

# AeroTraj:

Trajectory Planning for Fast, and Accurate 3D Reconstruction Using a Drone-based LiDAR

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# 3D Reconstruction



3D Model

Process of building 3D models

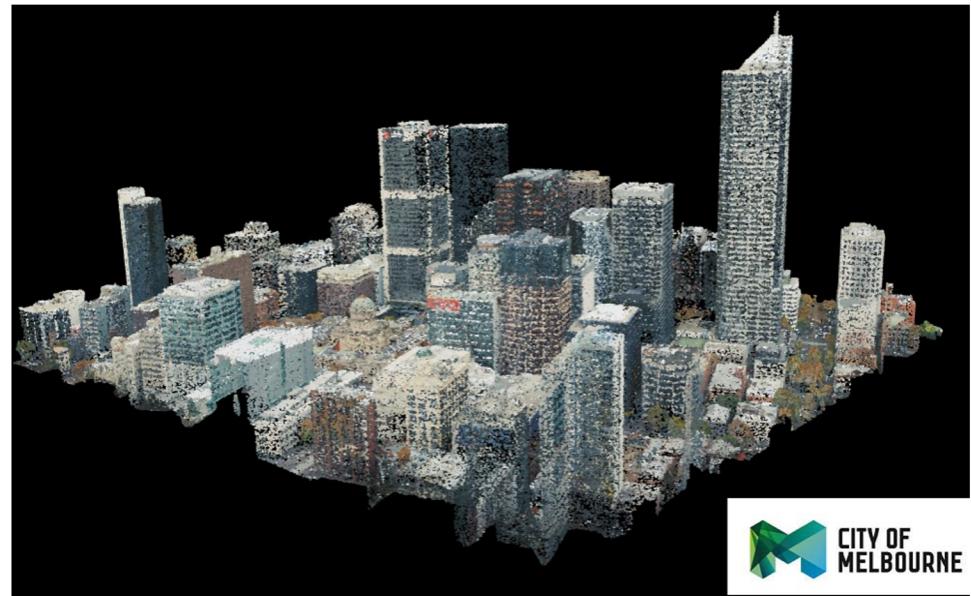
3D representation of the world

# 3D Model Representations

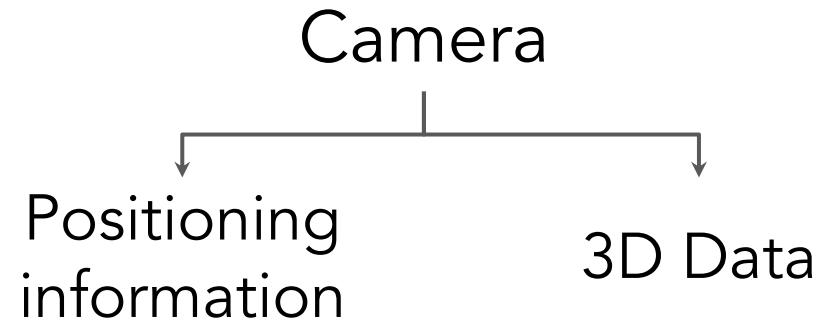
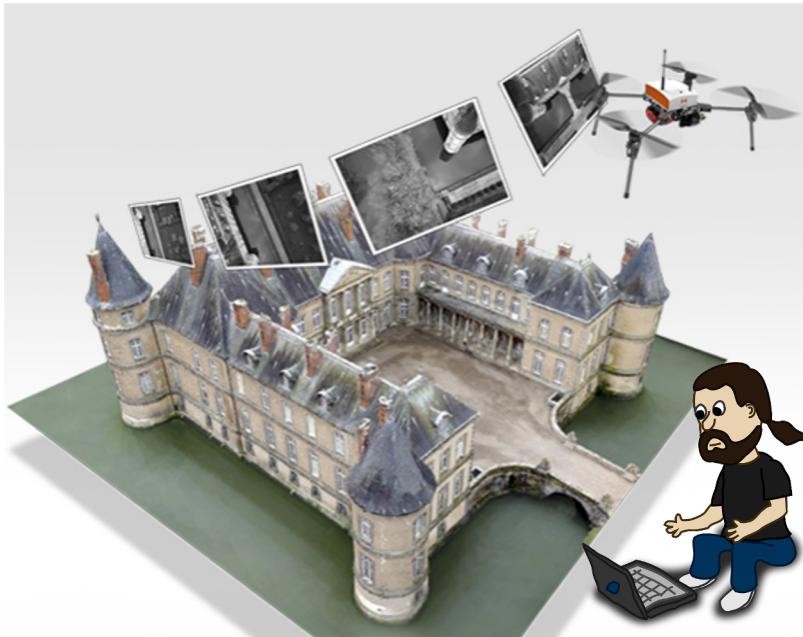
## 3D Point Cloud

Points:

- 3D position (x, y, and z)
- Intensity
- Color (RGB)

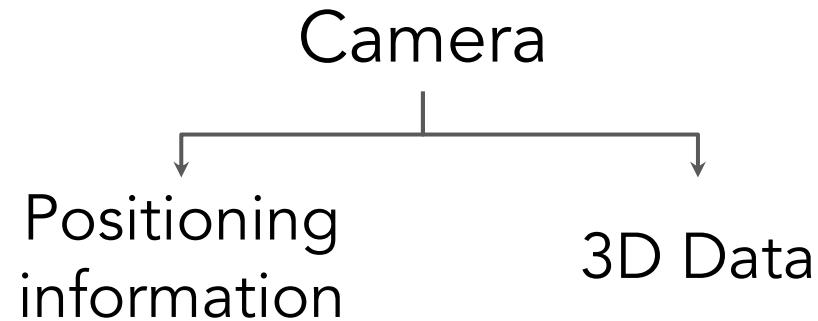
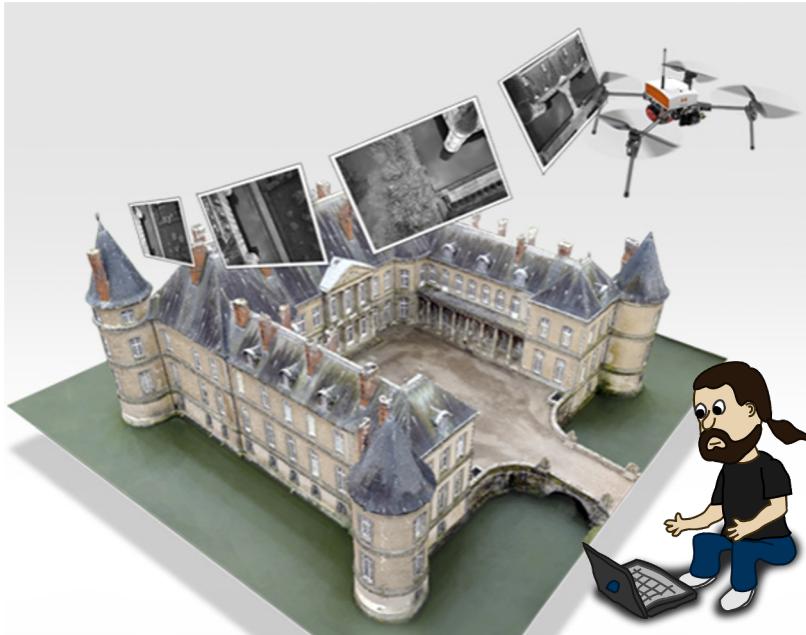


