Chapters 1 – 7: Overview

- Photogrammetric mapping: introduction, applications, and tools
- GNSS/INS-assisted photogrammetric and LiDAR mapping
- LiDAR mapping: principles, applications, mathematical model, and error sources and their impact.
- QA/QC of LiDAR mapping
- Registration of Laser scanning data
- Point cloud characterization, segmentation, and QC

- This chapter will be focusing on LiDAR-based orthophoto and Digital Terrain Model (DTM) generation.

Chapter 8

OCCLUSION-BASED PROCEDURE FOR TRUE ORTHOPHOTO GENERATION AND LIDAR DATA CLASSIFICATION

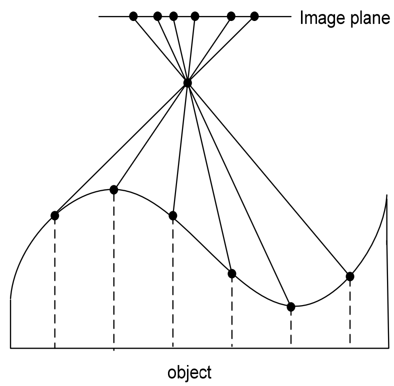
Overview

- Introduction
- Orthophoto generation
  - Literature review
  - Procedure
- LiDAR data classification
  - Literature review
  - Procedure
  - Experimental results
- Concluding remarks

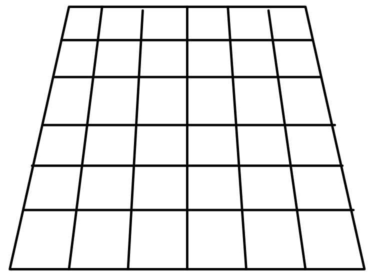
True Orthophoto Generation

Image and Map characteristics

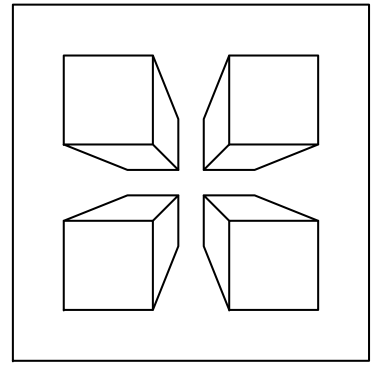
Image



Perspective projection

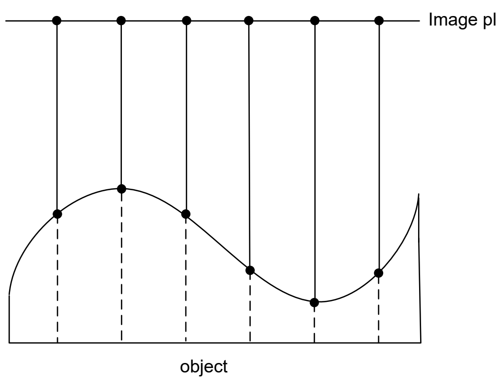


Non-uniform scale

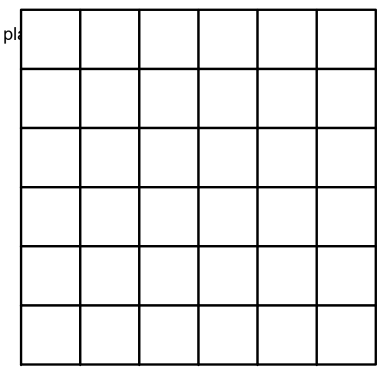


Relief displacement

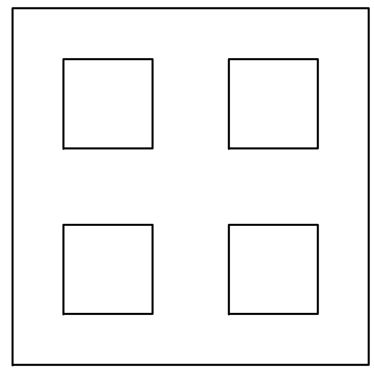
map



Orthogonal projection



Uniform scale

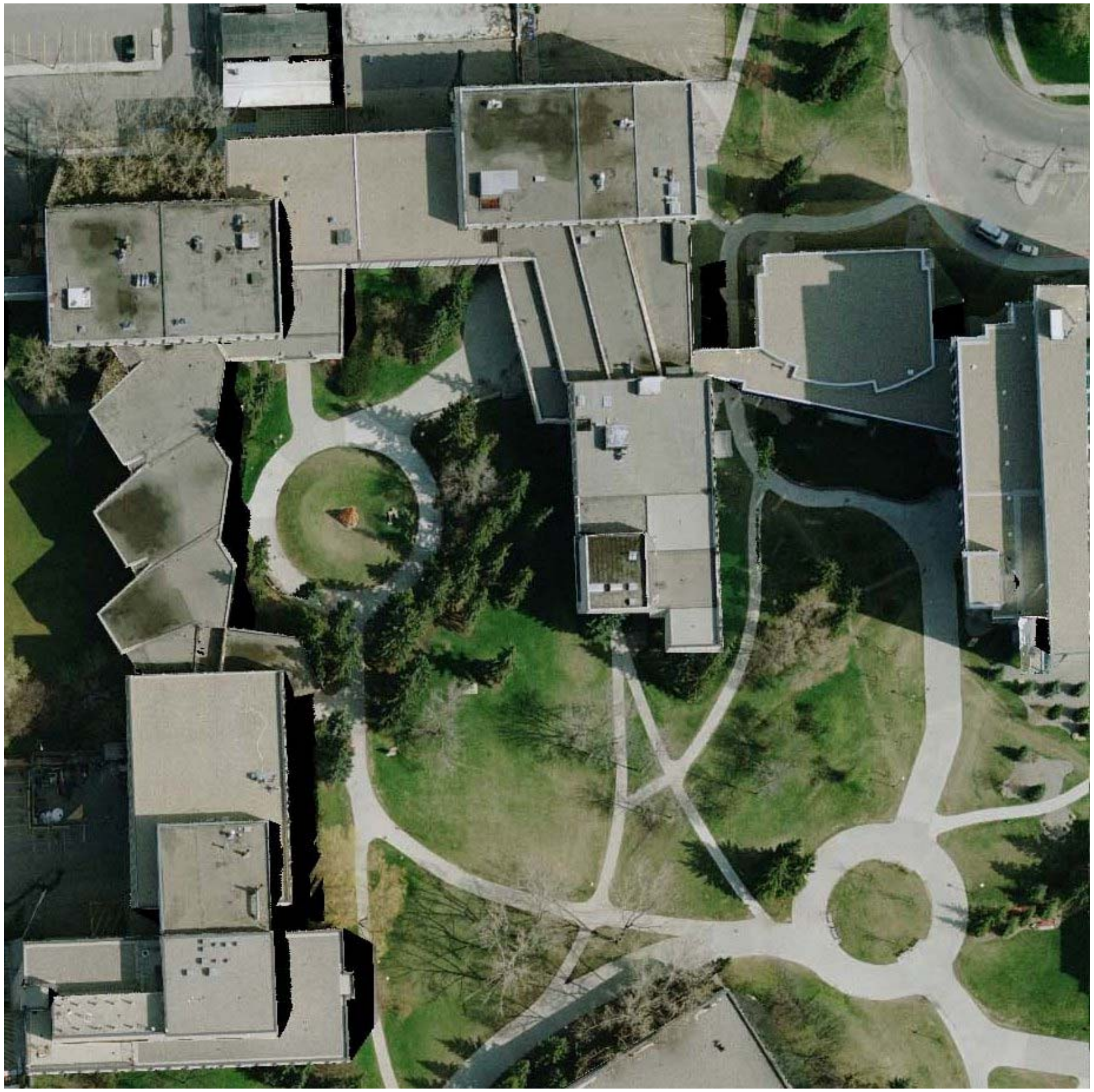


No relief displacement

An orthophoto is a digital image which has the same characteristics of a map.

Perspective Image

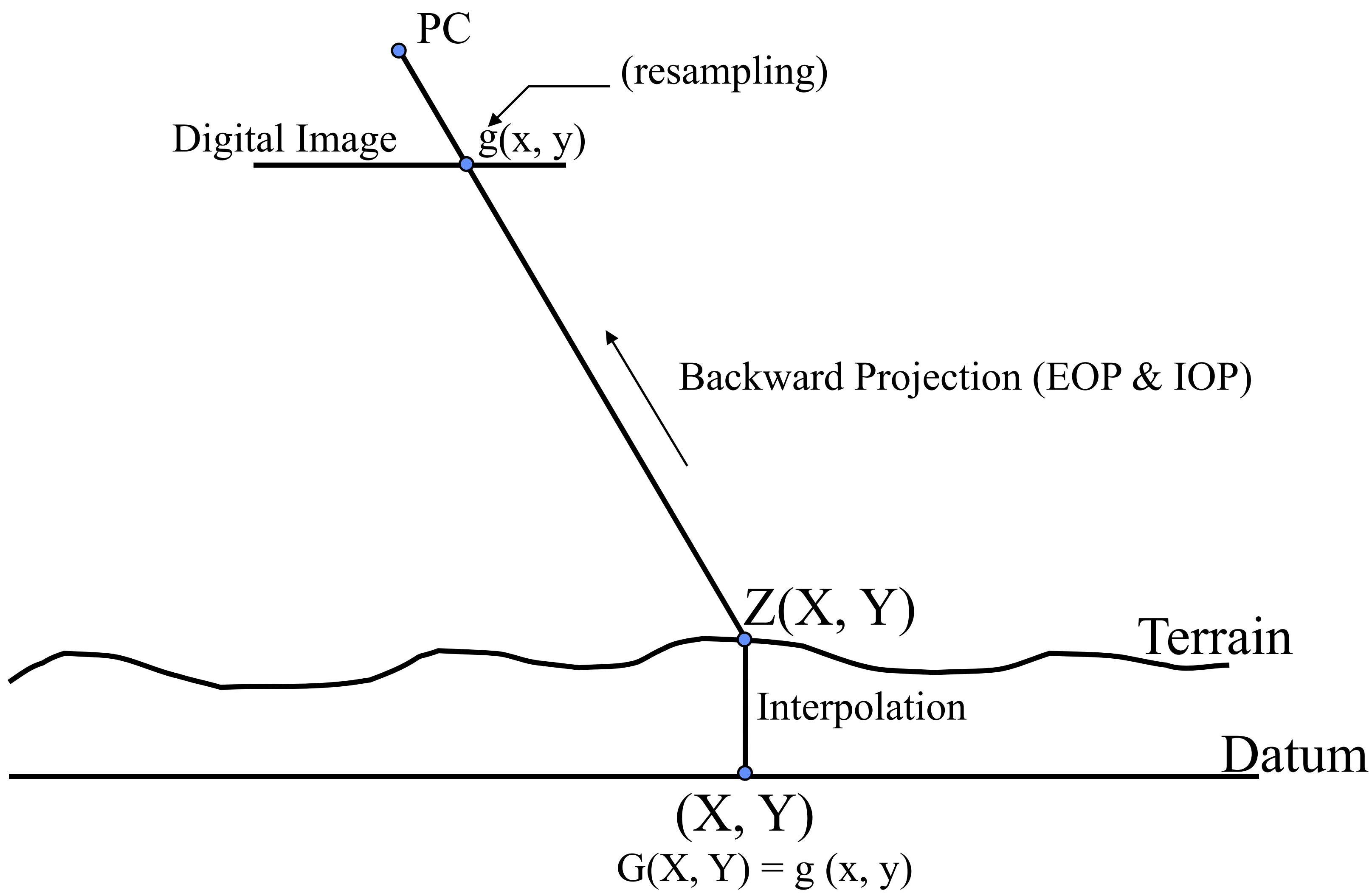
Orthophoto



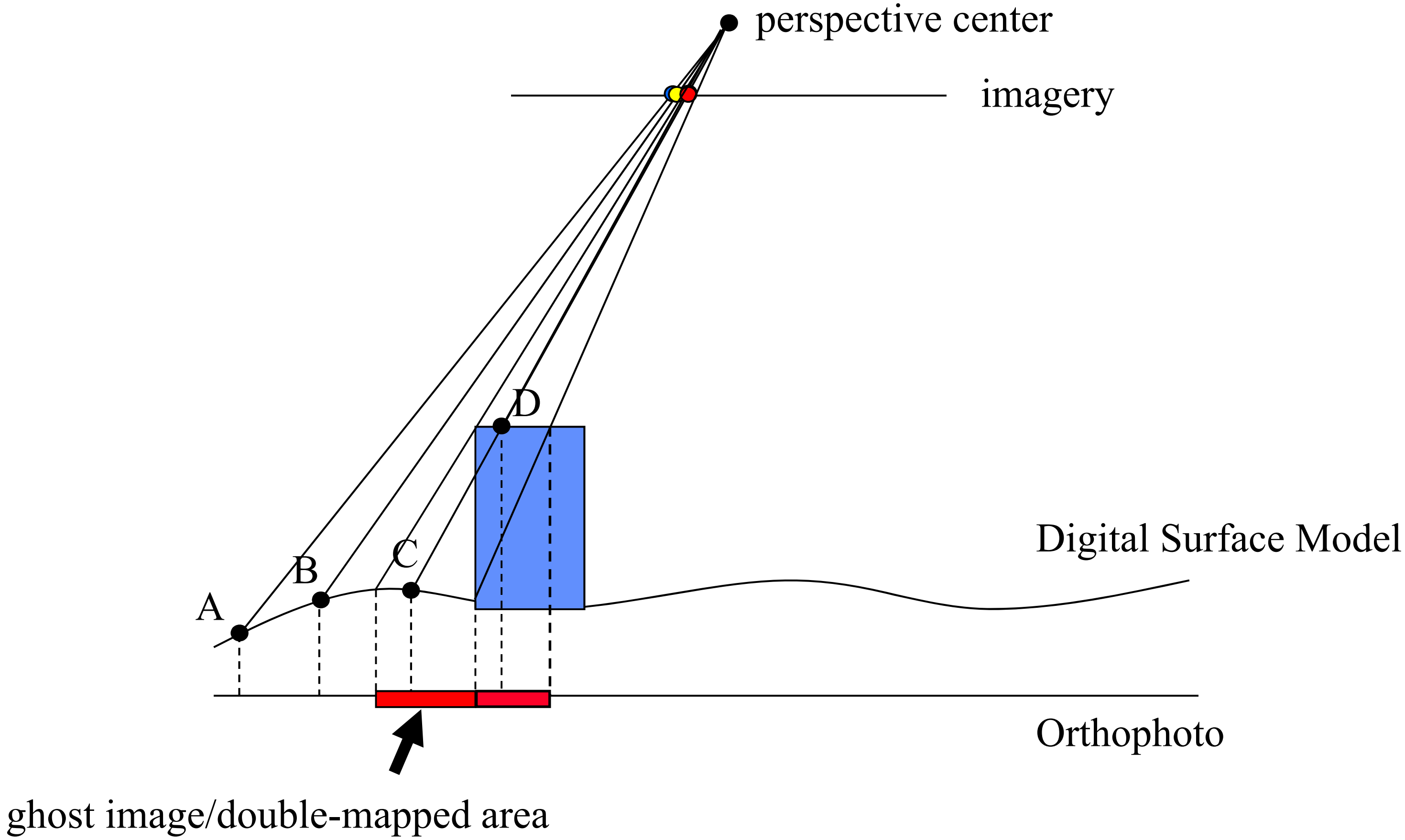
Orthophoto Generation: Prerequisites

- Digital image:
  - Wide range of operational photogrammetric systems
- Interior Orientation Parameters (IOPs) of the used camera:
  - Camera calibration procedure
- Exterior Orientation Parameters (EOPs) of that image:
  - Image georeferencing techniques
- Digital Surface Model (DSM) or Digital Terrain Model (DTM)
  - LiDAR, imagery, Radar, …

