Fast 3D Model Generation in Urban Environments

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Machine Vision Seminar 2011

Outline

- Overview
- Goals and Objectives
- Approach
- Ground-based Modeling

Overview

Why do we need 3D Models?

- Urban Planning
- Virtual Reality
- Simulation
- Special Effects
- Car Navigation

Overview

Known Techniques

(relative to the paper)

- remote sensing
- using lines extracted from merged camera images
- 3D laser scanners
- 2D laser scanners on mobile robot

Overview

Challenges?

- acquisition is difficult and time-consuming.
- significant manual intervention.
- data acquired in a stop-and-go fashion.
- impossible to monitor changes over time.

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Goals and Objectives

reconstruct 3D city models for

virtual walk-throughs and fly-throughs

- automated
- fast
- photorealistic
- scalable

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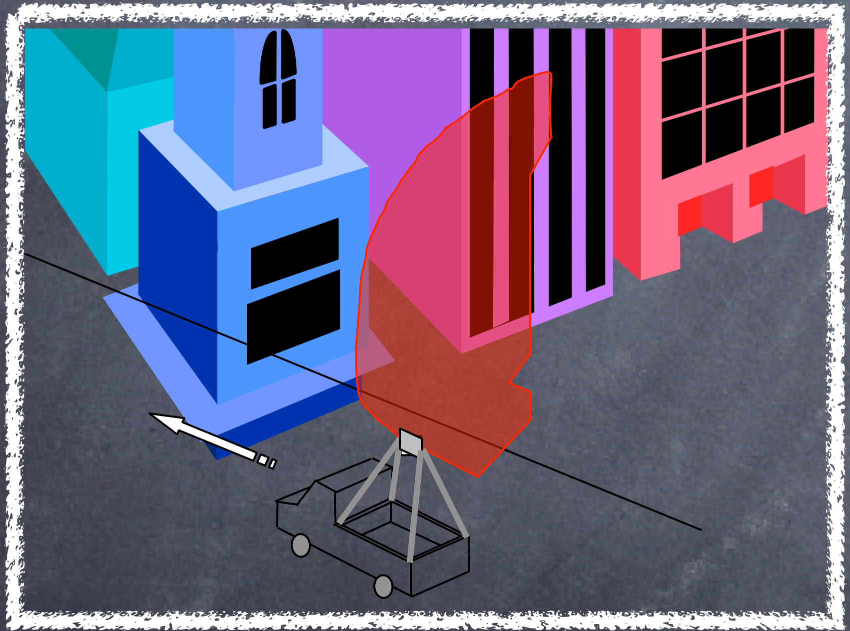
Approach

ground-based modeling

building facades



airborne modeling

rooftops & terrain

registration
+
fusion

3D city model

Outline

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- Ground-based Modeling

Ground-based Modeling

- data-acquisition system
- scan matching
- path computation
- point cloud generation
- mesh generation
- texture mapping

Ground-based Modeling

Data-acquisition system

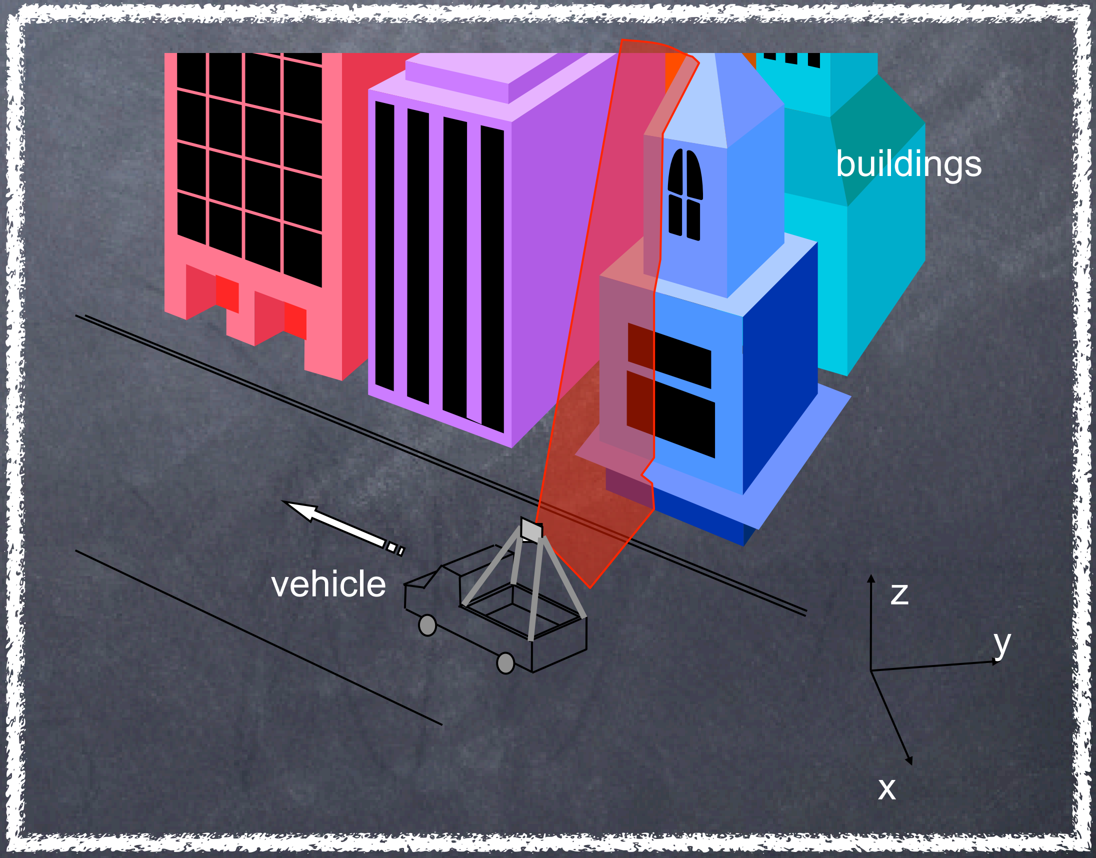
- pickup truck
- 2 fast 2D laser scanners
- sync'd digital camera
- heading sensor
- true ground speed sensor

Ground-based Modeling

Drive-by Scanning

continuous data acquisition
from ground-level while driving

vertical 2D laser scanner
to acquire the geometry:
shape of complete
building facades

