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CE 59700: LASER SCANNING

Contact Information

- Instructor:
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  - Lectures (HAMP 2117):
    - Monday (3:30 p.m. – 6:20 p.m.)
  - Office Hours:
    - Flexible (upon e-mail request for setting up an appointment)
- Course webpage:
  - http://purdue.edu/CE/DPRG

Course Objectives

- Gain familiarity with the basic principles of LiDAR mapping.
- Emphasis:
  - Data acquisition,
  - Georeferencing of mobile mapping systems,
  - System calibration,
  - Quality control of point cloud coordinates,
  - Registration of overlapping point clouds,
  - Data characterization,
  - Data processing,
  - Quality control of the data processing results, and
  - Integration of point cloud and image data.

Course Notes and Textbooks

- Material presented in class, as well as supplemental notes, will be available through the course webpage.
  – Contains all the required material for the course work and exams.
- Supplementary References (optional):
  – Selected research papers will be made available throughout the semester.

Grading Scheme

- Class participation: 5%
- Midterm exam: 15%
- Project presentations and final report: 50%
  - Some suggested project topics are provided later.
  - Midterm presentation
  - Final presentation & technical report
- Final exam: 30%
- Exams are open book/notes.

Course Contents

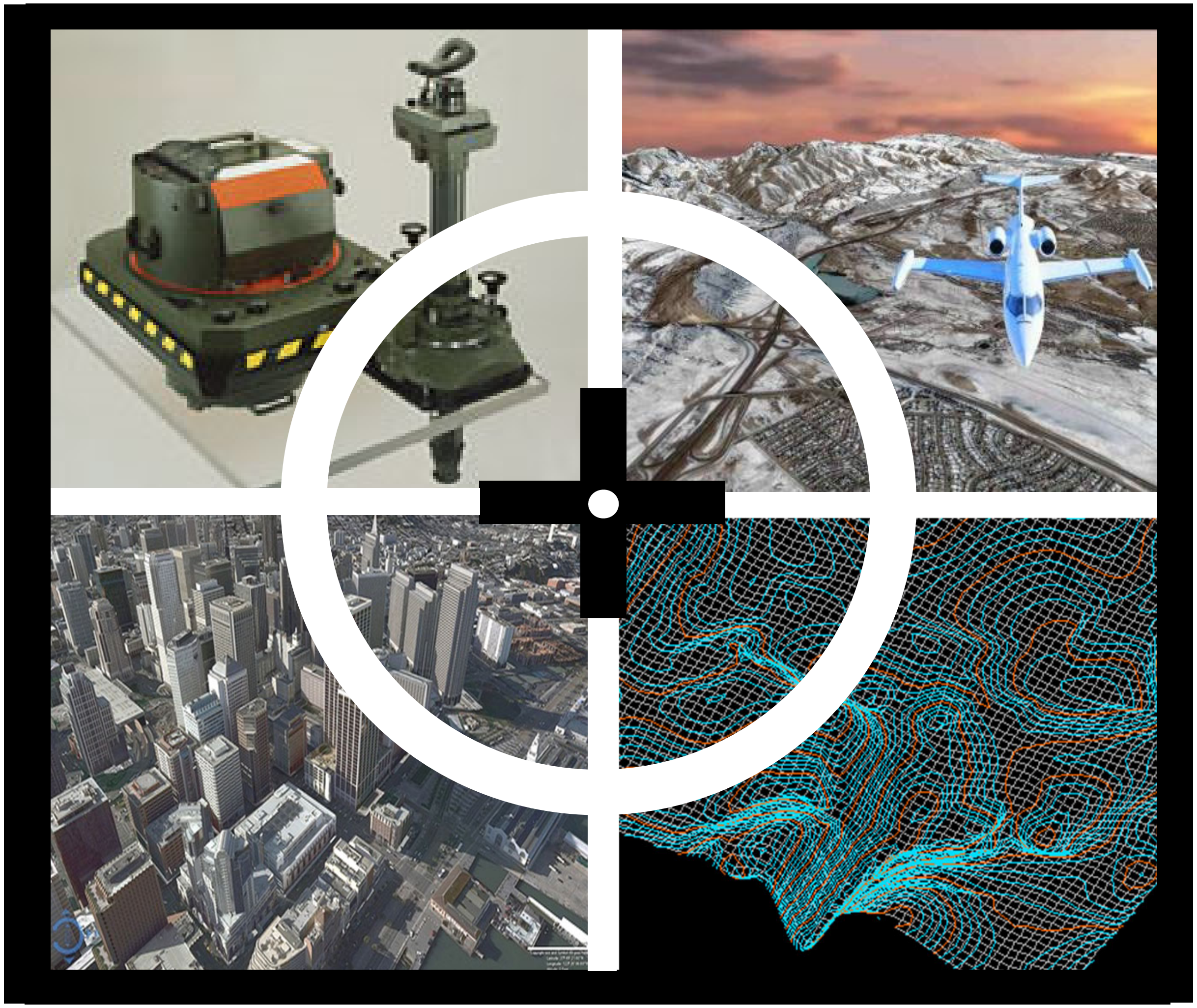
- Principles of Photogrammetric Mapping
- Photogrammetric and LiDAR Georeferencing
- LiDAR Mapping Principles
- Quality Assurance and Quality Control of LiDAR Mapping
- Registration of Laser Scanning Point Clouds
- Adaptive Processing of LiDAR Data for Extracting Planar and Linear Features
- Occlusion-based Procedure for True Orthophoto Generation and LiDAR Data Classification
- Automatic Detection and Reconstruction of Right-Angled-Corner Buildings

Chapter 1: Overview

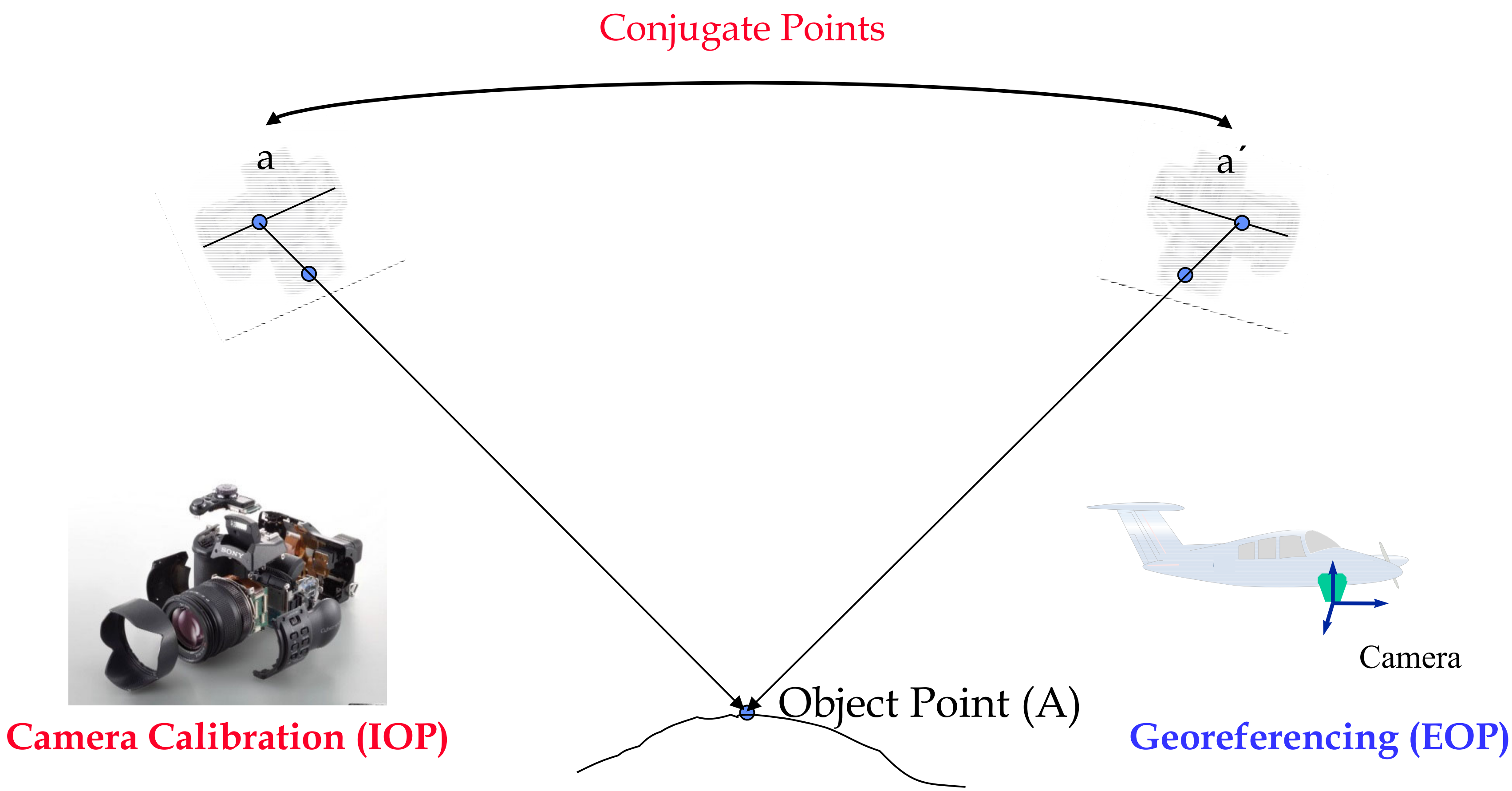
- **Principles of Photogrammetric Mapping**
- Photogrammetry: Definition and applications
- Photogrammetric tools:
  - Rotation matrices
  - Photogrammetric orientation: interior and exterior orientation
- Photogrammetric point positioning
  - Collinearity equations/conditions (single camera systems)
  - GNSS/INS-assisted photogrammetric systems
  - Multi-camera photogrammetric systems
- Photogrammetric bundle adjustment
  - Structure of the design and normal matrices