Differential Orthophoto Generation

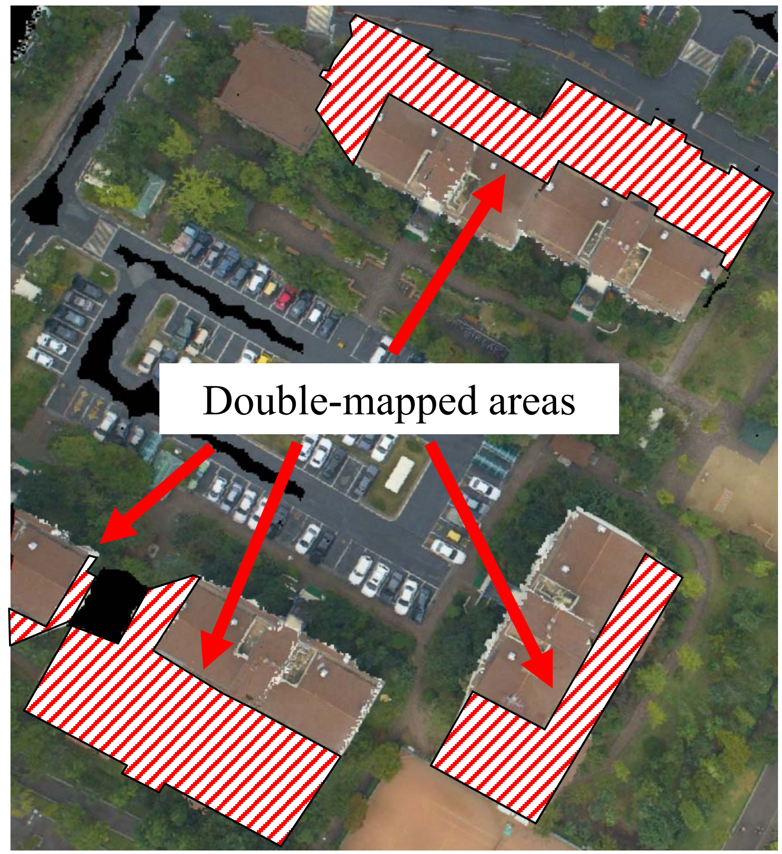


Differential Orthophoto Generation



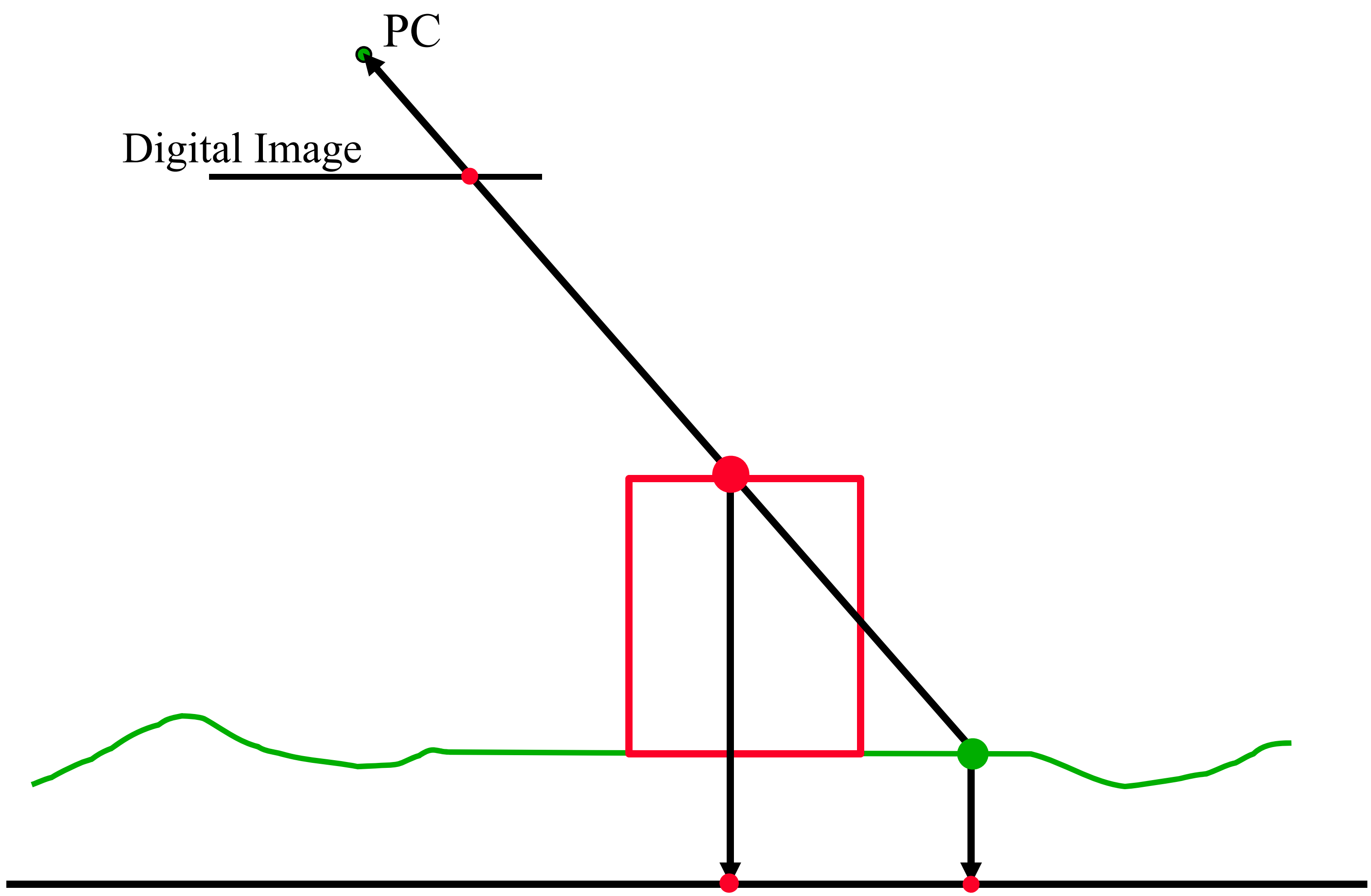
Differential Orthophoto Generation

Original Imagery



Generated Orthophoto

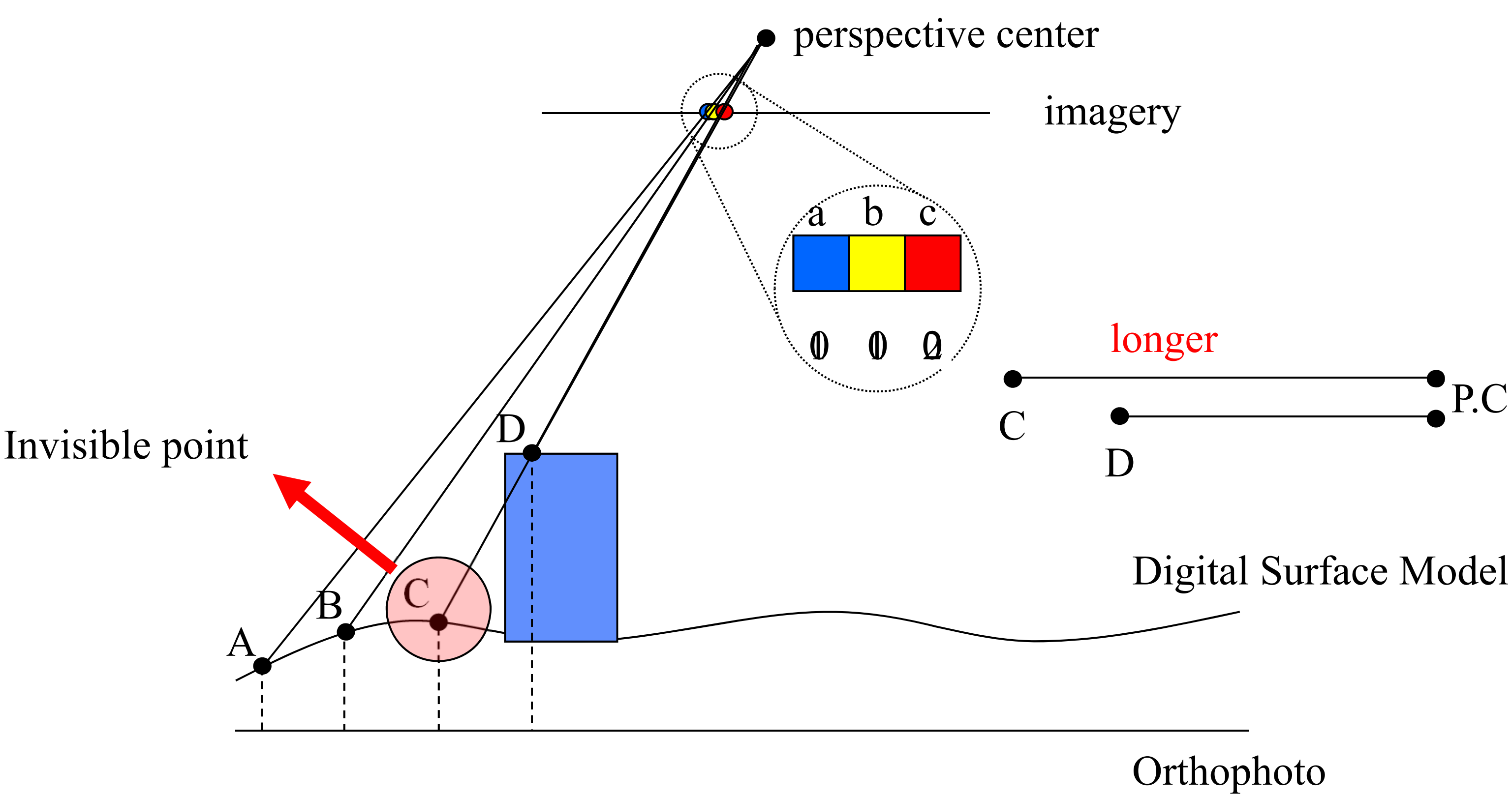
Orthophoto Generation & Visibility Analysis



Indirect (backward) transformation

True Orthophoto Process – Existing Method

Z-Buffer Method



True Orthophoto Process – Existing Method

Z-Buffer Method

Original Imagery

Generated True Orthophoto

True Orthophoto Process – Existing Method

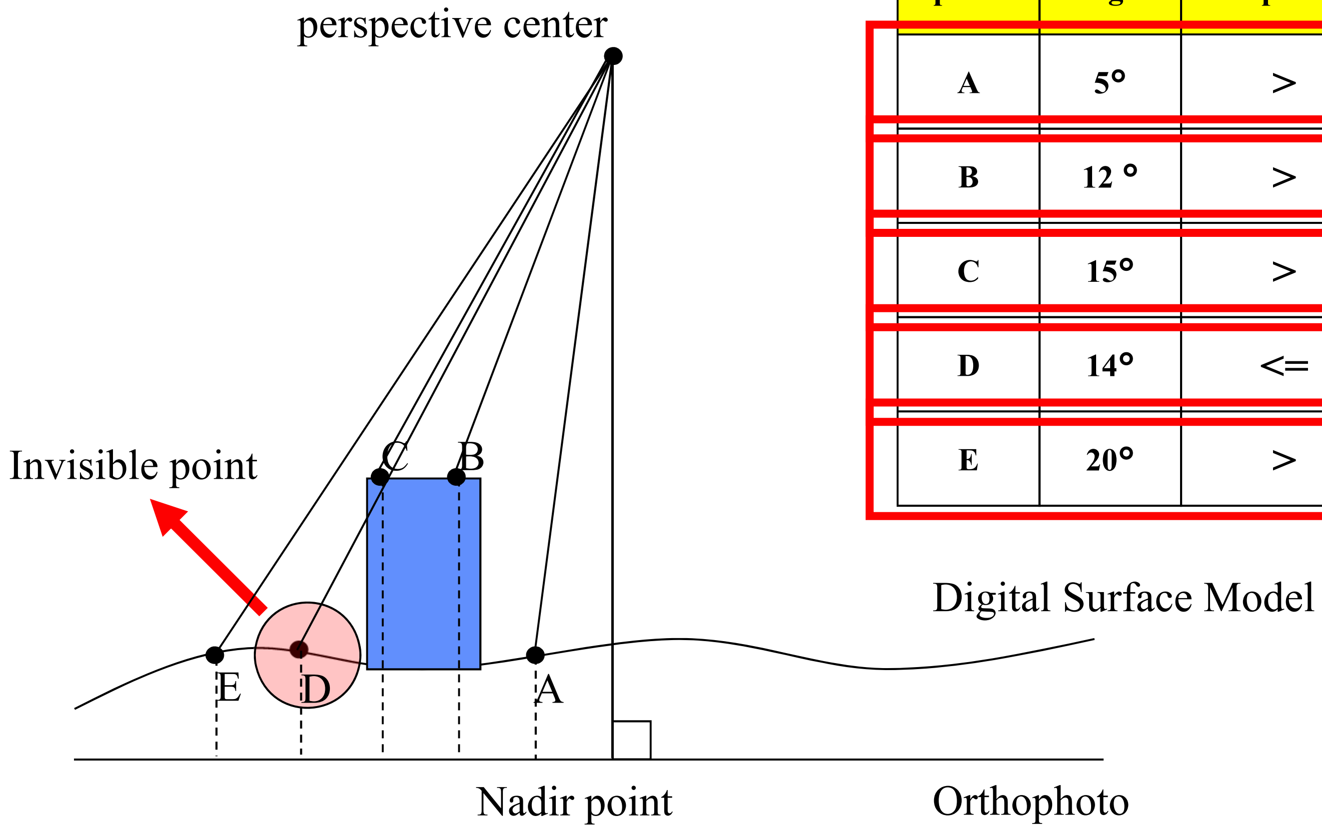
Z-Buffer Method

Generated True Orthophoto

True Orthophoto Generation

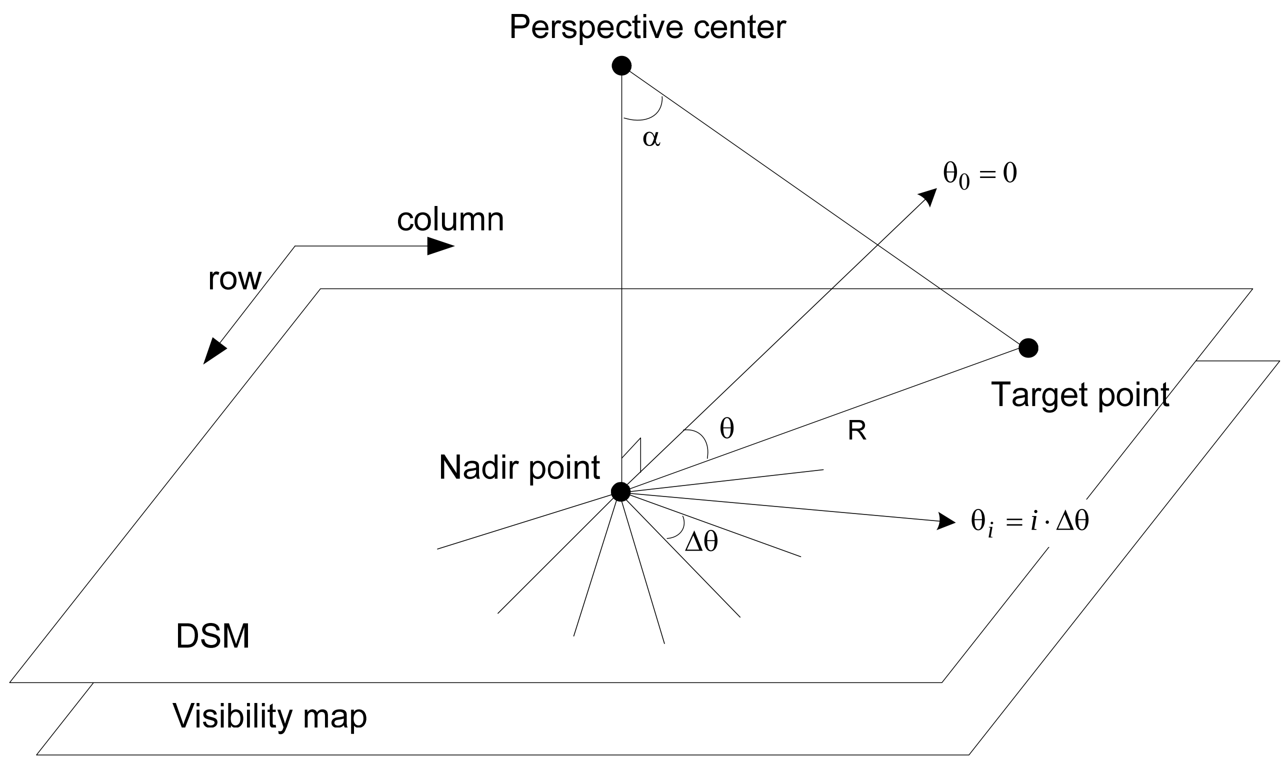
Angle-based Method

point	angle	comparison	max angle	visible / hidden
A	5°	>	0°	visible
B	12 °	>	5 °	visible
C	15°	>	12°	visible
D	14°	<=	15°	invisible
E	20°	>	15°	visible



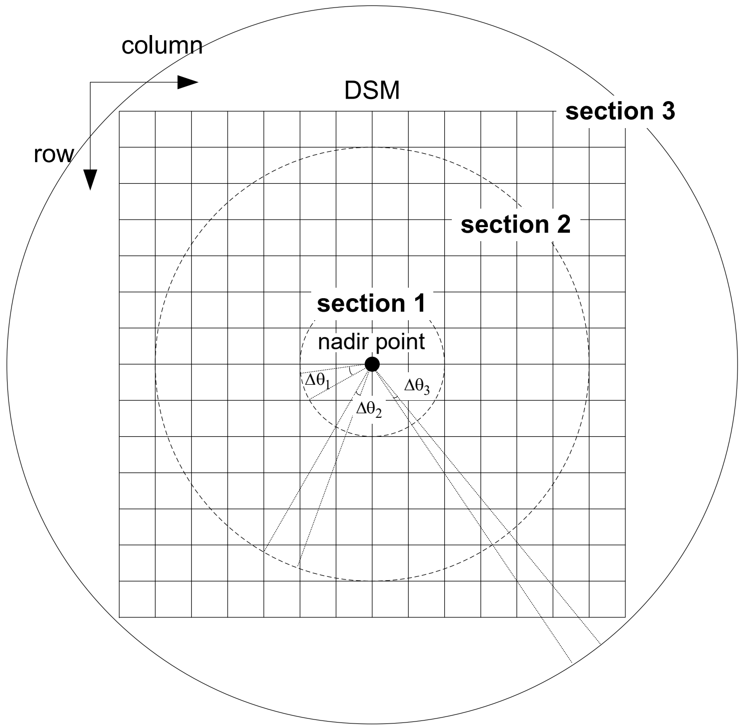
True Orthophoto Generation

Angle-based Method



Radial Sweep for the Angle-Based Method

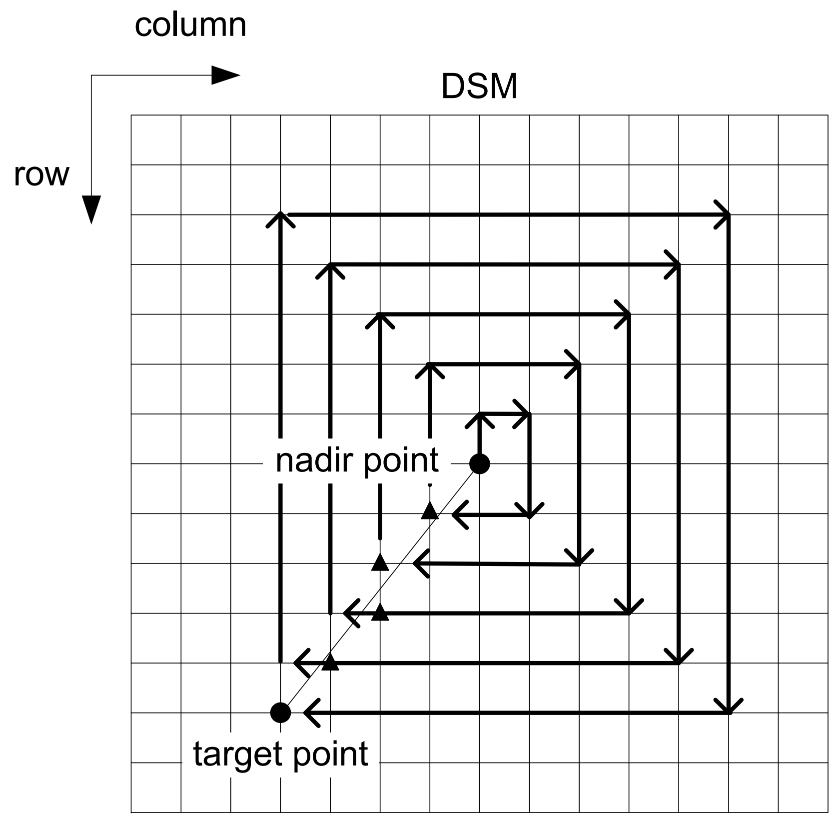
True Orthophoto Gen.: Adaptive Radial Sweep



