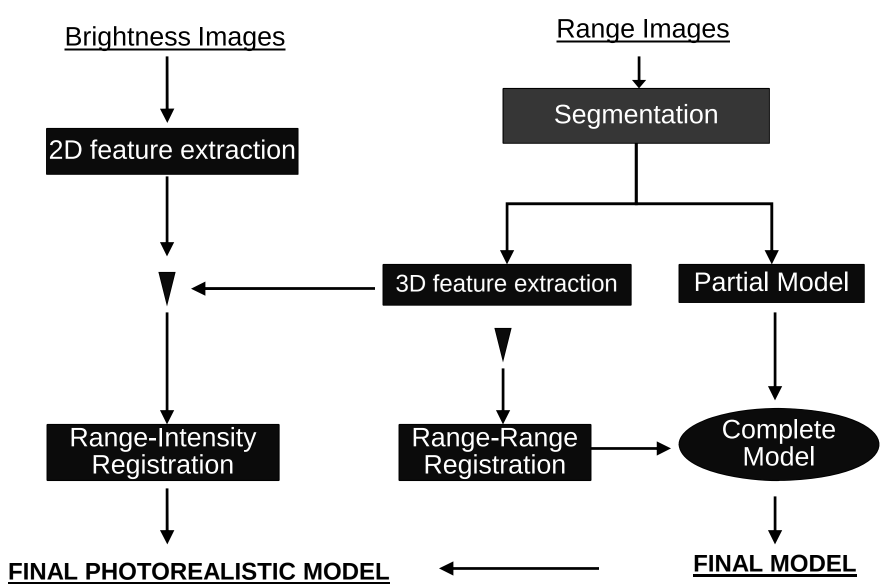
3D Photography

3D Pipeline
Planar Segmentation

System Overview



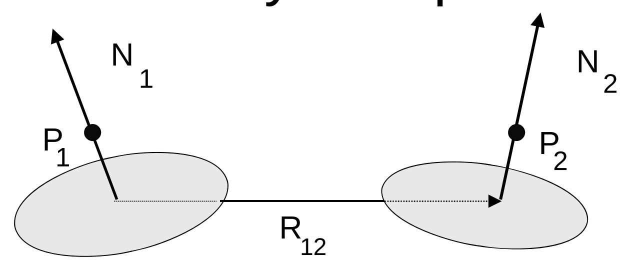
Planar Segmentation Module

- Points clustered into segmented planar areas (SPAs).
- Planar surfaces fit to SPAs.
- Boundaries of SPAs computed as 2D polygons.
- Linear features extracted at
  - Boundaries of SPAs.
  - Intersections between neighboring SPAs.
- Linear features used for range-range registration.
- Linear features of intersection used for modeling corners.
- SPAs used for modeling planar scene areas.

Clustering into Segmented Planar Areas

- Local classification of points:
  - Fit local plane to neighborhood of range points.
    - Compute local normal per point.
  - Classify range points: planar, non-planar, uknown.
- Hough-based global classification of points:
  - Points globally clustered based on their local normal.
- Merge into **8-connected** clusters of points using
  - Local and global classifications.
- Combined classifications reduces false-positives.

Co-Planarity Comparison

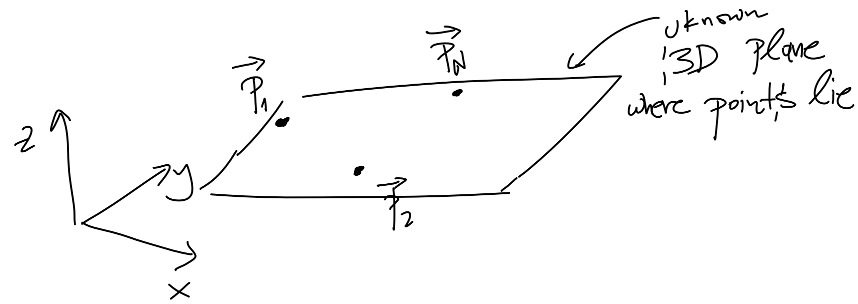


- Patches fit in K by K neighborhood around points P1 and P2.
- Eigenvector corresponding to smallest eigenvalue is the normal
- Both points have been classified using hough-based method.

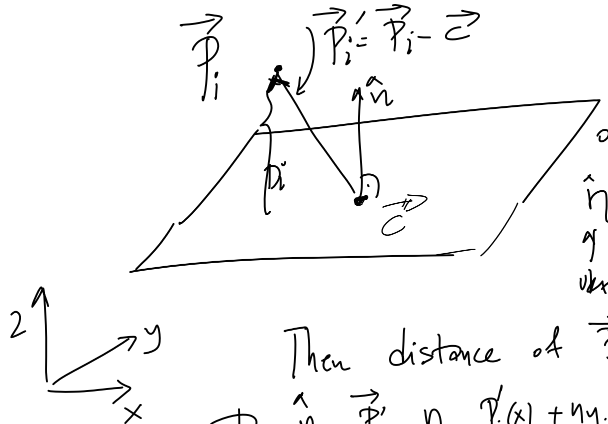
P1 and P2 are **coplanar** iff:

- Error in planar fit around both points < fit threshold
- Both points are in same cluster of hough-based normal class.
- $a=\cos^{-1}(N_1 \cdot N_2)$ < angle threshold
- $d=\max(|R_{12} N_1|, |R_{12} N_2|)$ < distance threshold

PROBLEM: Given n 3D Points $\vec{P}_1, \dots, \vec{P}_N$ find "best" plane.



