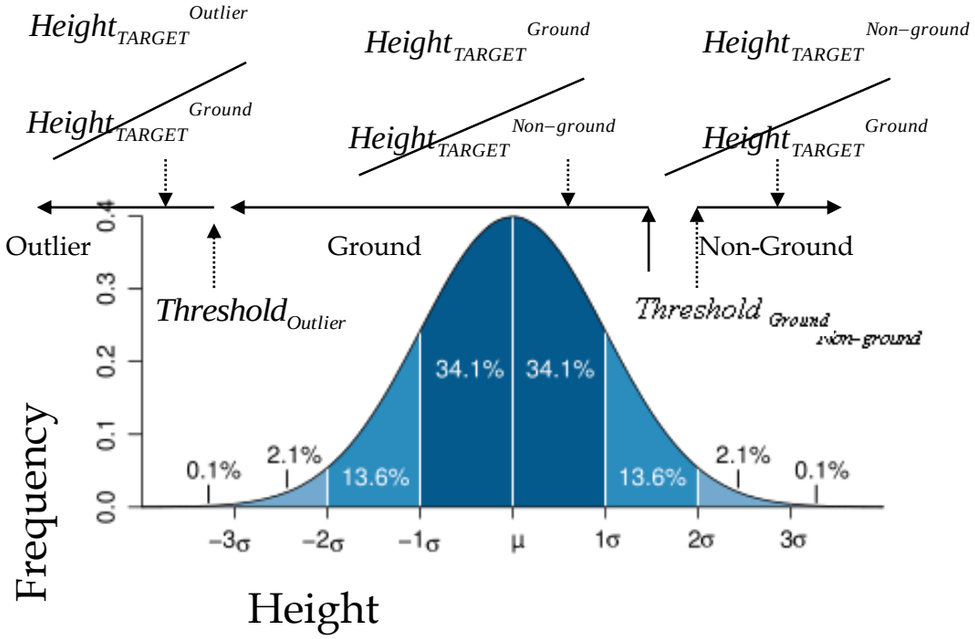
$Threshold_{Outlier}$: Threshold for detecting low outliers