$$\Delta\theta_1 \rangle \Delta\theta_2 \rangle \Delta\theta_3$$

DSM partitioning for the adaptive radial sweep method

True Orthophoto Gen.: Spiral Sweep



Conceptual procedural flow of the spiral sweep method

Comparative Analysis

Differential rectification

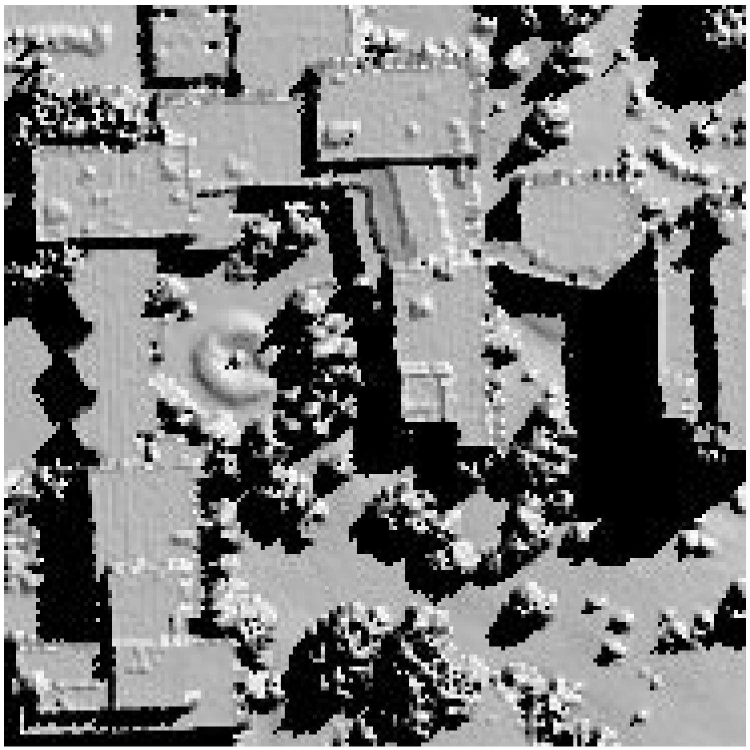
Z-buffer method

Angle-based (adaptive radial sweep) method

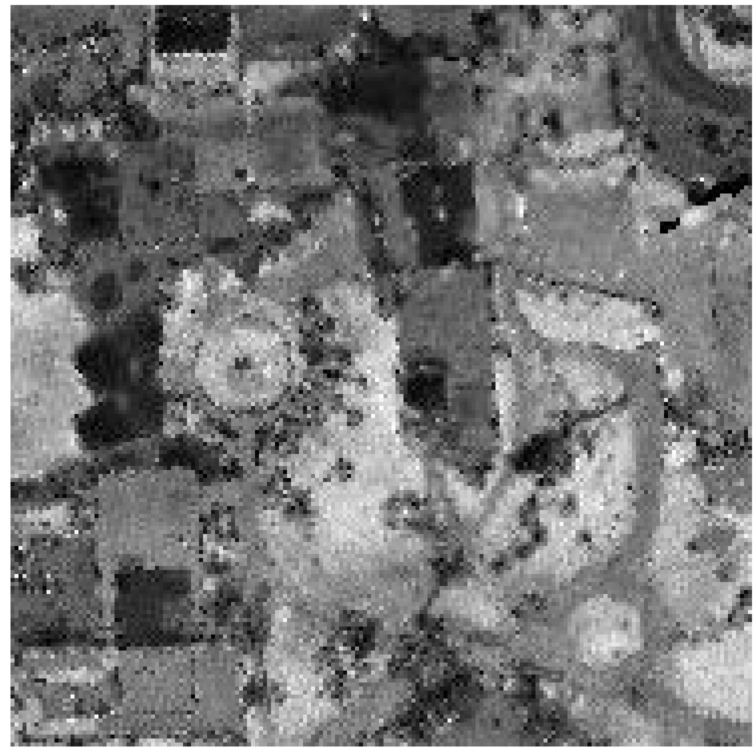
Angle-based (spiral sweep) method

Original Image

LiDAR Surface Model

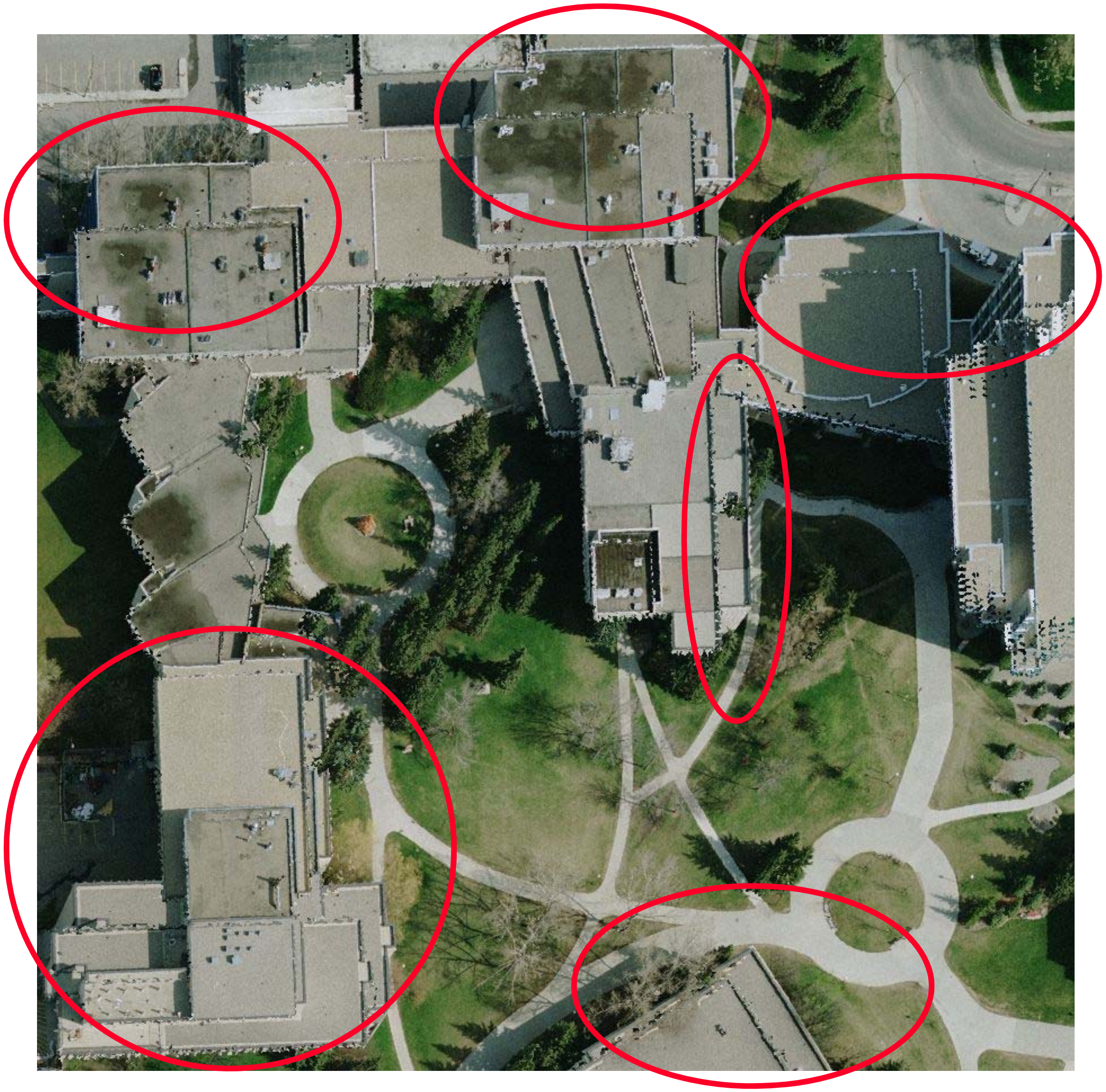


Elevation Data

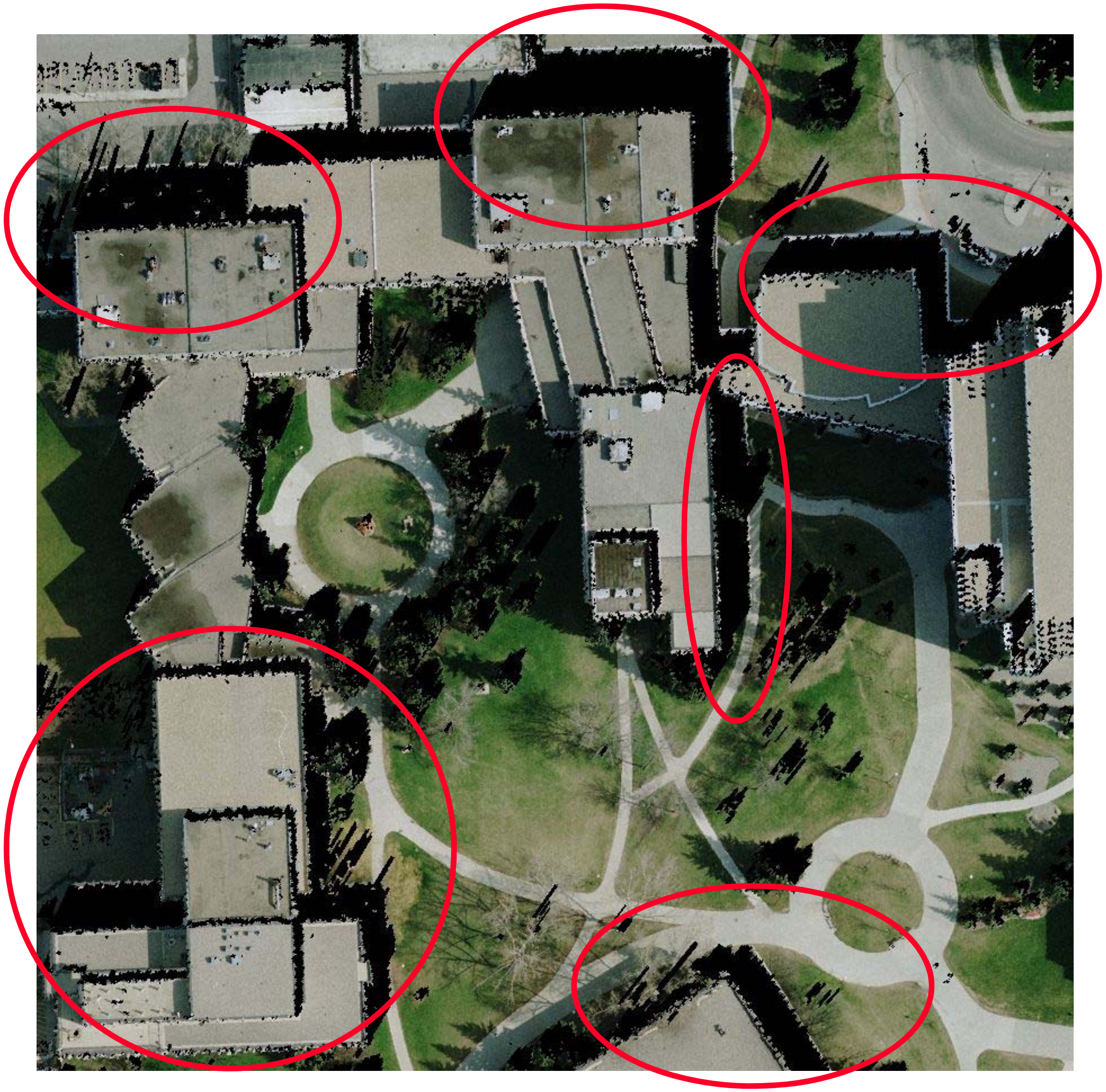


Intensity Data

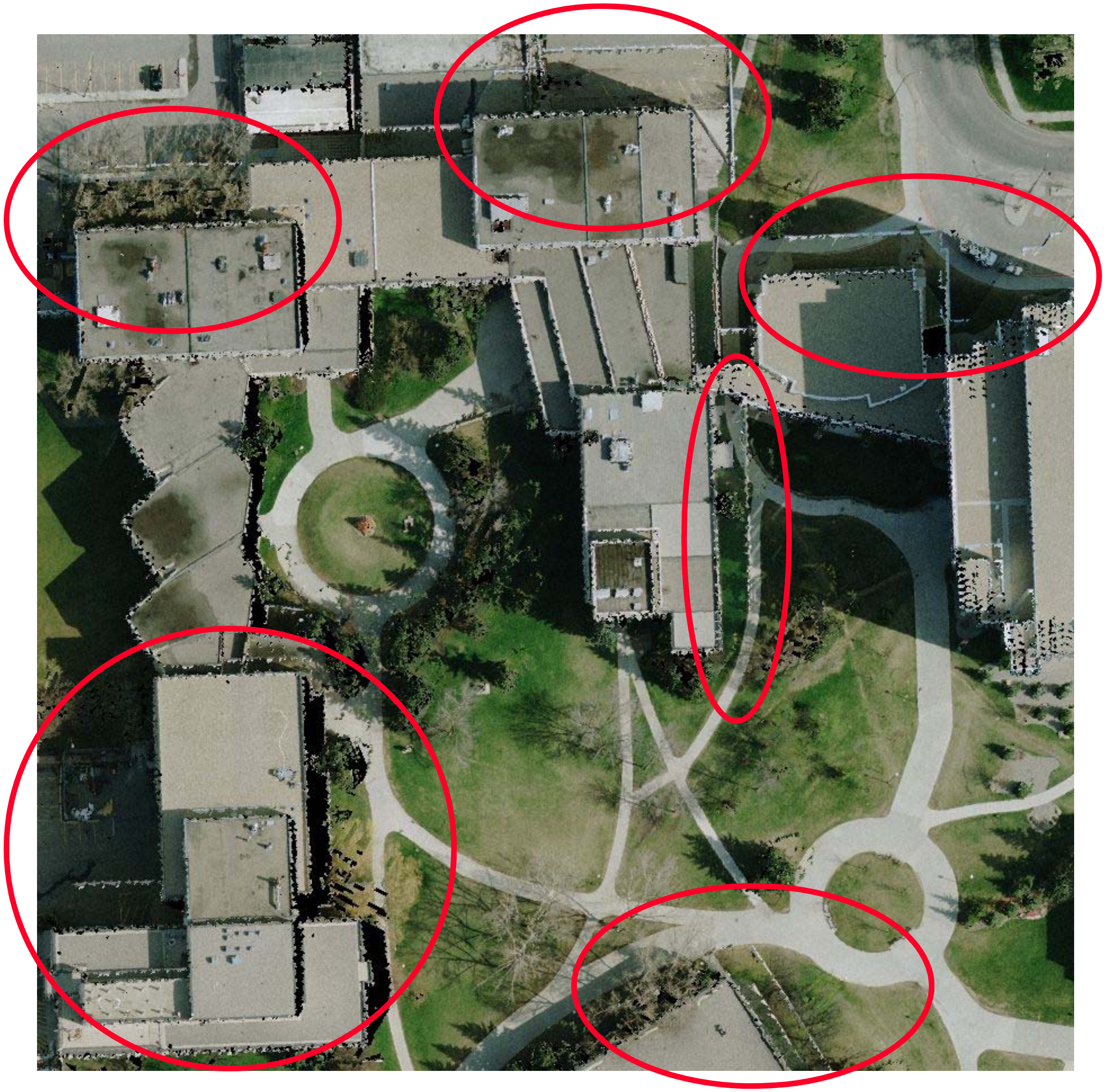
Orthophoto with Ghost Images



True Orthophoto without Ghost Images

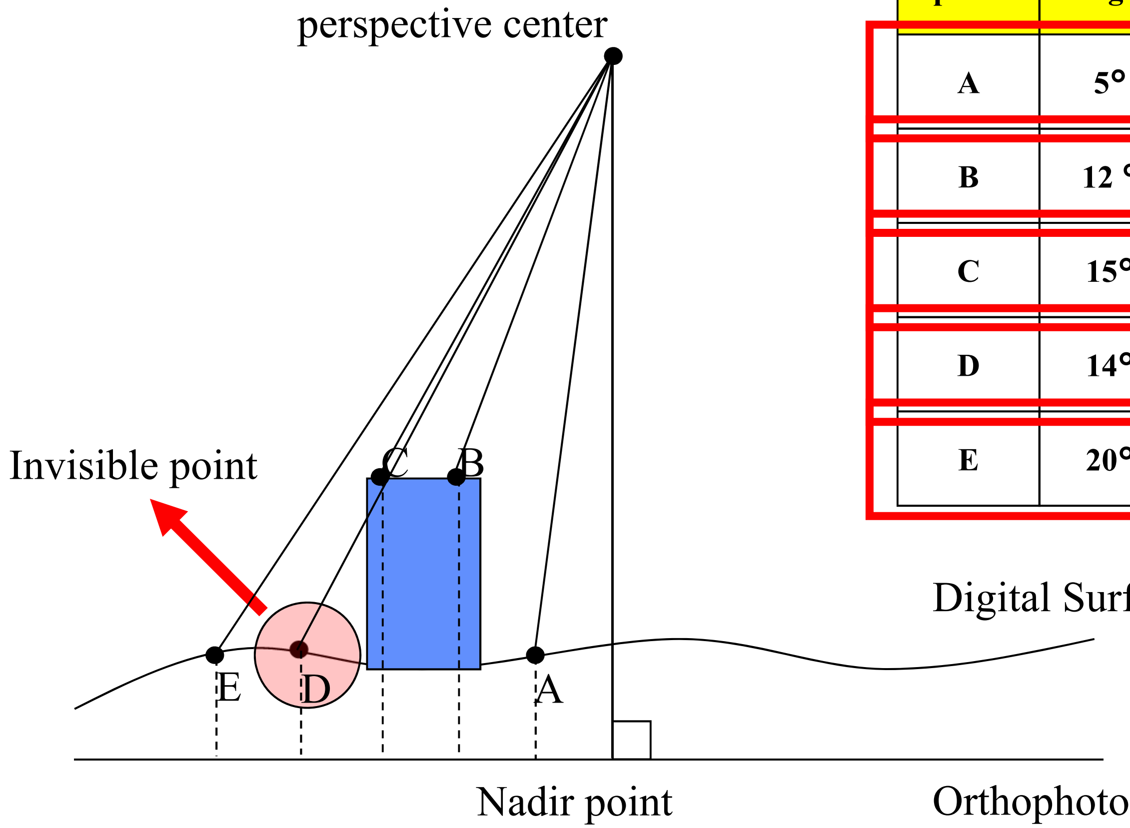


True Orthophoto After Occlusion Filling



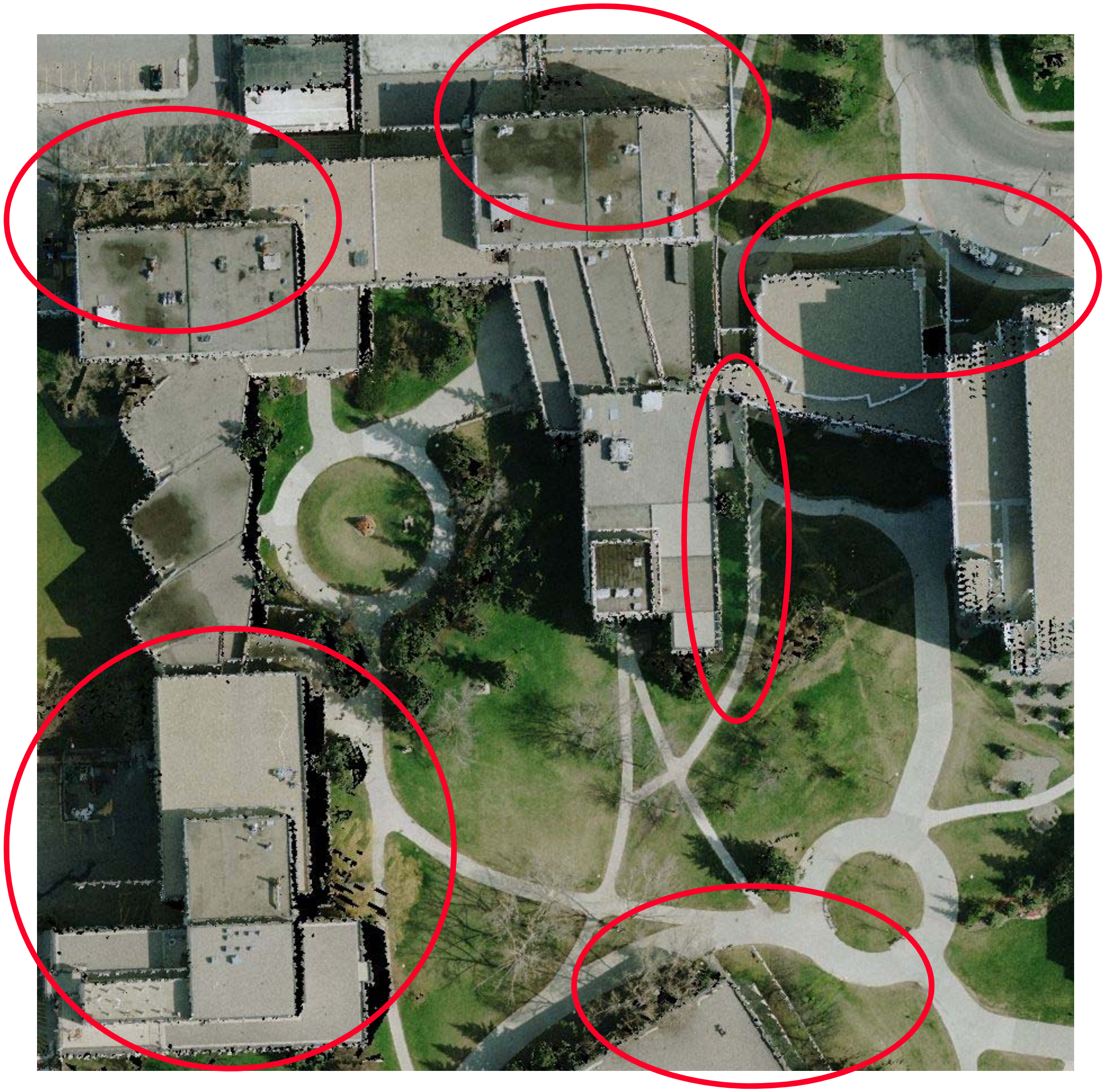
Occlusion Extension

Angle-based Method

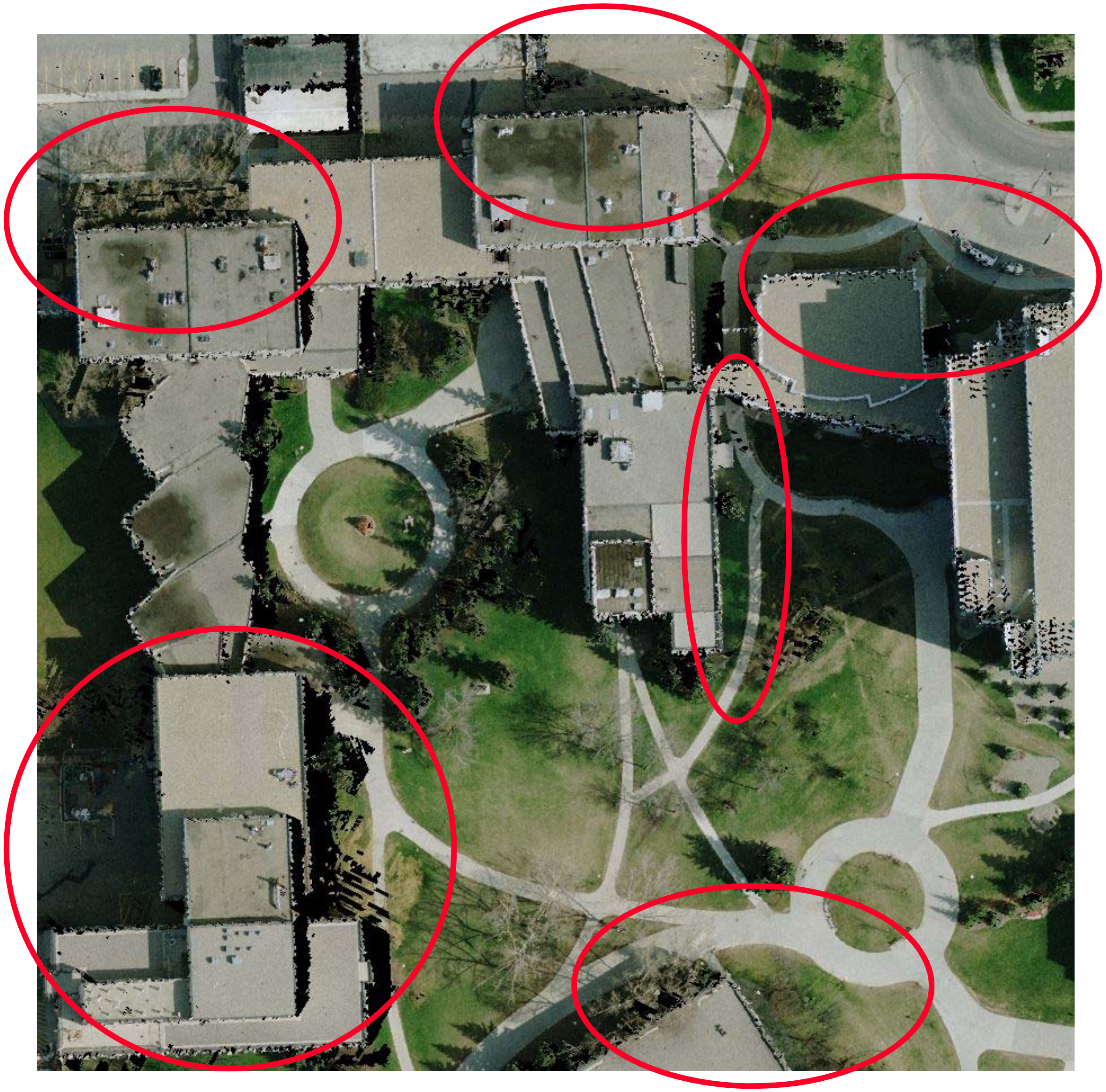


point	angle	comparison	max angle	visible / hidden
A	5°	>	0°	visible
B	12 °	>	5 °	visible
C	15°	>	12°	visible
D	14°	<=	15°	invisible
E	20°	>	16°	visible

True Orthophoto After Occlusion Filling



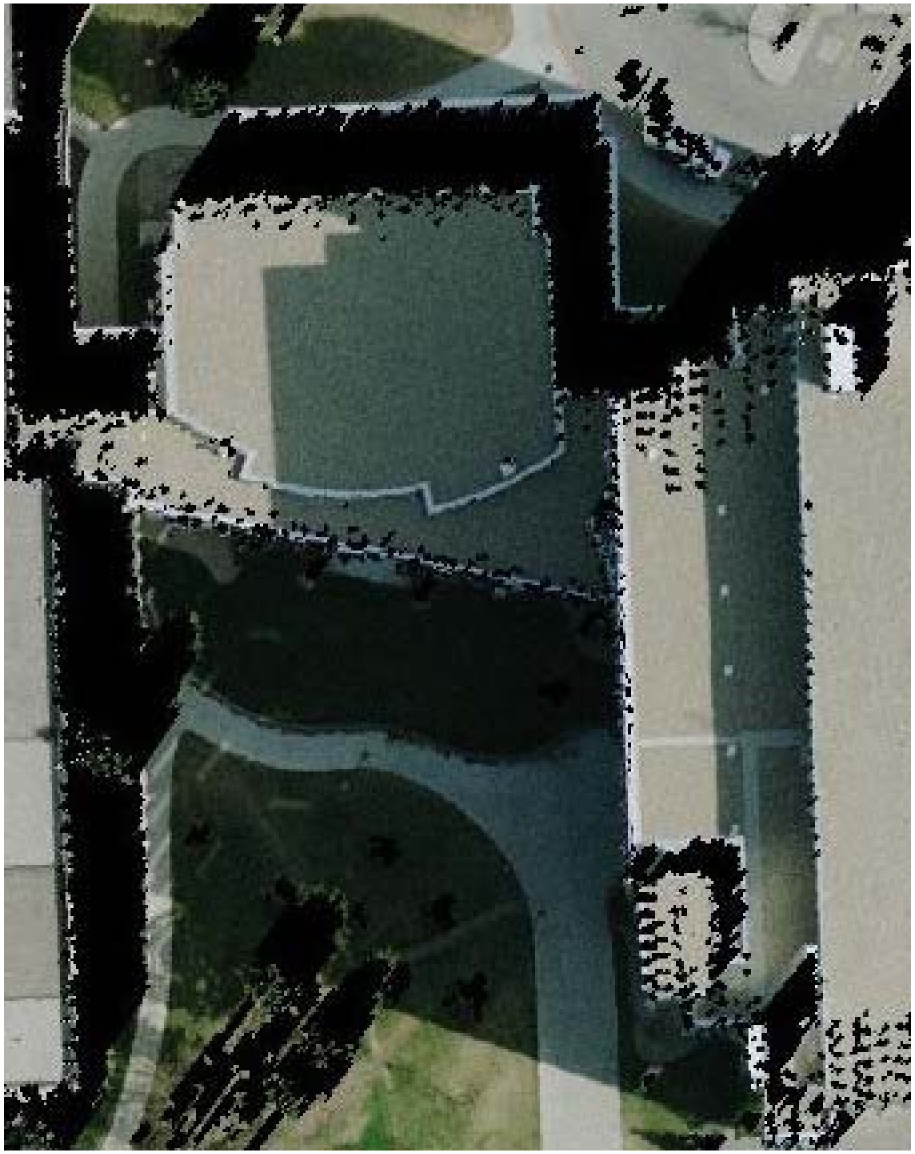
True Orthophoto After Occlusion Extension