# Photogrammetry



\* ICRA 2015, CVPR 2016, ICRA 2017, ISPRS 2017

# Photogrammetry: Shortcomings



Slow & offline

Human-in-the-loop

Inaccurate reconstruction

\* ICRA 2015, CVPR 2016, ICRA 2017, ISPRS 2017

# Our Goal

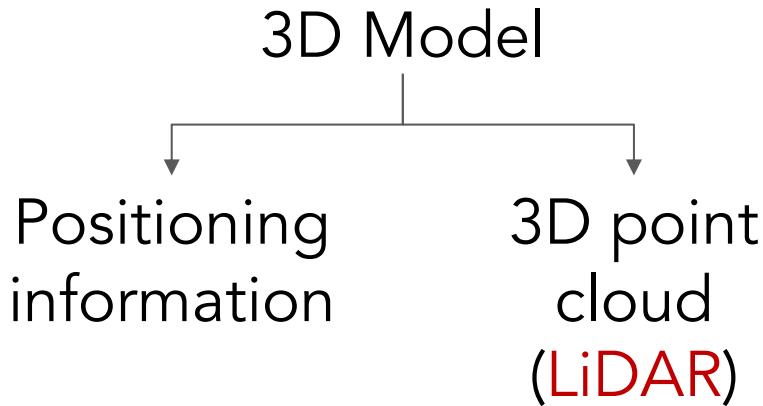
Automated, Fast, and Accurate 3D Reconstruction

# Fast 3D Reconstruction



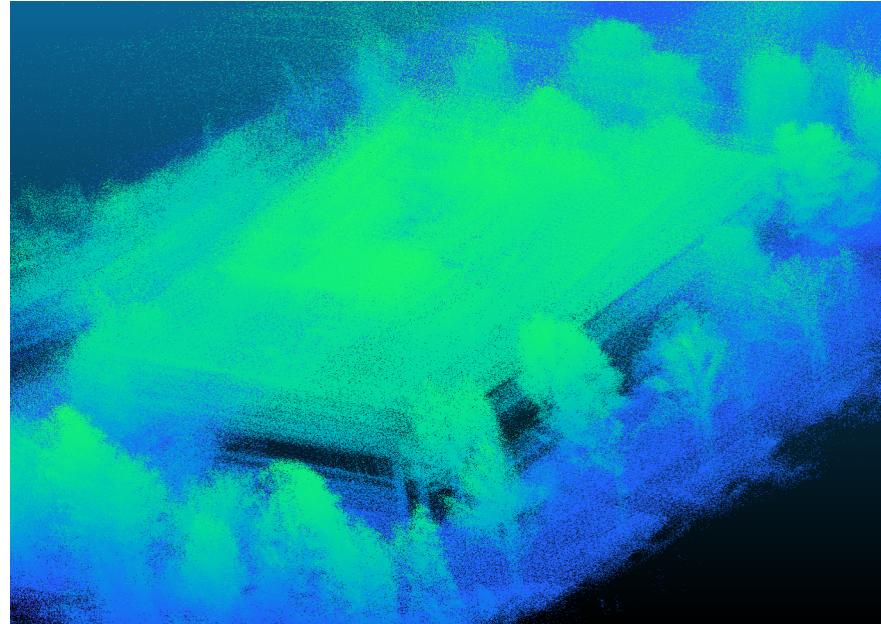
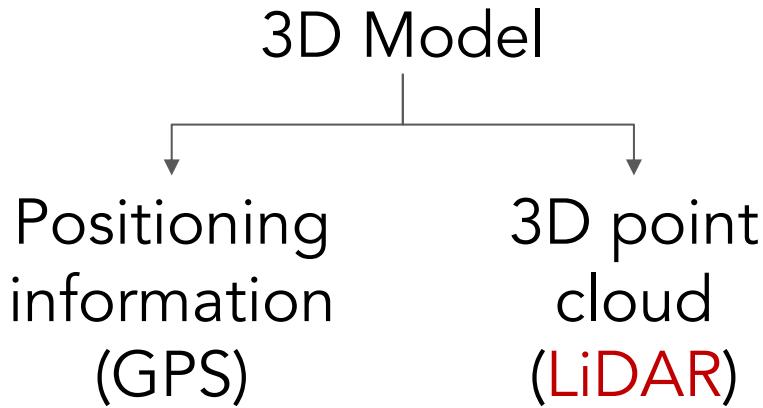
Building to reconstruct