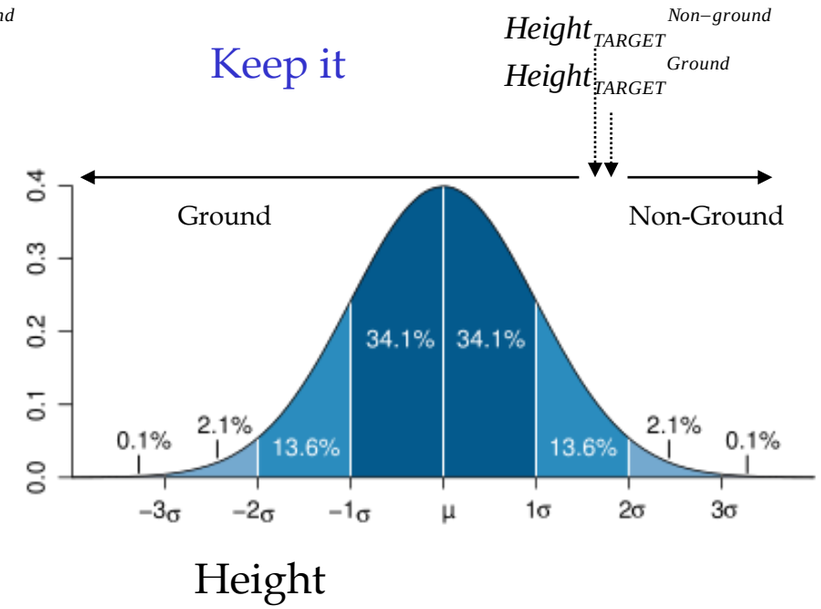


LiDAR Classification: Filtering

- **Examples of outliers:** multi-path errors, errors in the laser range finder

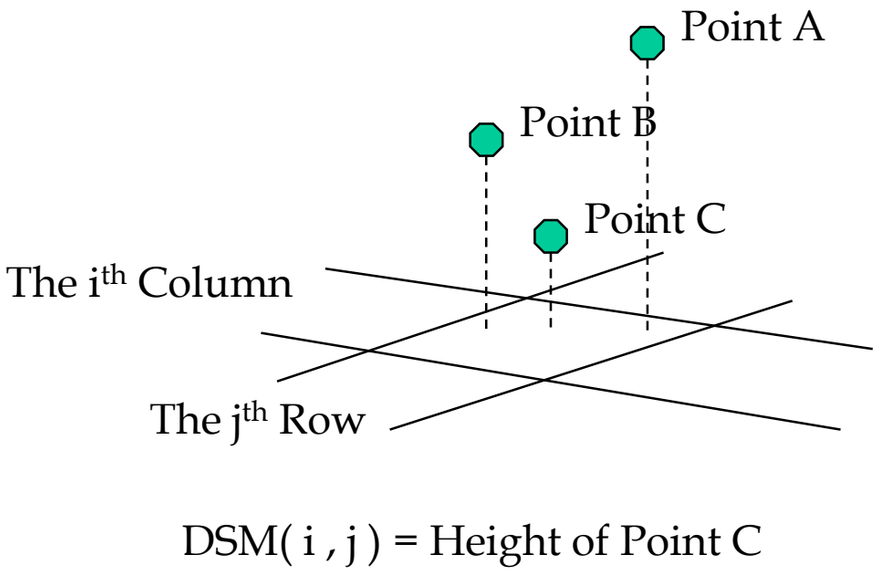
LiDAR Classification: Filtering



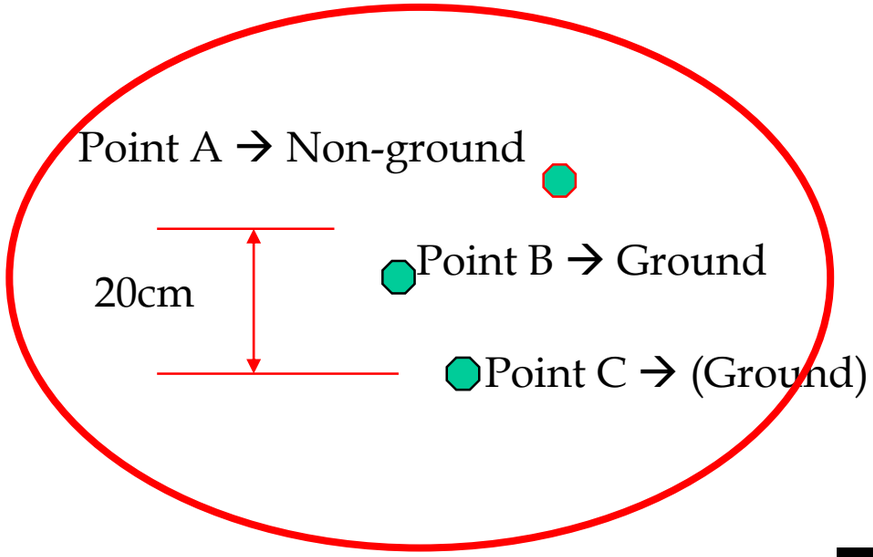


LiDAR Classification: Point Cloud Class.

- **If a cell is classified as non-ground, all the LiDAR points in that cell are classified as non-ground points.**
- **If the cell is classified as a ground point, then**
  - The lowest LiDAR point in that cell is classified as ground.
  - The LiDAR points that are at least 20 cm higher than the lowest LiDAR point are classified as non-ground points.