Photogrammetry

- Objective: Derive the positions and shapes of objects from imagery



Photogrammetric Reconstruction



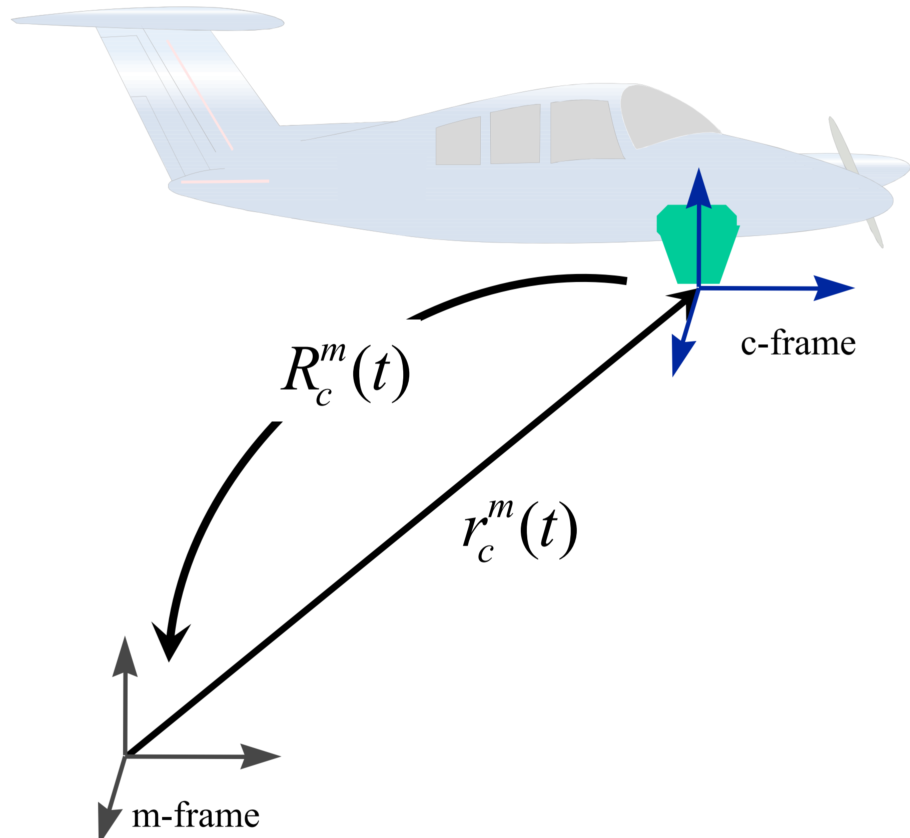
- **The interior orientation parameters of the involved cameras have to be known.**
- **The position and the orientation of the camera stations have to be known.**

Chapter 2: Overview

- **Photogrammetric and LiDAR Georeferencing**
- Introduction
- Georeferencing Alternatives:
  - Indirect georeferencing
  - Integrated Sensor Orientation (ISO)
  - Direct georeferencing
- Direct Georeferencing: Operational Example
  - Terrestrial Mobile Mapping Systems (MMS)
- Accuracy Analysis of Different Georeferencing Techniques
- Concluding Remarks

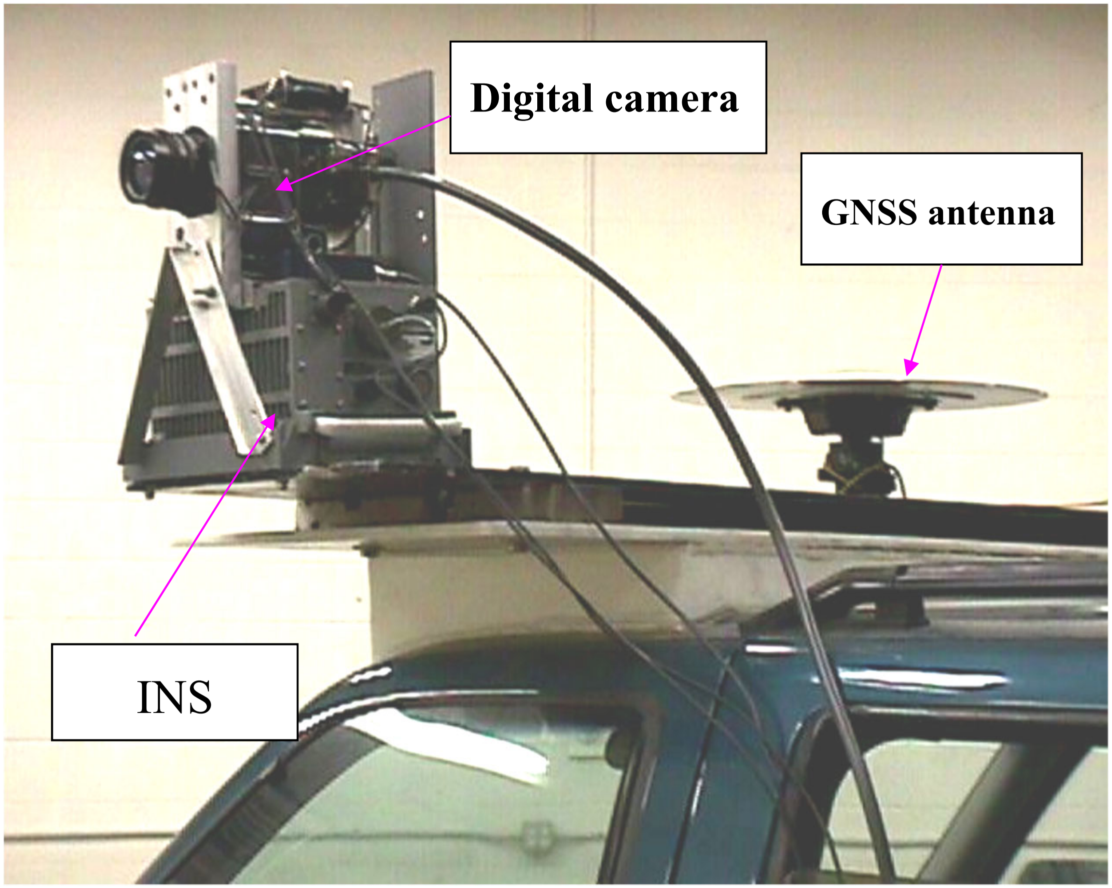
Georeferencing

- Exterior Orientation Parameters (EOP) define the position, $r_c^m(t)$, and orientation $R_c^m(t)$, of the camera/LiDAR coordinate system relative to the mapping reference frame at the moment of exposure.



Direct Georeferencing: Airborne System

Direct Georeferencing: Land-based System



Direct georeferencing in practice

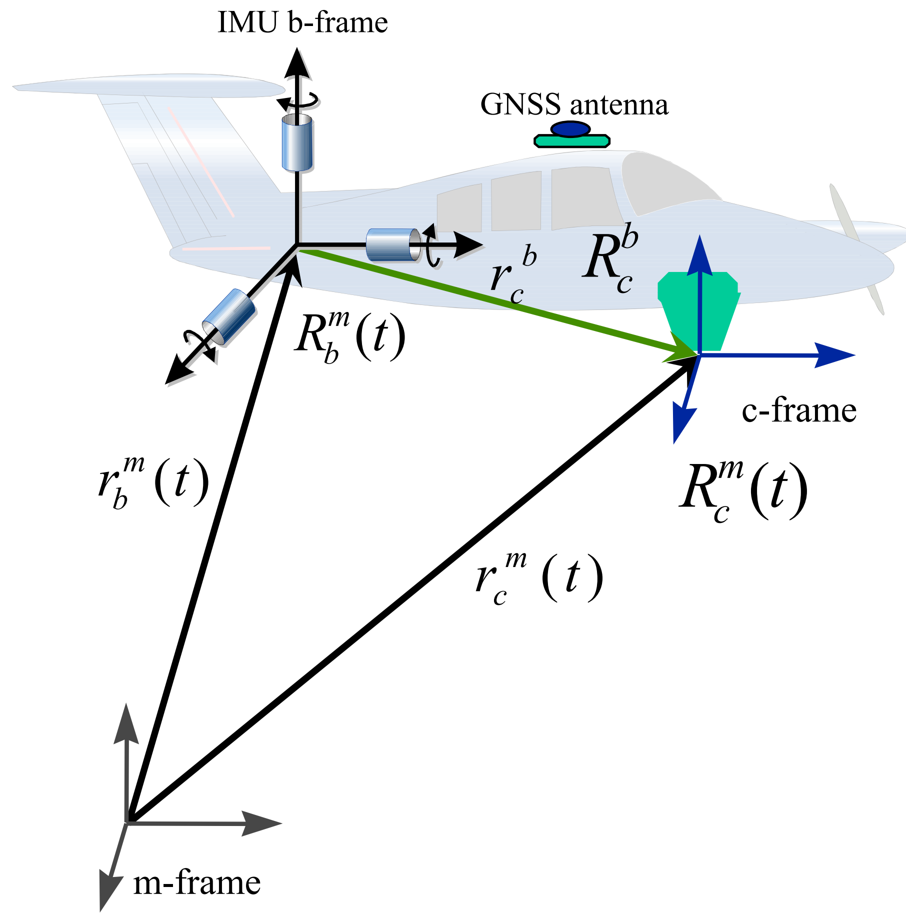
Direct Georeferencing

$$r_c^m(t) = r_b^m(t) + R_b^m(t)\, r_c^b$$

Camera position | GNSS/INS position | GNSS/INS attitude | Calibration

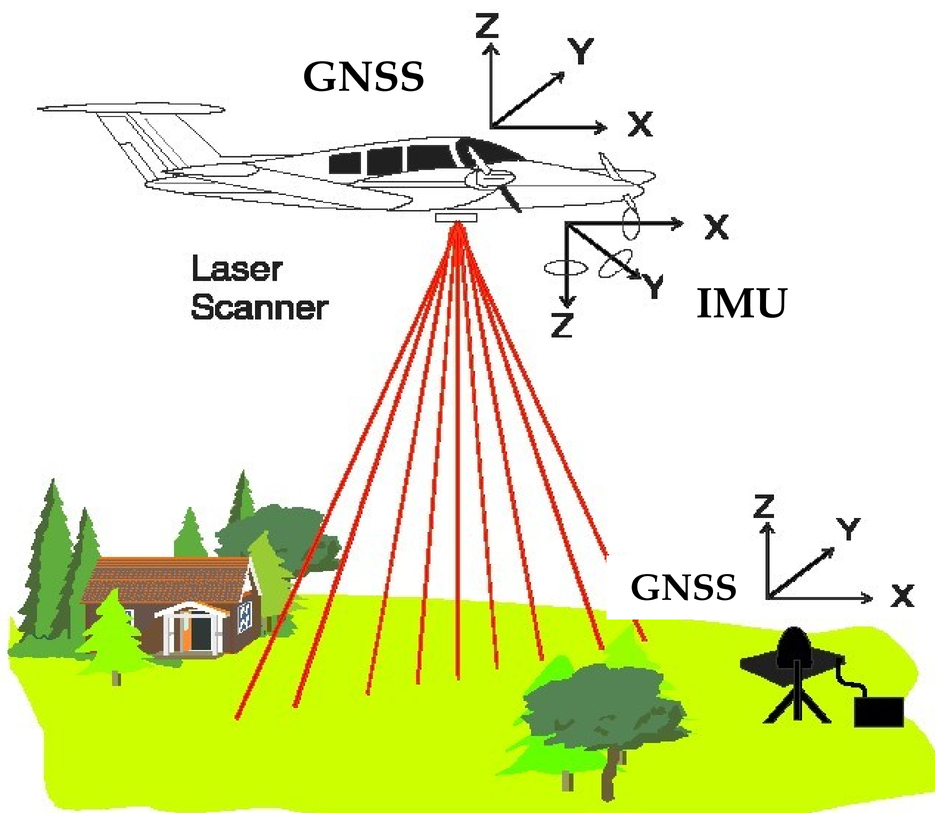
$$R_c^m(t) = R_b^m(t)\; R_c^b$$

Camera attitude | GNSS/INS attitude | Calibration



Airborne LiDAR Mapping

- Three Measurement Systems
  - GNSS
  - IMU
  - Laser scanner emits laser beams with high frequency and collects the reflections.