# Fast 3D Reconstruction



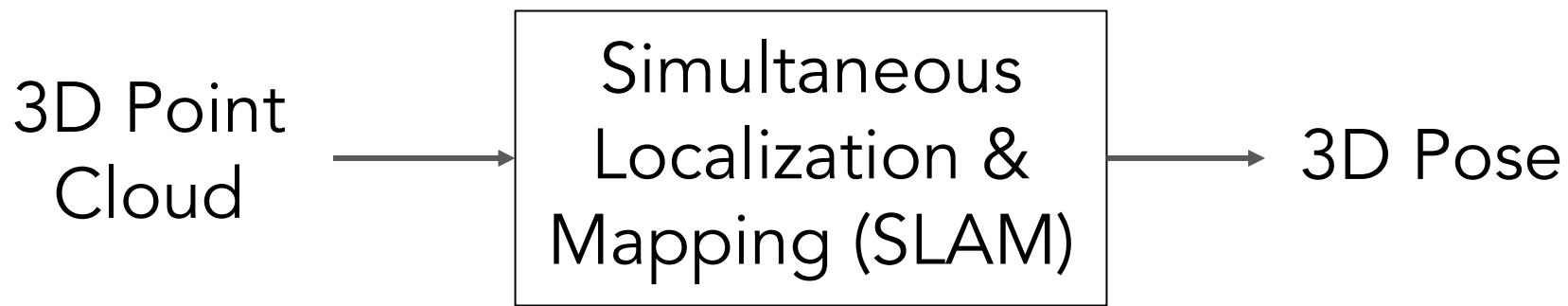
Building to reconstruct

# Fast, and Accurate 3D Reconstruction

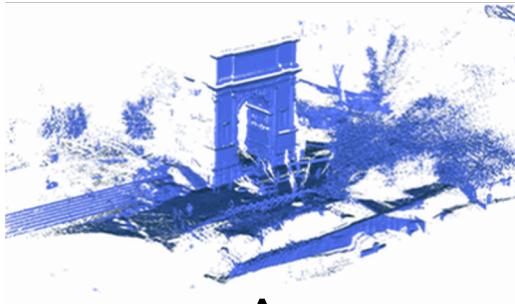


Fuzzed 3D Model with GPS

# SLAM for Positioning



# SLAM for Positioning



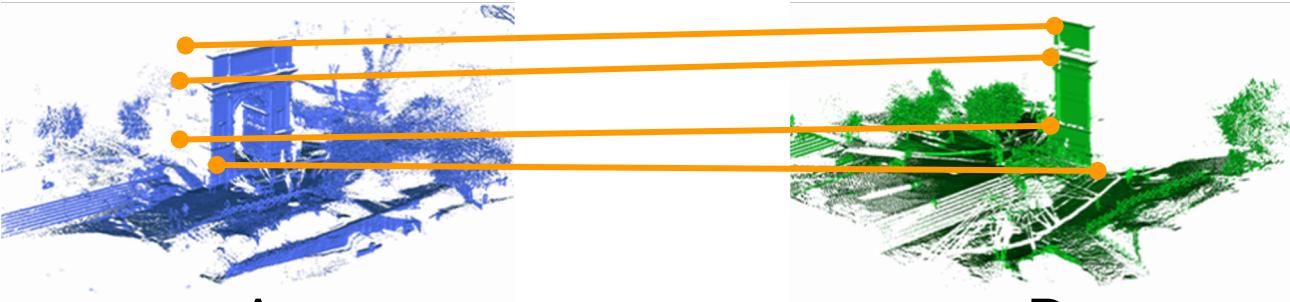
A



B

Aligning 3D point clouds

# SLAM for Positioning



$T_1 = \text{Align}(A, B)$

A

B

Aligning 3D point clouds

# SLAM for Positioning

$T_1 = \text{Align} (A, B)$

A

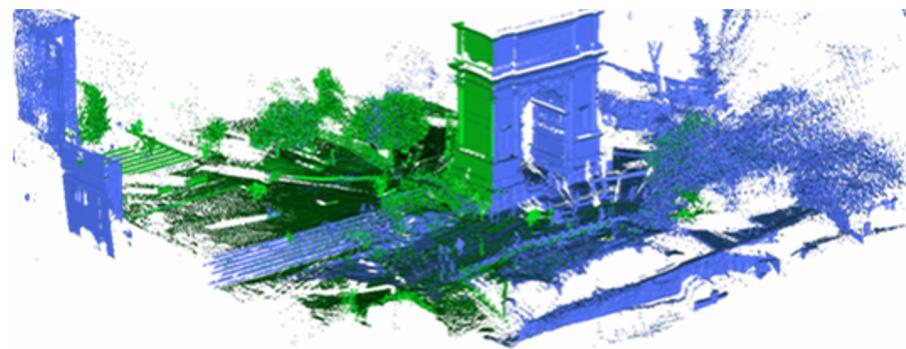
B

$$Z = A + T_1 * B$$

# SLAM for Positioning



$T_1 = \text{Align} (A, B)$       A



$$Z = A + T_1 * B + T_2 * C + T_3 * D$$

# Challenges

Challenge	Mechanism
Limited compute	
Limited battery	
SLAM positioning	

# SLAM Positioning: A Drone's Perspective

## Vehicle LiDAR SLAM



Whole point cloud

# SLAM Positioning: A Drone's Perspective

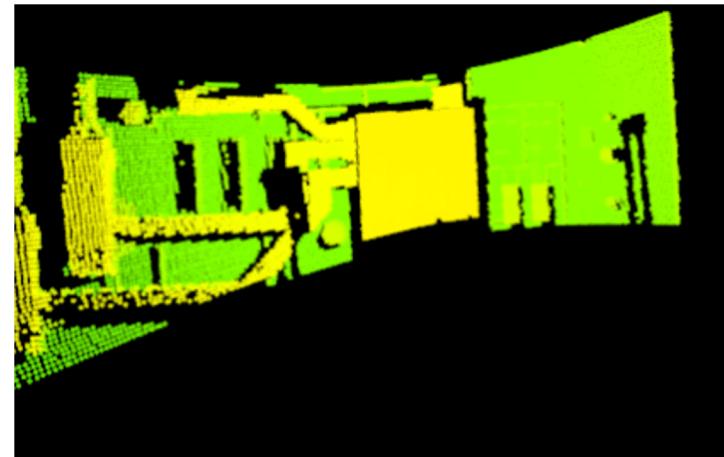
Challenging to align sparse point clouds

Vehicle LiDAR SLAM



Whole point cloud

Drone LiDAR SLAM



9% of the point cloud

# AeroTraj: Fast, and Accurate 3D Reconstruction

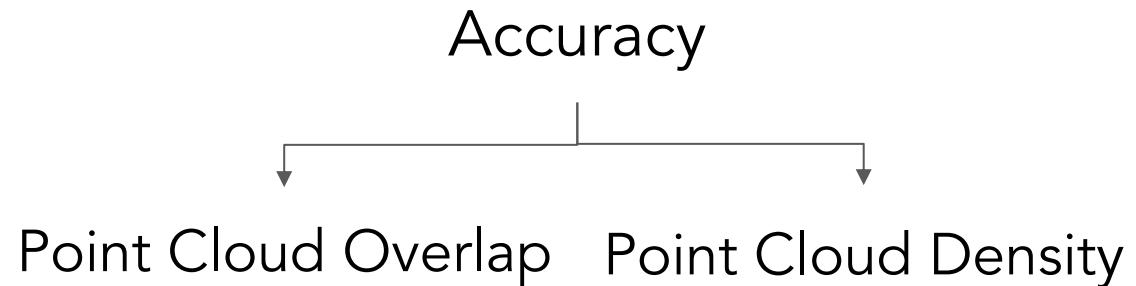
Input	Area of Interest Reconstruction LoD
Output	3D Model at LoD

\*LoD (Level of Detail)