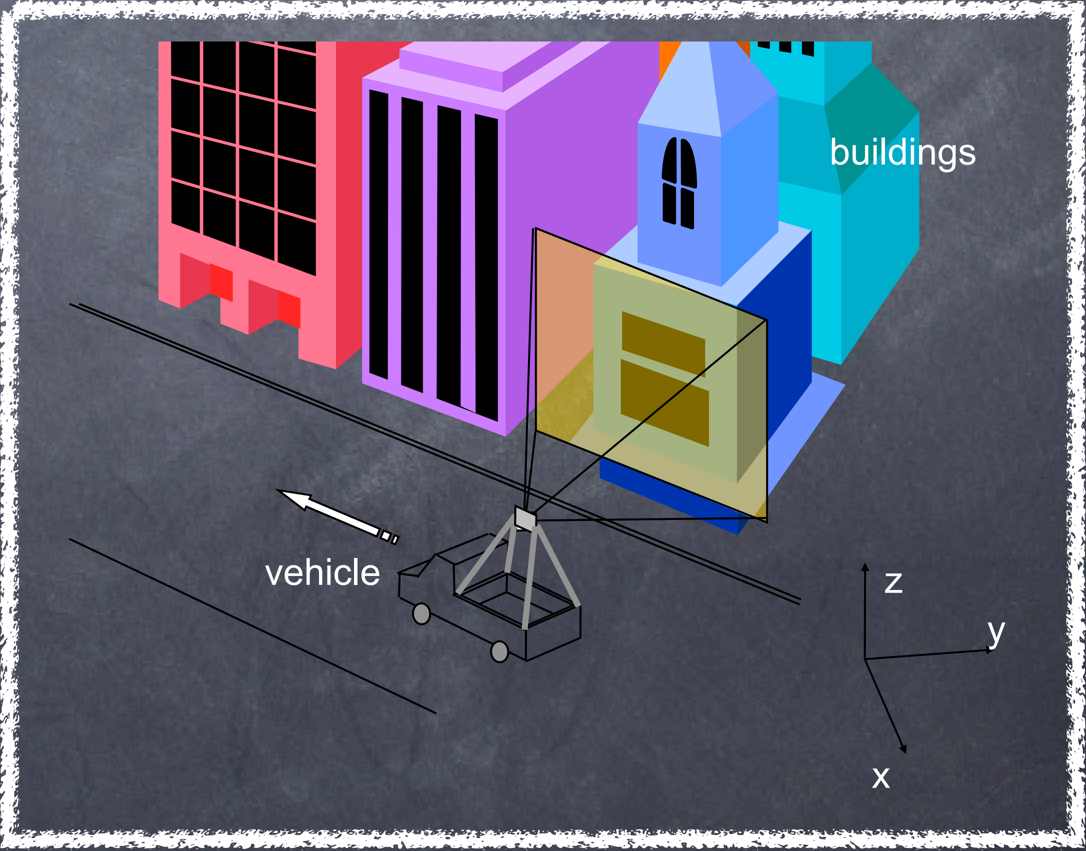


Ground-based Modeling

Drive-by Scanning

continuous data acquisition
from ground-level while driving

synchronized digital camera to acquire the texture



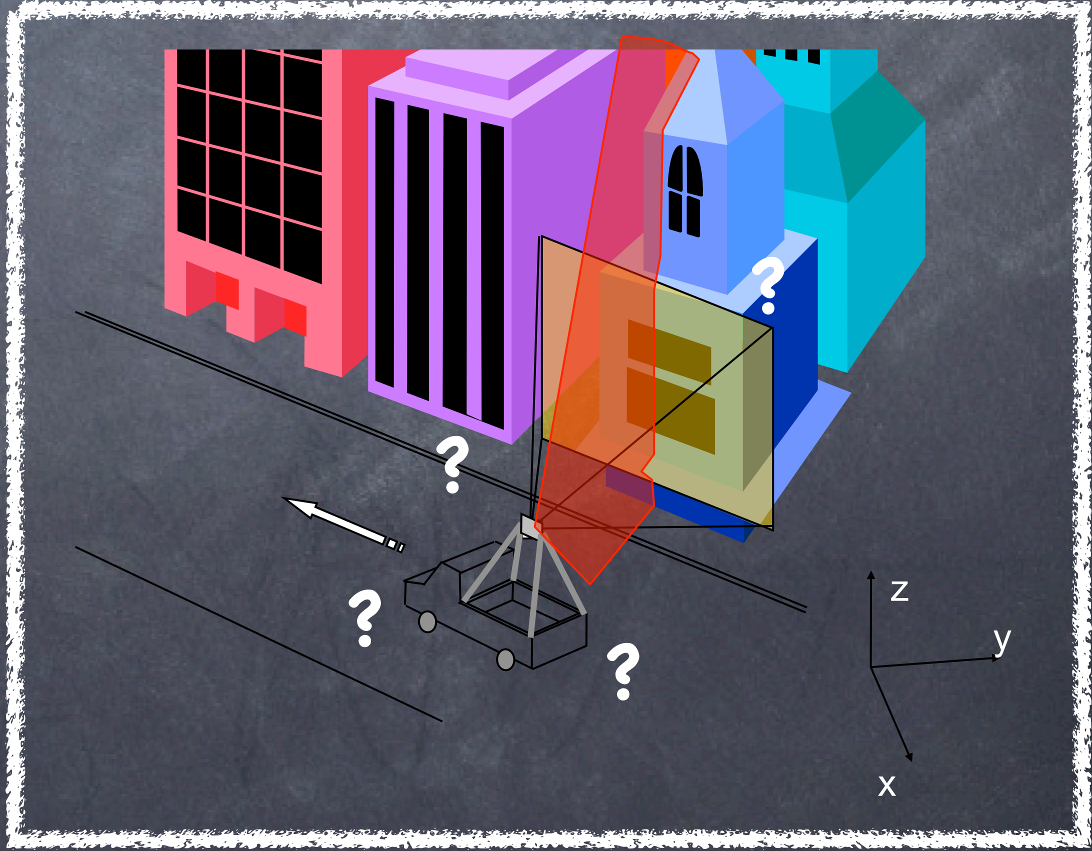
Ground-based Modeling

Drive-by Scanning

continuous data acquisition
from ground-level while driving

problem: localization?

position and orientation of truck and its sensor unit need to be accurately determined

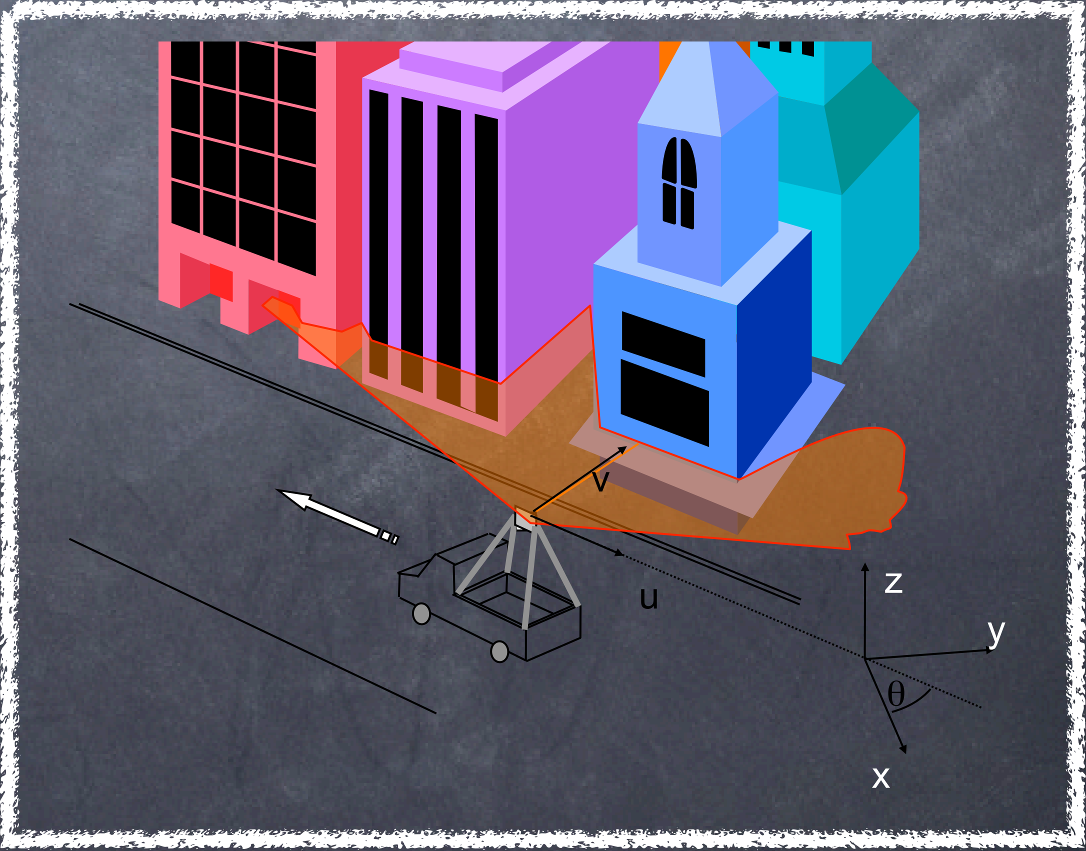


Ground-based Modeling

Drive-by Scanning

continuous data acquisition
from ground-level while driving

horizontal 2D laser scanner to localize the truck: pose estimation



Ground-based Modeling

Drive-by Scanning

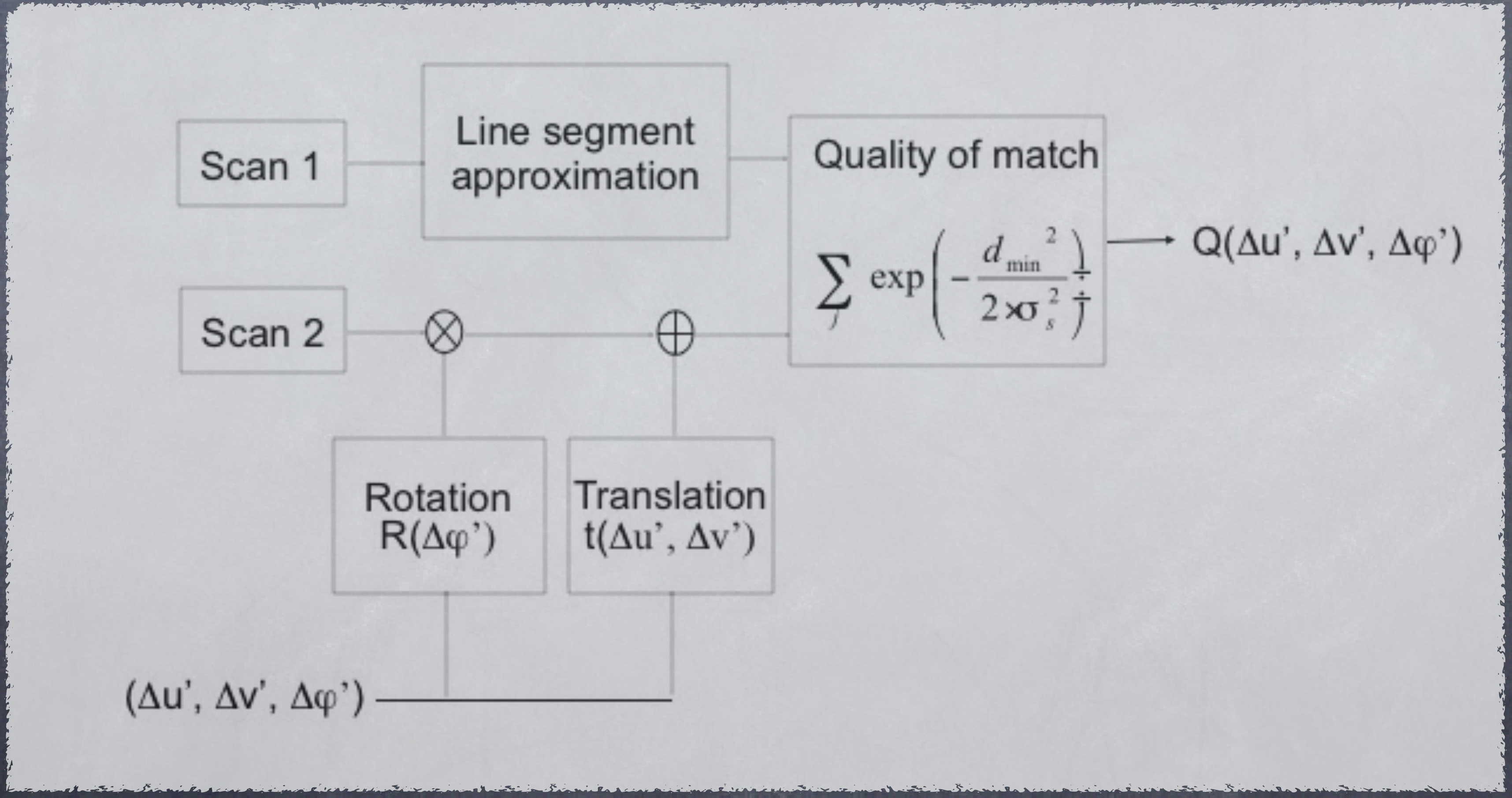
continuous data acquisition
from ground-level while driving

- scanners and cameras are sync'd by trigger signals
- heading sensor is used to determine orientation
- TGSS provides non-contact speed measurements.