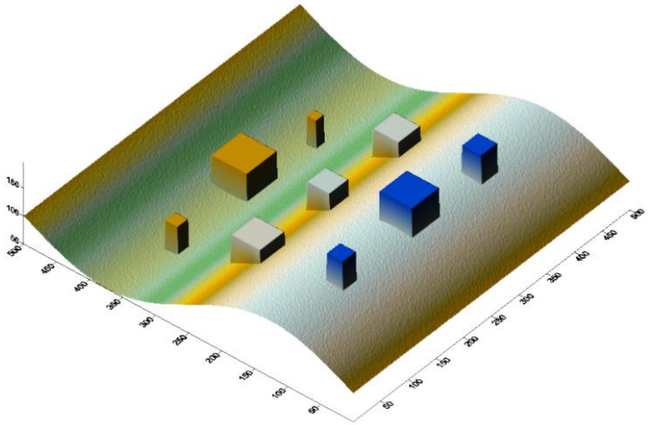


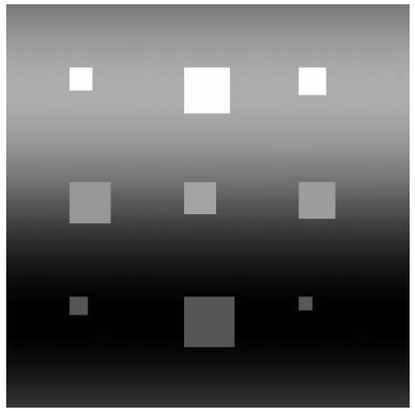
DSM(i , j) = Height of Point C



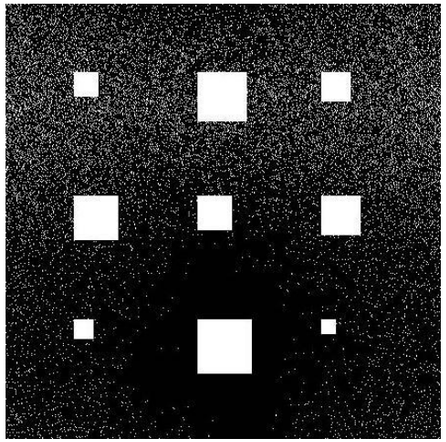
LiDAR Classification: Results

Simulated Dataset

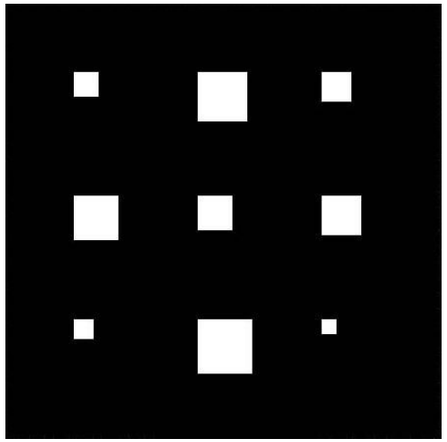




DSM