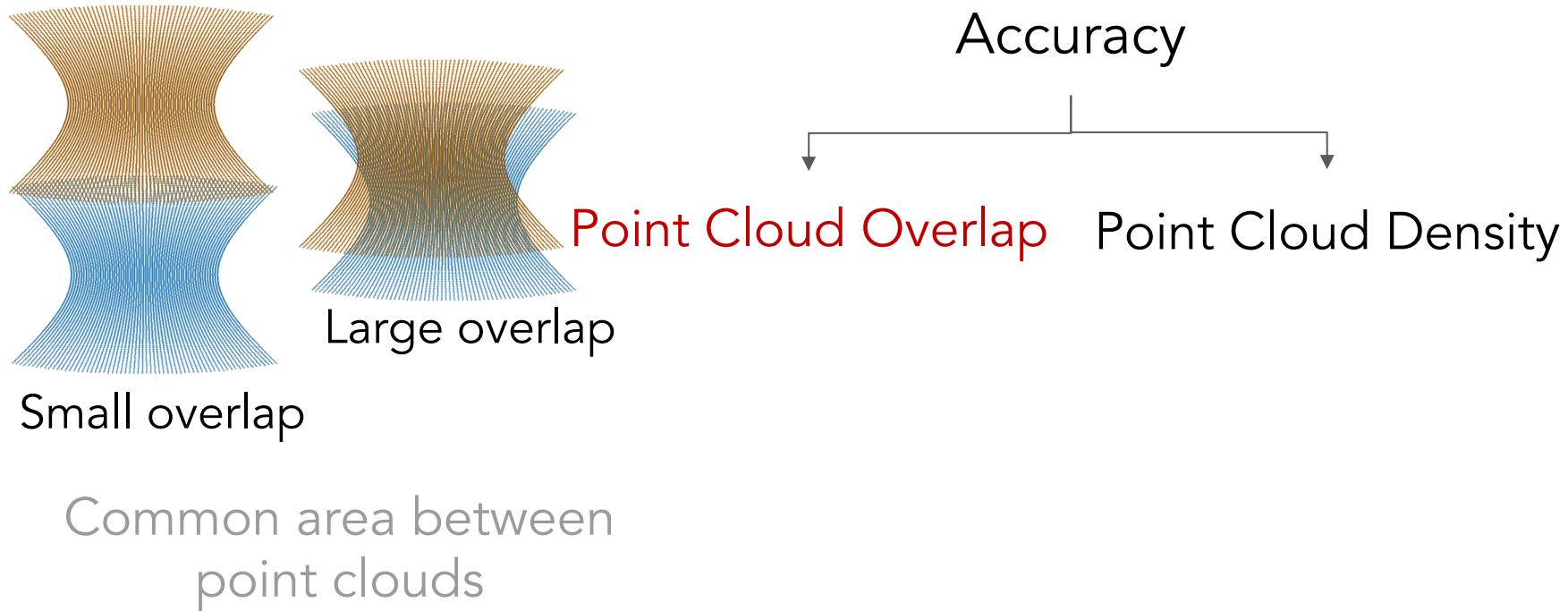
# Contributions

Challenge	Mechanism
Limited compute	
Limited battery	
SLAM positioning	Trajectory optimization & In-flight feedback

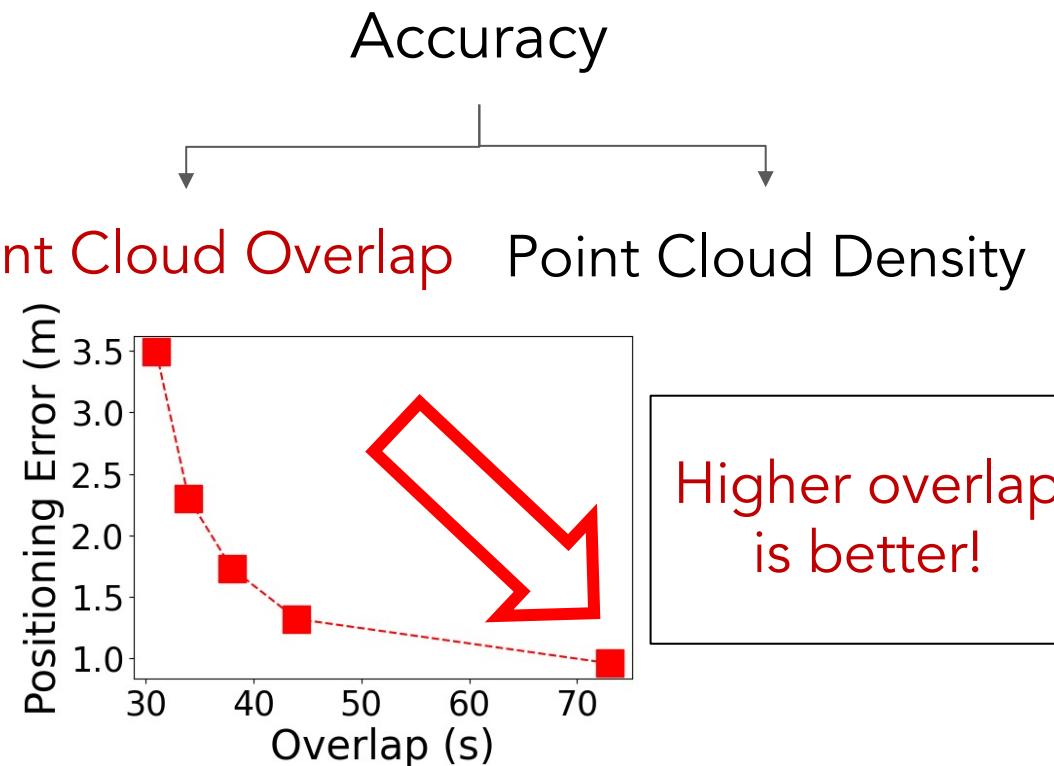
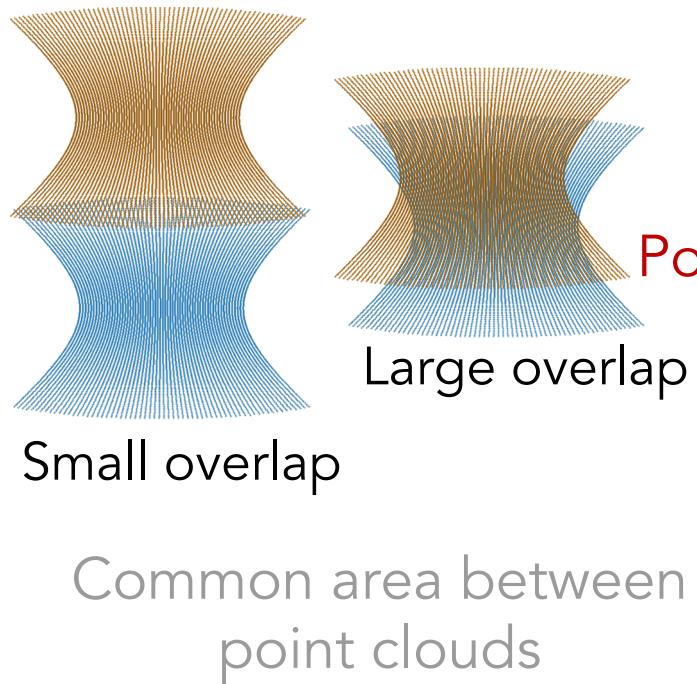
# SLAM Positioning: Accuracy