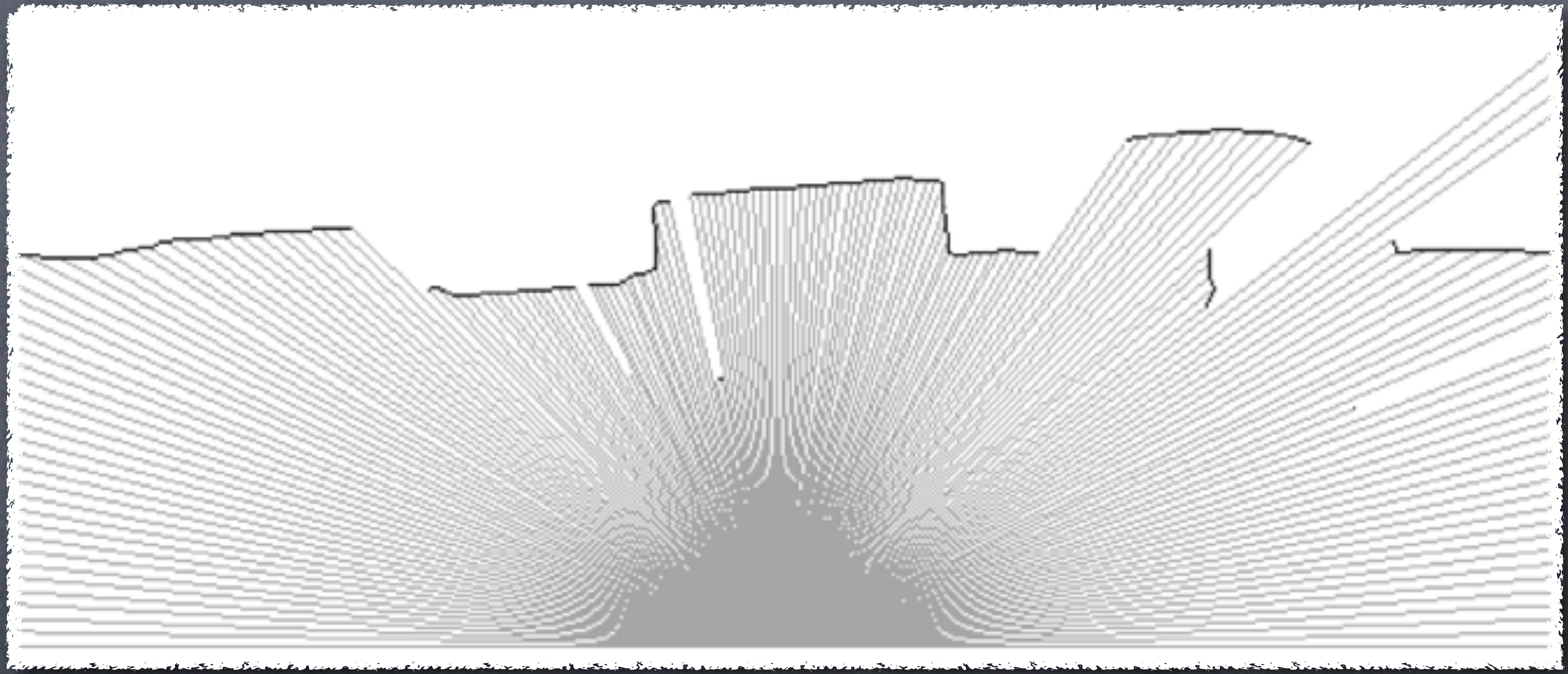
Ground-based Modeling

- data-acquisition system
- scan matching
- path computation
- point cloud generation
- mesh generation
- texture mapping

Scan Matching
Flowchart



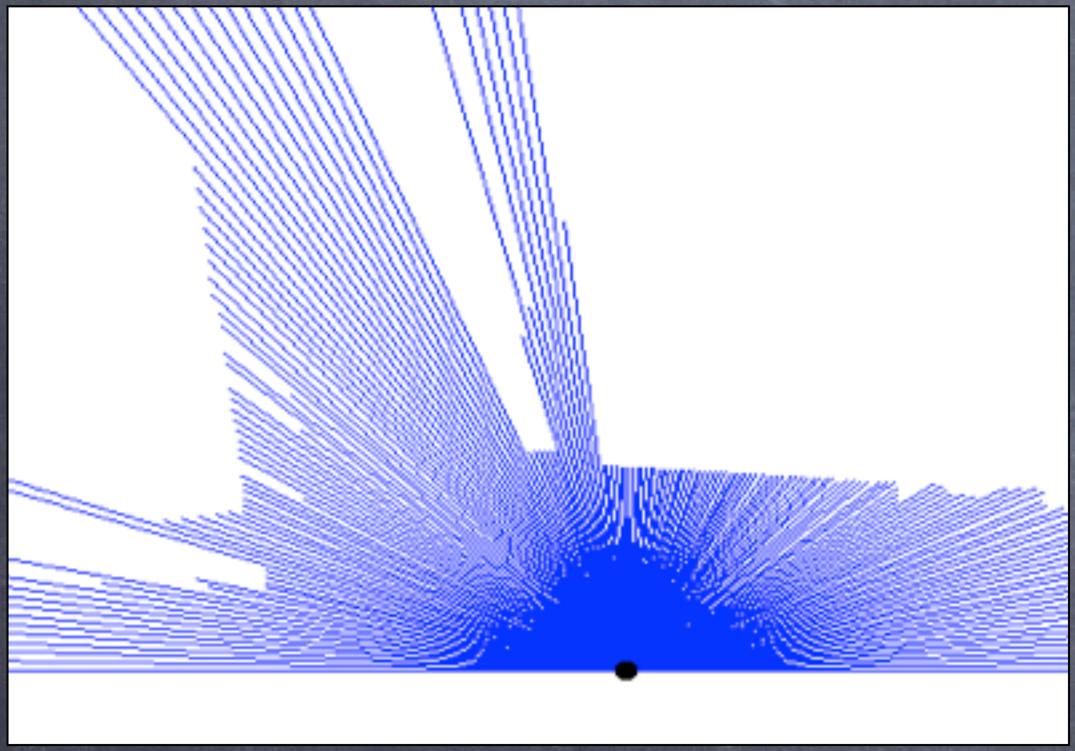
Line Segment Approximation of Reference Scan



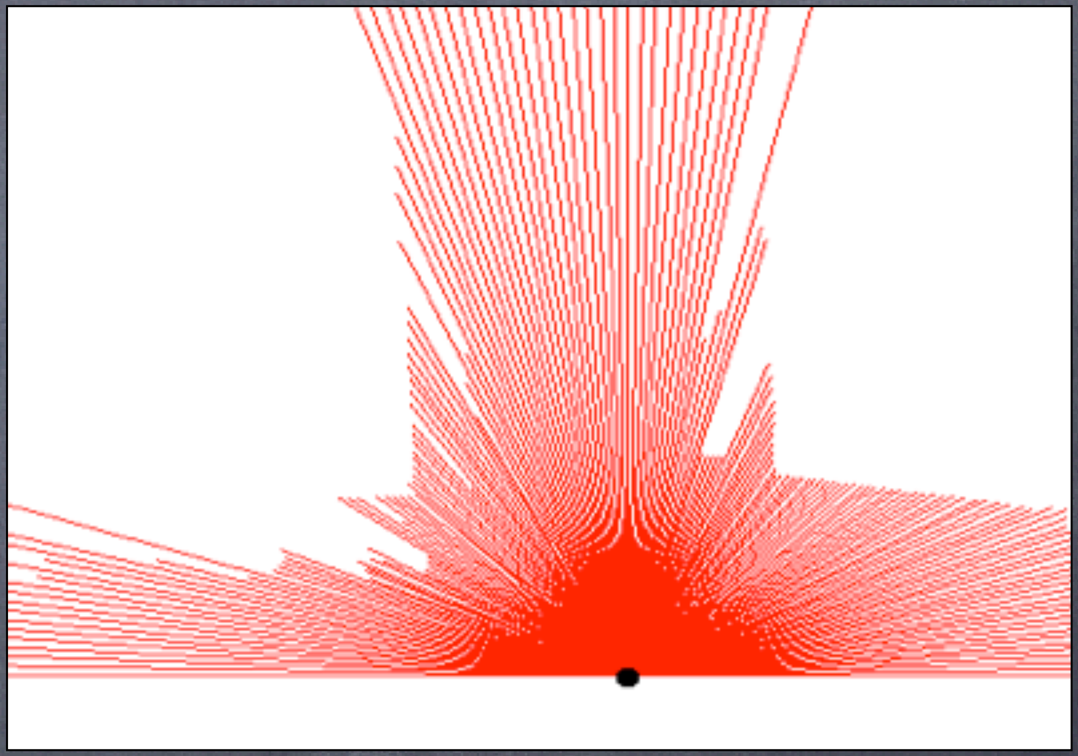
connect successive points to form a line; if the difference between their depth values does not exceed a depth dependent threshold