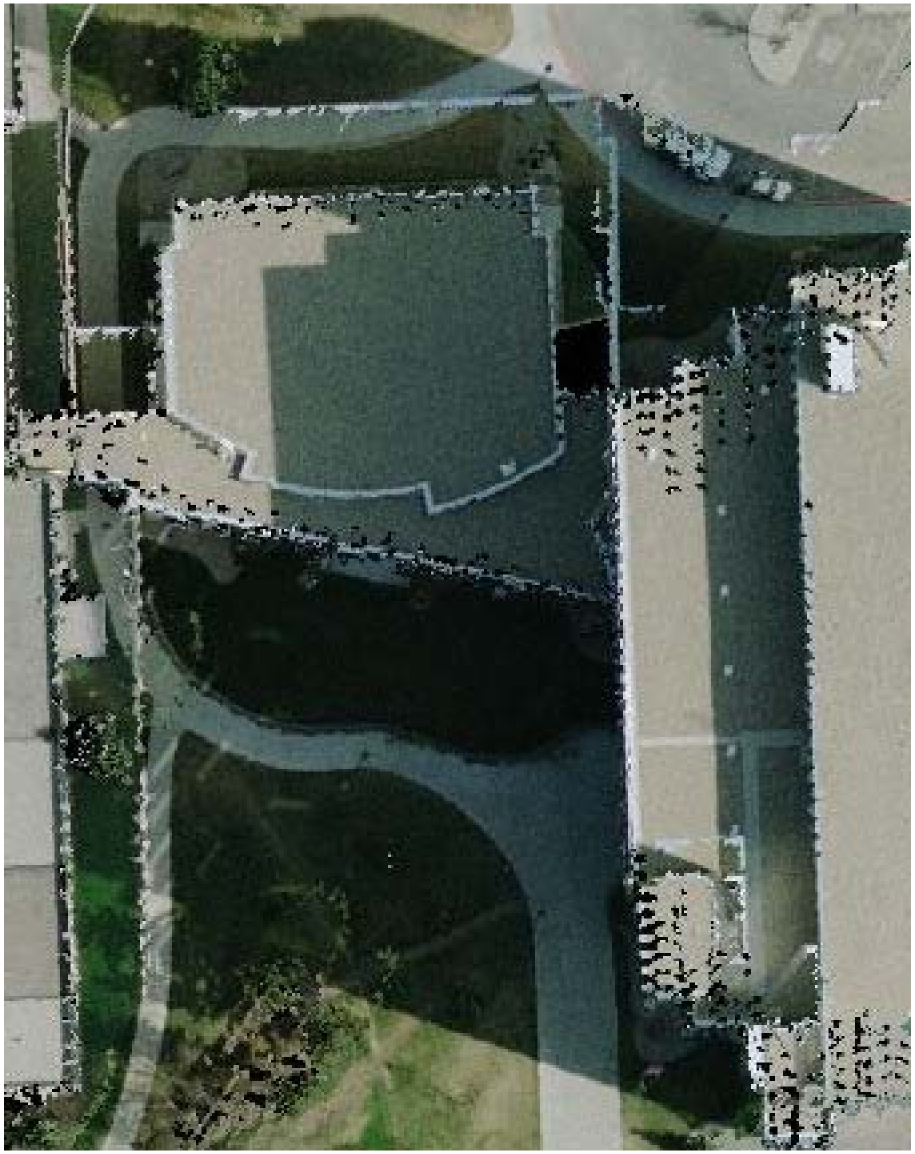
True Orthophoto After Boundary Enhancement

Orthophoto with Ghost Images

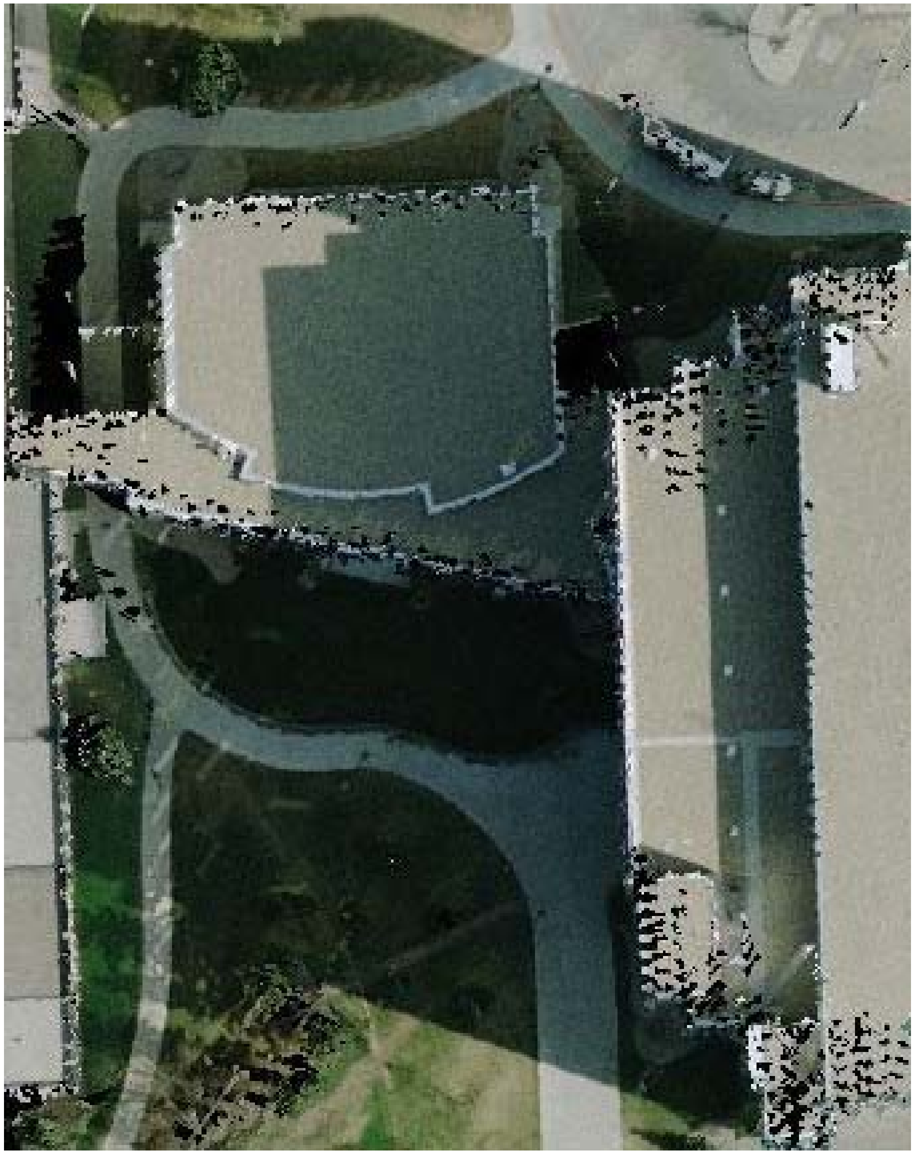
True Orthophoto without Ghost Images



True Orthophoto After Occlusion Filling



True Orthophoto After Occlusion Extension



True Orthophoto After Boundary Enhancement

Classification of LiDAR Data (Ground/Non-Ground Points)

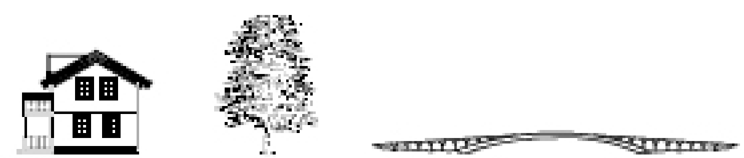
LiDAR Classification: Introduction

- 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.

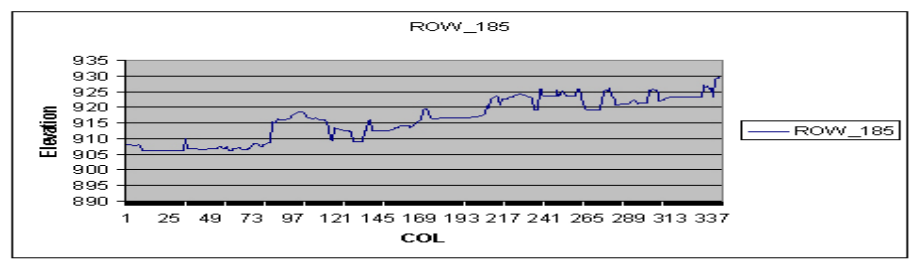
LiDAR Classification: Introduction

- 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



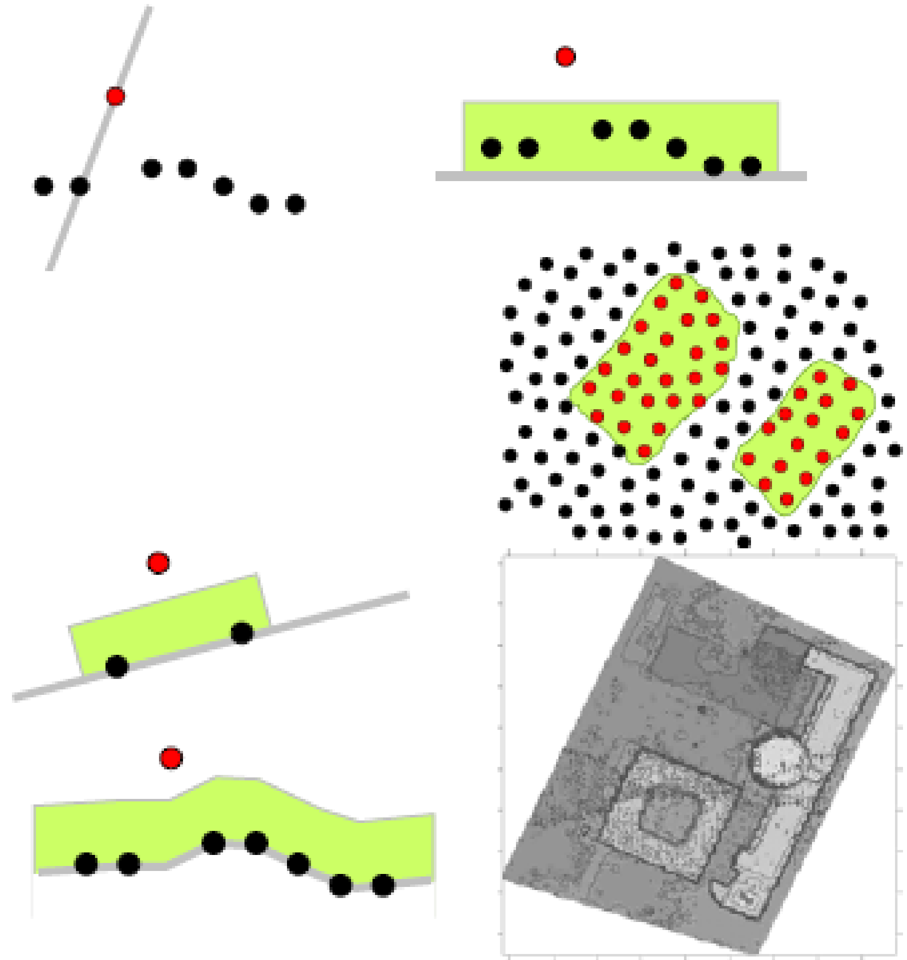
Non-Ground Profile



LiDAR Profile

LiDAR Classification: Literature

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



LiDAR Classification: Literature Review

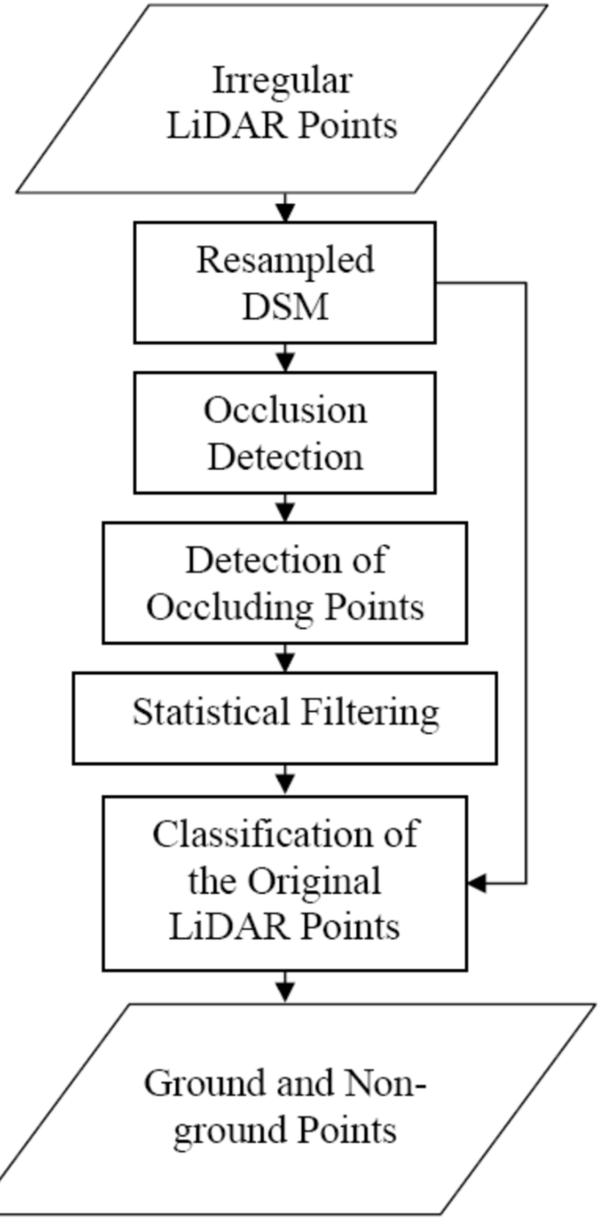
- Modified Block Minimum (Wack and Wimmer, 2002)
- Modified Slope-based Filter (Vosselman, 2000)
- Morphological Filter (Zhang et al., 2003)
- Active Contour (Elmqvist et al., 2001)
- Progressive TIN Densification (Axelsson, 2000)
- Robust Interpolation (Pfeifer et al., 2001)
- Spline Interpolation (Brovelli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

LiDAR Classification: Concept

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

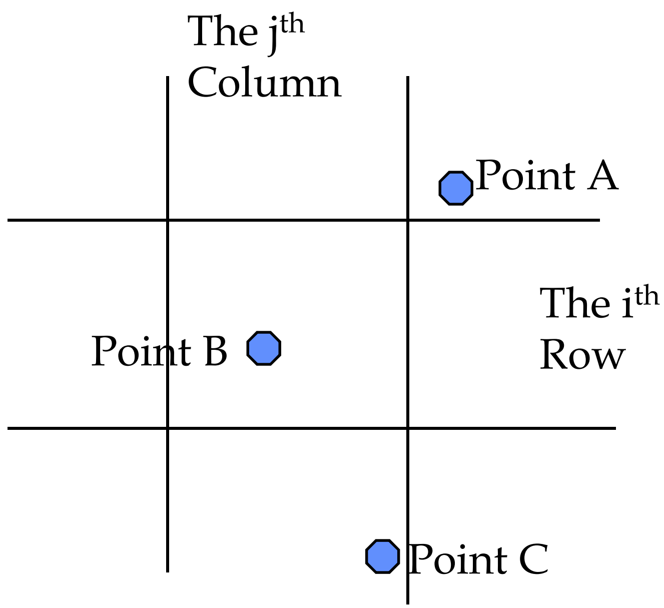
Perspective Projection

LiDAR Classification: Processing Flow



LiDAR Classification: Methodology

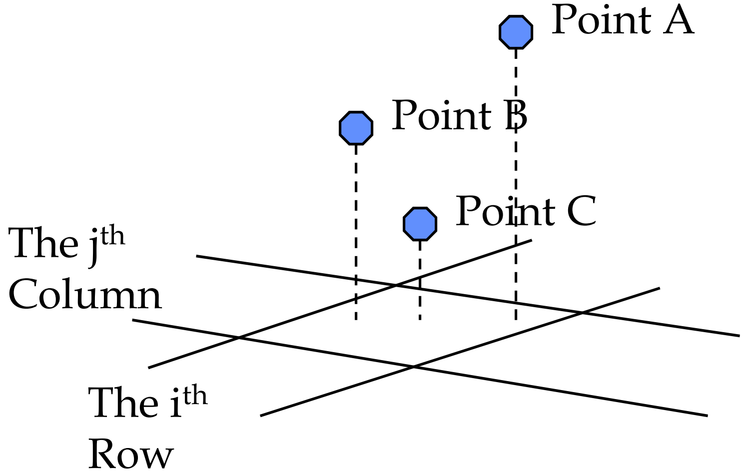
- LiDAR data is irregularly distributed.
- We start by interpolating the LiDAR data.
  - The average point density is used to estimate the optimum GSD for resampling.
  - We use the **nearest neighbor interpolation** to avoid blurring the height discontinuities.



DSM(i , j) = Height of Point B

LiDAR Classification: Methodology

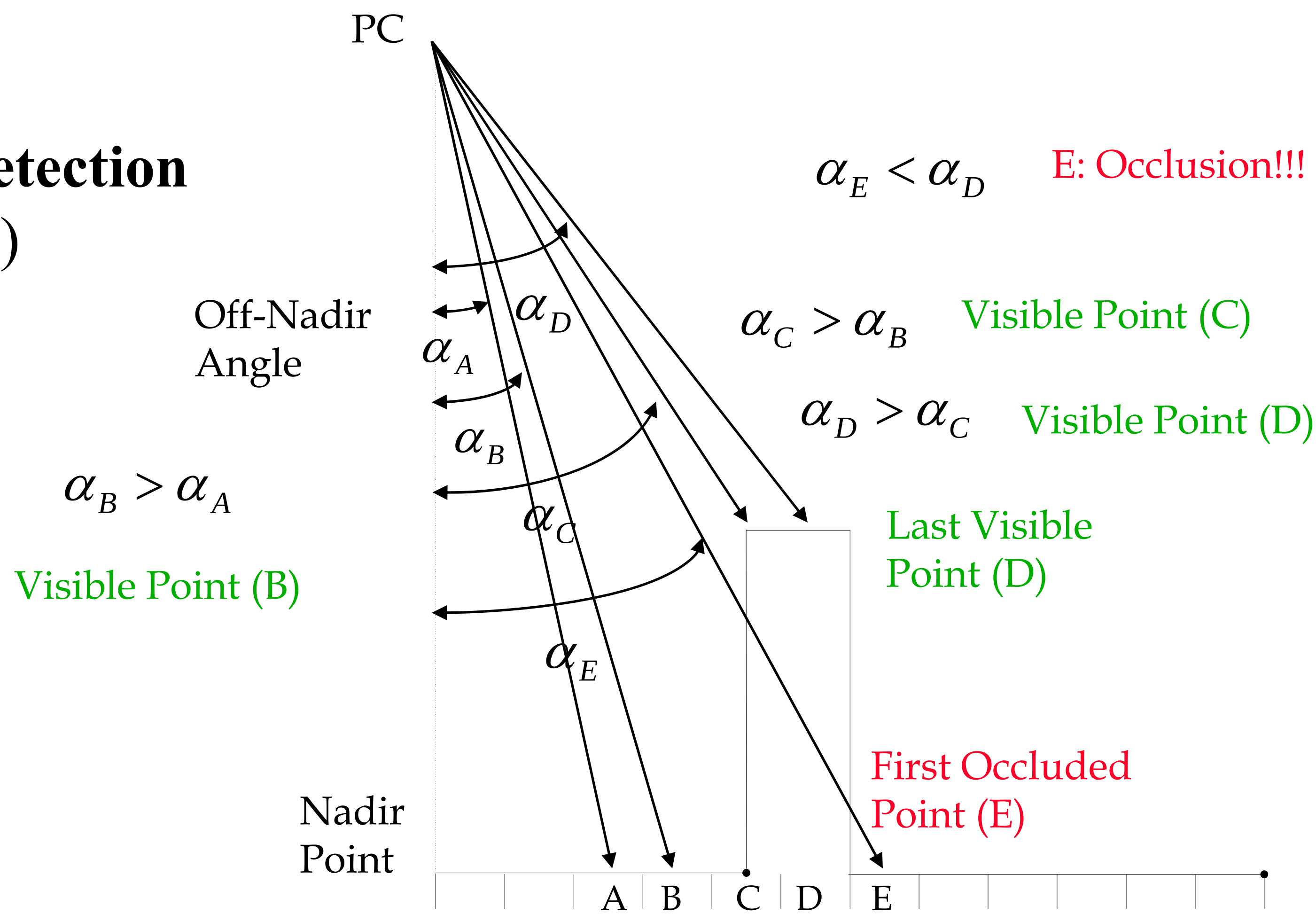
- If there is **more than 1 point** located in a given cell, we pick the one with the **lowest height** and assign its height to that cell.