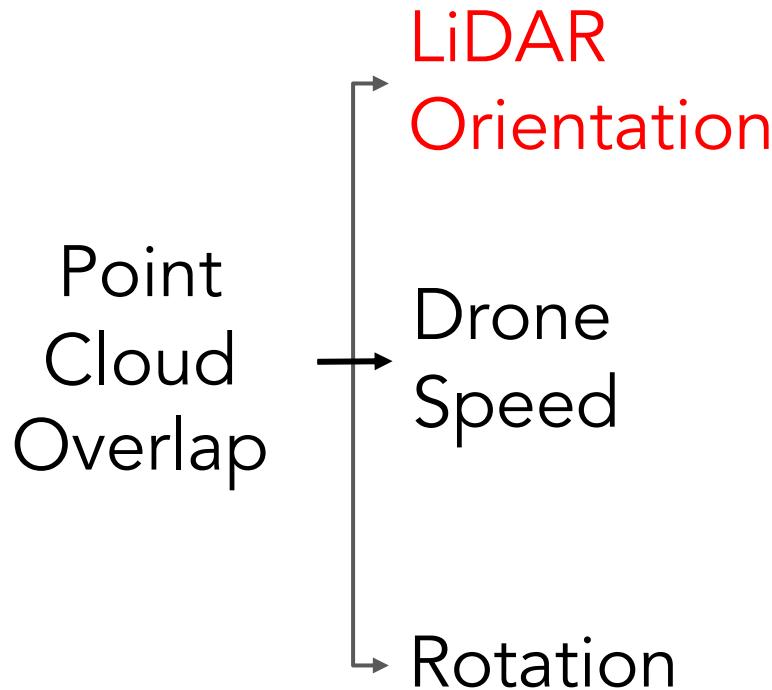
# SLAM Positioning: Point Cloud Overlap



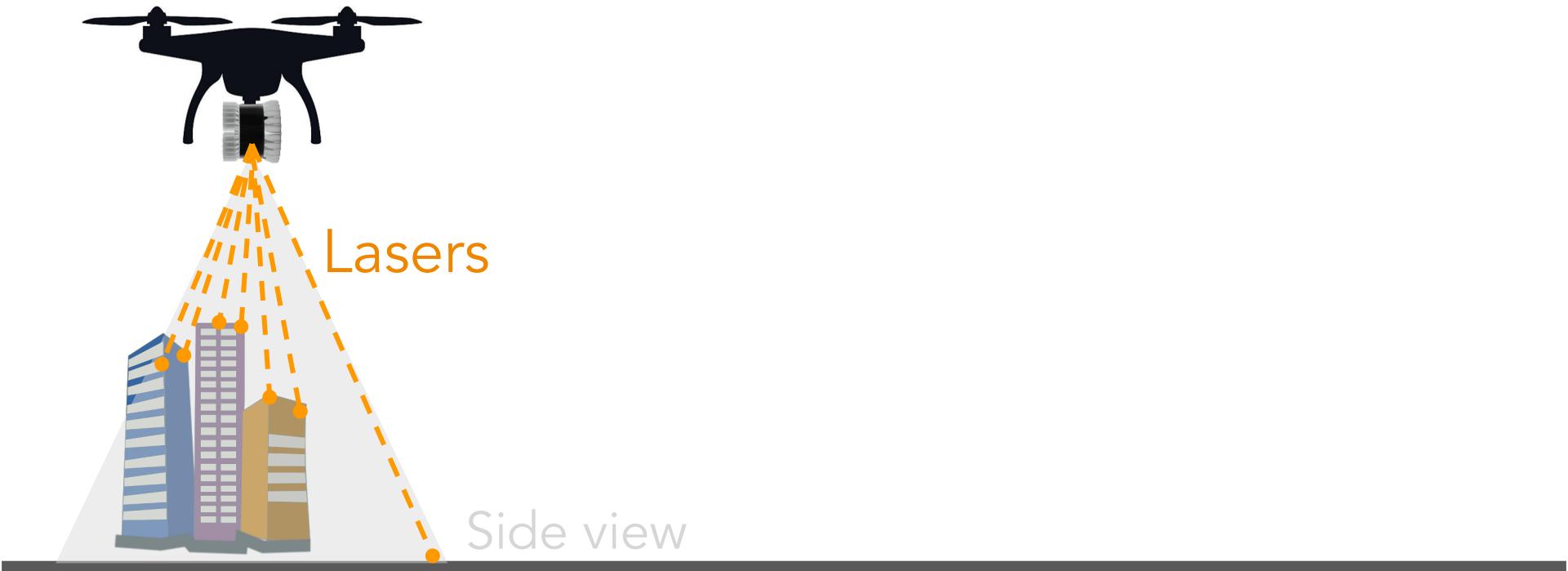
# SLAM Positioning: Point Cloud Overlap



# Controlling Point Cloud Overlap: LiDAR Orientation



# Controlling Point Cloud Overlap: LiDAR Orientation

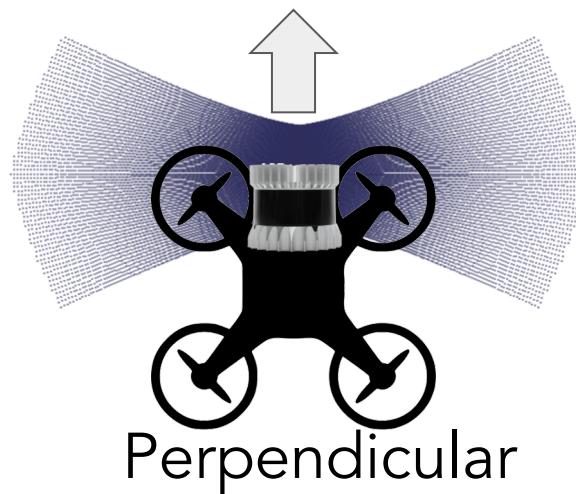


# Controlling Point Cloud Overlap: LiDAR Orientation

## Direction of motion



Side view