Scan Matching

Pose Estimation



$t = t_0$



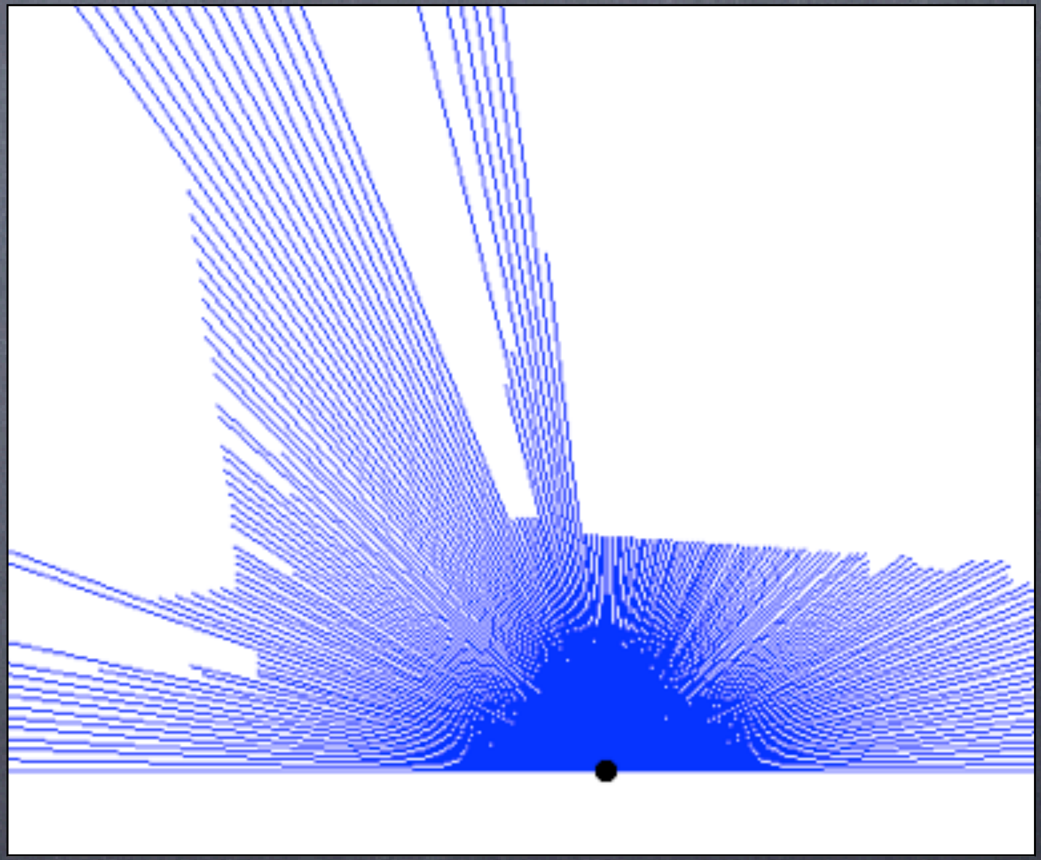
$t = t_1$

horizontal scans at two different time instances

Scan Matching

Pose Estimation

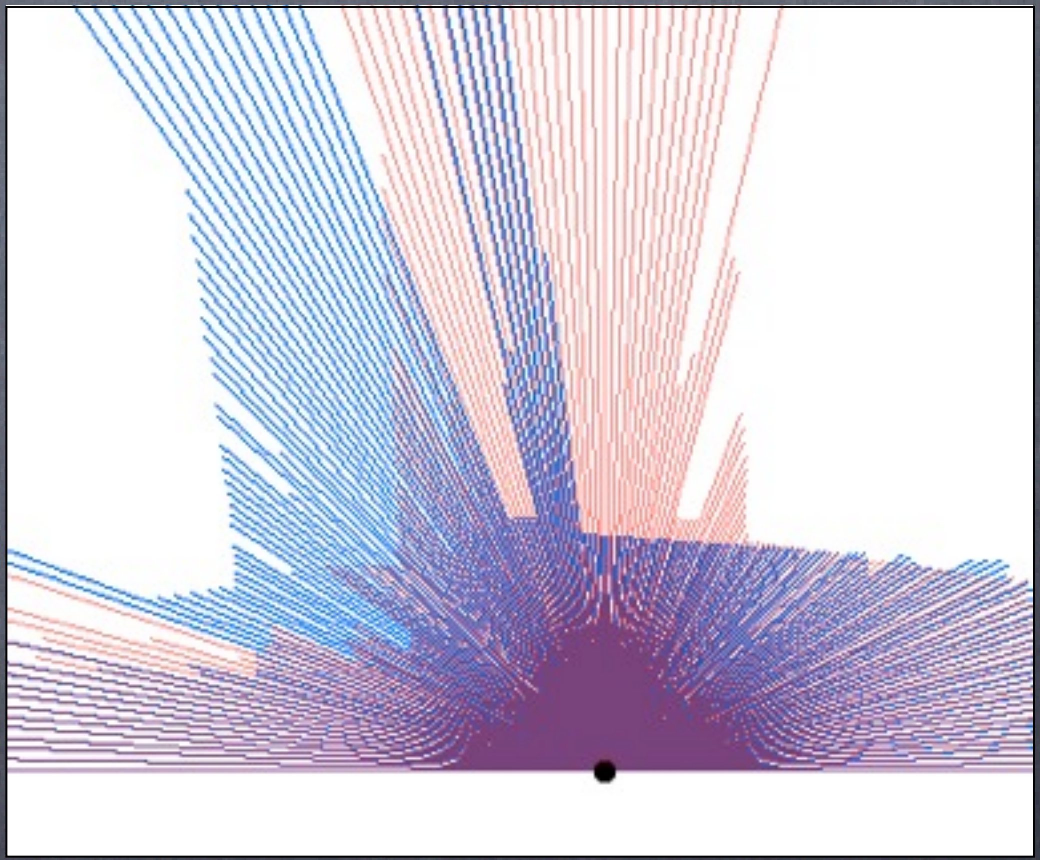
- reference scan: $t = t_0$



Scan Matching

Pose Estimation

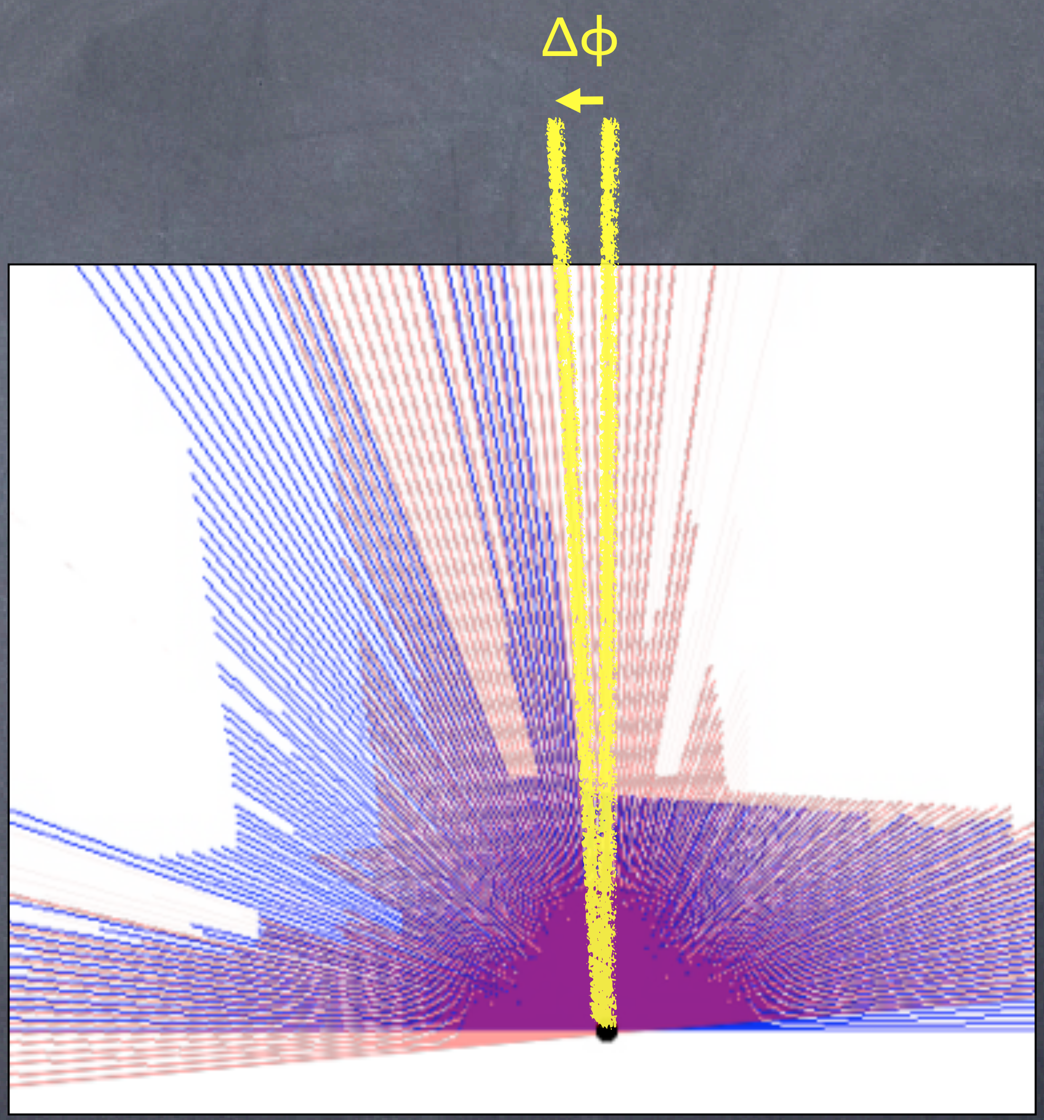
- reference scan: $t = t_0$
- second scan: $t = t_1$



Scan Matching

Pose Estimation

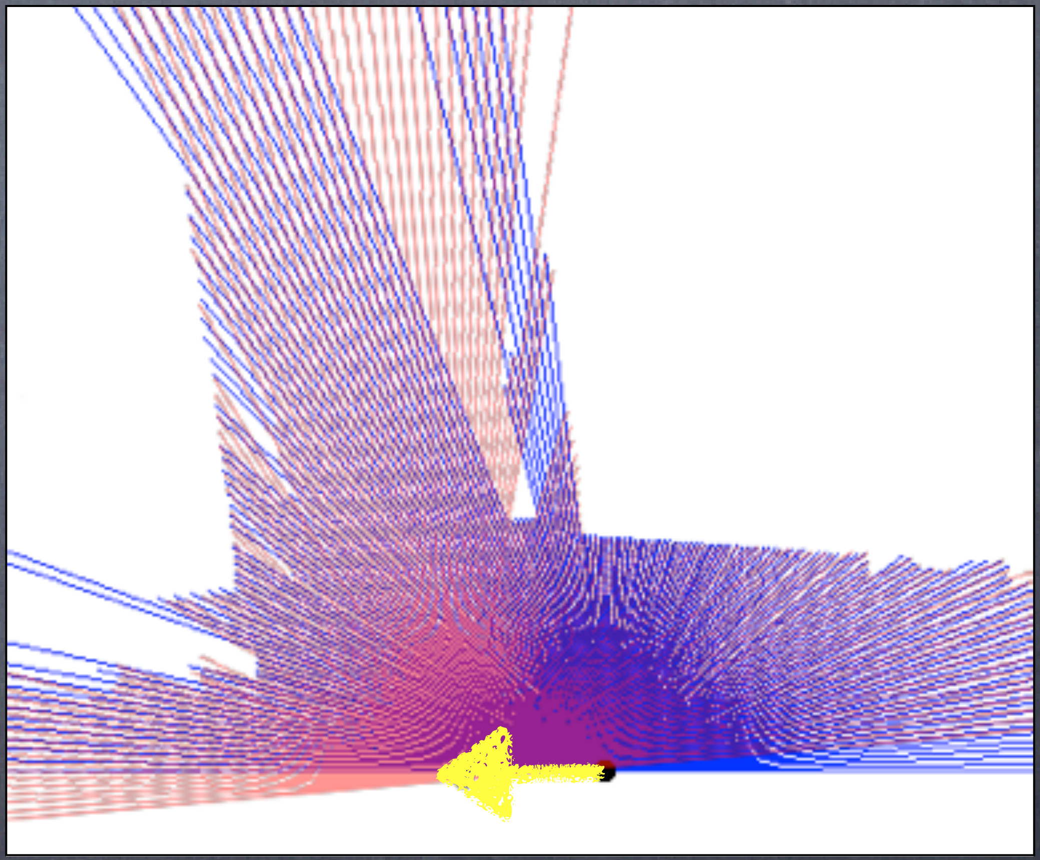
- reference scan: $t = t_0$
- second scan: $t = t_1$
- rotate by $\Delta\phi$