Kinematic Terrestrial Laser Scanning

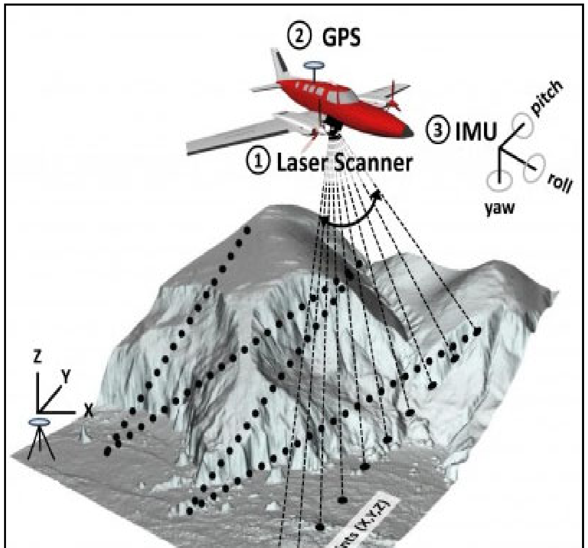
- Three Measurement Systems
  - GNSS
  - IMU
  - Laser scanner emits laser beams with high frequency and collects the reflections.

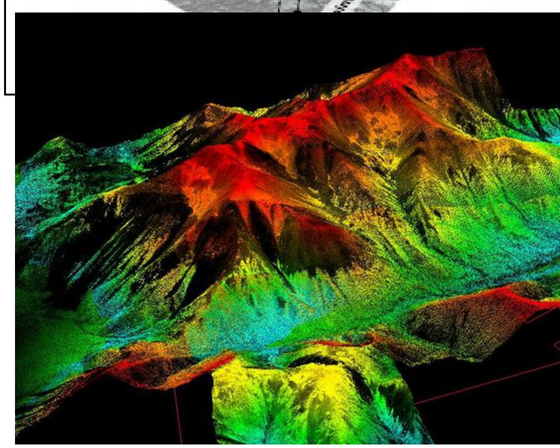
Chapter 3: Overview

- **<u>LiDAR Mapping Principles</u>**
- Passive versus active sensors
- LASER principles
- LiDAR principles
- LiDAR equation
- Error sources (systematic and random errors) & their impact
- LiDAR vs. photogrammetric mapping

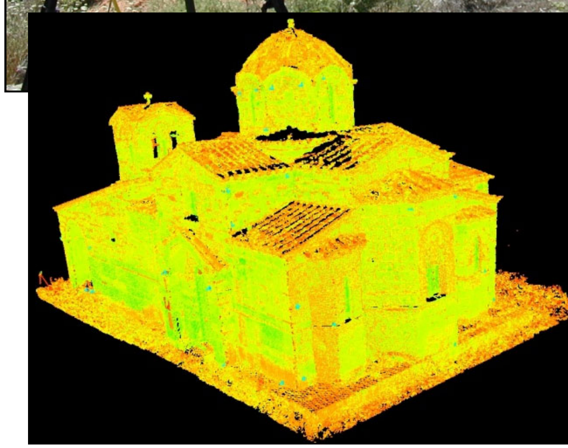
LiDAR Principles

Airborne Laser Scanning

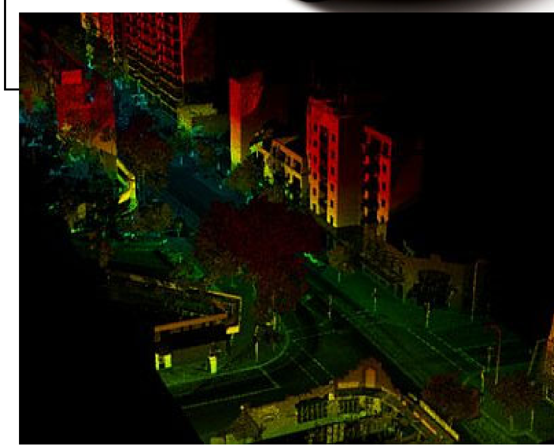




Static Terrestrial Laser Scanning



Kinematic Terrestrial Laser Scanning

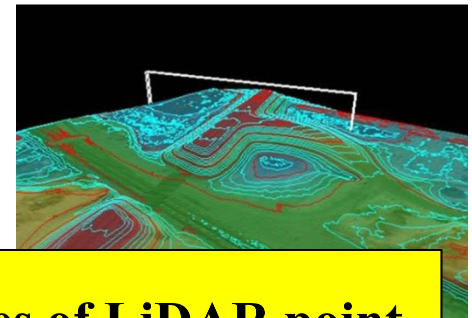


LiDAR Principles

LiDAR Principles

Heritage Documentation

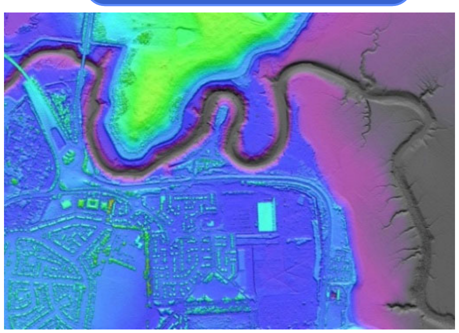
Transportation Planning



LiDAR Data

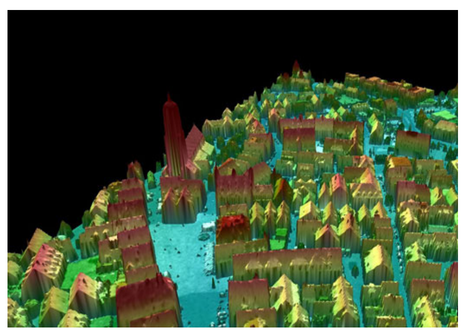
We need to understand the underlying principles of LiDAR point positioning and the factors that affect the quality of derived points.