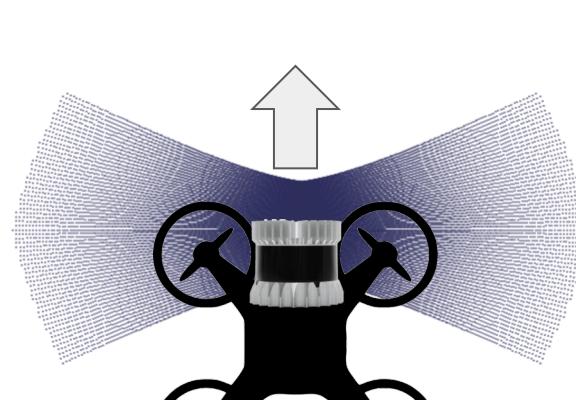
Top view

# Controlling Point Cloud Overlap: LiDAR Orientation

Direction of motion

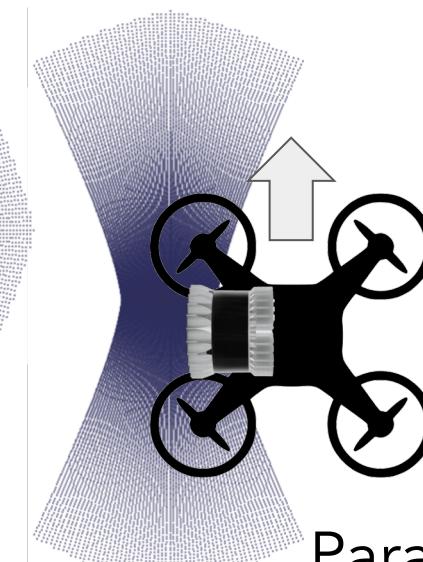


Side view



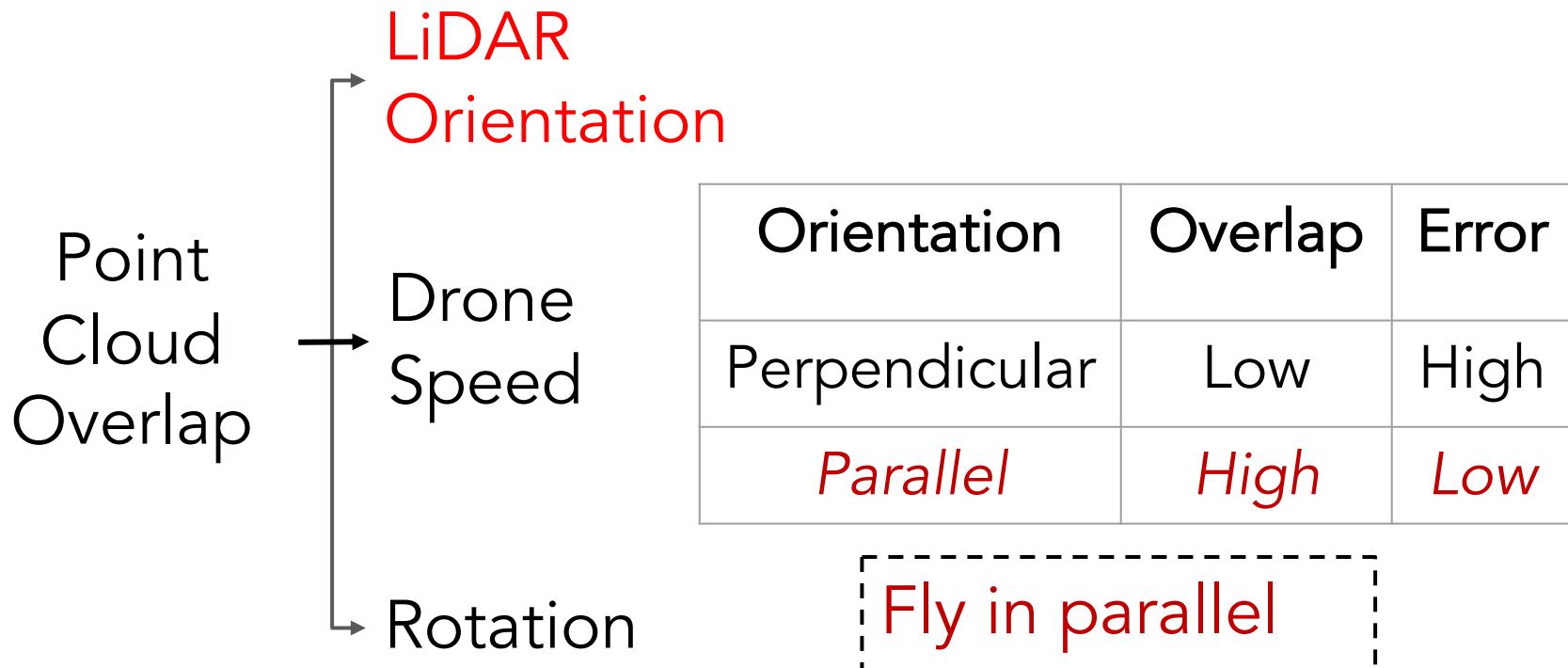
Perpendicular

Top view

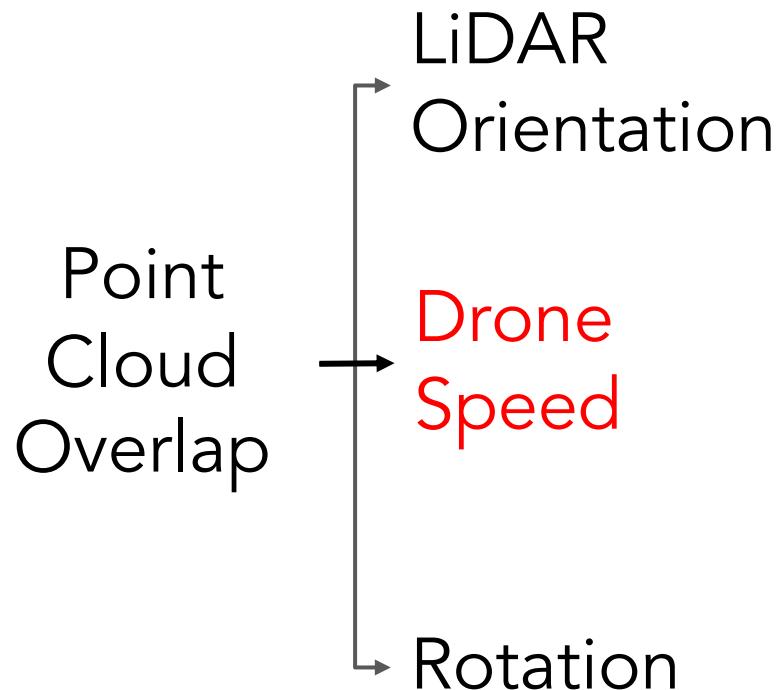


Parallel

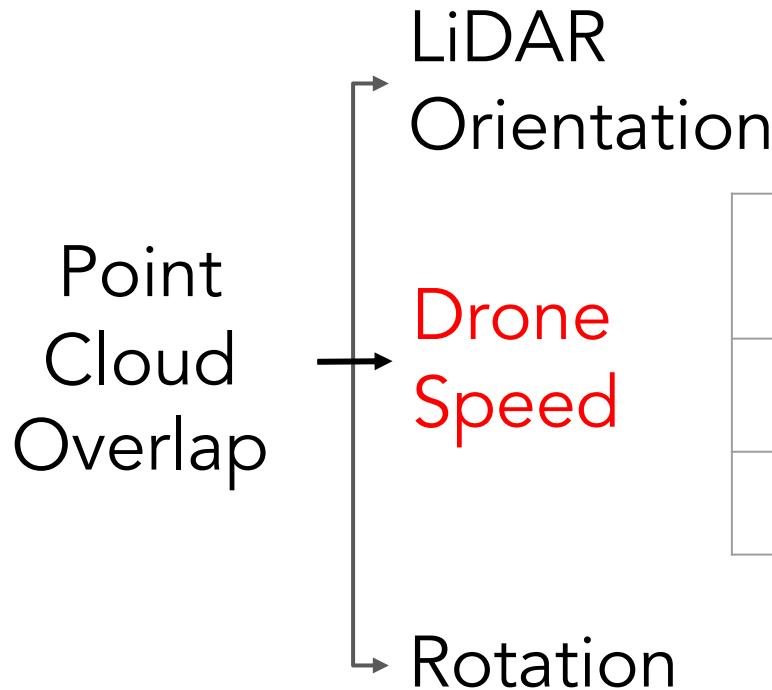
# Controlling Point Cloud Overlap: LiDAR Orientation