Classification Results without filter



Classification Results using filter

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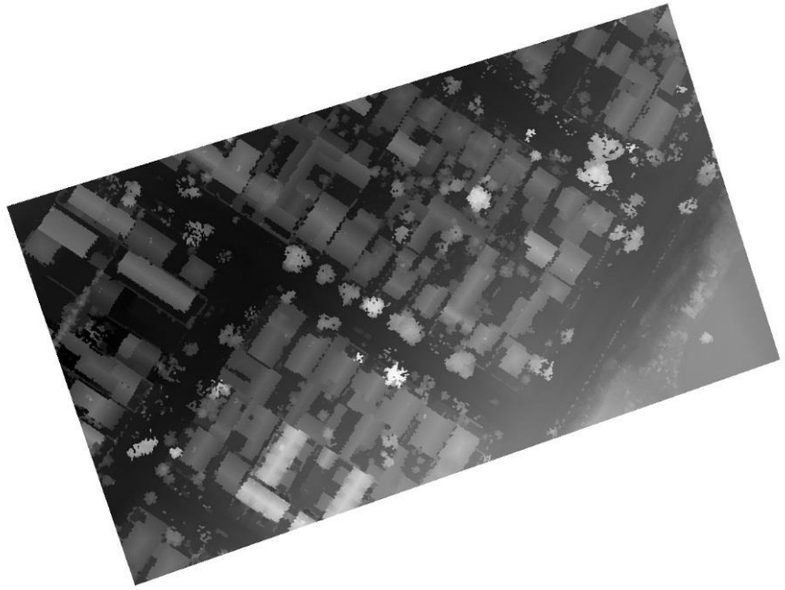
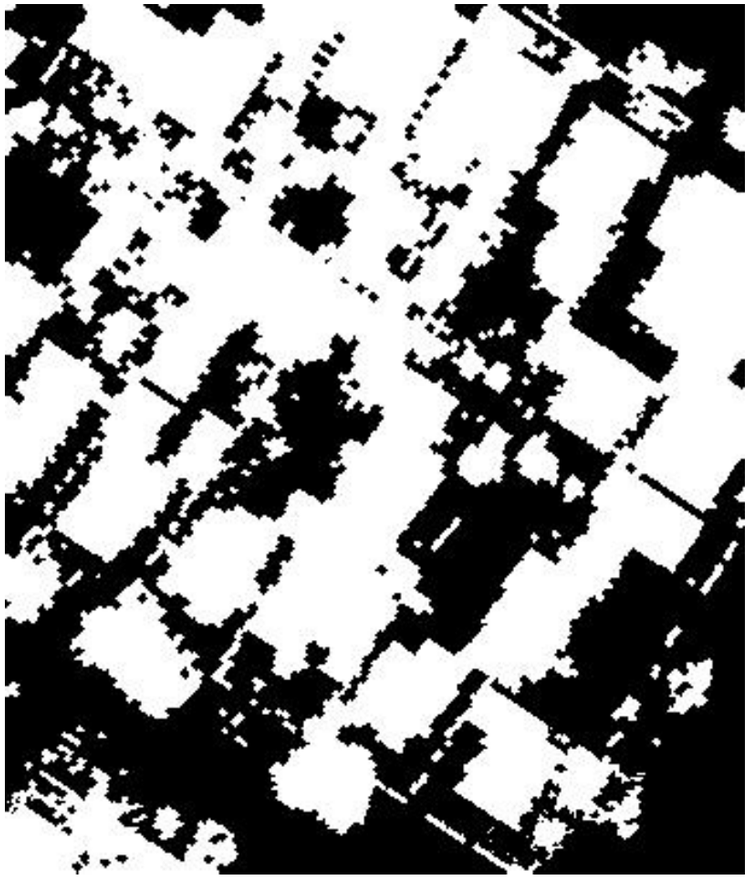
LiDAR Classification: Results (Real Data)



LiDAR Classification: Results (Real Data)