DSM(i , j) = Height of Point C

LiDAR Classification: Methodology

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

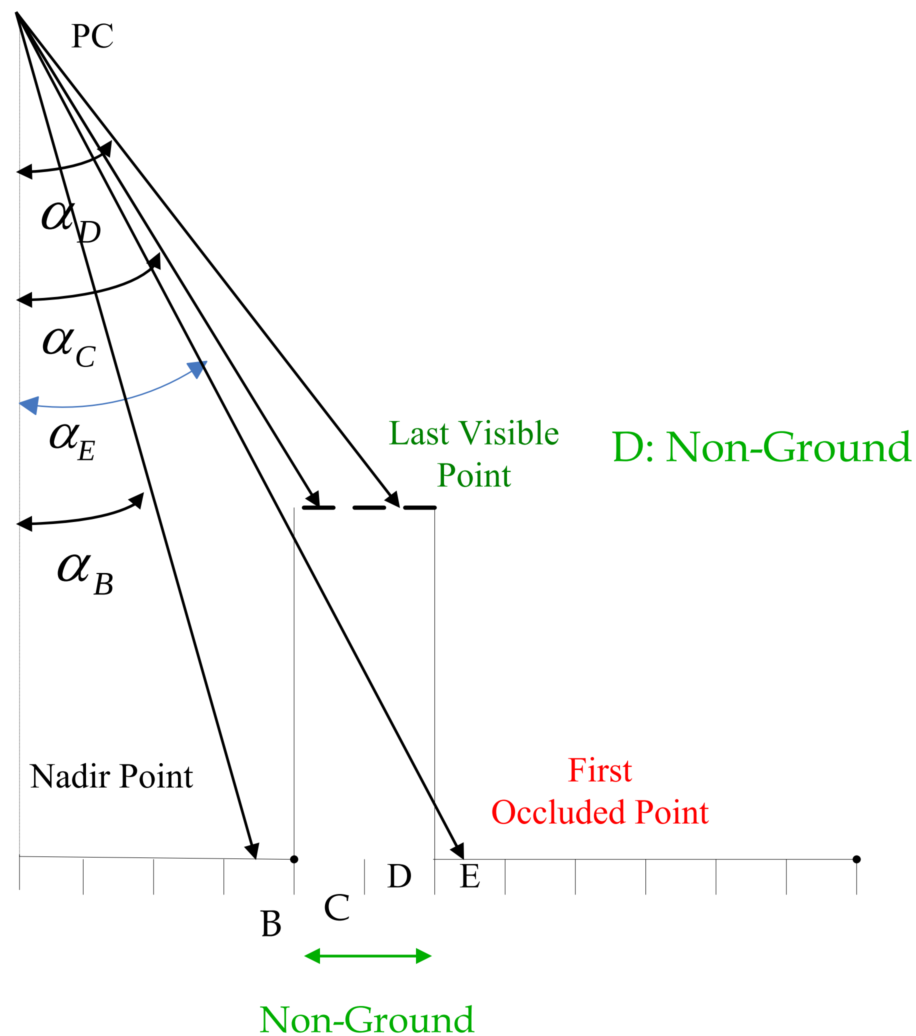


LiDAR Classification: Methodology

- **Detect the Points Causing Occlusion**

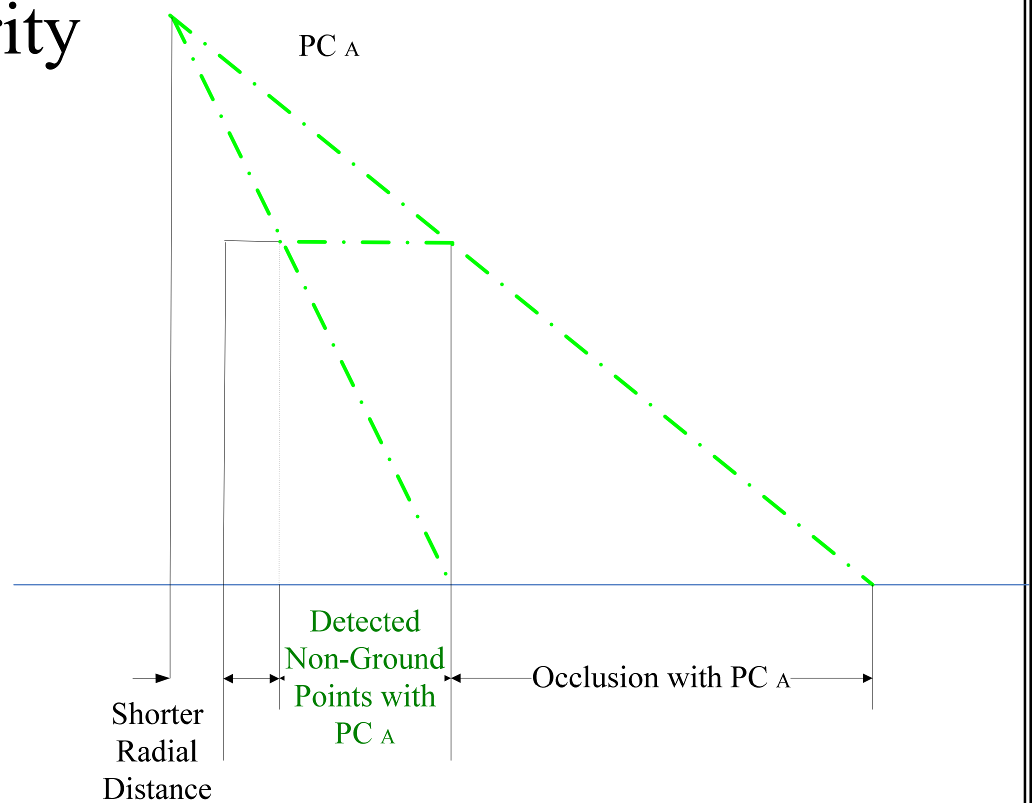
C: Non-Ground $\alpha_C > \alpha_E$

B: Ground $\alpha_B < \alpha_E$



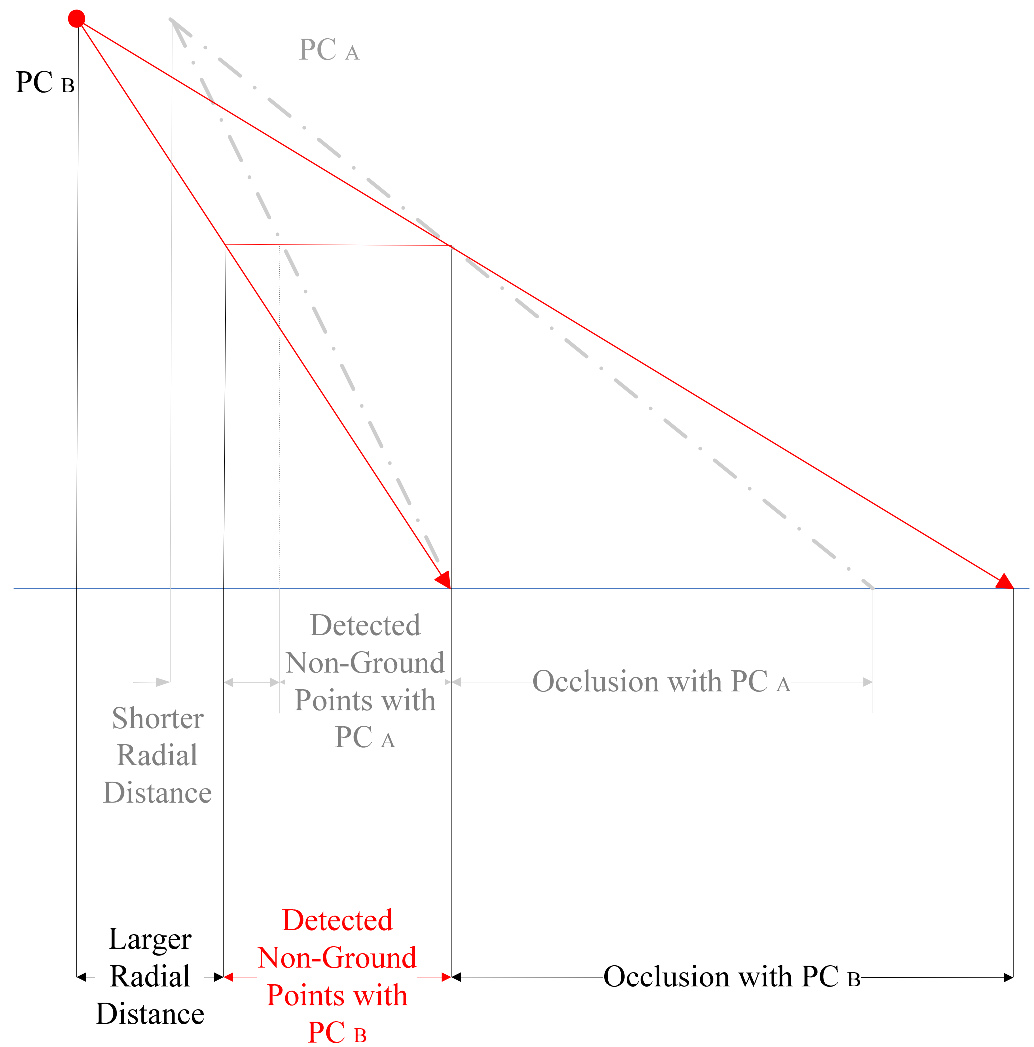
LiDAR Classification: Methodology

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



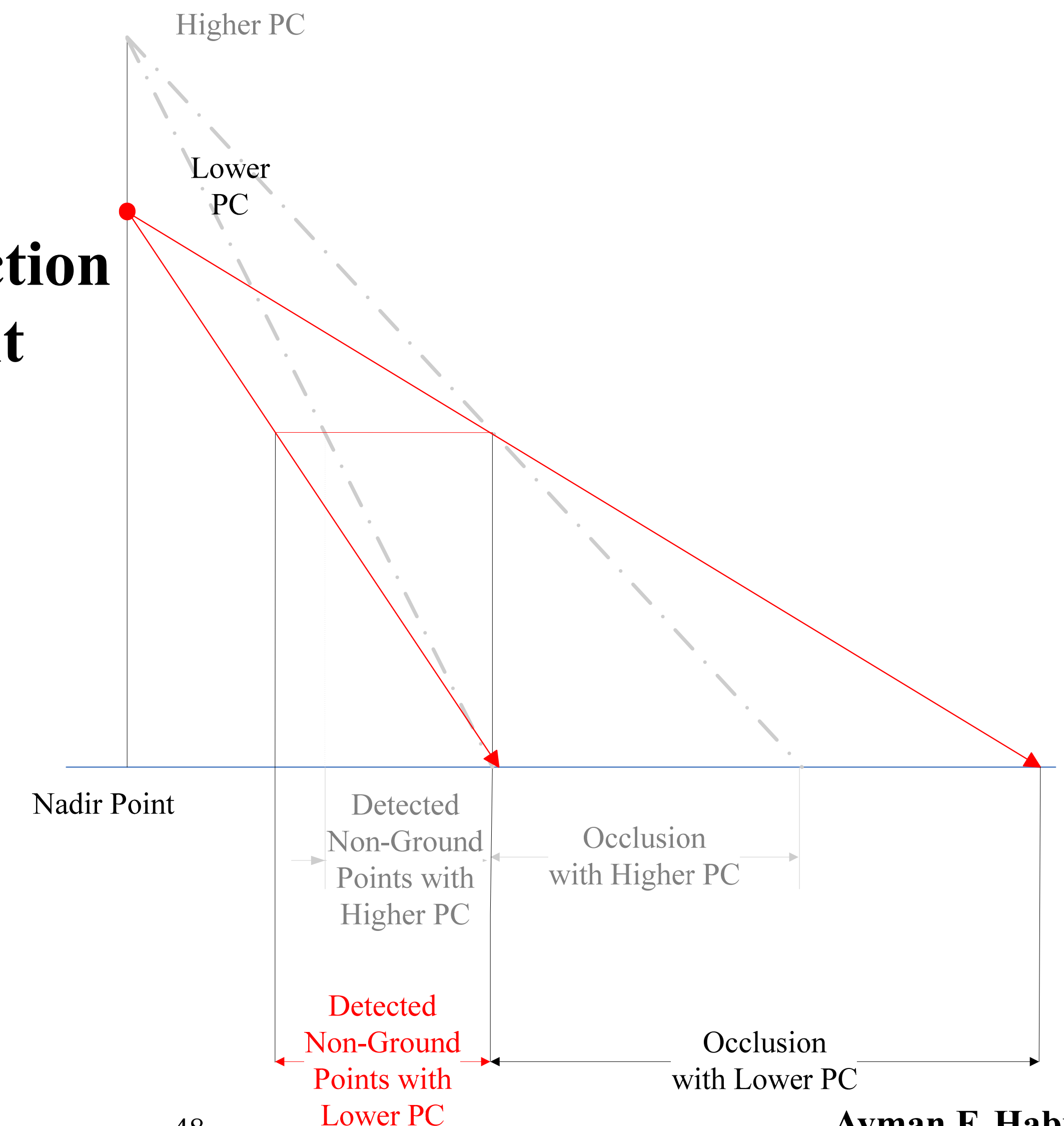
LiDAR Classification: Methodology

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



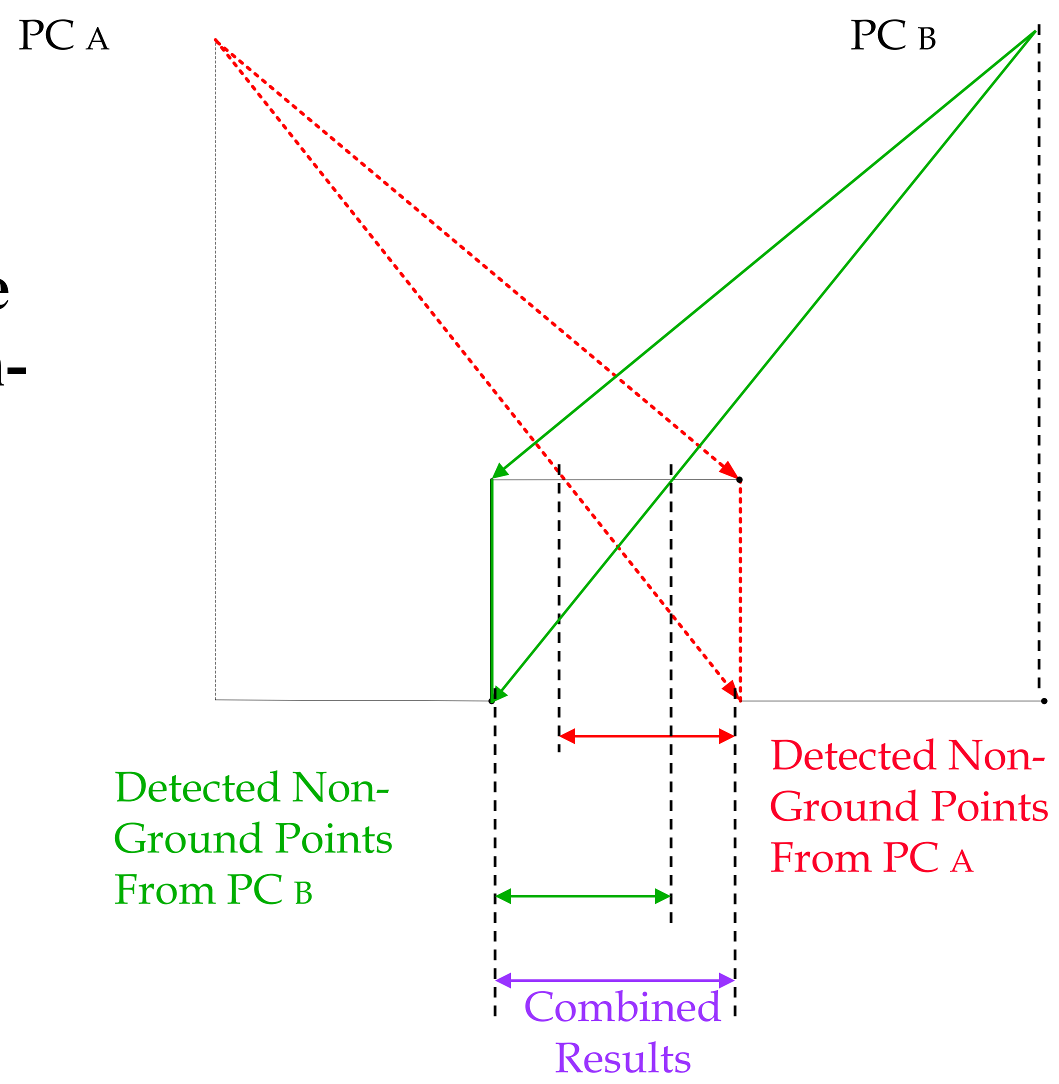
LiDAR Classification: Methodology

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

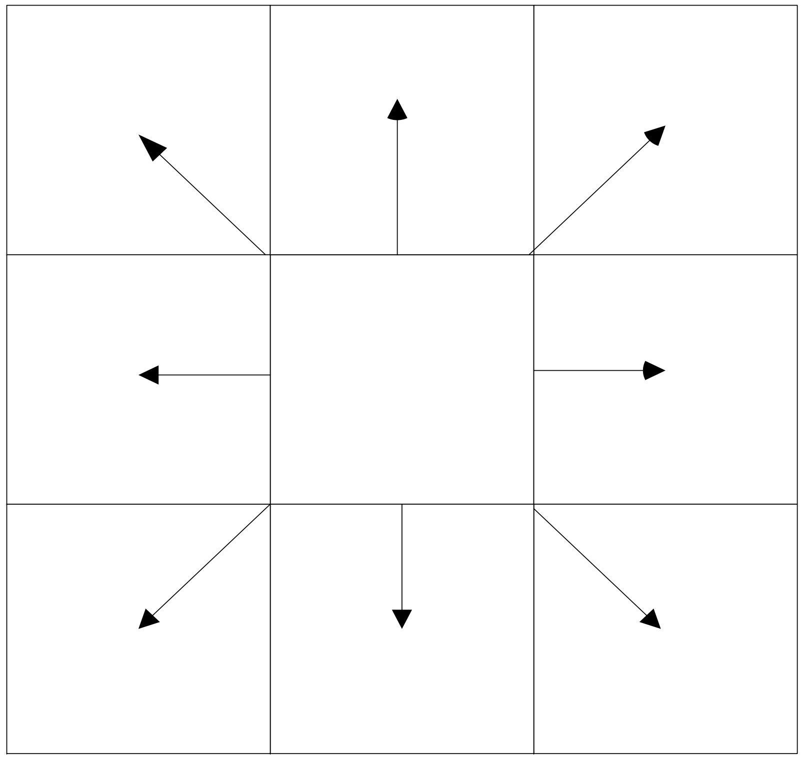


LiDAR Classification: Methodology

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

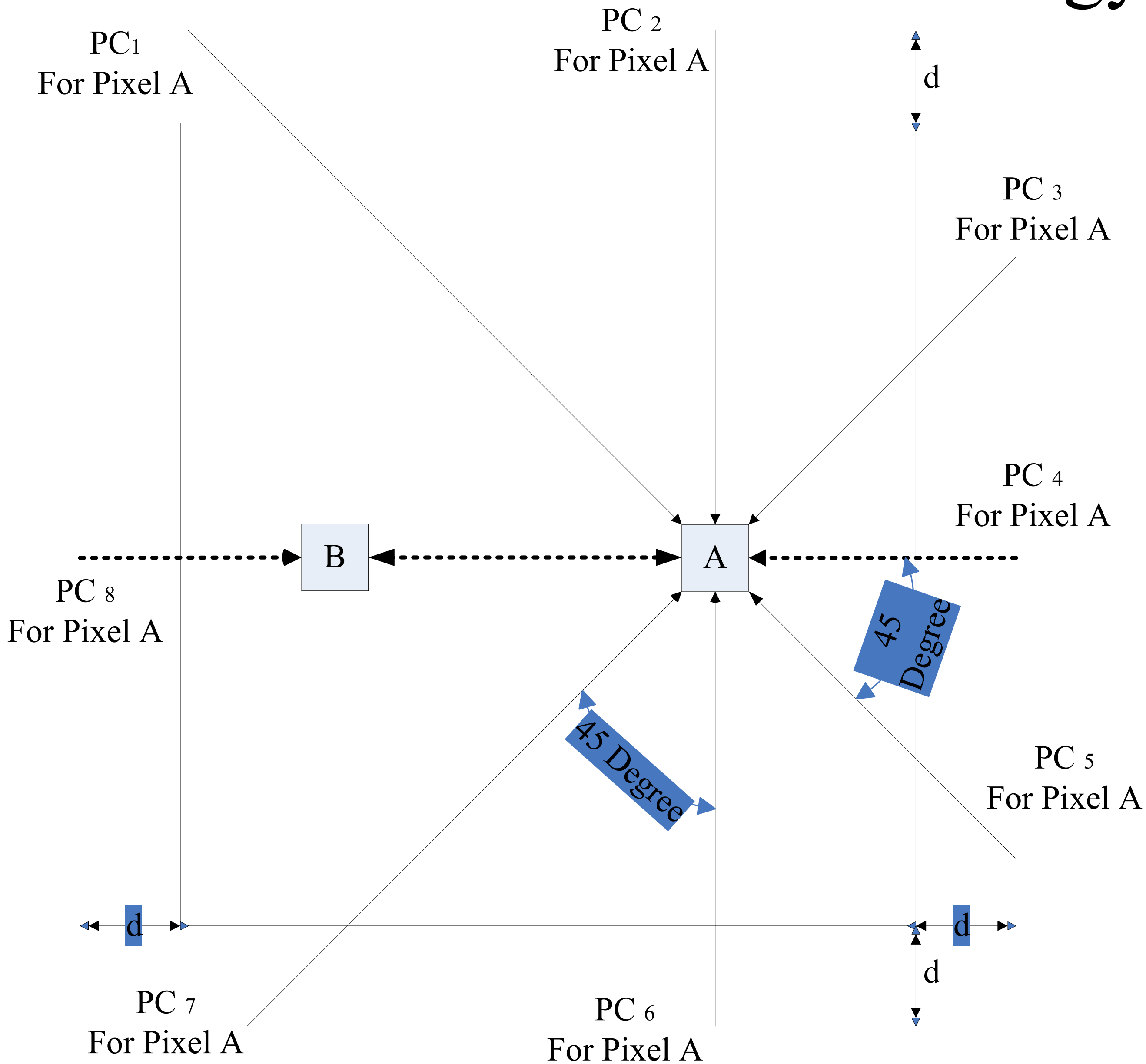


LiDAR Classification: Methodology

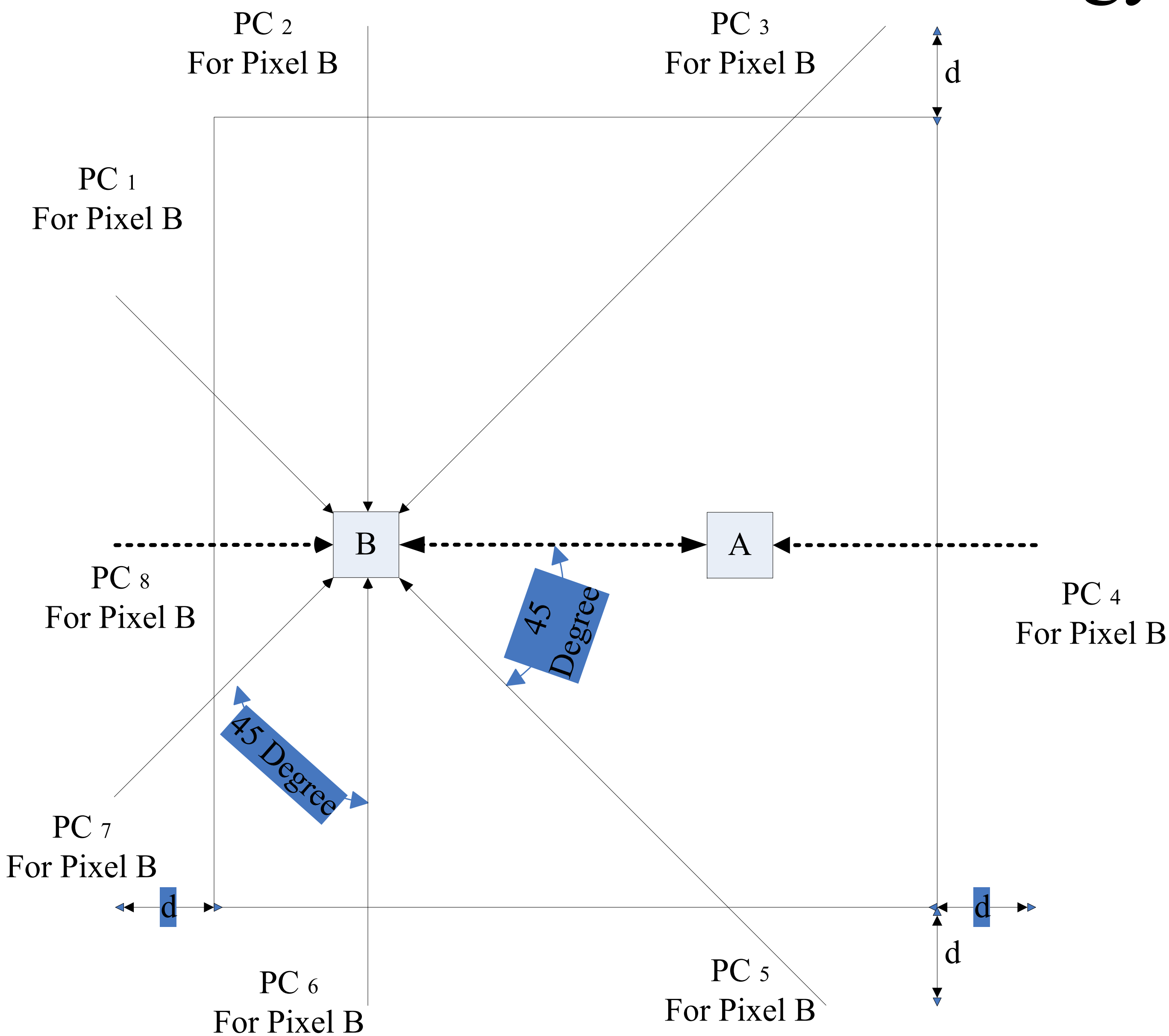


The eight neighbors of any given pixel are checked to see if they are occluded by that pixel or not.

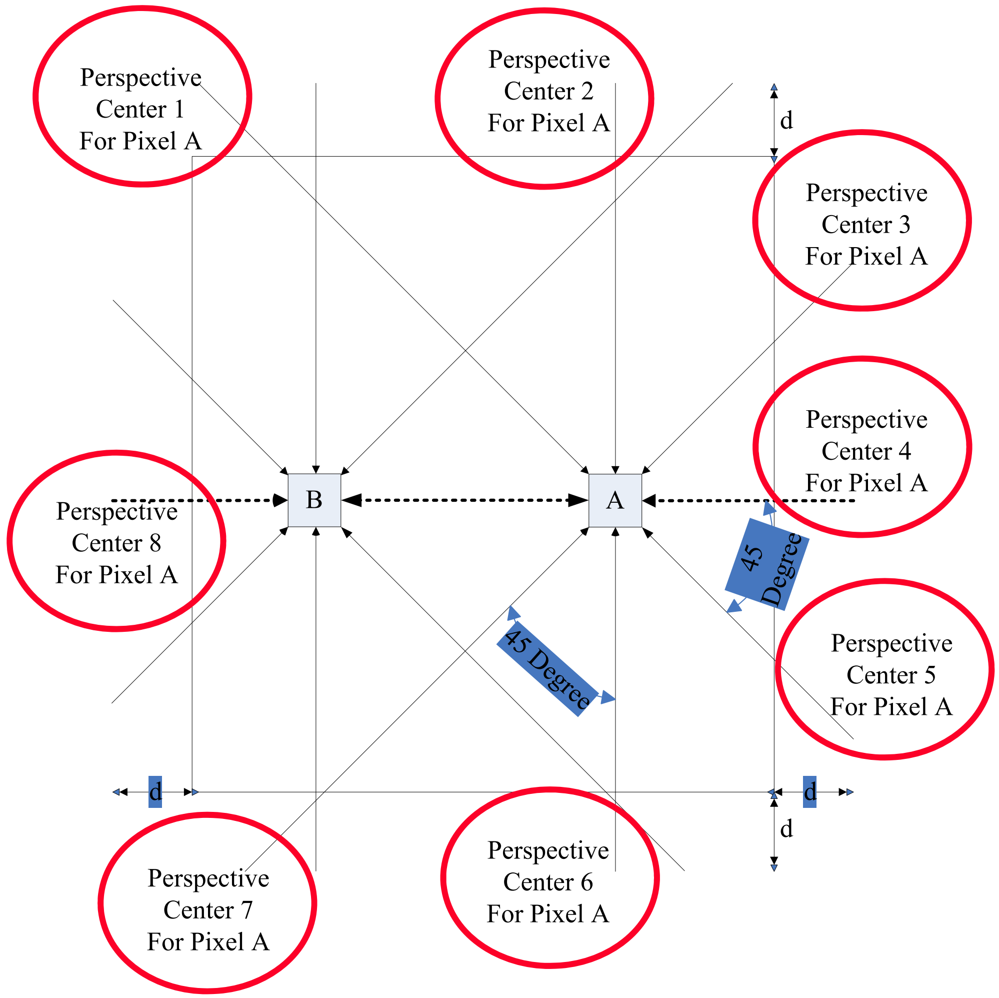
LiDAR Classification: Methodology



LiDAR Classification: Methodology



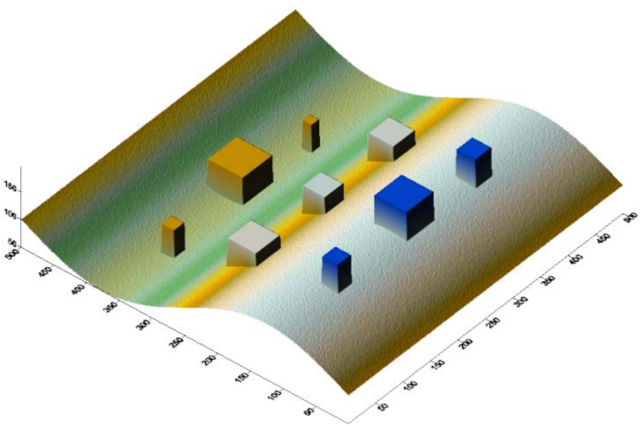
LiDAR Classification: Methodology



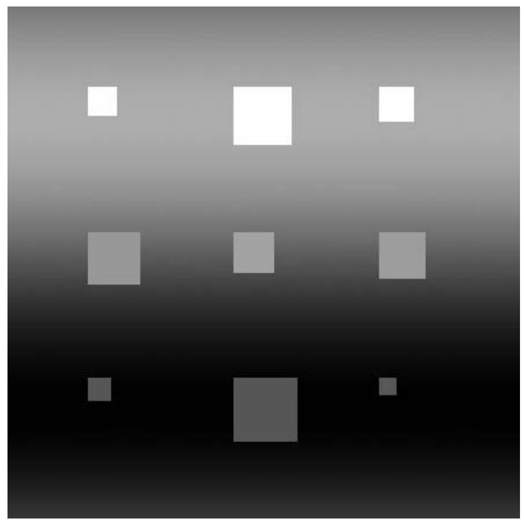
The eight neighbors of any given pixel are checked to see if they are occluded by that pixel or not.