Flood Plain Mapping



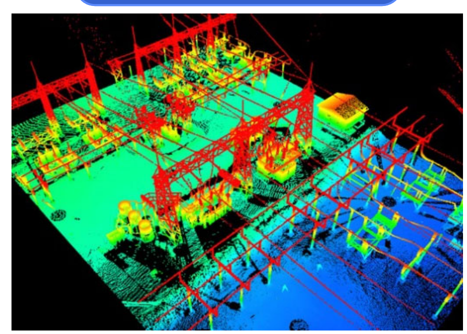
Source: www.maritimejournal.com

3D City Modeling



Source: www.trimble.com

Power Line Mapping



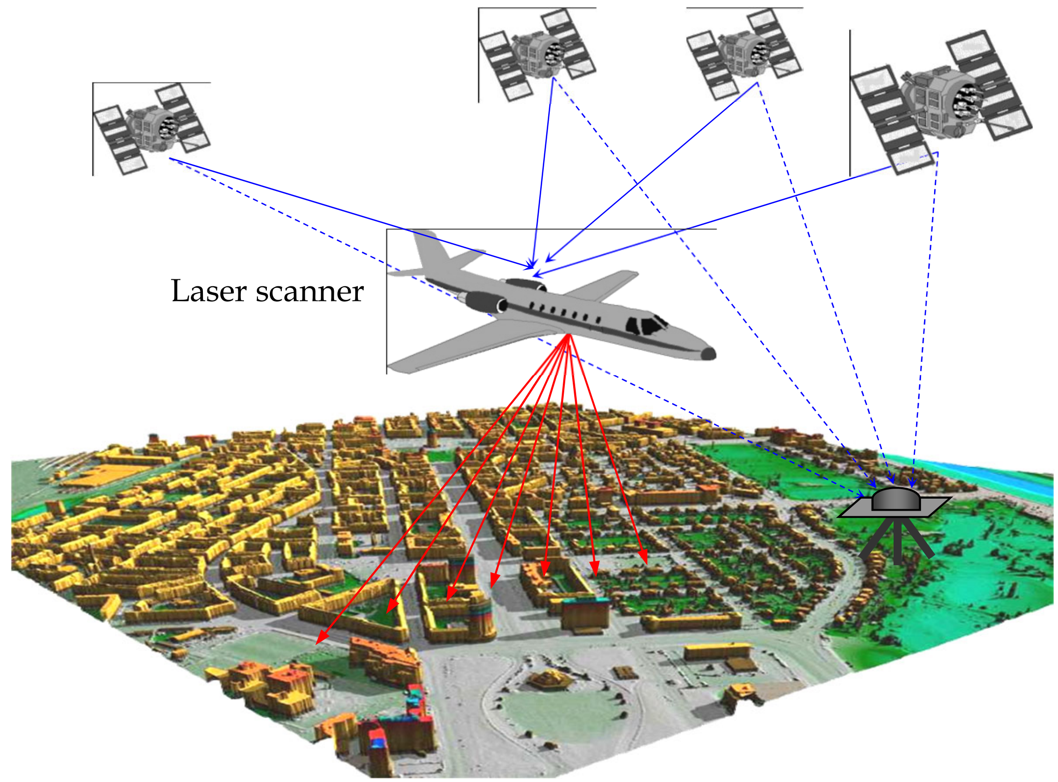
Source: www.merrick.com

Chapter 4: Overview

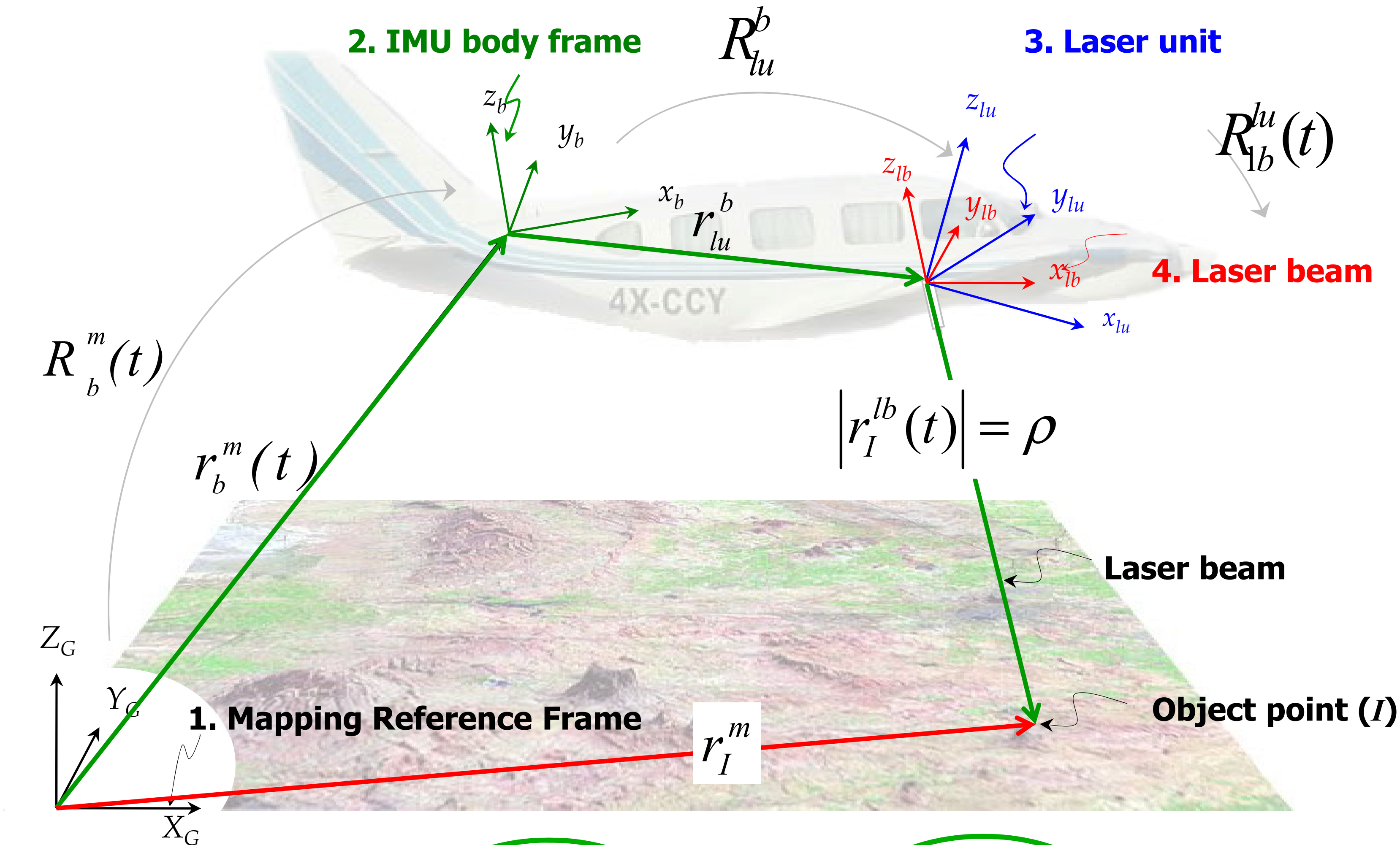
- **<u>Quality Assurance and Quality Control of LiDAR Mapping</u>**
- Motivation
- Quality Assurance (QA) and Quality Control (QC)
  - Introduction
  - Prerequisites
- QA/QC of Photogrammetric Mapping
- QA/QC of LiDAR Mapping:
  - LiDAR system calibration
  - Geometric validation of LiDAR data
- Concluding Remarks

LiDAR Quality Assurance

- QA activities/measures include:
  - Optimum mission time
  - Distance to GNSS base station
  - Flying height
  - Pulse repetition rate
  - Beam divergence angle
  - Scan angle
  - Percentage of overlap
  - System calibration

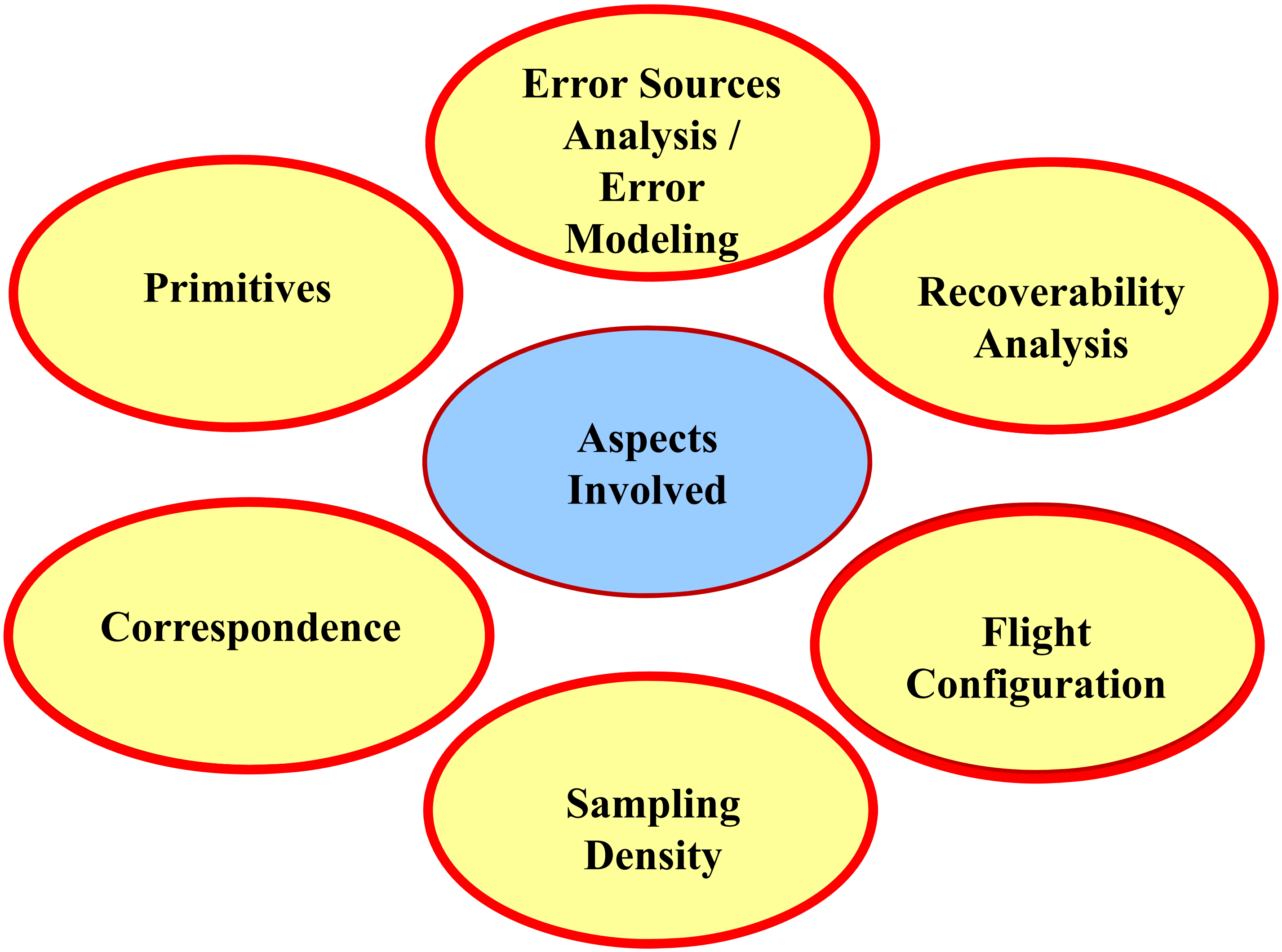


LiDAR QA: System Calibration

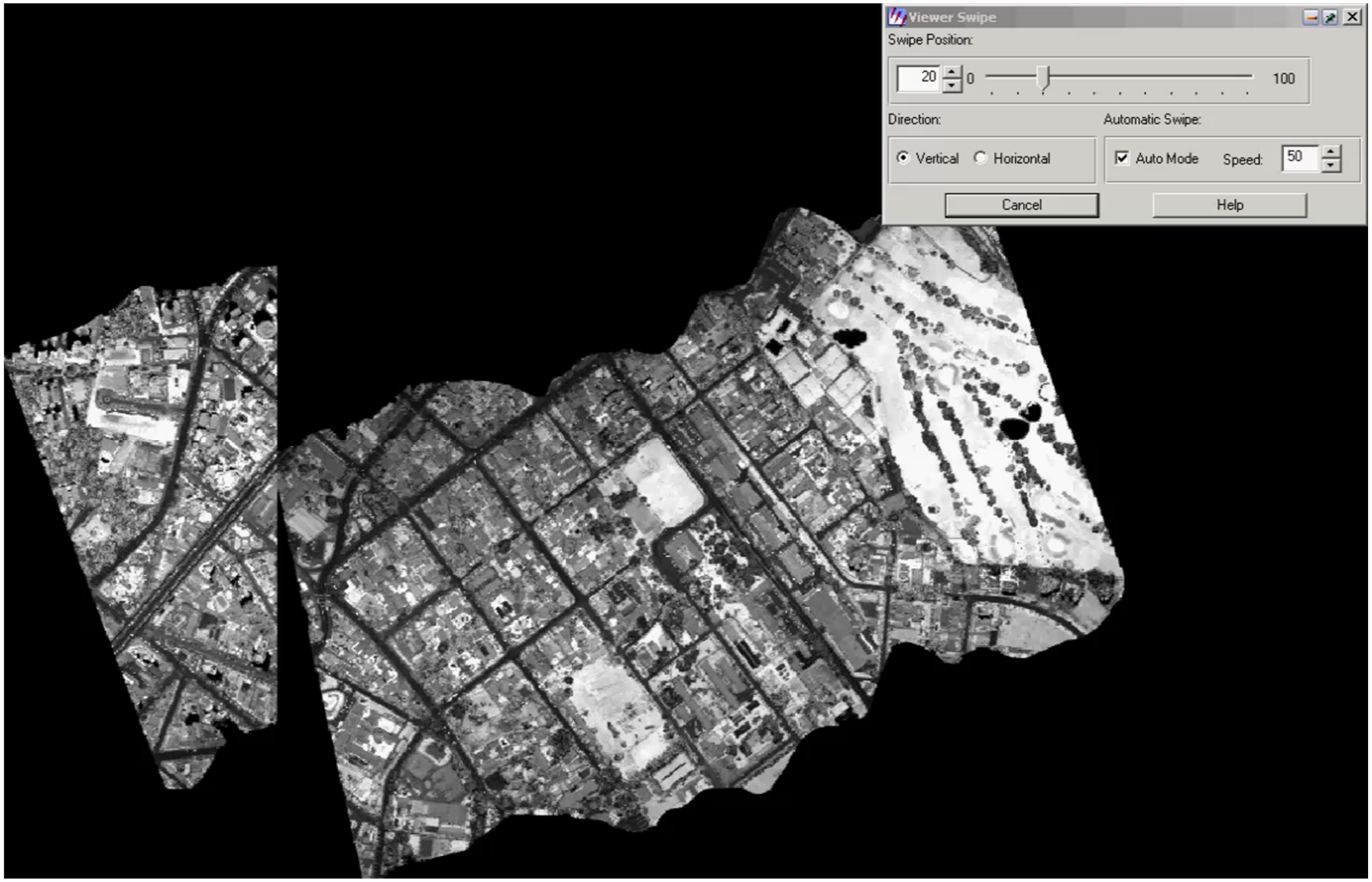


$$r_I^m = r_b^m(t) + R_b^m(t)\, r^b_{lu(\Delta X, \Delta Y, \Delta Z)} + R_b^m(t)\, R^b_{lu(\Delta\omega, \Delta\varphi, \Delta\kappa)}\, R^{lu}_{lb(S_\alpha \alpha, S_\beta \beta)}\, r^{lb}_{I(\rho, \Delta\rho)}$$