Scan Matching

Pose Estimation

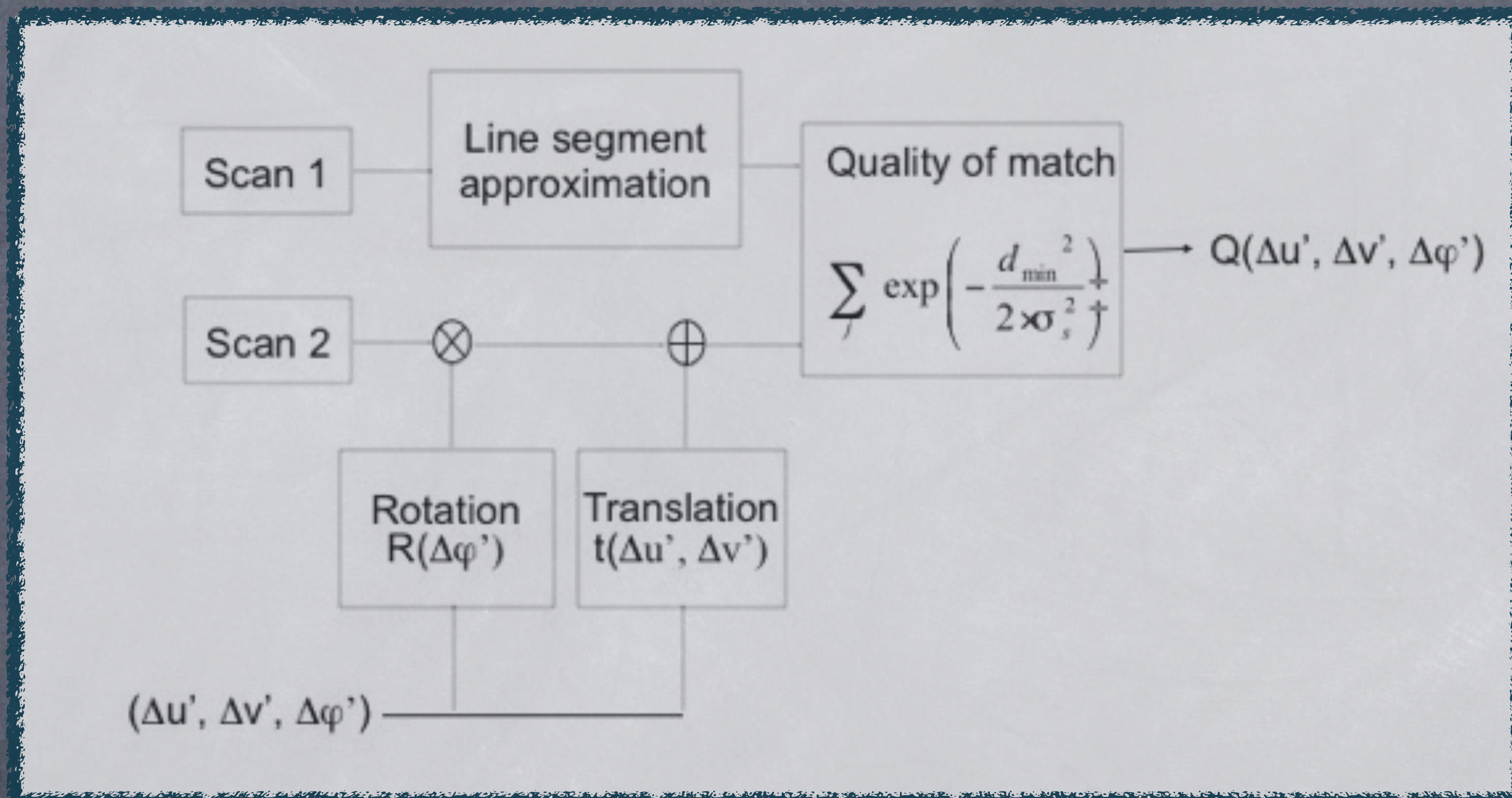
- reference scan: $t = t_0$
- second scan: $t = t_1$
- rotate by $\Delta\phi$
- translate $(\Delta u, \Delta v)$



$(\Delta u, \Delta v)$

Scan Matching

Post Processing

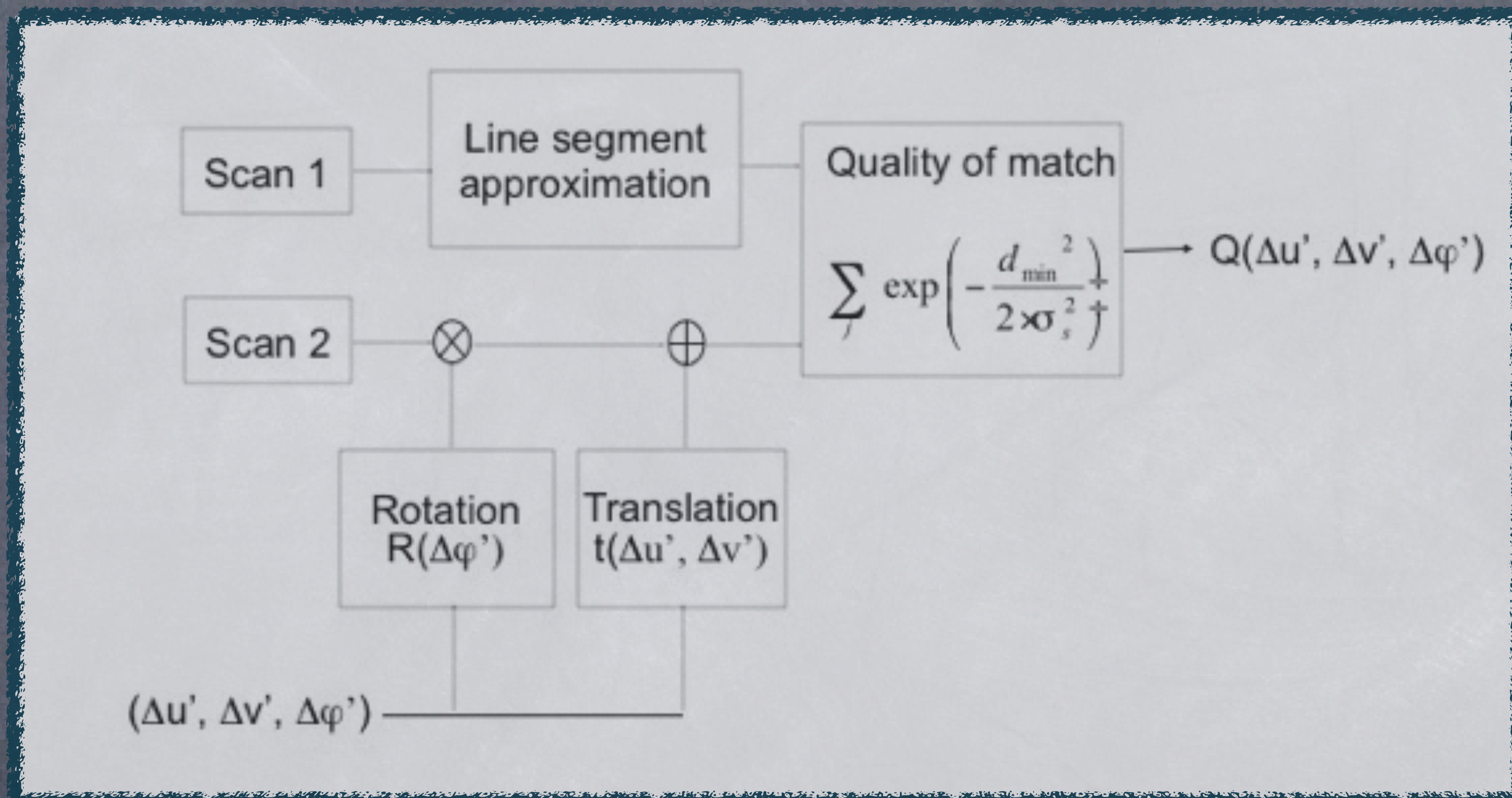


transform the point of second scan in coordinate system of reference scan.

$$\vec{p}'_j(\Delta u, \Delta v, \Delta\varphi) = R(\Delta\varphi)\cdot\vec{p}_j + \vec{t}\ .$$