# Controlling Point Cloud Overlap: Drone Speed



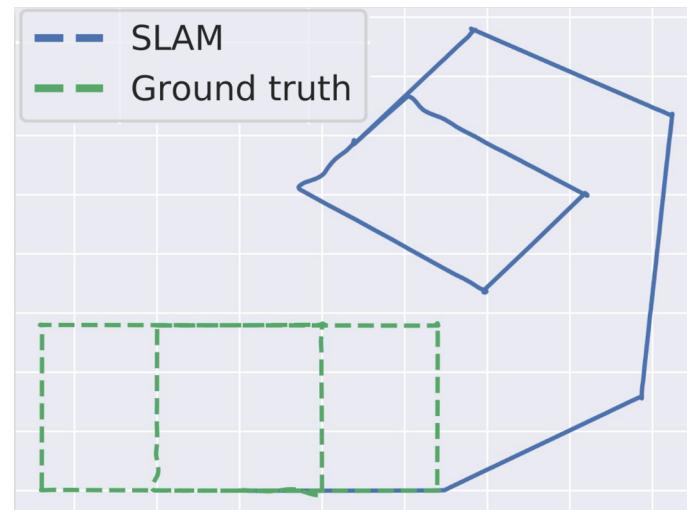
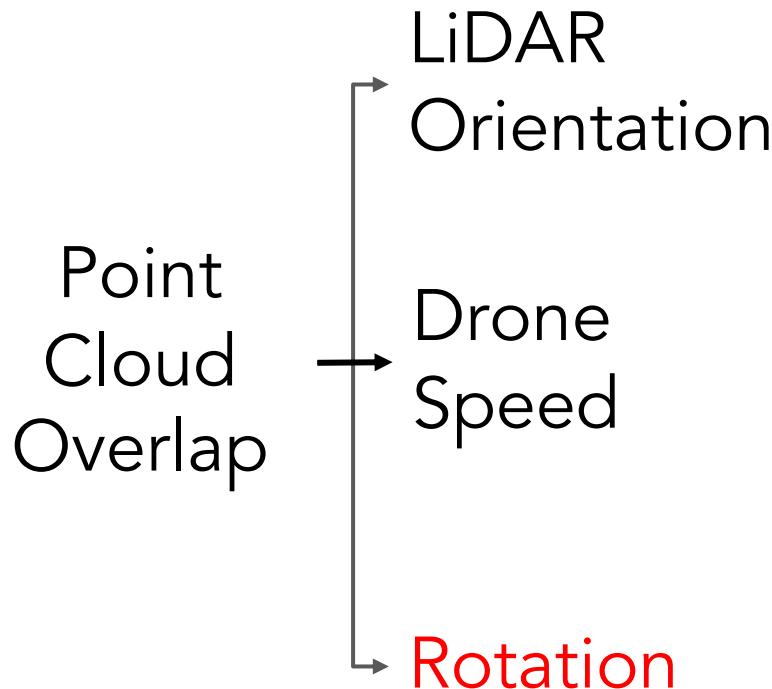
# Controlling Point Cloud Overlap: Drone Speed



Speed	Overlap	Error
Fast	Low	High
Slow	High	Low

*Fly slowly*

# Controlling Point Cloud Overlap: Rotation



Avoid rotations

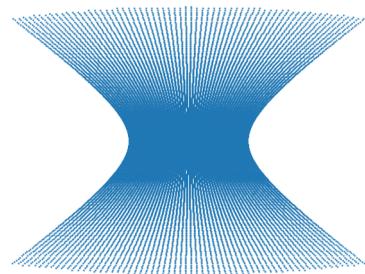
# SLAM Positioning: Point Cloud Density

Accuracy

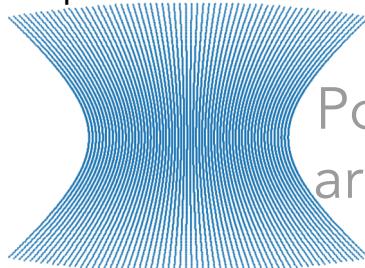
Point Cloud Overlap    Point Cloud Density

Points per unit  
area (pts/m<sup>2</sup>)