LiDAR Classification: Results

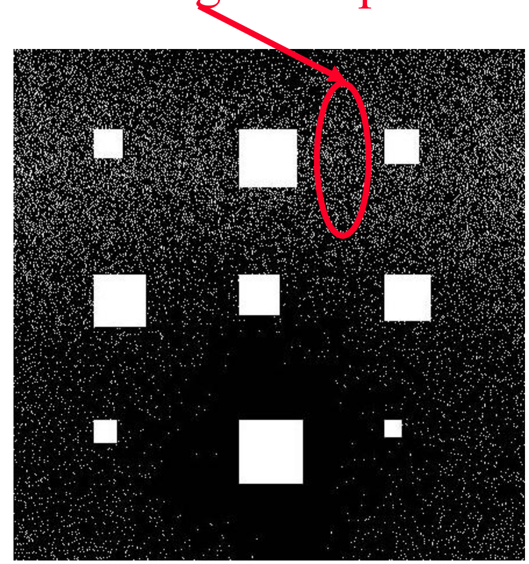
Simulated Dataset



Simulated Dataset



DSM



Identified Occluding Points (in white)

LiDAR Classification: Methodology

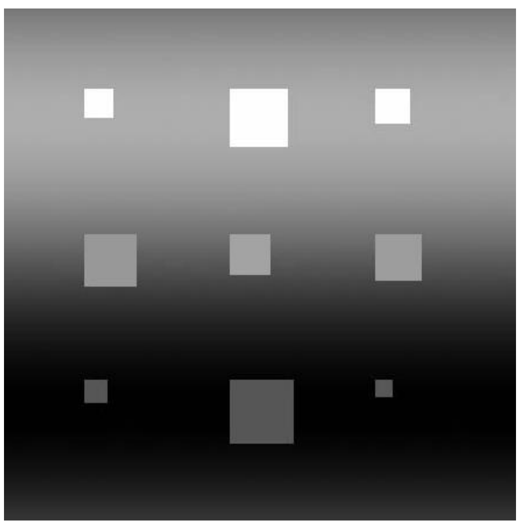
- Multiple projection centers at pre-specified locations will:
  + Improve our capability of detecting non-ground points
    - Useful when dealing with large and low buildings
  – Enhance the noise and high-frequency components of the terrain
    - Will lead to false hypotheses regarding instances of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

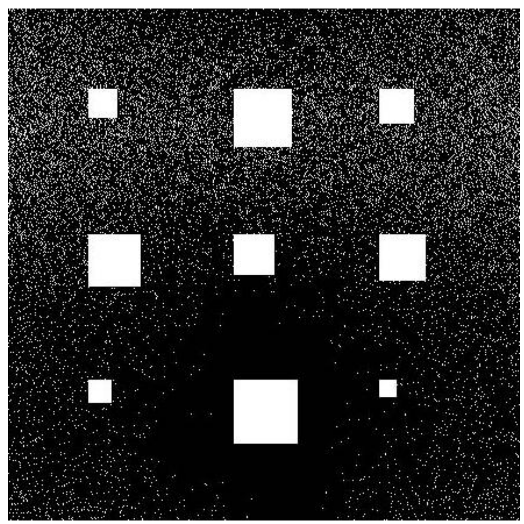
LiDAR Classification: Methodology

- 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

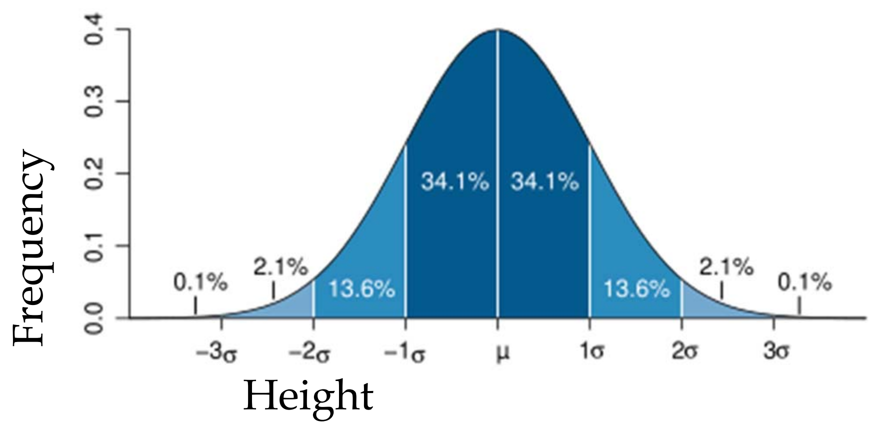




Identified Occluding Points (in white)

LiDAR Classification: Filtering

- We designed 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".



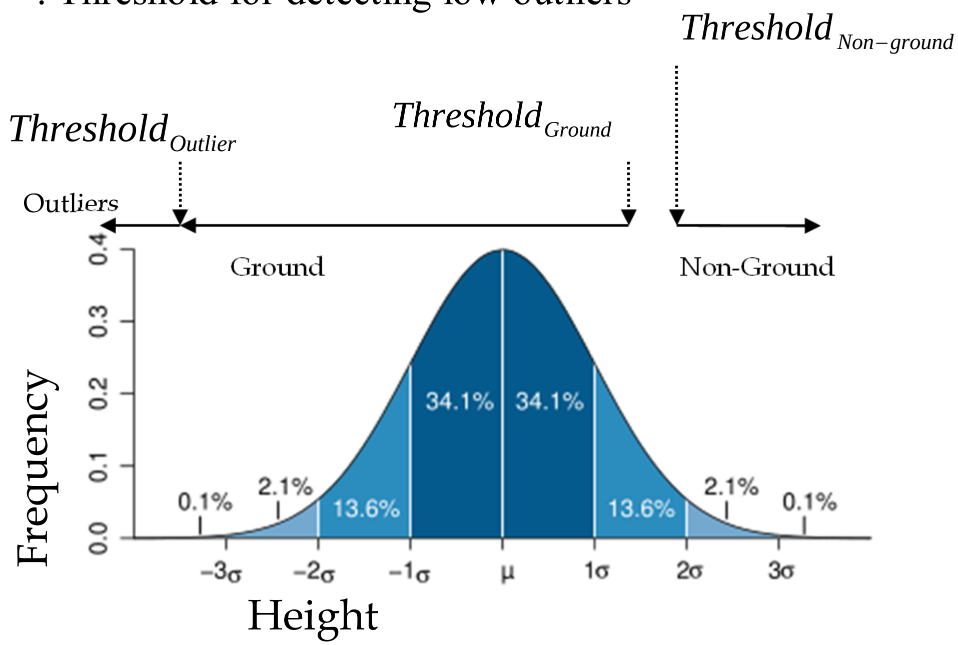
LiDAR Classification: Filtering

- 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

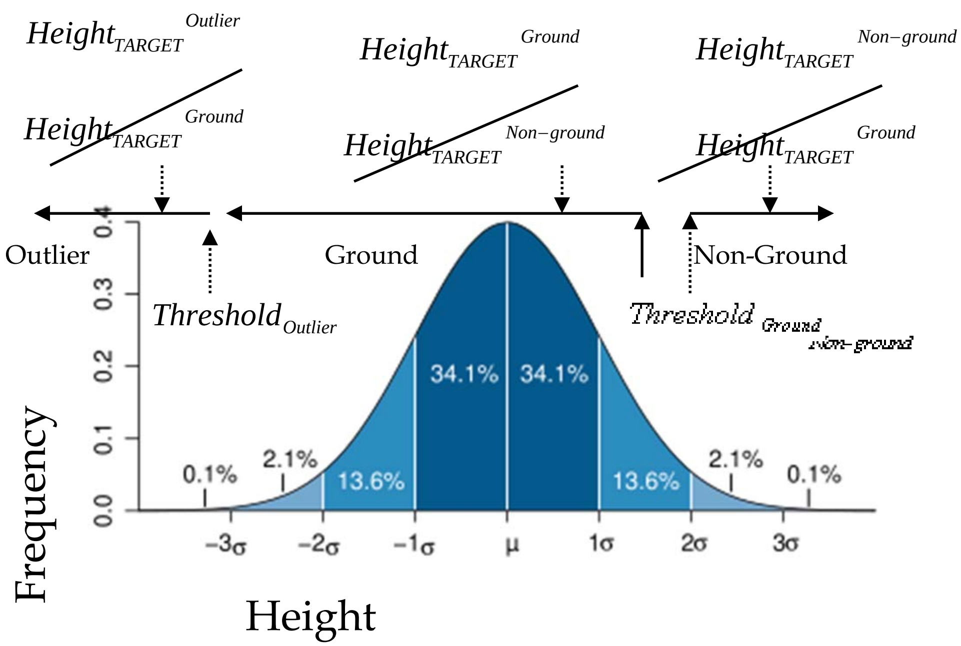
$Threshold_{Outlier}$: Threshold for detecting low outliers

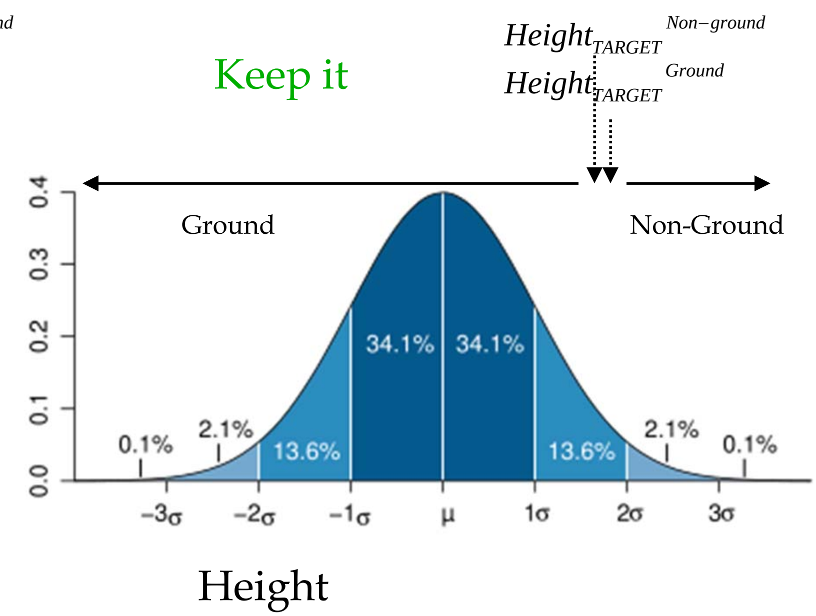


LiDAR Classification: Filtering

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

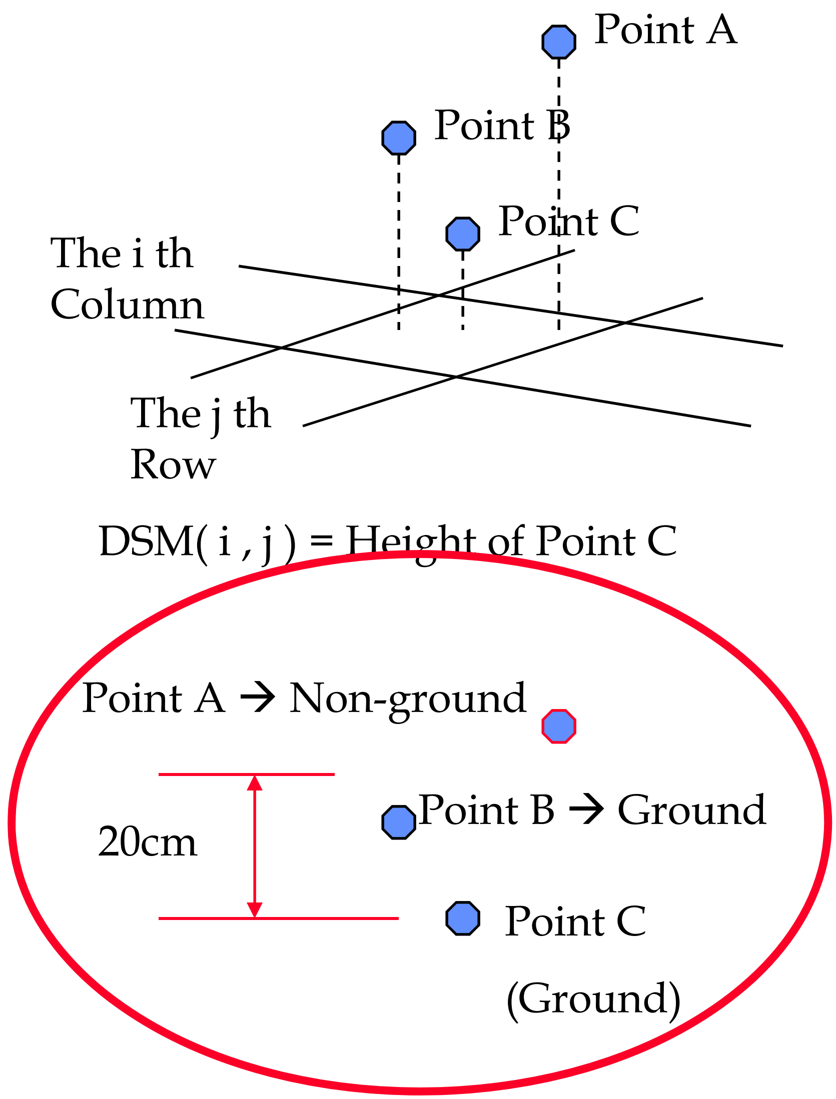
LiDAR Classification: Filtering





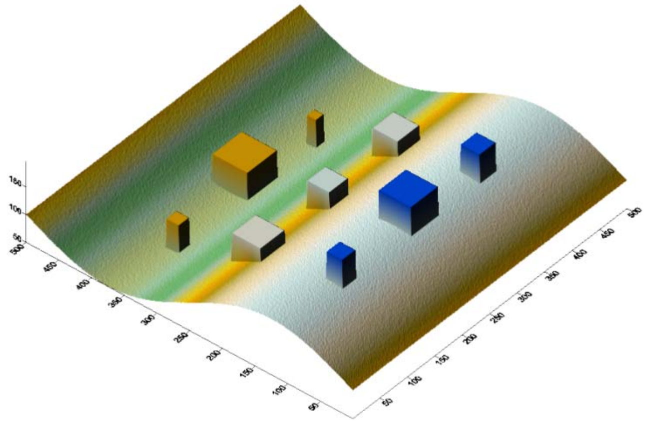
LiDAR Classification: Point Cloud Class.