LiDAR QA: System Calibration

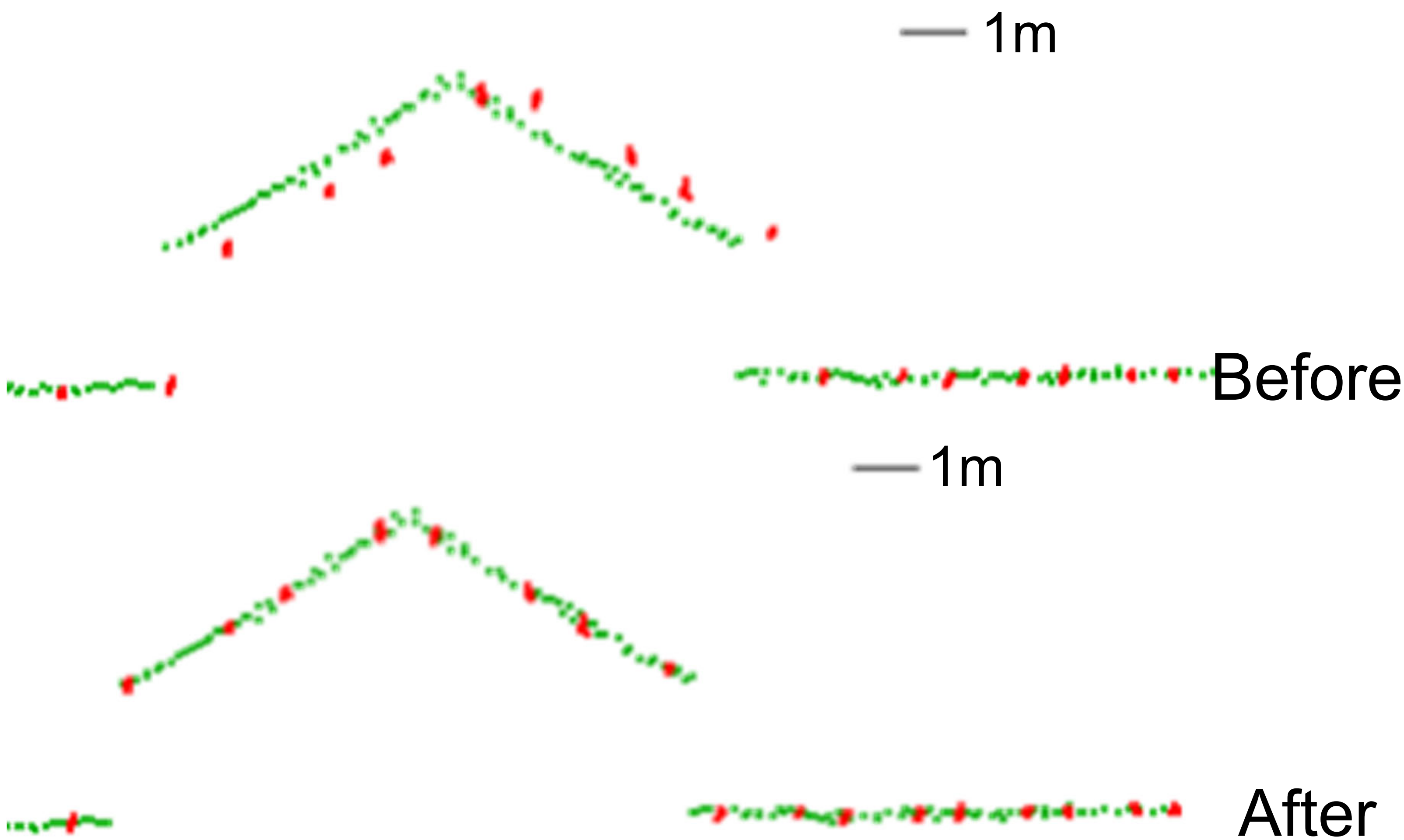


LiDAR Internal QC



LiDAR QA/QC

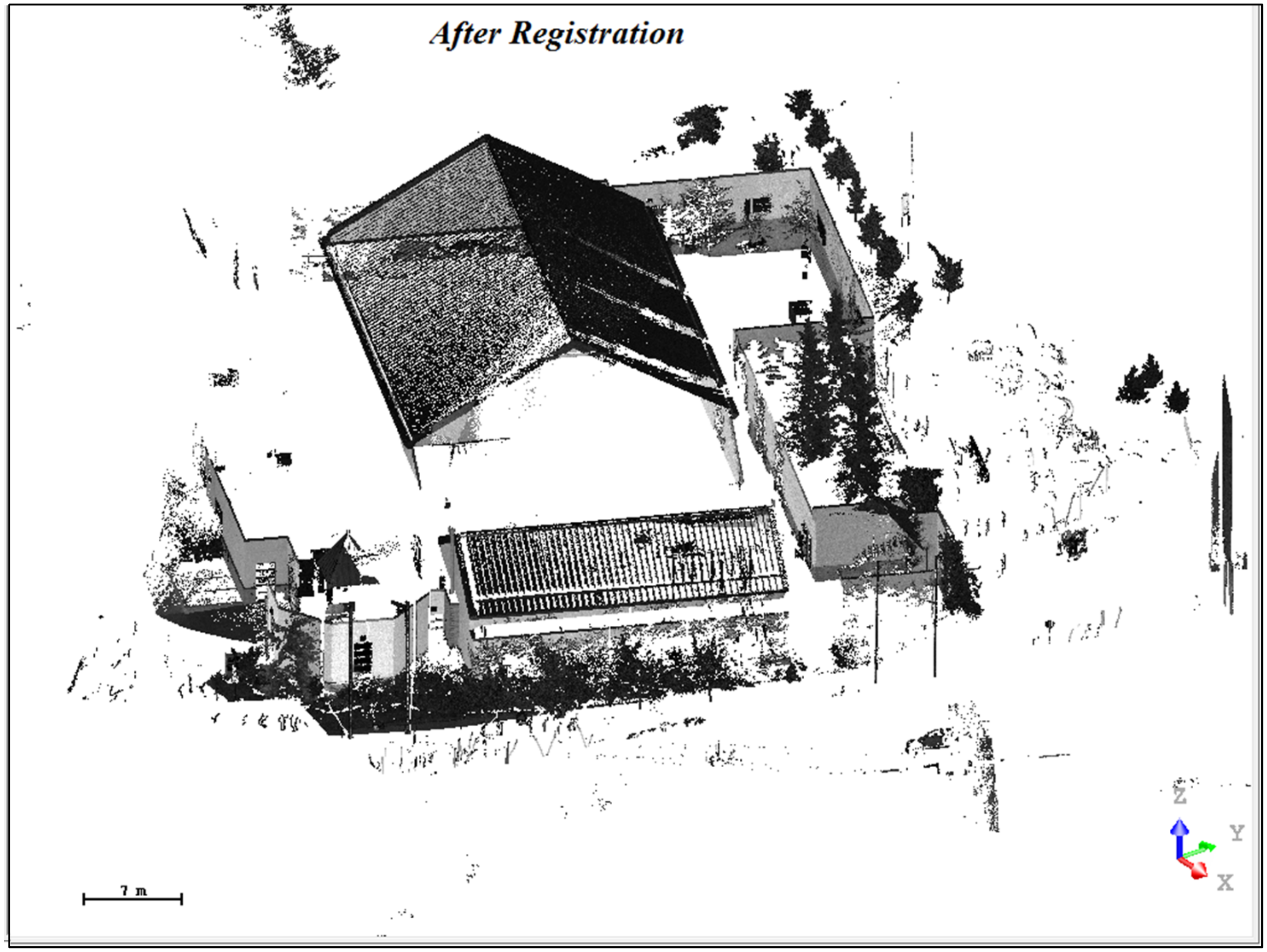
- Profile: AA'



Chapter 5: Overview

- **Registration of Laser Scanning Point Clouds**
- Introduction: Terrestrial Laser Scanners (TLS) and applications
- Prior work: Registration paradigm, point-based registration, feature-based registration
- Methodology: Linear features extraction, parameter estimation alternatives, matching process, and parameter refinement
- Experimental results: Segmentation and registration results
- Conclusions and future work

TLS Registration

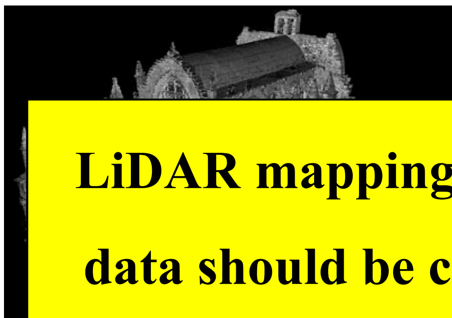


Chapter 6: Overview

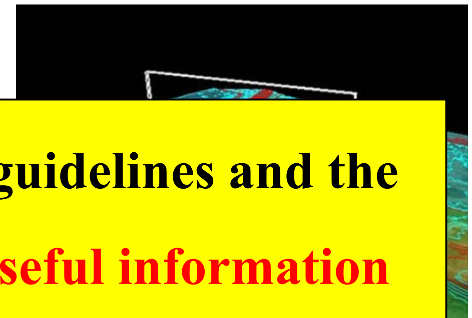
- **Adaptive Processing of LiDAR Data for Extracting Planar and Linear Features**
- LiDAR Mapping Principles
- LiDAR Data Characterization
  - Local Point Density (LPD) Estimation
- Planar & Linear Feature Segmentation
  - Spatial-Domain Segmentation
  - Parameter-Domain Segmentation
  - Quality Control of the Segmentation Outcome
- Concluding Remarks
- Current & Future Work

LiDAR Mapping

Heritage Documentation

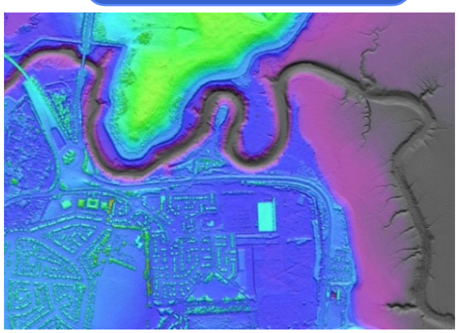


Transportation Planning



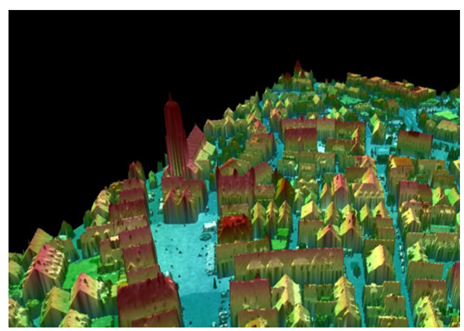
LiDAR mapping should have reliable QA/QC guidelines and the data should be carefully processed to extract useful information for these applications.