# SLAM Positioning: Point Cloud Density



High density  
point cloud



Low density  
point cloud

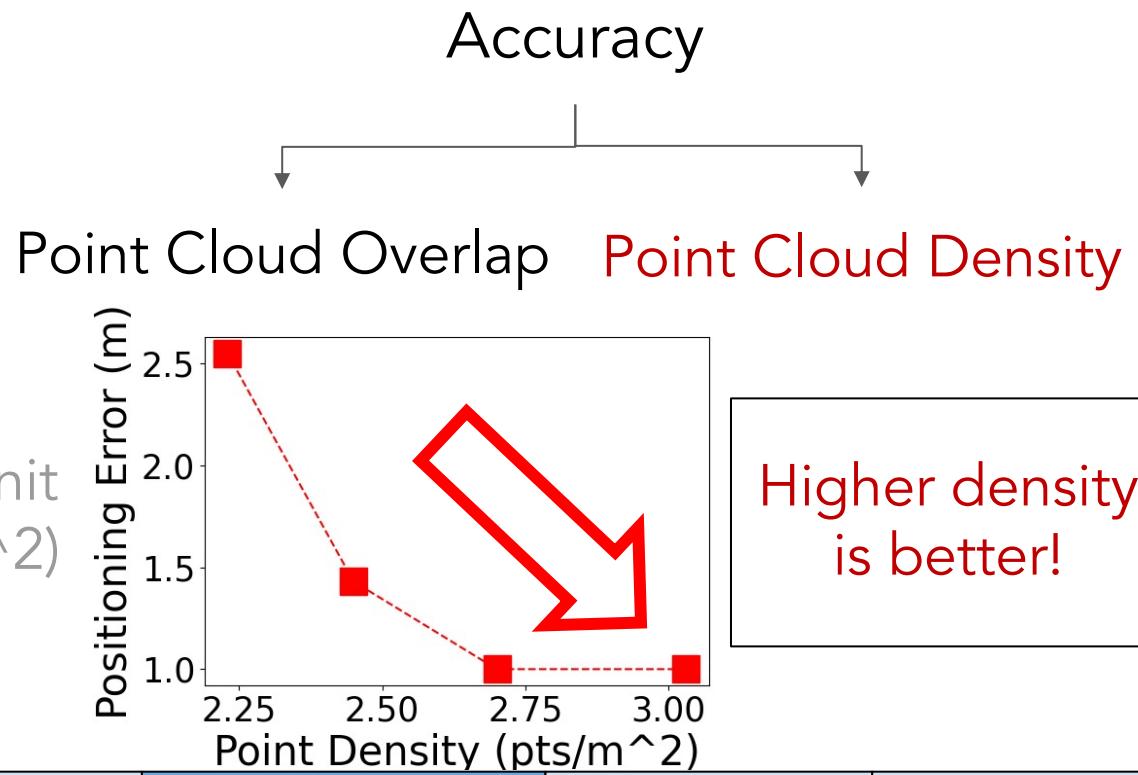
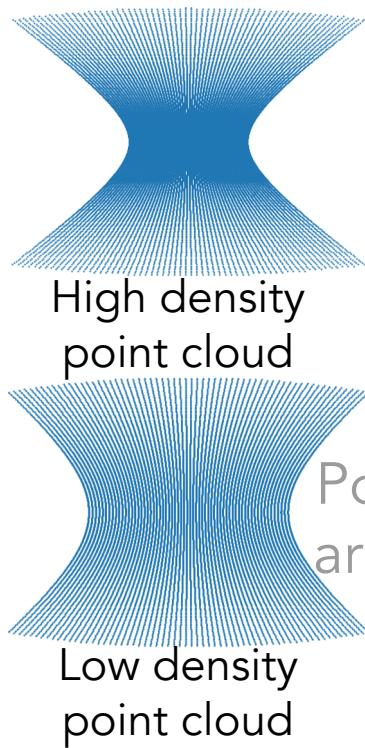
Points per unit  
area ( $\text{pts}/\text{m}^2$ )

Accuracy



Point Cloud Overlap    Point Cloud Density

# SLAM Positioning: Point Cloud Density



# Controlling Point Cloud Density: Distance

Accuracy



Point Cloud Overlap    Point Cloud Density

Height	Density	Error
Far	Low	High
Close	High	Low

Fly close to surface

# Optimized Trajectory Generation

*Goal:* Minimize trajectory length

Accuracy constraints

LoD constraints

Building geometry

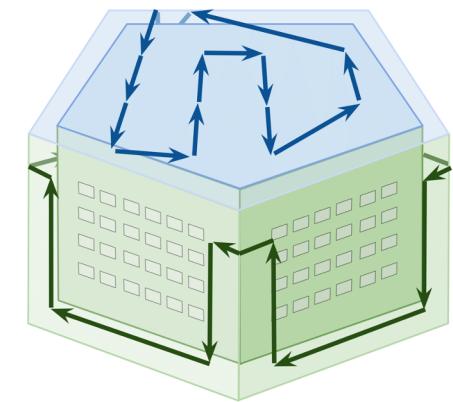
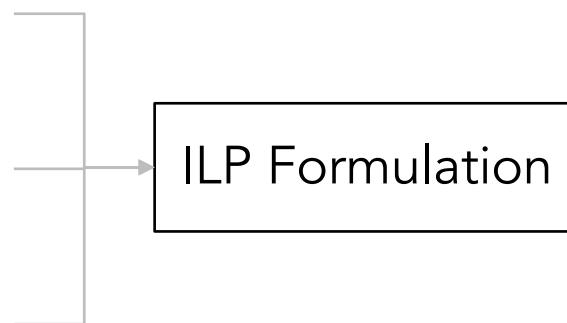
# Optimized Trajectory Generation

Goal: Minimize trajectory length

Accuracy constraints

LoD constraints

Building geometry



# Contributions

Challenge	Mechanism
Limited compute	
Limited battery	
Model accuracy	Trajectory generation & In-flight feedback

# Drift Detection and Re-calibration

**Detection:** Trajectory comparison with GPS

**Mitigation:** Loop closure

# AeroTraj: Evaluation

3D Model Reconstruction

Performance Evaluation

Ablation Study

Data Collection

Boundary Estimation

# AeroTraj 3D Reconstruction Accuracy

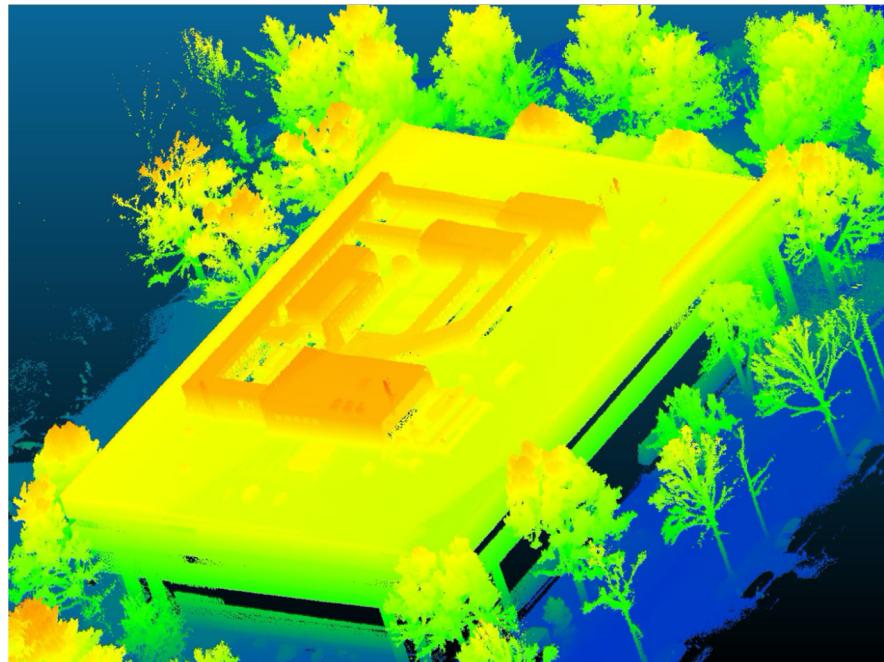
Large building (100m x 50m x 20m)			
Scheme	Accuracy (m)	Completeness (m)	Reconstruction Time (s)
ColMap			
AeroTraj			

# AeroTraj 3D Reconstruction Accuracy

Scheme	Accuracy (m)	Completeness (m)	Reconstruction Time (s)
Large building (100m x 50m x 20m)			
ColMap	0.16	0.75	31600
AeroTraj	0.09	0.05	<i>in-flight</i>

AeroTraj can do fast and high-quality 3D reconstructions

# AeroTraj: Fast, Accurate, and Automated 3D Reconstruction



3D model of large building complex built using AeroTraj