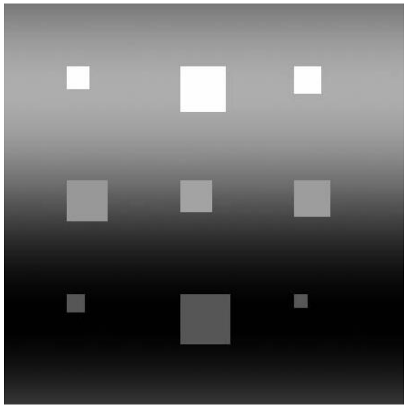
- If a cell is classified as non-ground, all the LiDAR points in that cell are classified as non-ground points.
- If the cell is classified as a ground point, then
  - The lowest LiDAR point in that cell is classified as ground.
  - The LiDAR points that are at least 20 cm higher than the lowest LiDAR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



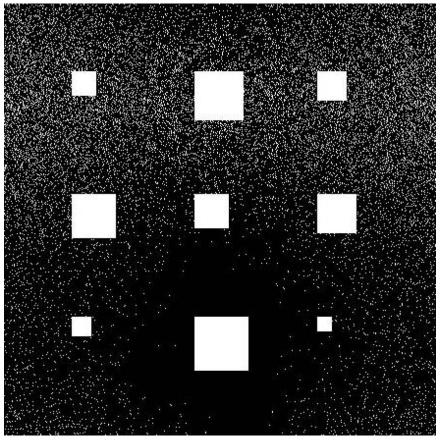
LiDAR Classification: Results

Simulated Dataset

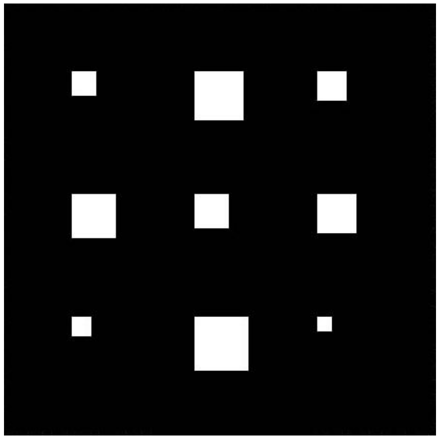




DSM



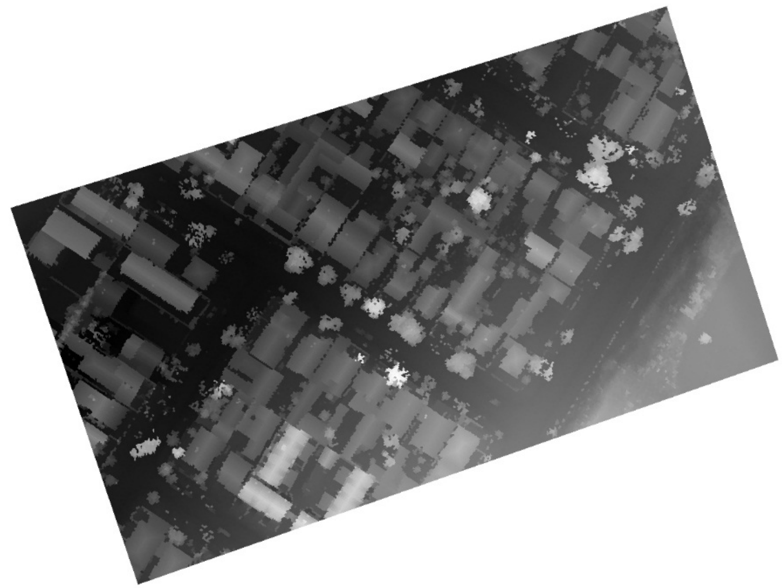
Classification Results without filter



Classification Results using filter

LiDAR Classification: Results

Real Dataset (1 - Brazil)



LiDAR Classification: Results

Real Dataset (1 - Brazil)

Occluding points in white

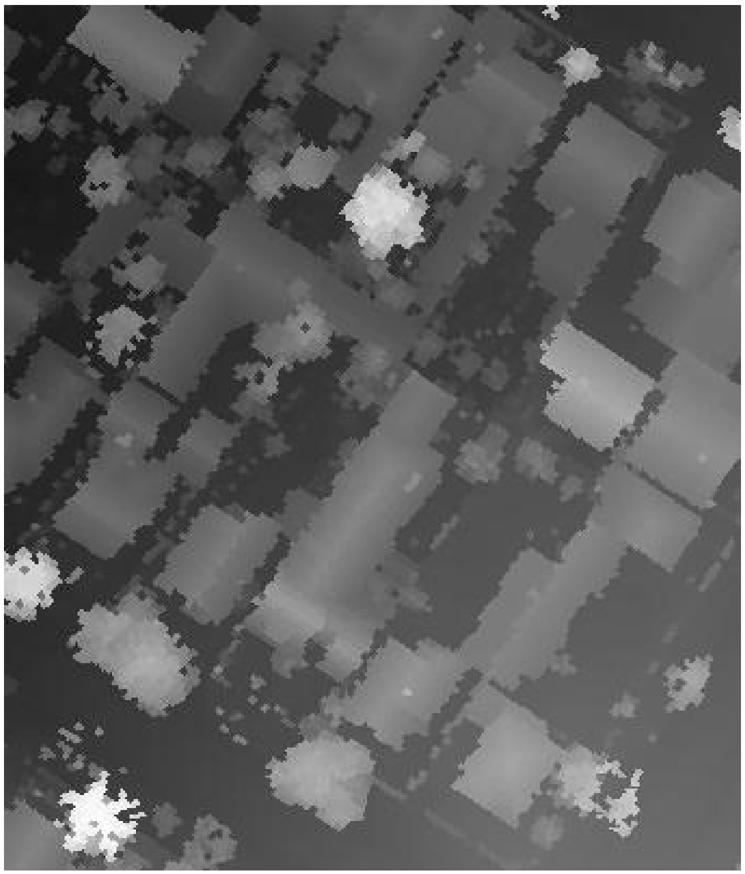
LiDAR Classification: Results

Real Dataset (1 - Brazil)

After Statistical Filtering

LiDAR Classification: Results

Real Dataset (1 - Brazil)



DSM → Non-ground objects

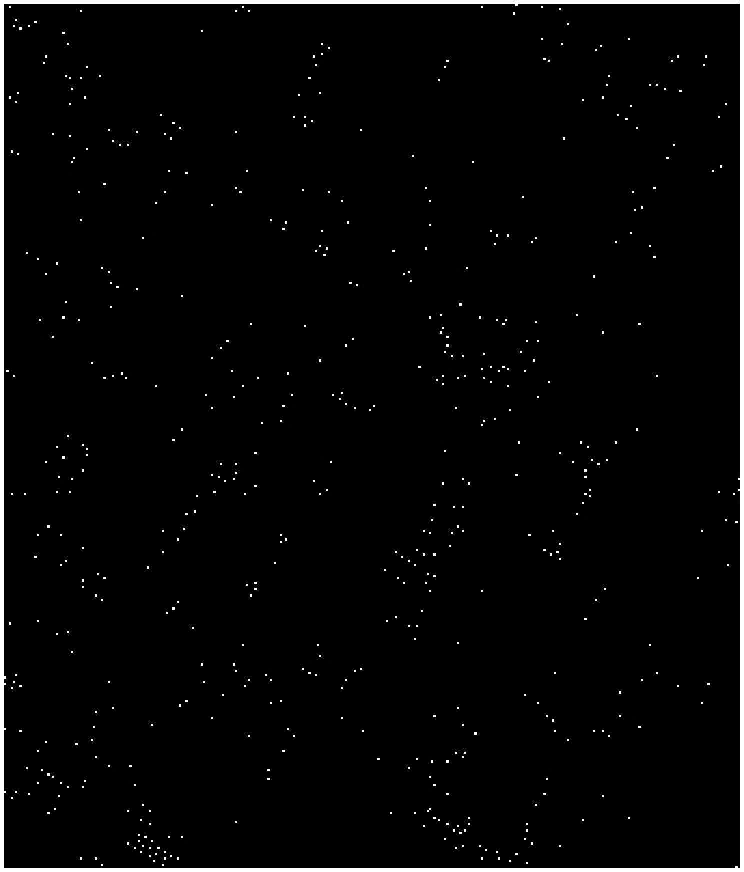
LiDAR Classification: Results

Real Dataset (1 - Brazil)

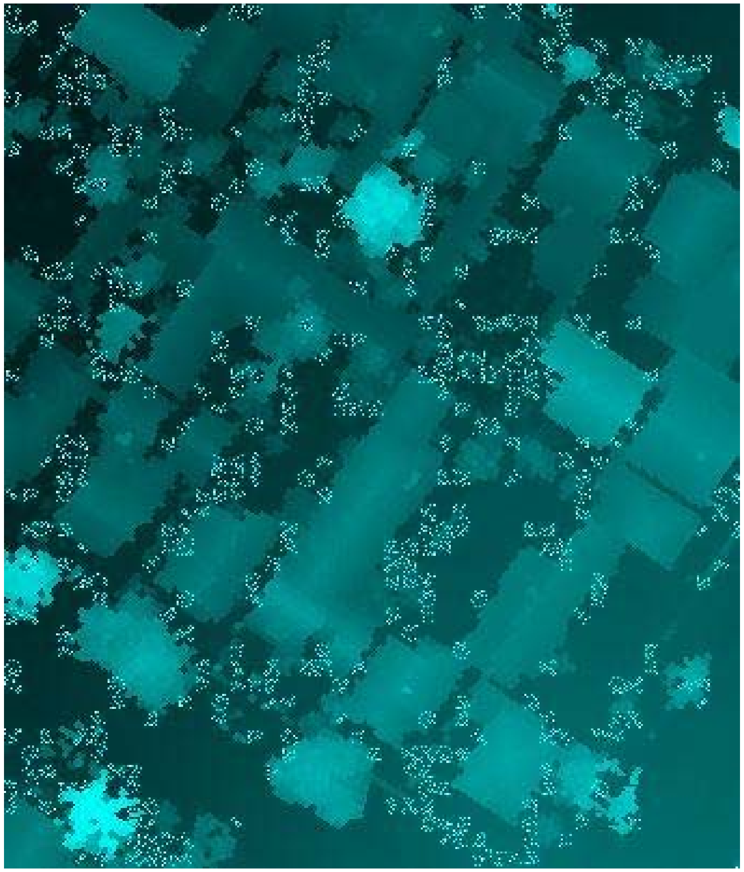
- Using the LiDAR DSM and an orthophoto over the same area, we manually generated a ground truth for ground and non-ground points classification.
- Comparing our result with the ground truth, the number of misclassified points divided by the total number of points was found to be 4.7%.

LiDAR Classification: Results

Real Dataset (1 - Brazil)



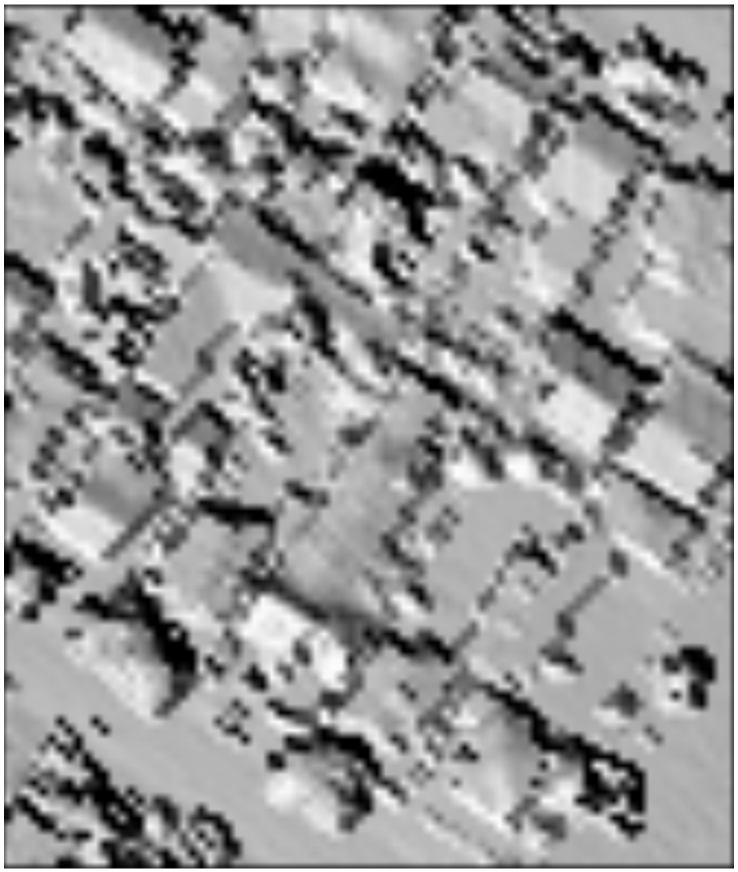
Misclassified Points



Misclassified Points displayed on DSM

LiDAR Classification: Results

Real Dataset (1 - Brazil)

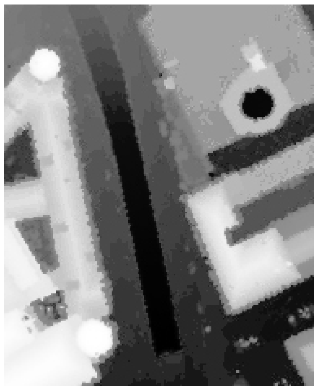


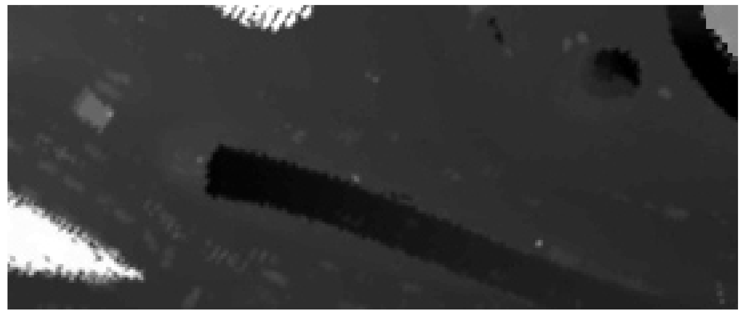
Original DSM

Derived DTM

LiDAR Classification: Results

Real Dataset (2 - Stuttgart)

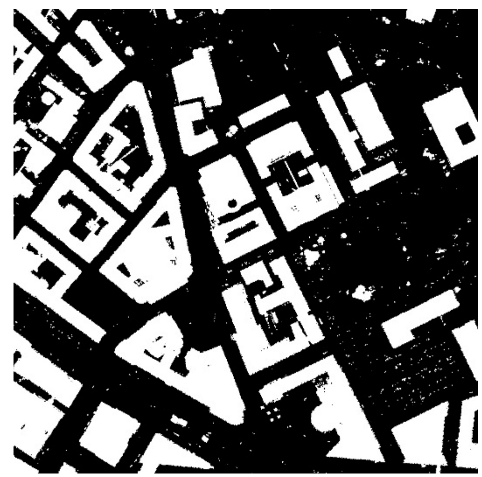




Discontinuous Terrain: Tunnels

DSM

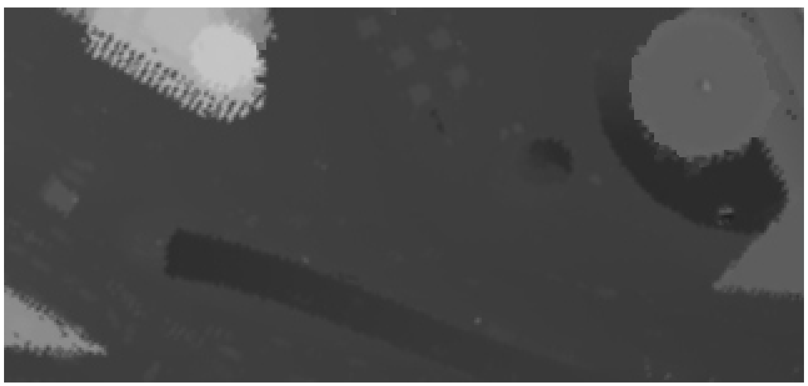
Occluding Points



Non-ground Points

LiDAR Classification: Results

Real Dataset (2 - Stuttgart)



DSM

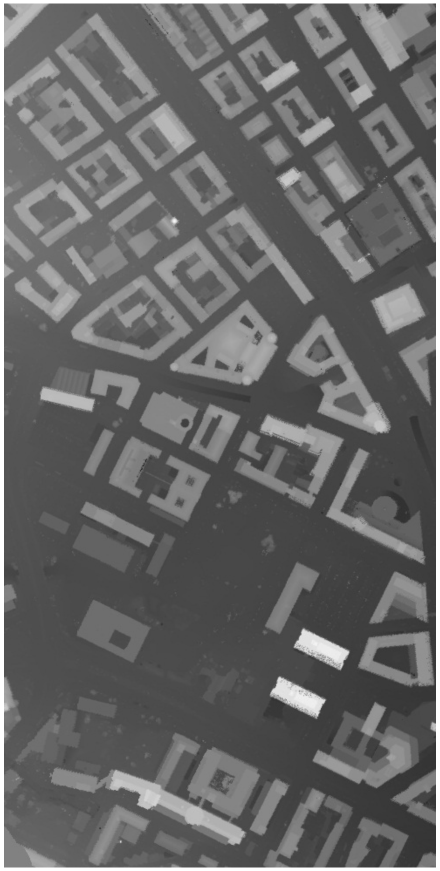
Occluding Points

Non-ground Points

LiDAR Classification: Results

Real Dataset (2 - Stuttgart)

DSM



Occluding Points

Non-ground Points

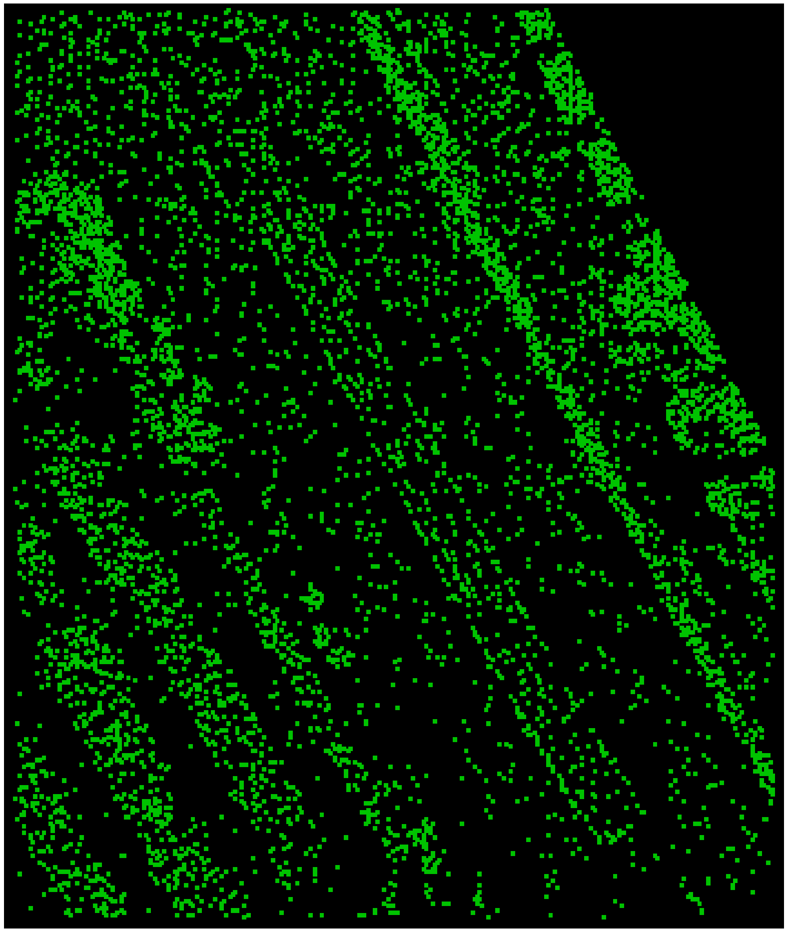
LiDAR Classification: Results

Real Dataset (3 - Calgary)