Flood Plain Mapping



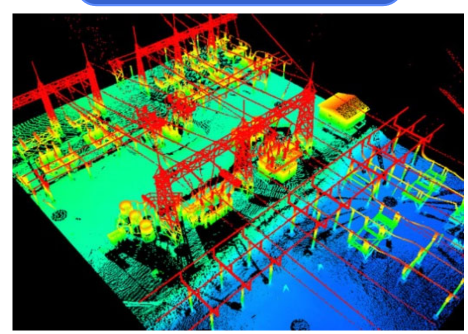
Source: www.maritimejournal.com

3D City Modeling



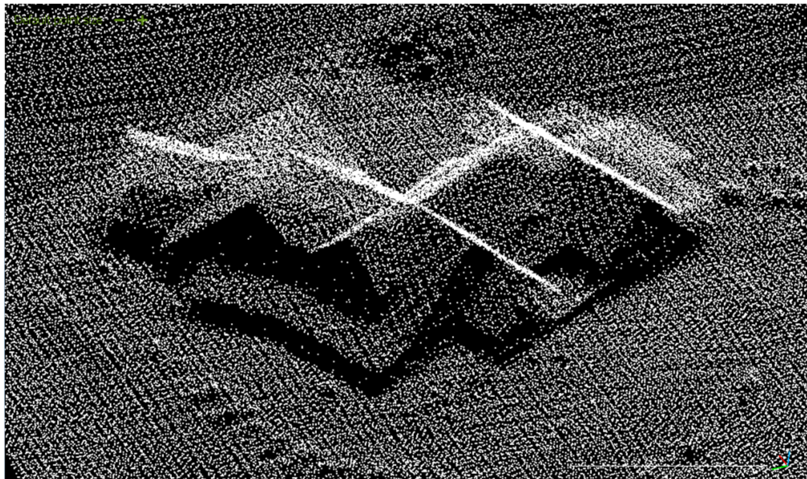
Source: www.trimble.com

Power–Line Mapping

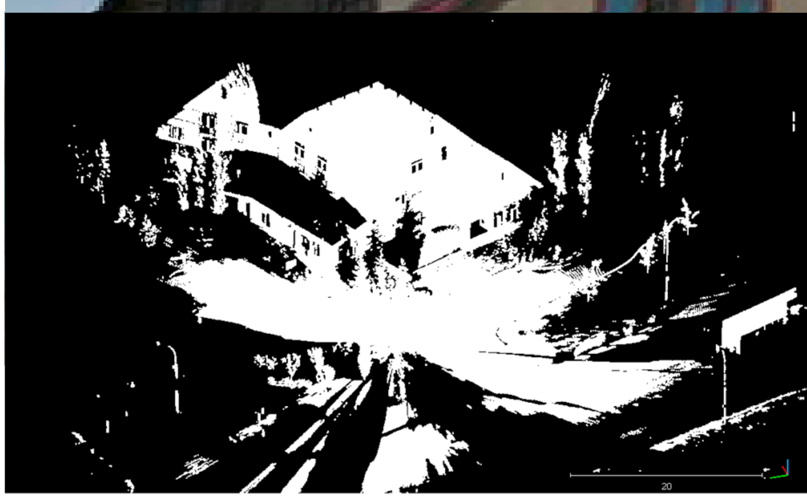


Source: www.merrick.com

LiDAR Mapping: Ultimate Goal



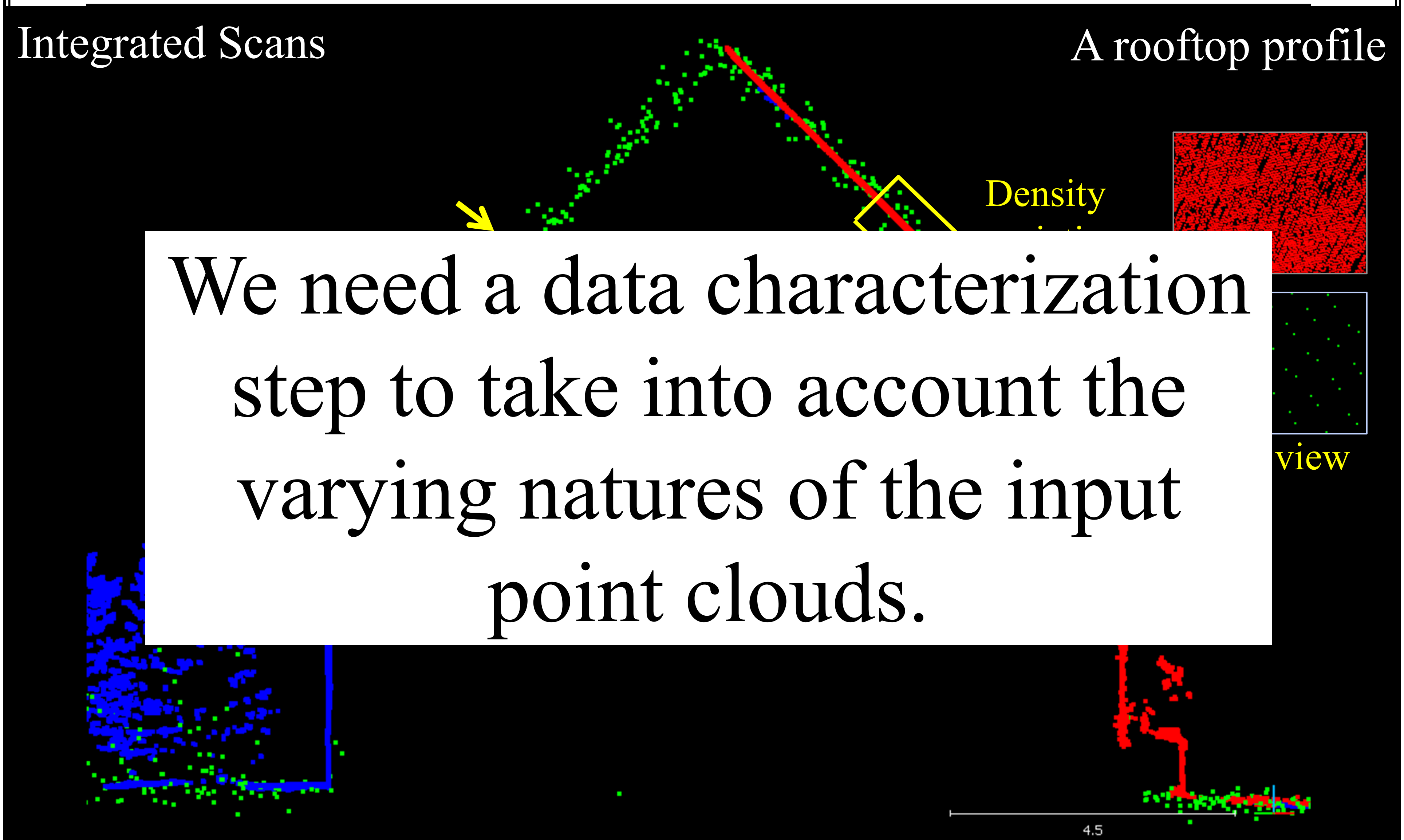
Airborne scan



Terrestrial scan

Combined and segmented scans

LiDAR Mapping: Ultimate Goal



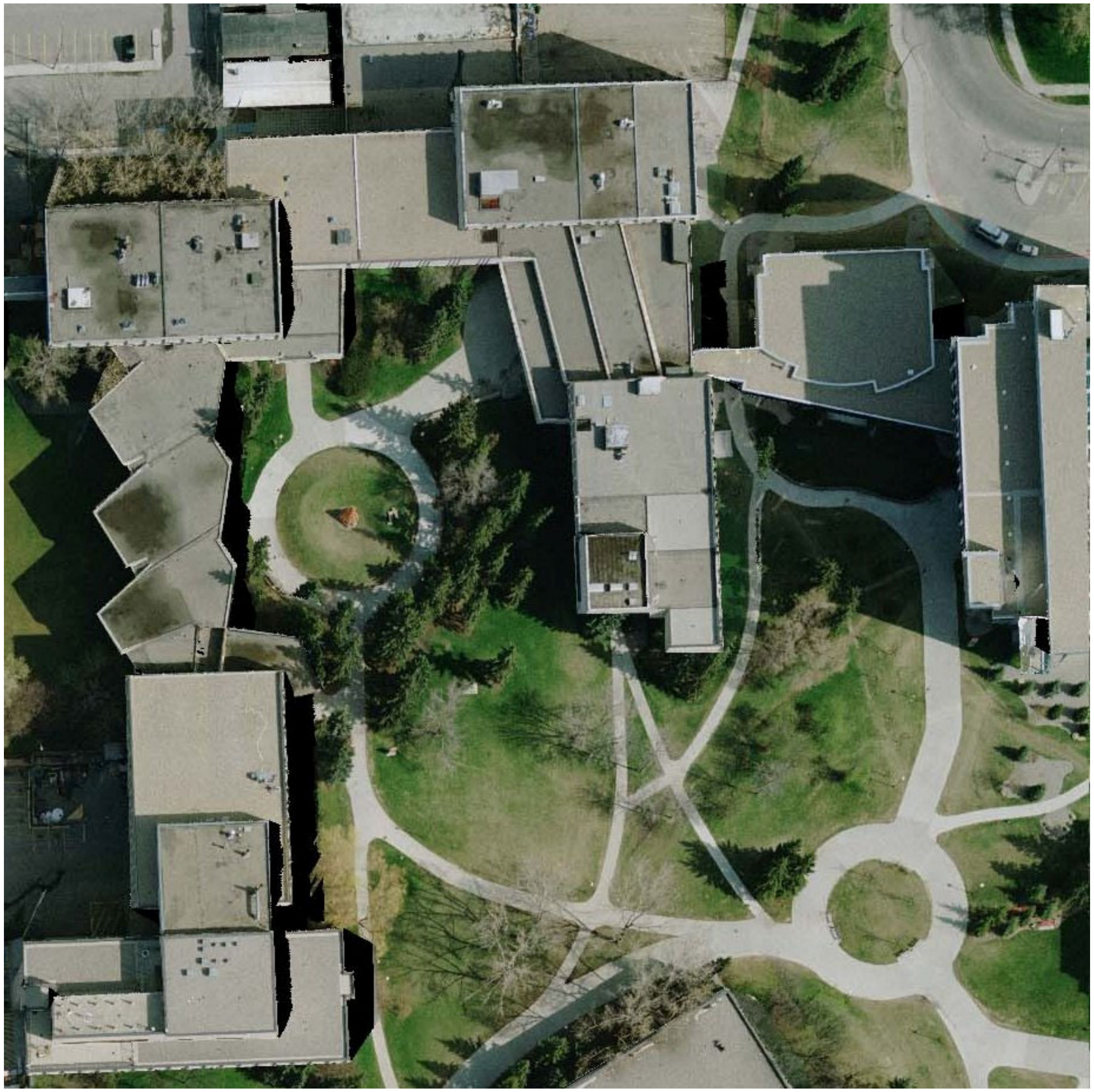
We need a data characterization step to take into account the varying natures of the input point clouds.