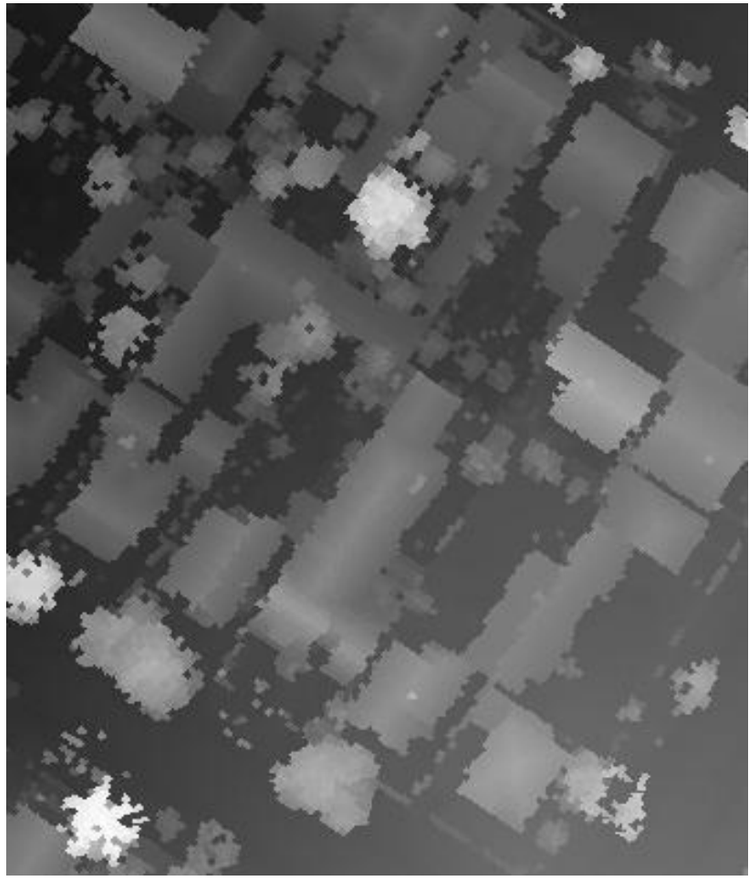
Occluding Points in White

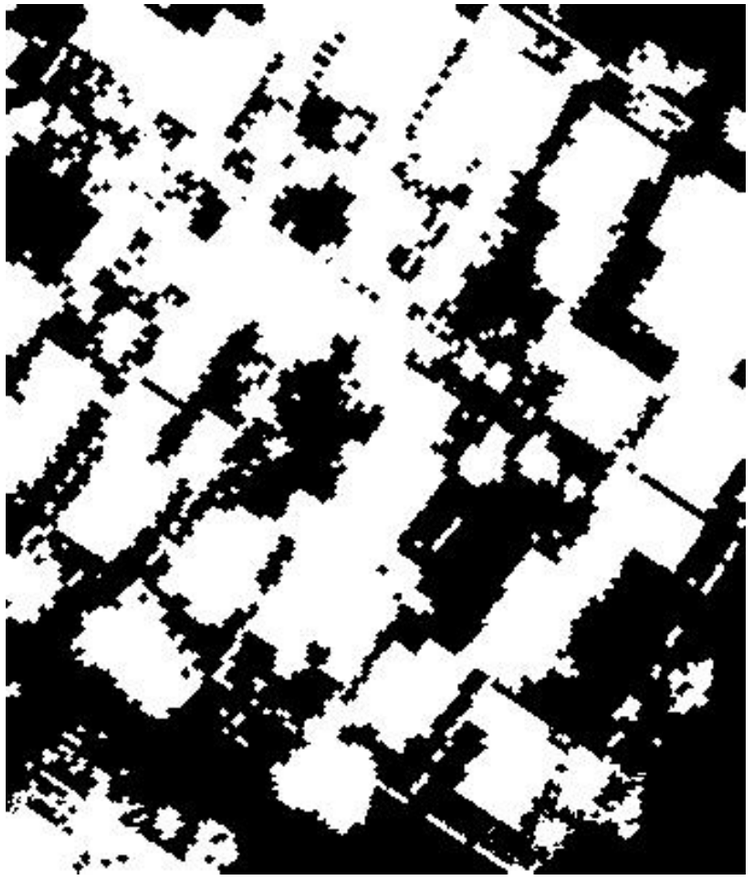
LiDAR Classification: Results (Real Data)



After Statistical Filtering

LiDAR Classification: Results (Real Data)