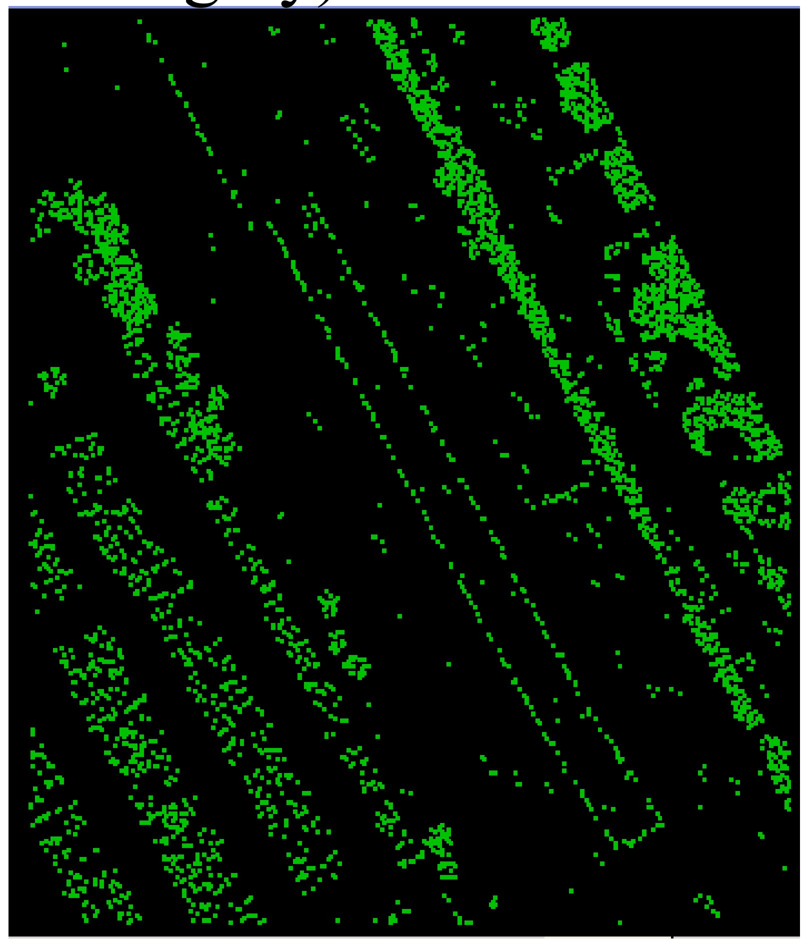
- A ROI near the University of Calgary is selected as an experimental data.
- The Transit Train trail extends into a tunnel under the ground.

LiDAR Classification: Results

Real Dataset (3 - Calgary)



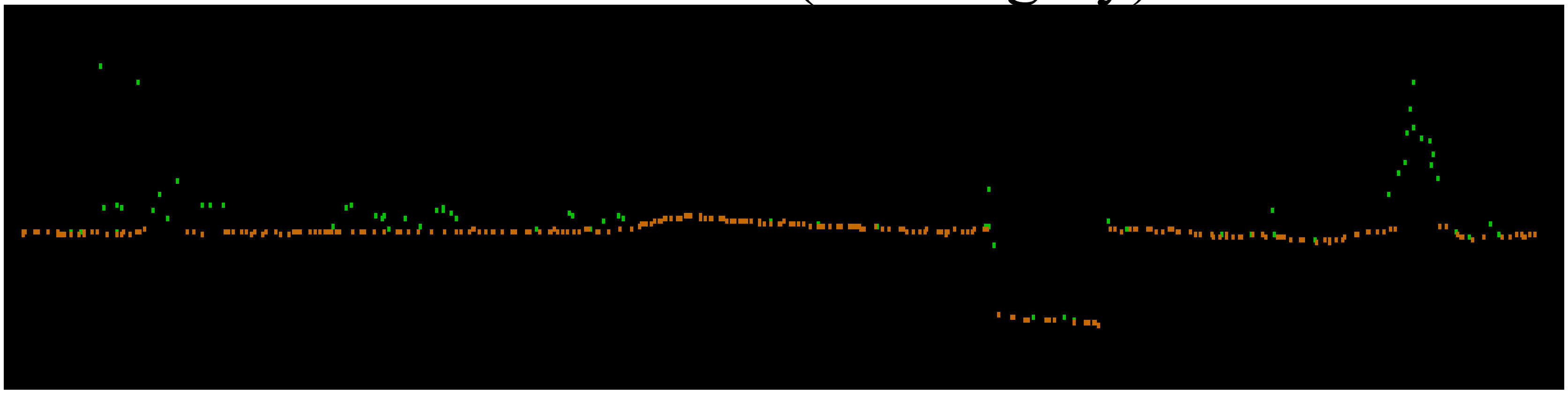
Non-ground points (**TerraScan**)



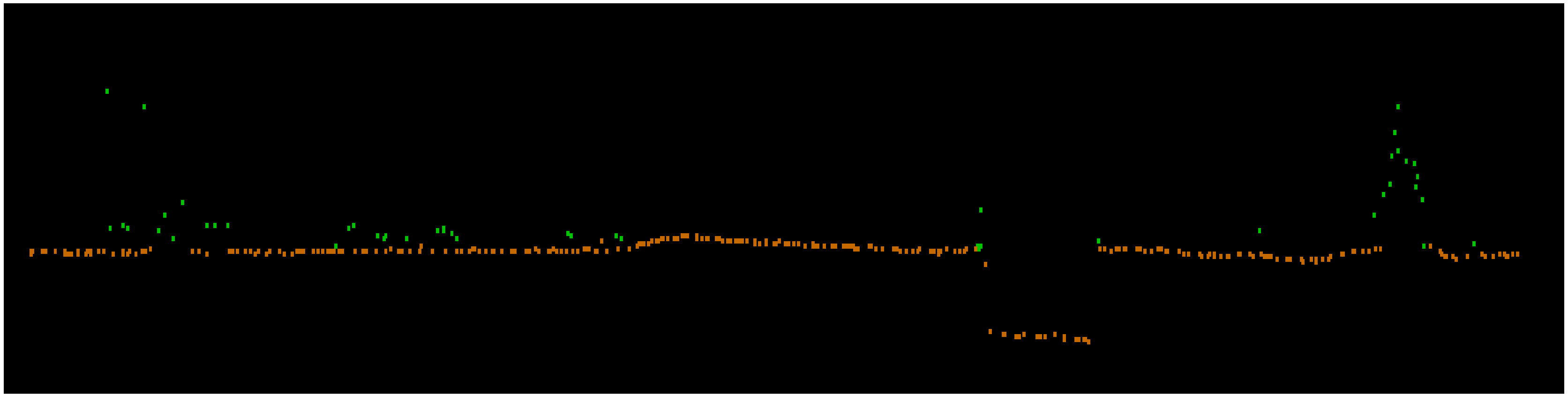
Non-ground points (Occlusion-based)

LiDAR Classification: Results

Real Dataset (3 - Calgary)



TerraScan's Result



Occlusion-Based Result

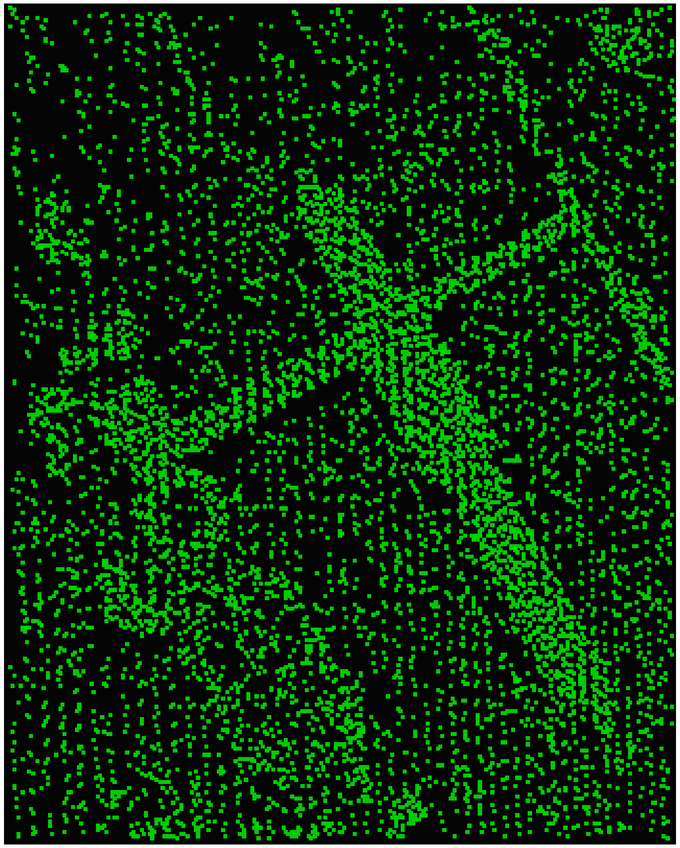
LiDAR Classification: Results

Real Dataset (3 - Calgary)

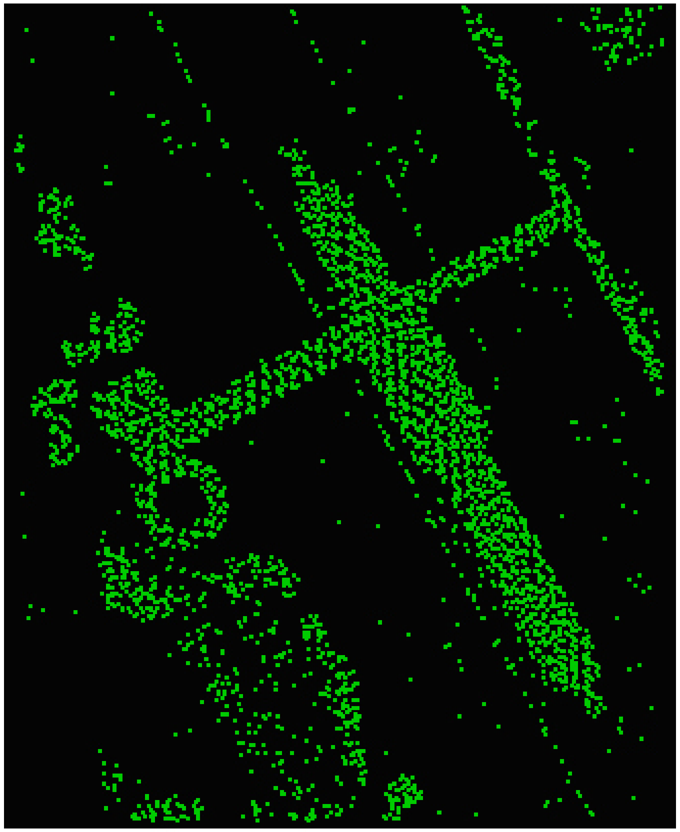
- Another ROI near the University station is selected as another experimental data.
- Complex contents
  - The Transit Train station,
  - Bridge,
  - Ramps, and
  - Trees.

LiDAR Classification: Results

Real Dataset (3 - Calgary)



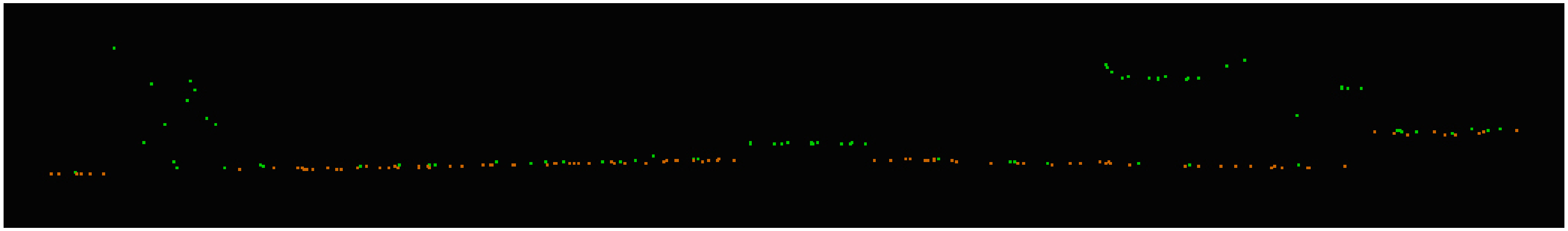
Non-ground points (**TerraScan**)



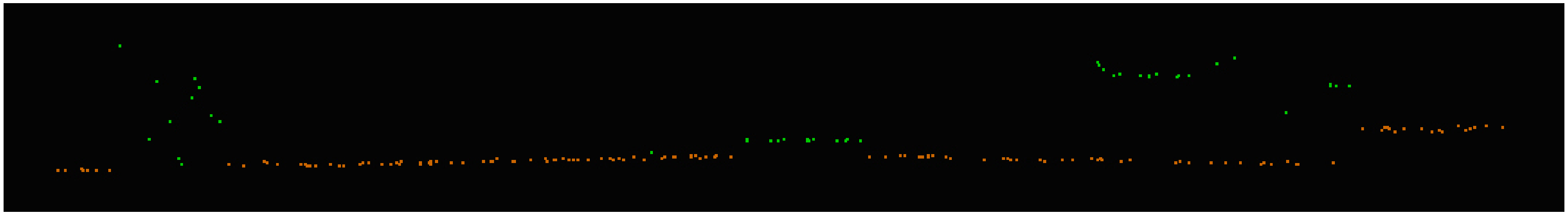
Non-ground points (**Occlusion-Based Results**)

LiDAR Classification: Results

Real Dataset (3 - Calgary)



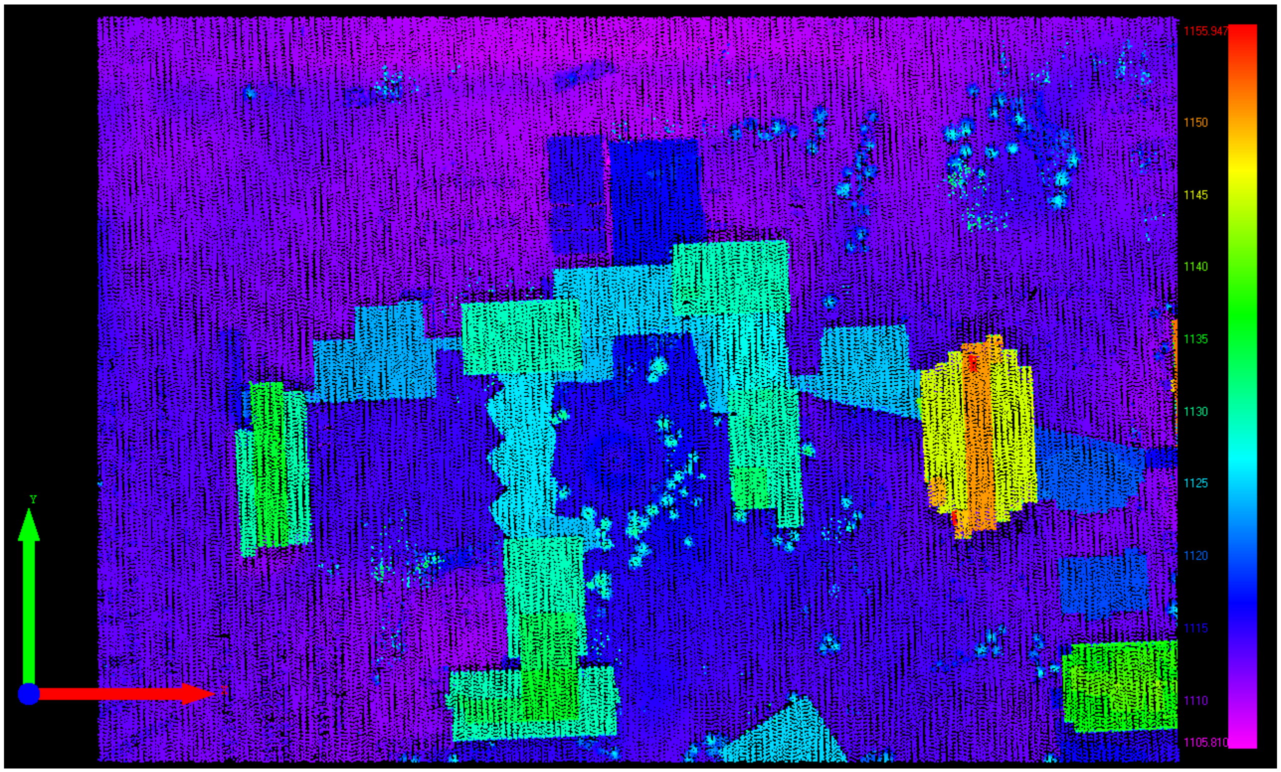
TerraScan's Result



Occlusion-Based Result

LiDAR Classification: Results

Real Dataset (4 - Calgary)



Original LiDAR Points over UofC

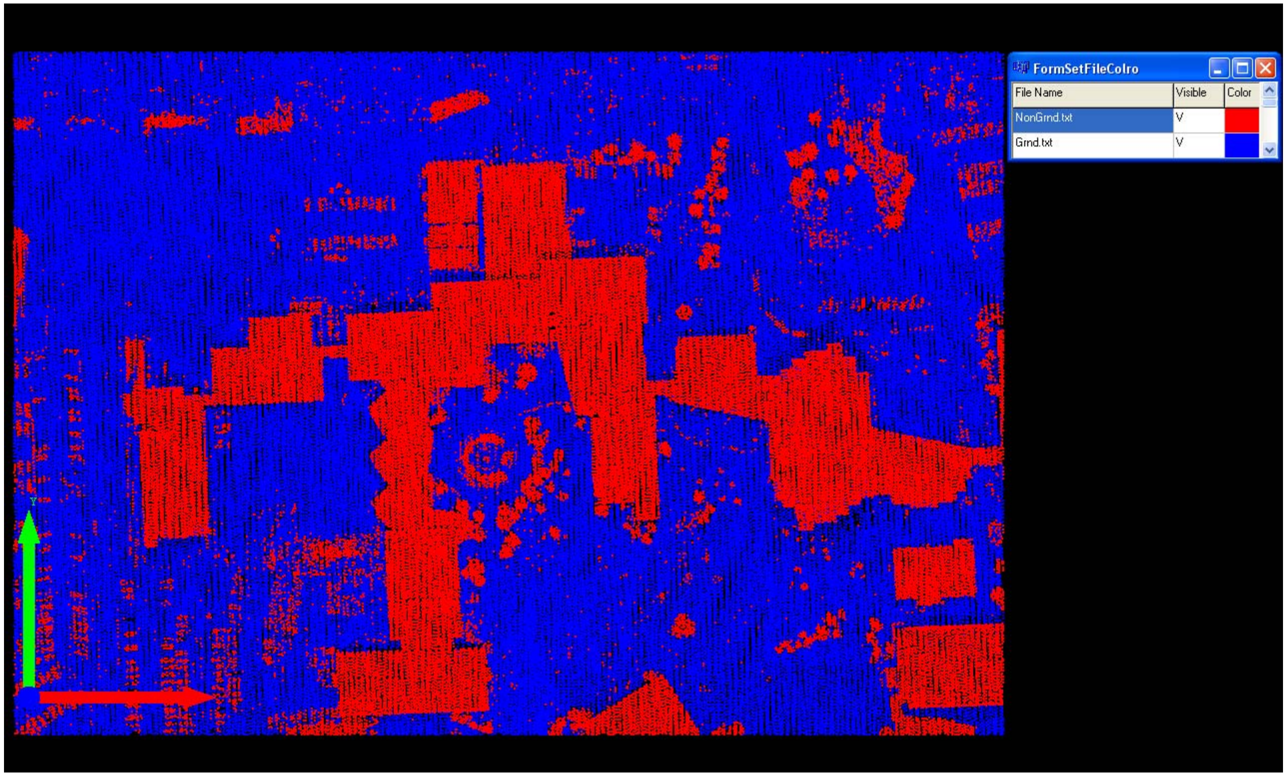
LiDAR Classification: Results

Real Dataset (4 - Calgary)

Aerial Photo over UofC

LiDAR Classification: Results

Real Dataset (4 - Calgary)



Ground/Non-Ground Points

LiDAR Classification: Conclusion

- The achieved results proved the feasibility of the suggested procedure.
- Default parameters are sufficient for most cases.
- The proposed procedure is capable of handling urban areas with complex contents:
  - Tall buildings, low and nearby buildings, trees, bushes, fences, bridges, ramps, cliffs, tunnels, etc.
- Future work will focus on further testing of the proposed methodology as well as improving its efficiency.
- Also, the classified non-ground points will be further classified into vegetation and man-made structures.
  - Building detection and change detection

Comments and Questions?