Scan Matching

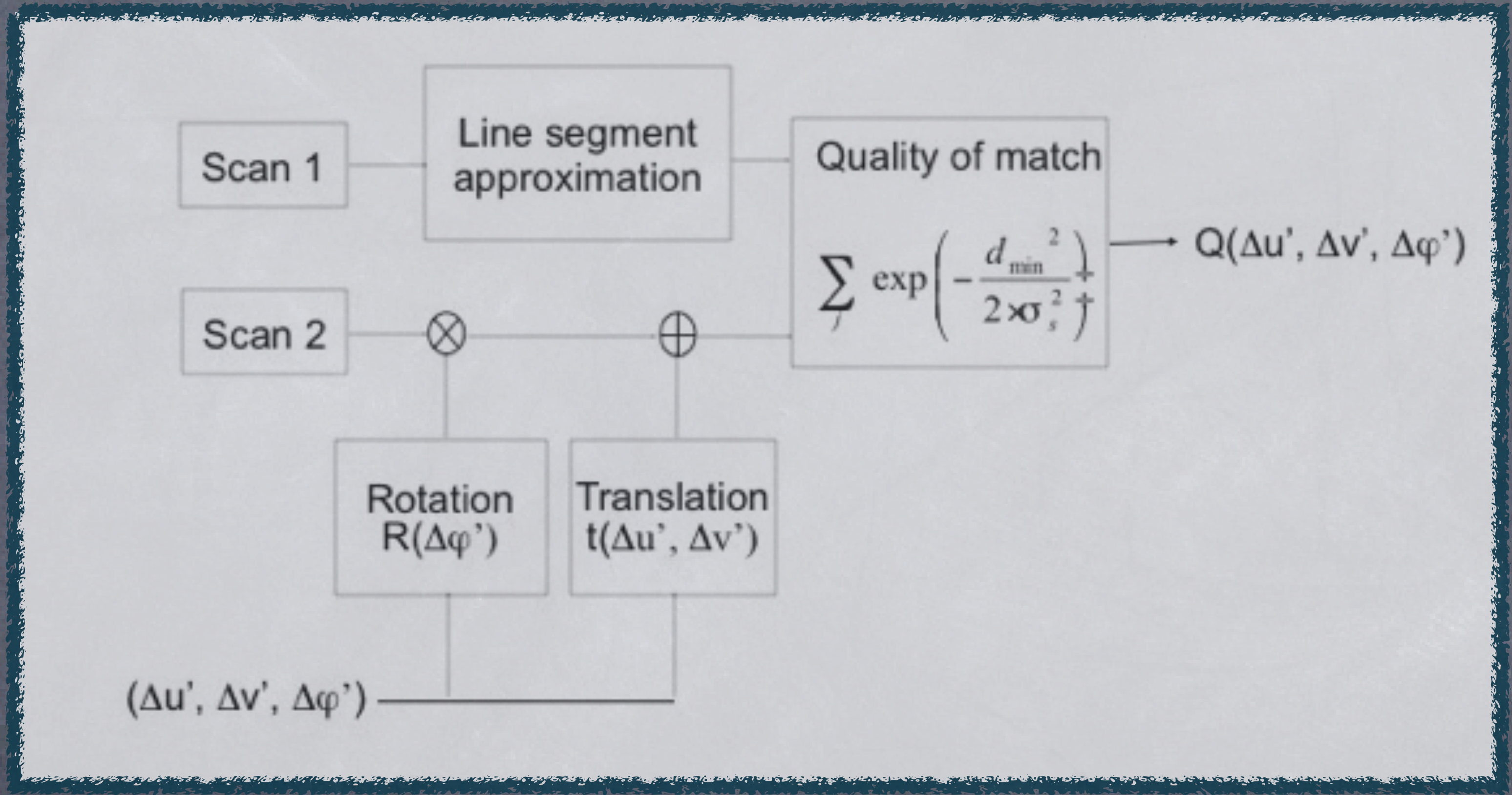
Post Processing



find the closest line segment corresponding to transformed points in the reference scan

$$d_{\min}(\overrightarrow{p'}_j(\Delta u,\Delta v,\Delta\varphi)) = \min_i\left\{d(\overrightarrow{p'}_j, l_i)\right\}.$$

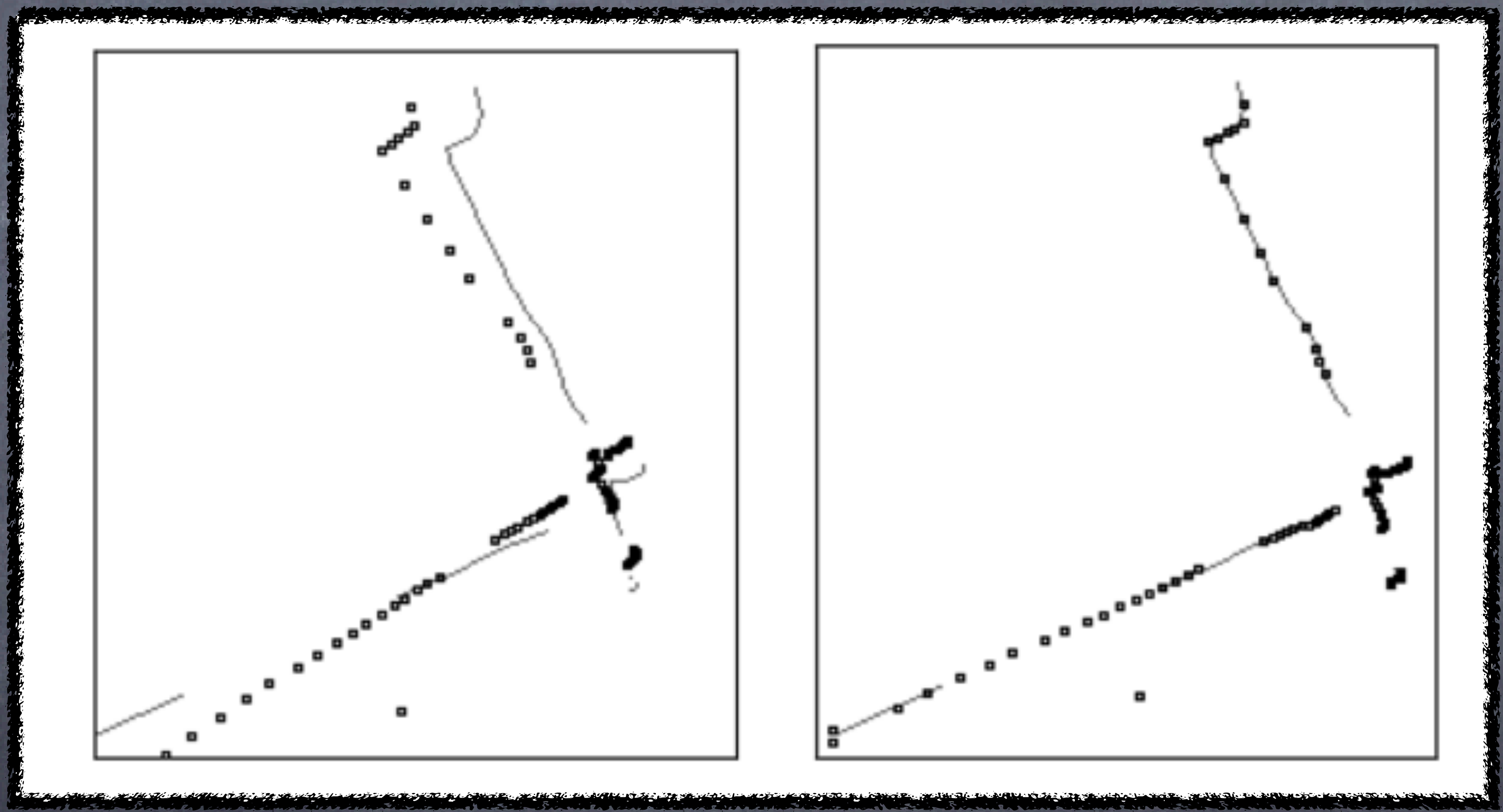
Scan Matching
Post Processing



maximize the quality of alignment function

$$Q(\Delta u, \Delta v, \Delta \varphi) = \sum_j \exp\left(- \frac{d_{\min}(\vec{p}'_j(\Delta u, \Delta v, \Delta \varphi))^2}{2 \cdot \sigma_s^2} \right)$$

Scan Matching
Results?



before match after match

Ground-based Modeling

- data-acquisition system
- scan matching
- path computation
- point cloud generation
- mesh generation
- texture mapping

Path Computation

- a global pose estimate is needed to generate 3D point clouds from vertical scans.
- problem?
  - no sensor used to provide a global pose estimate. (how about using GPS?)
- solution?
  - compute traversed path by successively adding relative pose estimates in the local coordinate system. (previously determined from horizontal scan matching)
  - use TGSS and heading sensor for consistency checks.

Path Computation

$$
\begin{aligned}
x_{i+1} &= x_i + \Delta u_i \cdot \cos(\theta_i + \Delta\varphi_i) - \Delta v_i \cdot \sin(\theta_i + \Delta\varphi_i) \\
y_{i+1} &= y_i + \Delta u_i \cdot \sin(\theta_i + \Delta\varphi_i) + \Delta v_i \cdot \cos(\theta_i + \Delta\varphi_i) \\
\theta_{i+1} &= \theta_i + \Delta\varphi_i
\end{aligned}
$$

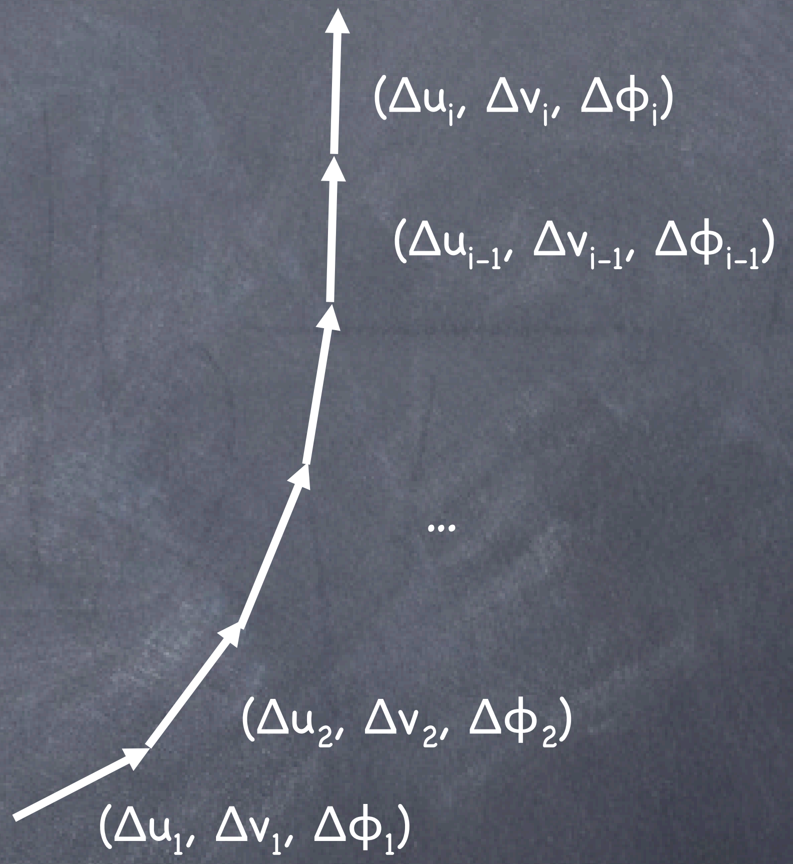
consistency checks :-

If there is a significant change in the computed displacement vector, we accept it as valid if both

a. successive vectors change similarly
b. the speedometer indicates a speed change