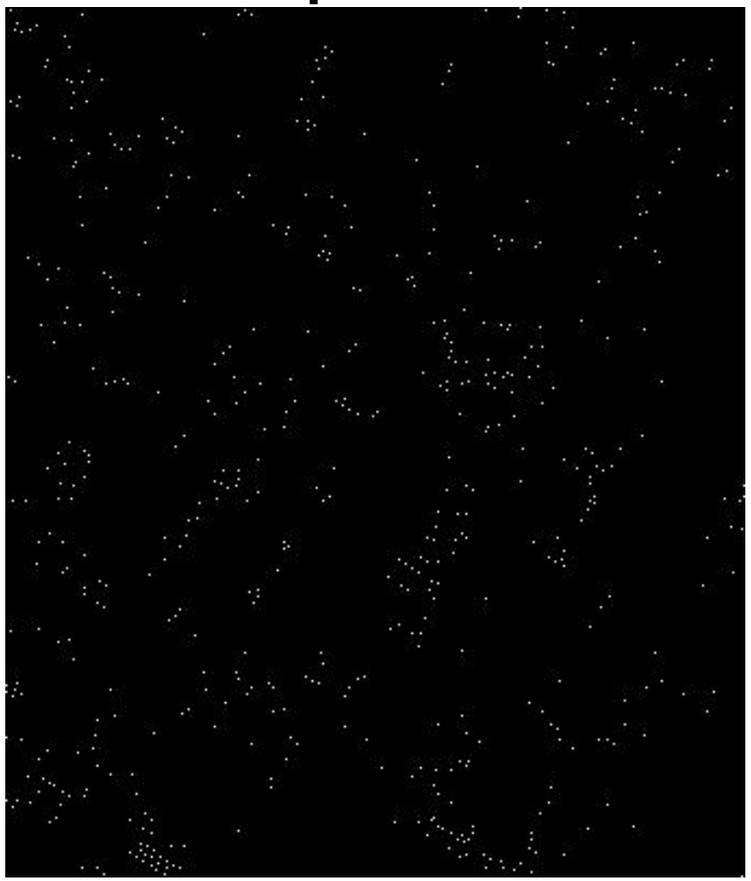




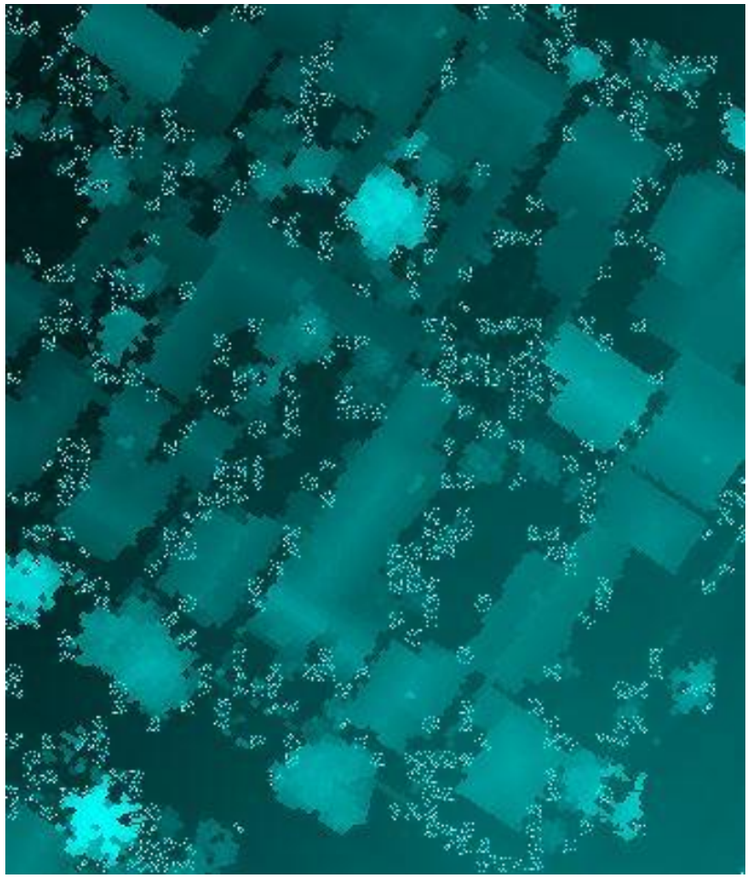
DSM → Non-ground Objects

LiDAR Classification: Results (Real Data)

- **Using the LiDAR DSM and an orthophoto over the same area, we manually generated a ground truth for ground and non-ground points classification.**
- **Comparing our result with the ground truth, the number of misclassified points divided by the total number of points was found to be 4.7%.**

