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

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3D Reconstruction

Process of building 3D models

3D representation of the world

3D Model
3D Model Representations

3D Point Cloud

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

Camera

Positioning information

3D Data

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

| Introduction | Problem Statement | Approach | Evaluation | Wrap-up |
|--------------|-------------------|----------|------------|---------|

Photogrammetry: Shortcomings

Camera

Positioning information

3D Data

Slow & offline

Human-in-the-loop

Inaccurate reconstruction

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

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Problem Statement

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Wrap-up
Our Goal

Automated, Fast, and Accurate 3D Reconstruction
Fast 3D Reconstruction

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Building to reconstruct
Fast 3D Reconstruction

3D Model

Positioning information

3D point cloud (LiDAR)

Building to reconstruct

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Fast, and **Accurate** 3D Reconstruction

3D Model

- Positioning information (GPS)
- 3D point cloud (LiDAR)

Fuzzed 3D Model with GPS
SLAM for Positioning

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3D Point Cloud → Simultaneous Localization & Mapping (SLAM) → 3D Pose
SLAM for Positioning

Aligning 3D point clouds

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SLAM for Positioning

Aligning 3D point clouds

\[ T_1 = \text{Align (A, B)} \]
SLAM for Positioning

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

\[ Z = A + T_1 \cdot B \]
SLAM for Positioning

\[ Z = A + T_1 \times B + T_2 \times C + T_3 \times D \]

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

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Challenges

| Challenge                  | Mechanism |
|----------------------------|-----------|
| Limited compute            |           |
| Limited battery            |           |
| SLAM positioning           |           |
Vehicle LiDAR SLAM

Whole point cloud
SLAM Positioning: A Drone’s Perspective

Challenging to align sparse point clouds

Vehicle LiDAR SLAM

Drone LiDAR SLAM

Whole point cloud

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

Accuracy

Point Cloud Overlap  Point Cloud Density

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**SLAM Positioning: Point Cloud Overlap**

- **Accuracy**
  - Point Cloud Overlap
  - Point Cloud Density

- **Common area between point clouds**

**Approach**
- Small overlap
- Large overlap

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SLAM Positioning: Point Cloud Overlap

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Common area between point clouds

Accuracy

Point Cloud Overlap

Point Cloud Density

Higher overlap is better!
Controlling Point Cloud Overlap: LiDAR Orientation

- LiDAR Orientation
- Drone Speed
- Rotation

### Approach

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Controlling Point Cloud Overlap: LiDAR Orientation

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Controlling Point Cloud Overlap: LiDAR Orientation

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Controlling Point Cloud Overlap: LiDAR Orientation

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Lasers

Direction of motion

Perpendicular

Parallel

Side view

Top view
Controlling Point Cloud Overlap: LiDAR Orientation

Point Cloud Overlap → LiDAR Orientation → Drone Speed

- Orientation: Perpendicular
  - Overlap: Low
  - Error: High
- Orientation: Parallel
  - Overlap: High
  - Error: Low

Rotation

Fly in parallel

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Controlling Point Cloud Overlap: Drone Speed

- LiDAR Orientation
- Point Cloud Overlap
- Rotation
- Drone Speed

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Controlling Point Cloud Overlap: Drone Speed

| Speed  | Overlap | Error |
|--------|---------|-------|
| Fast   | Low     | High  |
| Slow   | High    | Low   |

Fly slowly
Controlling Point Cloud Overlap: Rotation

- LiDAR Orientation
- Drone Speed
- Rotation

Avoid rotations
SLAM Positioning: Point Cloud Density

Accuracy

Point Cloud Overlap  Point Cloud Density

Points per unit area (pts/m^2)
SLAM Positioning: Point Cloud Density

- High density point cloud
- Low density point cloud
- Points per unit area (pts/m²)

Accuracy

Point Cloud Overlap

Point Cloud Density

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SLAM Positioning: Point Cloud Density

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High density point cloud

Low density point cloud

Points per unit area (pts/m^2)

Accuracy

Point Cloud Overlap

Point Cloud Density

Higher density is better!
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

ILP Formulation

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## 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

| Scheme       | Accuracy (m) | Completeness (m) | Reconstruction Time (s) |
|--------------|--------------|------------------|-------------------------|
| Large building (100m x 50m x 20m) |              |                  |                         |
| 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             | *in-flight*             |

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