If there is a significant change in the orientation angle, we accept the measurement if both

a. succeeding angles change similarly
b. the heading sensor indicates an angle change



concatenate steps to path

Path Computation

Tradeoff

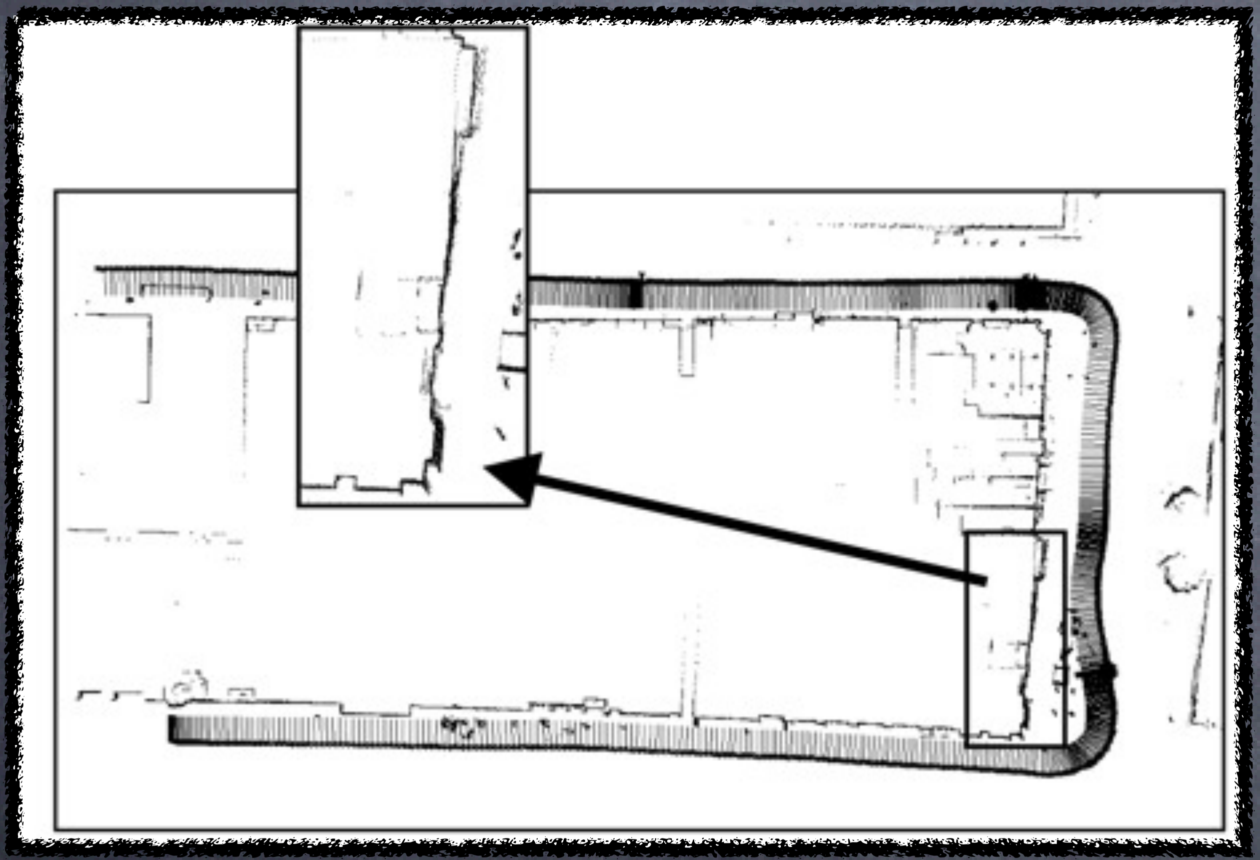
- errors in the estimate accumulate in each iteration
- subsample the scan by a <u>large factor</u> to recover the path in few steps?

or

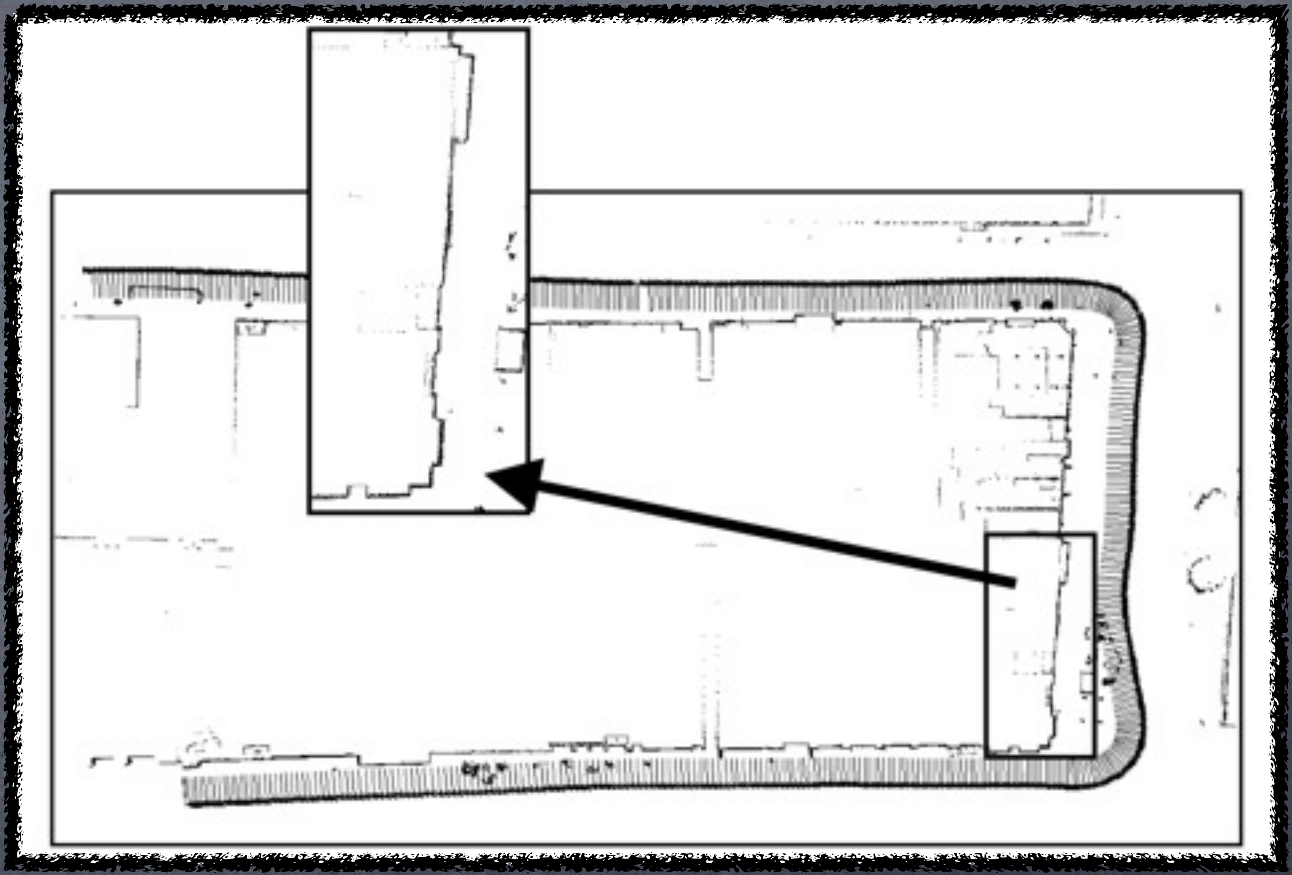
- subsample the scans by a <u>small factor</u> to maximize overlap for accurate match?
- solution? use an adaptive subsampling factor.

Path Computation

Results



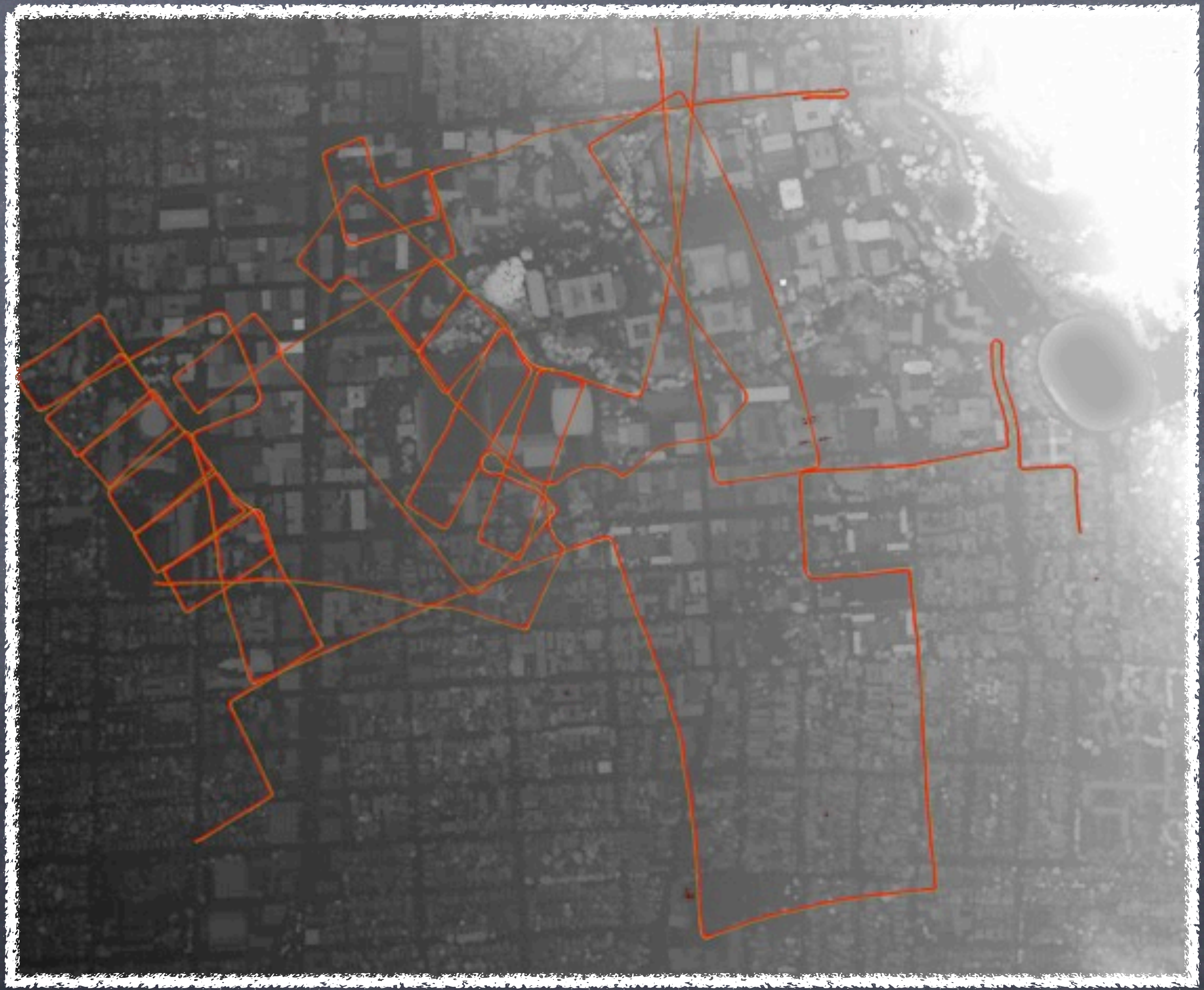
path computed using a fixed subsampling factor



path computed using adaptive subsampling

(beyond the paper)