Chapter 7: Overview

- **<u>Occlusion-based Procedure for True Orthophoto Generation and LiDAR Data Classification</u>**
- Introduction
- Orthophoto generation
  - Literature review
  - Procedure
- LiDAR data classification
  - Literature review
  - Procedure
  - Experimental results
- Concluding remarks

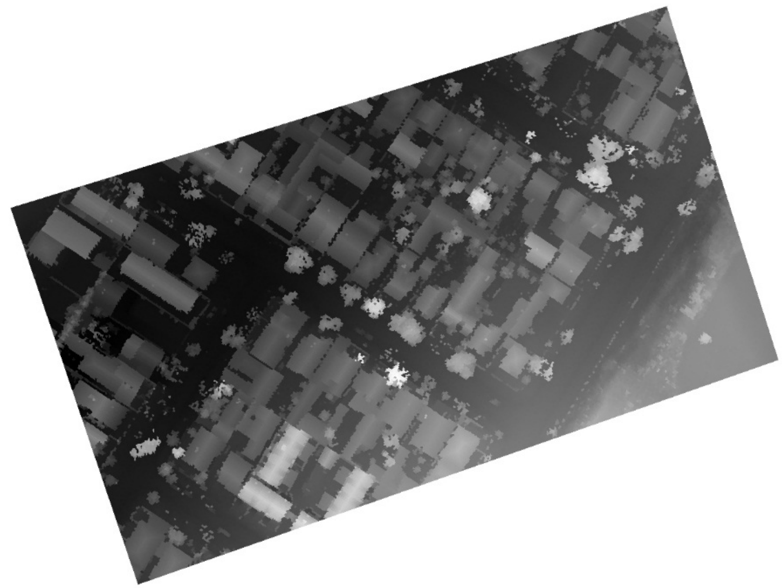
Perspective Image

Orthophoto



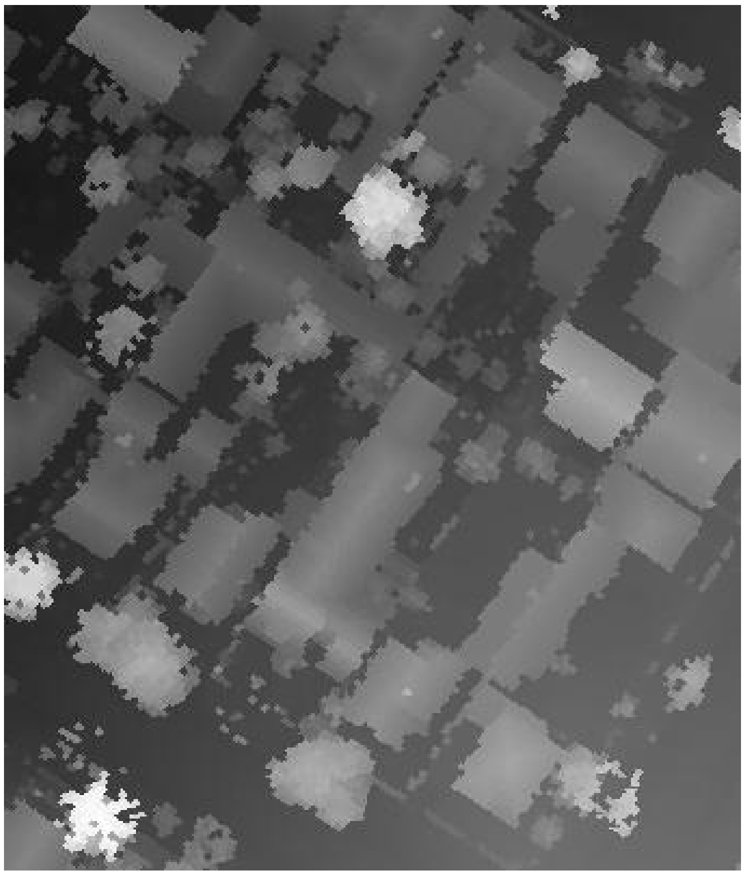
LiDAR Classification

Original Image



LiDAR DSM

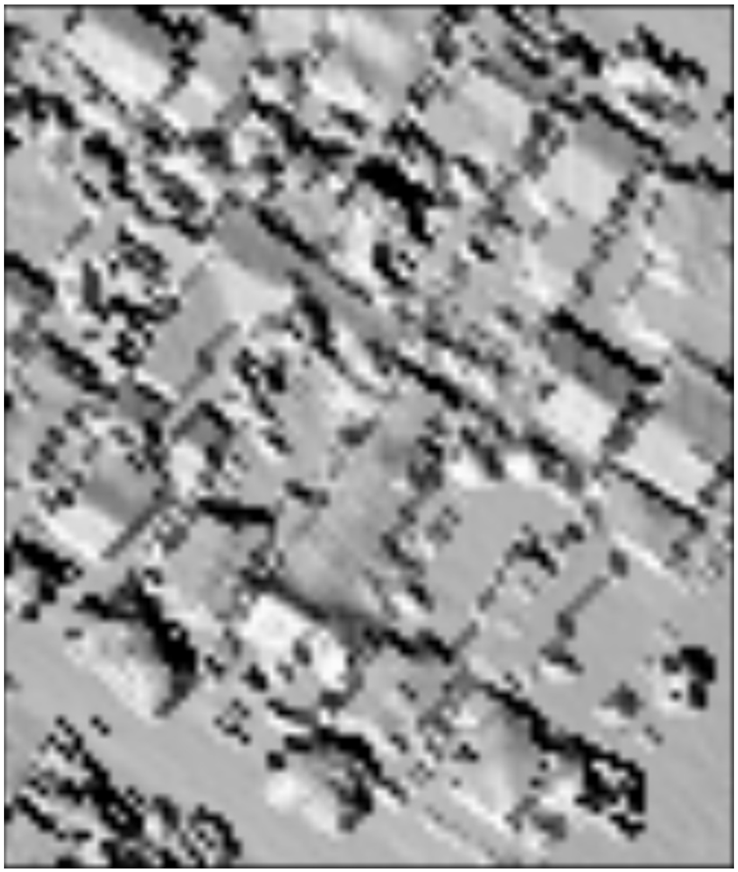
LiDAR Classification



Original DSM

Off-ground Points

LiDAR Classification



Original DSM

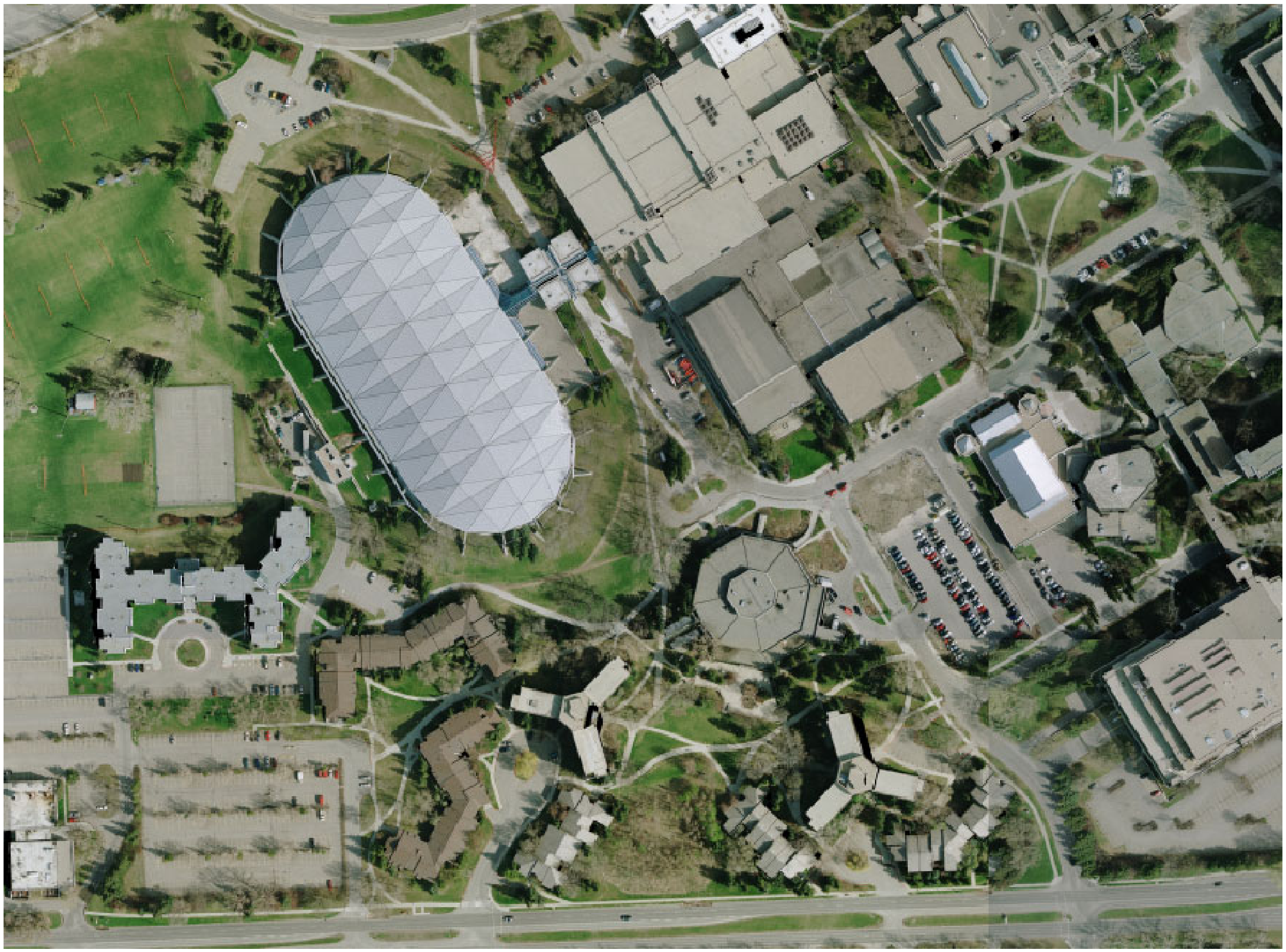
Derived DTM

Chapter 8: Overview

- **Automatic Detection and Reconstruction of Right-Angled-Corner Buildings**
- Introduction
- Existing DBM Generation Methodologies
- Research Objectives
- Proposed Methodology
- Experimental Results
- Concluding Remarks
- Current & Future Work