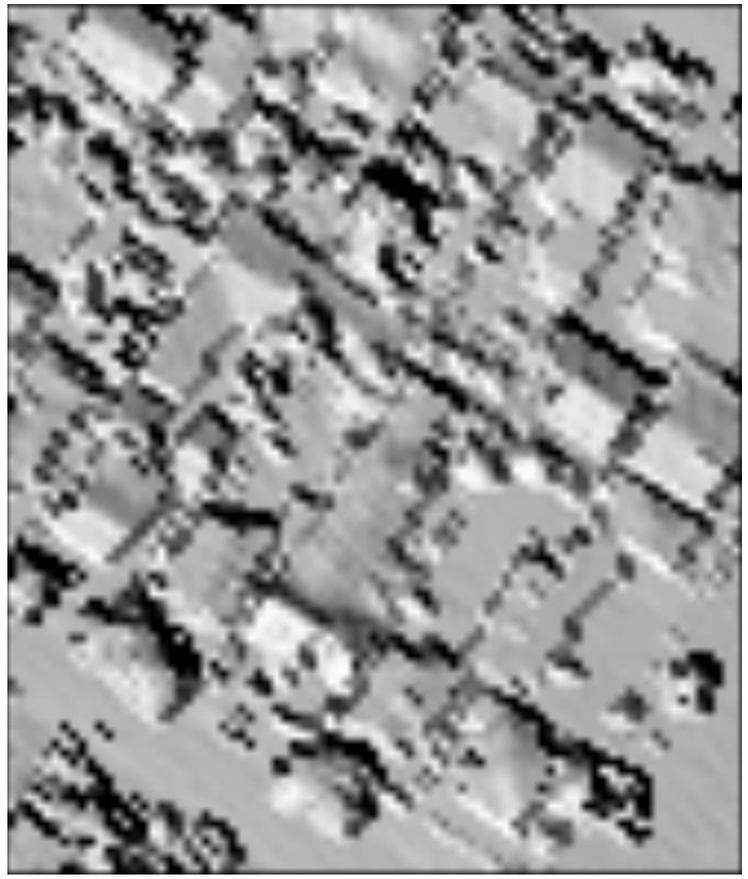


Misclassified Points

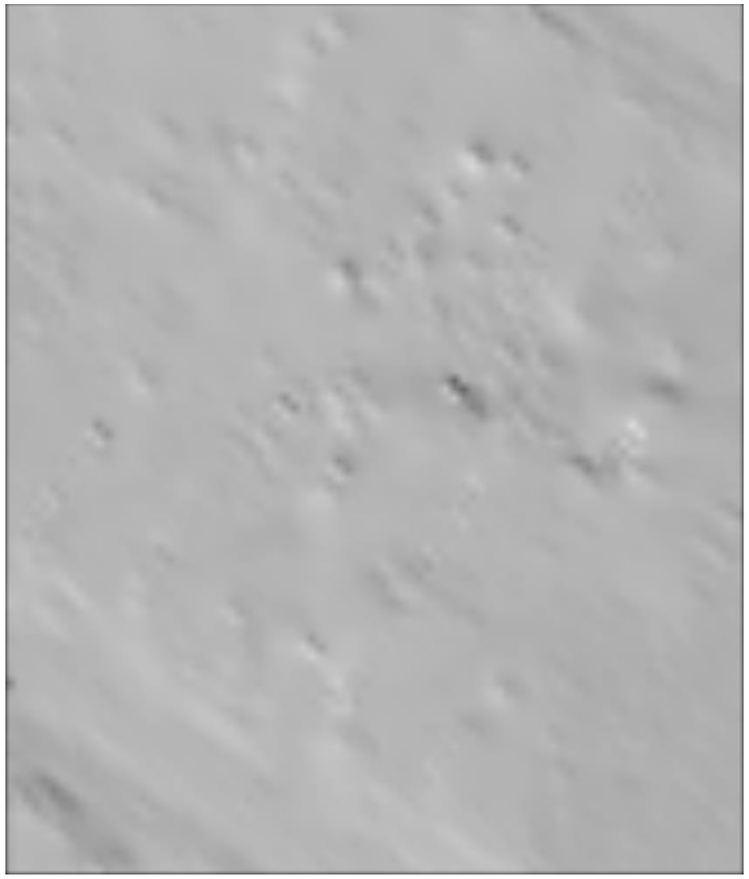


Misclassified Points displayed on DSM

LiDAR Classification: Results (Real Data)