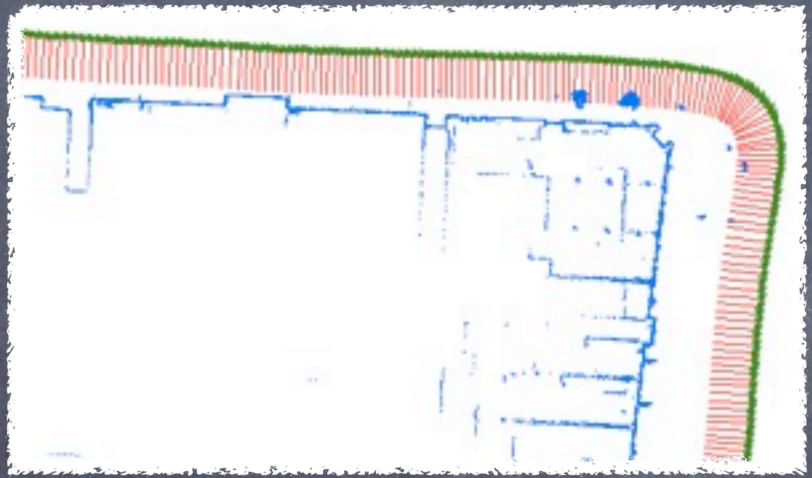
Problem?



needs global correction

(beyond the paper)

Global Correction with Monte Carlo Localization



or

register ground-based laser scans with edge map from airborne-images or digital surface models (DSM)

(beyond the paper)

Monte-Carlo Localization

before MCL correction

after MCL correction

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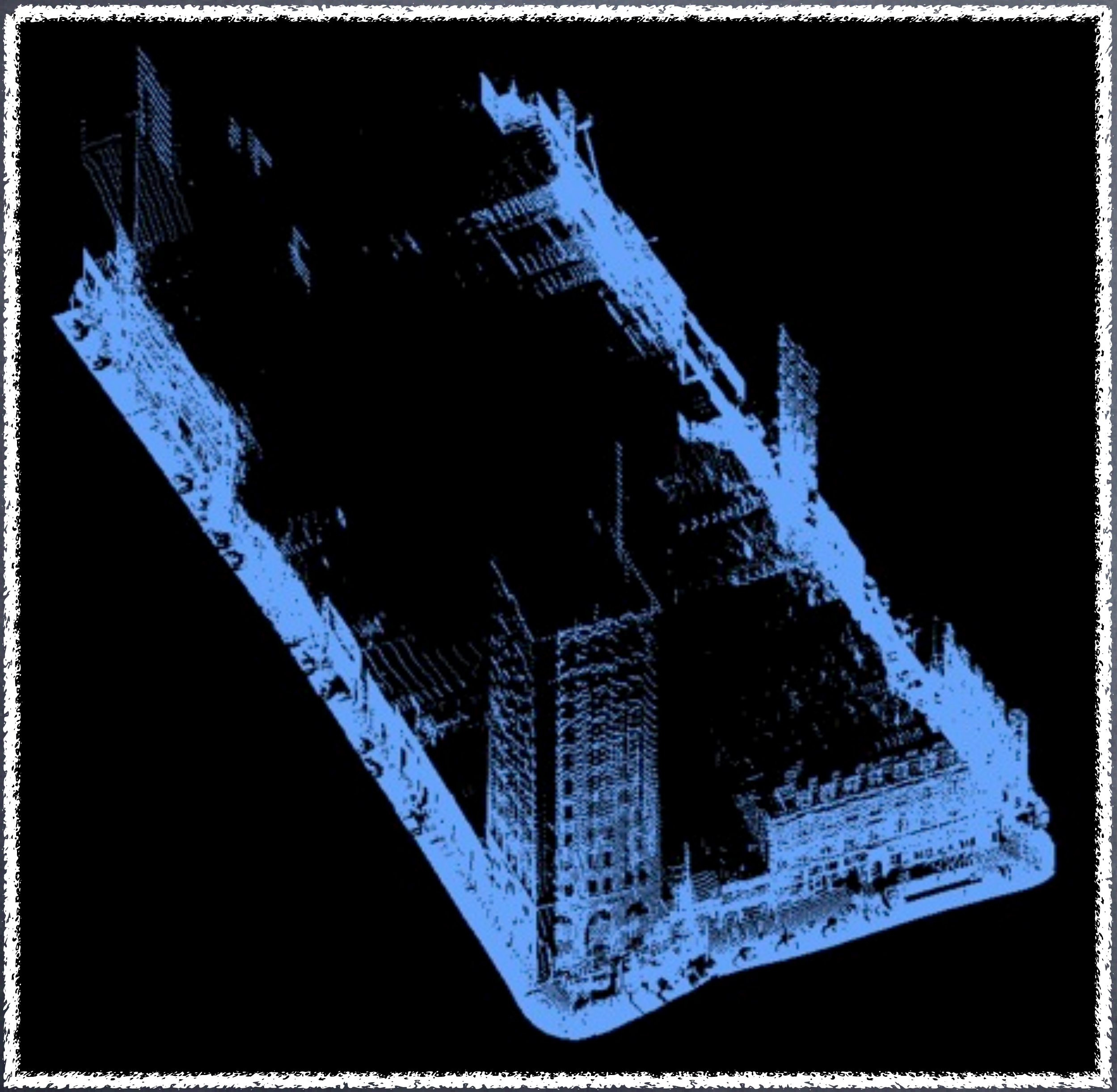
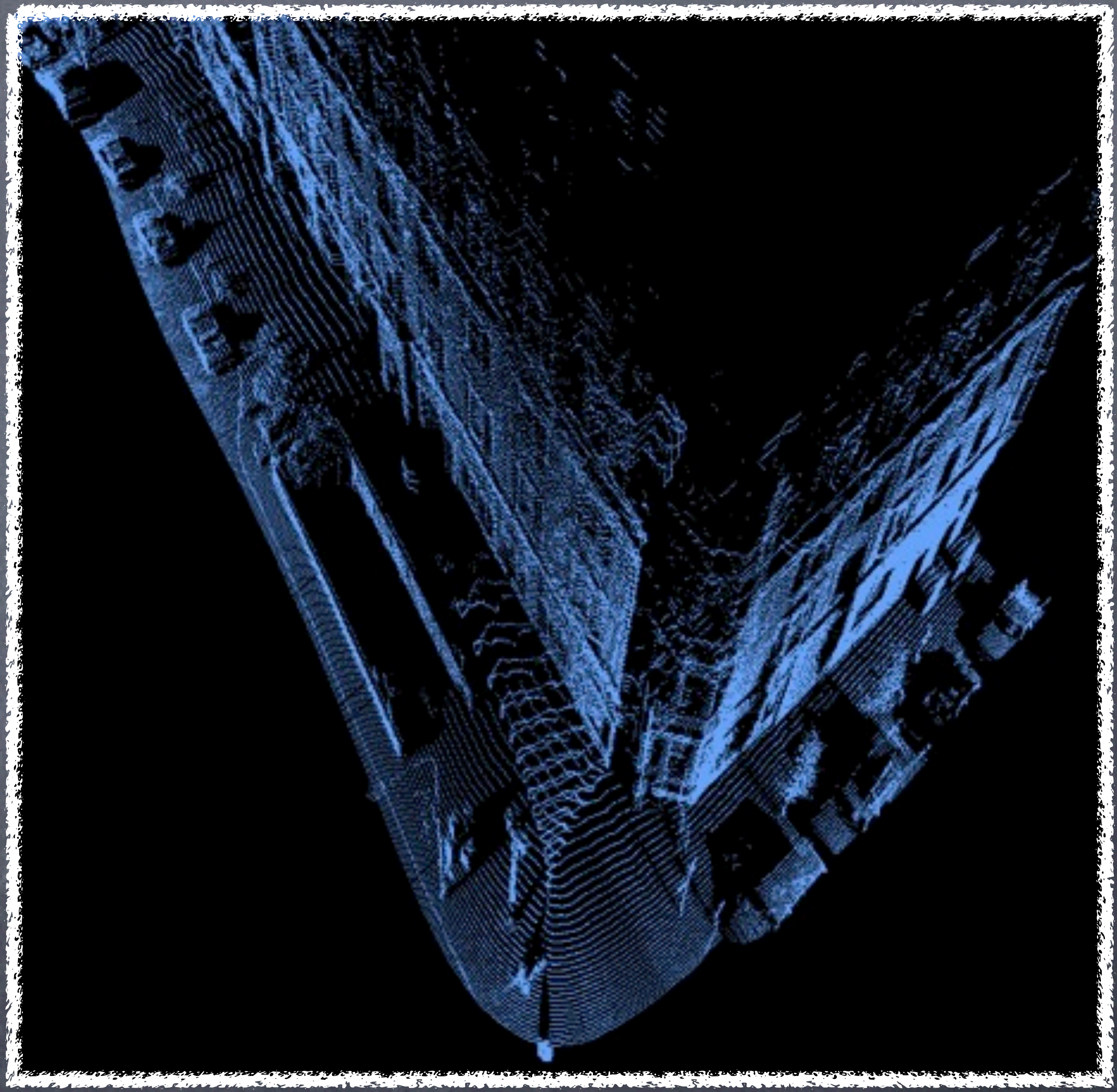
Point Cloud Generation





stack the vertical scans at appropriate distances from each other to get point cloud.

Ground-based Modeling

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(beyond the paper)

Mesh Generation

- structure vertical scan vertices as a 2D grid
- connect adjacent vertices if depth discontinuity < threshold

Ground-based Modeling

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(beyond the paper)
Texture Mapping

- assign 2D texture from digital camera images to corresponding 3D mesh triangles.

References

- Fruh and Zakhor. Fast 3D model generation in urban environments. Multisensor Fusion and Integration for Intelligent Systems, 2001. MFI 2001. International Conference on (2002) pp. 165-170