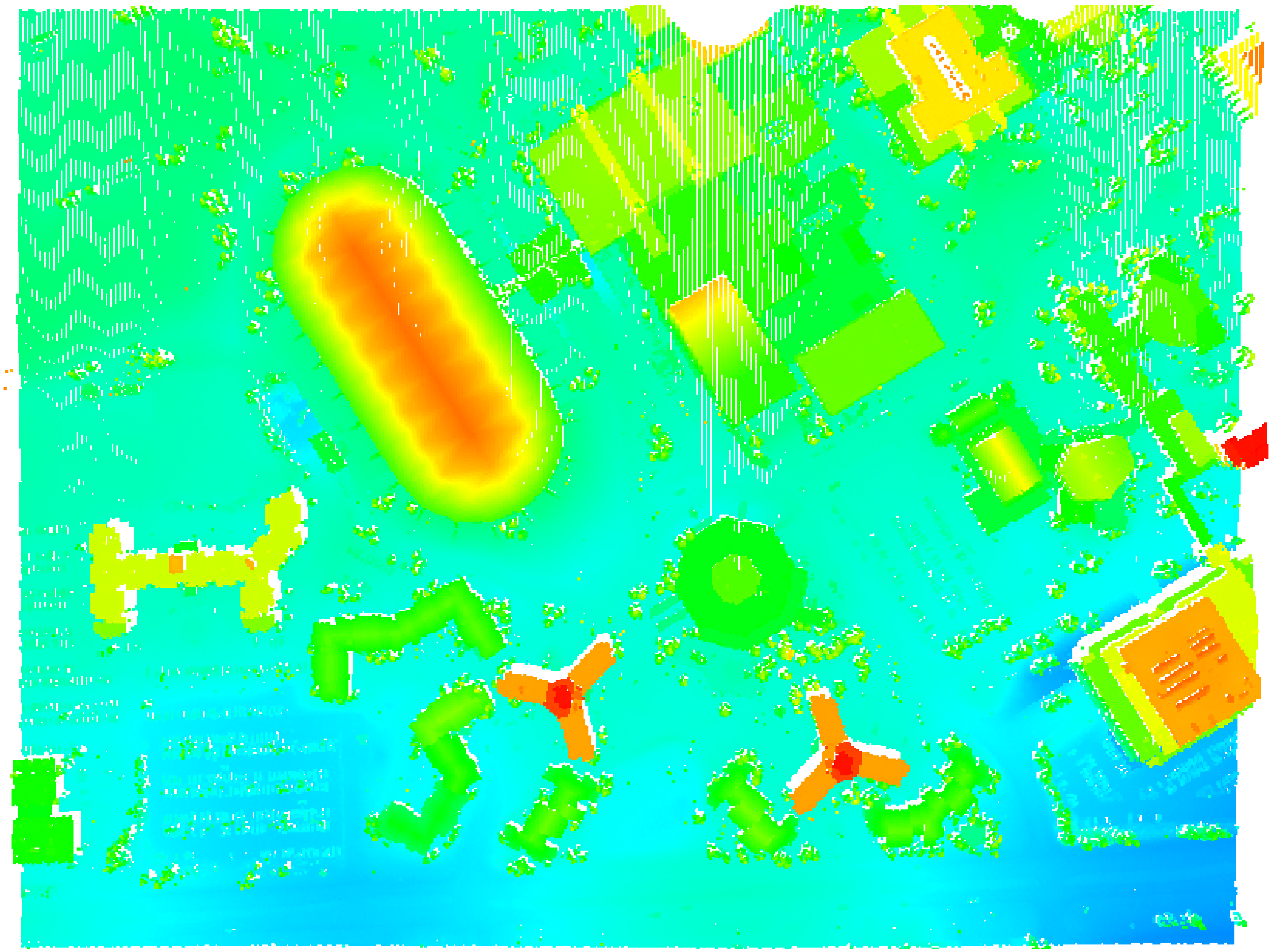
DBM Generation

- Orthophoto over the test area

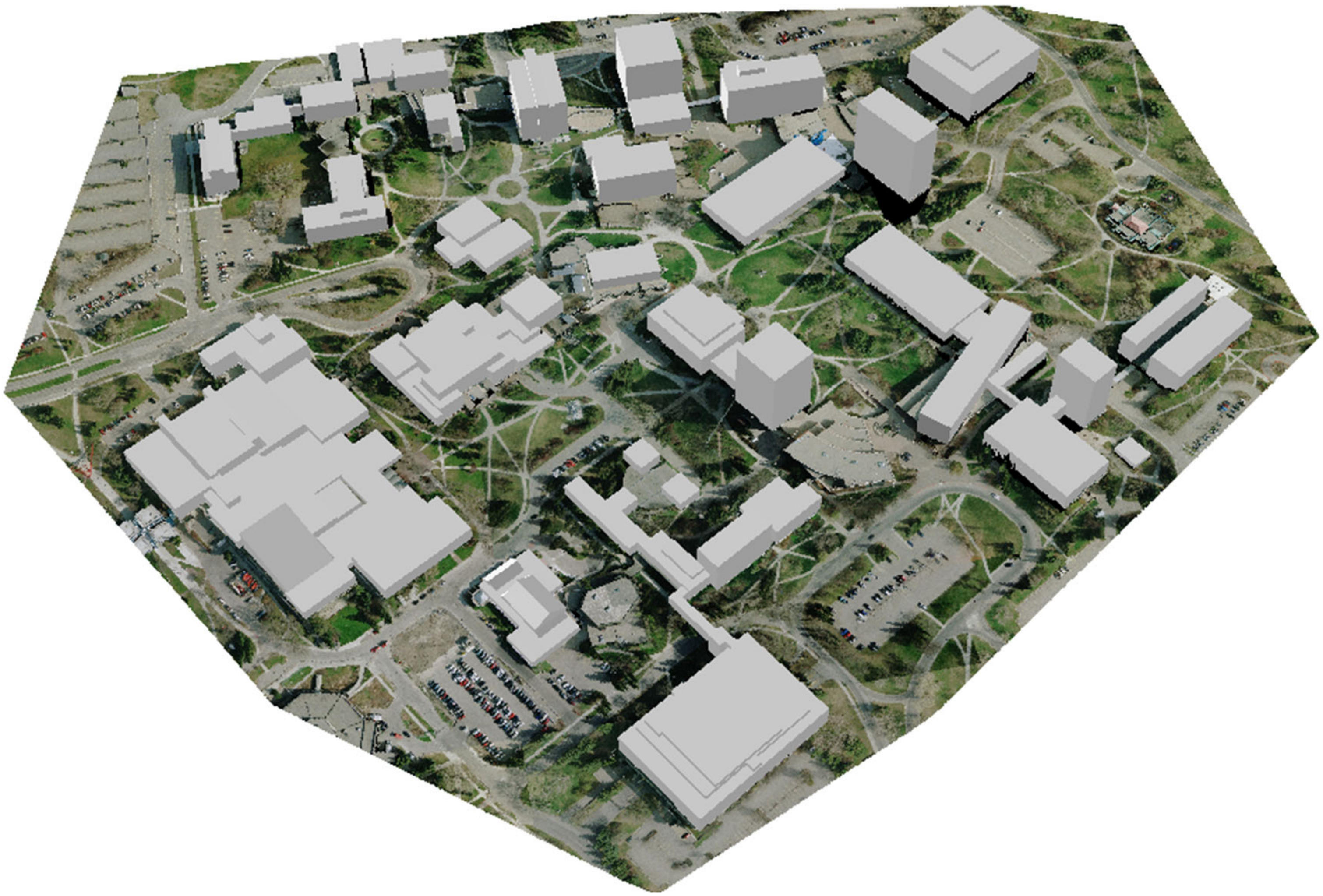


DBM Generation

- Original LiDAR data



Realistic 3D Modeling / Visualization



Suggested Project Topics

- Structuring/organization/query of point cloud data:
  - Kd-tree data structure
  - Octree data structure
  - Approximate Nearest Neighbor Search (ANN)
- LiDAR point positioning:
  - Pulse-based Time-of-Flight (ToF) systems
  - Phase-shift-based Time-of-Flight (ToF) systems
  - Triangulation-based systems
- LiDAR system calibration:
  - Airborne system calibration
  - Mobile terrestrial system calibration
  - Static terrestrial system calibration

Suggested Project Topics

- Quality control of the LiDAR point positioning
  - Point-based QC procedures
  - Feature-based QC procedures
  - Internal versus external QC procedures
- Classification of point cloud data:
  - Terrain/off-terrain classification
  - Planar, pole-like, and rough feature (local neighborhood) classification
- Segmentation of point cloud data:
  - Spatial-domain segmentation
  - Parameter-domain segmentation
  - Hybrid segmentation approaches
  - Quality control of the segmentation outcome

Suggested Project Topics

- LiDAR data characterization:
  - Local point density estimation
  - Noise level evaluation
- Down-sampling LiDAR data:
  - Random down-sampling
  - Distance-based down-sampling
  - Adaptive down-sampling
- Registration of LiDAR data:
  - Coarse-based registration
  - Fine-based registration
  - Point-based registration
  - Feature-based registration
  - Heterogeneous data registration

Suggested Project Topics

- Integration of LiDAR and image data:
  - True orthophoto generation
  - Point-based color-coding of LiDAR data
  - Feature-based texturing of LiDAR data
  - Object detection and extraction (e.g., Digital Building Model – DBM – generation)
- LiDAR versus 3D range cameras
- LiDAR systems:
  - Discrete systems
  - Waveform LiDAR
  - Photon-counting LiDAR
  - Flash LiDAR

Suggested Project Topics

- LiDAR applications:
  - Flood plain mapping
  - Heritage documentation
  - 3D-city modeling
  - Power-line mapping
  - Transportation planning
- LiDAR versus photogrammetric mapping:
  - Operational principles
  - Point-positioning alternatives
  - Characteristics
  - System calibration alternatives
  - Quality control procedures
  - Pros/cons

Suggested Project Topics

- Unique point extraction from LiDAR data:
  - 3D point descriptors
  - 3D SIFT
  - Spin images

- Note: The above list is just provided as suggested topics.
  - Other related topics are welcome.

Suggested Project Topics

- The project should have a good balance between literature review and implementation.
- For each of the suggested topics, group projects are permitted. If applicable, the following should be discussed.
  - Technical details of the individual approaches
  - Pros/cons of the individual approaches
  - Comparative evaluation of the performance of the different approaches
- The project (team, if applicable) selection should be finalized by Friday, January 24th.