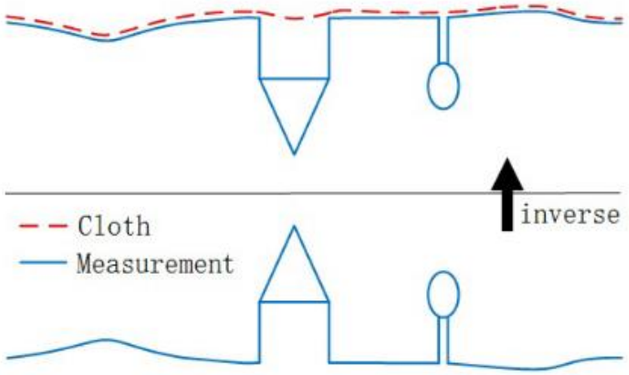
Original DSM

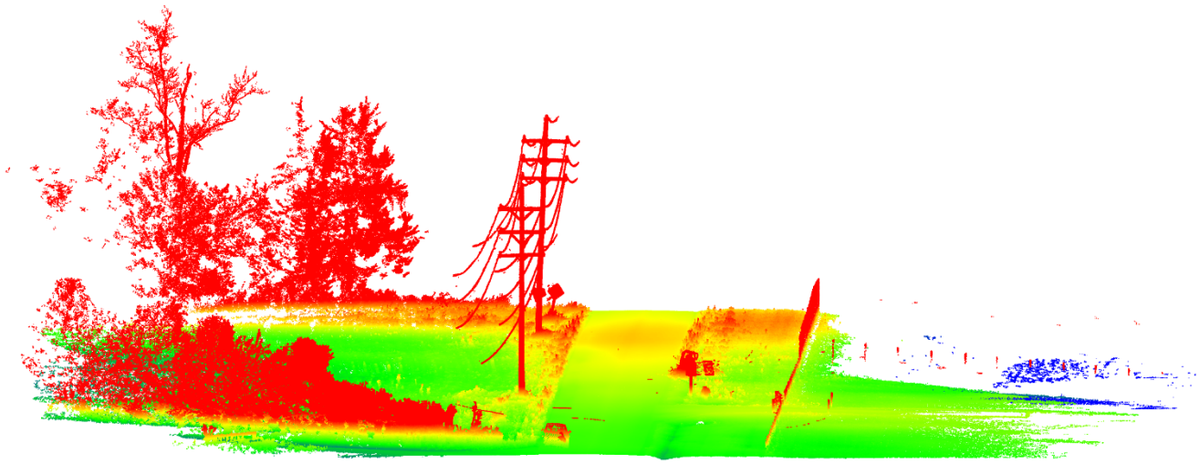


Derived DTM

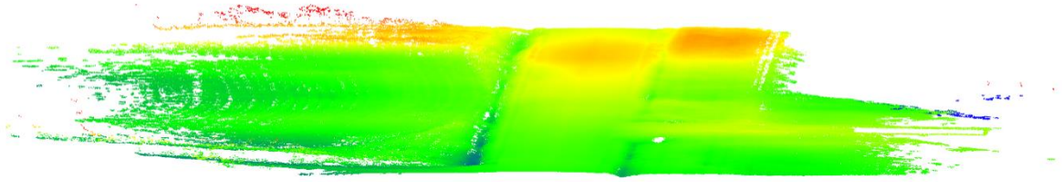
Cloth Simulation for DTM Generation

- **Objective: generate the digital terrain model (DTM) and extract the bare earth point cloud**
- **Method: modified based on DTM generation by cloth simulation (Zhang et al., 2016)**
  - Turn the point cloud upside down, and define a cloth with some rigidness
  - Place the cloth above the terrain, and let it drop under the influence of gravity
  - The final shape of the cloth is the DTM





Point cloud (colored by height)



Bare earth point cloud (colored by height)

Zhang, W., Qi, J., Wan, P., Wang, H., Xie, D., Wang, X., & Yan, G. (2016). An easy-to-use airborne LiDAR data filtering method based on cloth simulation. *Remote Sensing*, *8*(6), 501.

Cloth Simulation for DTM Generation

1. Turn the point cloud upside down
2. Define a cloth with some rigidness, and place it above the inverted point cloud
3. Let the cloth drop under the influence of gravity
4. The final shape of the cloth is the DTM
5. Use the cloth as a base to classify ground (bare earth) and non-ground points