OBSERVATION 1: BEST PLANE PASSES THROUGH CENTER OF MASS $\vec{c} = \frac{1}{N} \cdot \sum_{i=1}^{N} \vec{P}_i$



Suppose that normal of best plane is

$\hat{n} = (n_x \; n_y \; n_z)^T$

unknown

Then distance of $\vec{P}_i$ from plane is:

$$D_i = \hat{n} \cdot \vec{P}_i' = n_x \cdot P_i'(x) + n_y \cdot P_i'(y) + n_z \cdot P_i'(z)$$

Our goal is to find $\hat{n}$: $\sum_{i=1}^{N} |D_i|^2$ is minimum

We should keep in mind though that $\hat{n}$ is a unit vector $(n_x^2 + n_y^2 + n_z^2 = 1)$

So using Lagrange Multipliers:

Minimize $\sum_{i=1}^{N} D_i^2 + \mu (n_x^2 + n_y^2 + n_z^2 - 1)$ wrt $n_x \; n_y \; n_z \; \mu$

$D_i = n_x P_i'(x) + n_y P_i'(y) + n_z P_i'(z)$

⟶ leads to the following equation.

$$A \cdot \hat{n} = \mu \cdot \hat{n} \quad \text{where} \quad A = \sum_{i=1}^{N} \vec{P}_i' \cdot \vec{P}_i'^T = \sum_i \begin{bmatrix} P_i'(x)^2 & P_i'(x) P_i'(y) & P_i'(x) P_i'(z) \\ P_i'(x) P_i'(y) & P_i'(y)^2 & P_i'(y) P_i'(z) \\ P_i'(x) P_i'(z) & P_i'(y) P_i'(z) & P_i'(z)^2 \end{bmatrix}$$

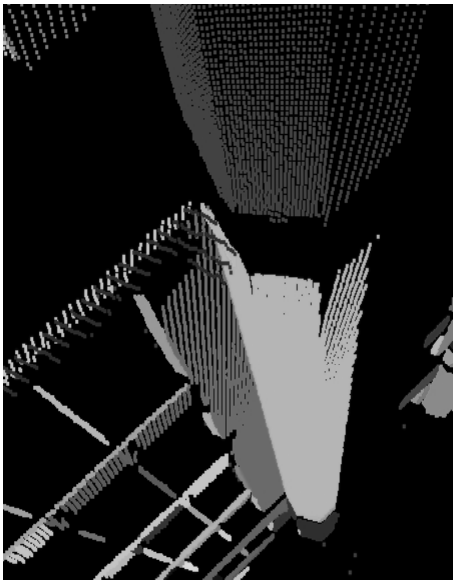
⟸

1) $\hat{n}$ is eigenvector of smallest eigenvalue

2) Smallest eigenvalue is distance from best plane!

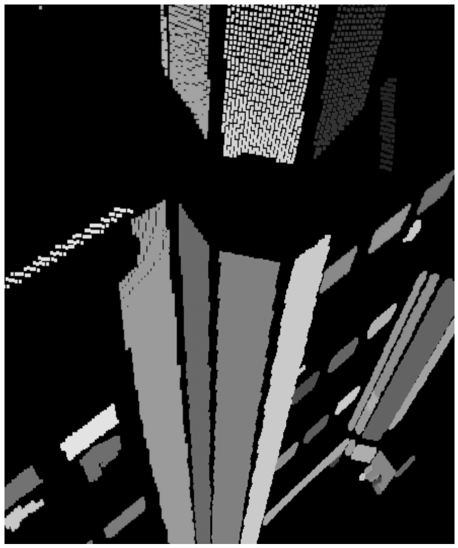
Result – Point Clustering

A closer look



Error in segmentation
if only local classification
is used

A closer look

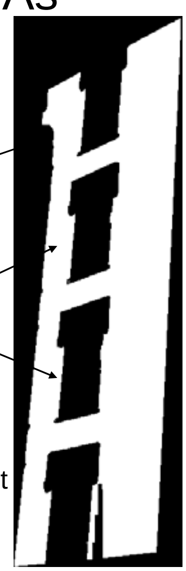


Correct segmentation provided by combination of local with global hough-based classification

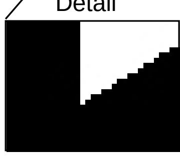
Computing Boundaries: Binary Images of SPAs

Outer boundaries

Inner boundaries (holes)



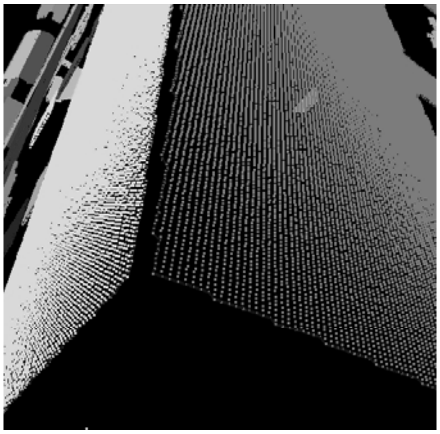
Detail

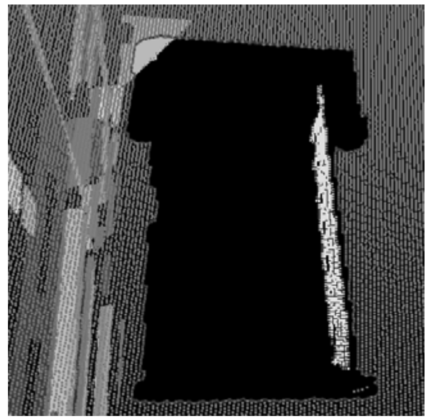


Detail reveals jugged boundaries due to range sensor's finite sampling

- Sequential labeling algorithm identifies inner holes.
- Boundary extraction via robust edge following

Computing Boundaries: From Binary to Range Images

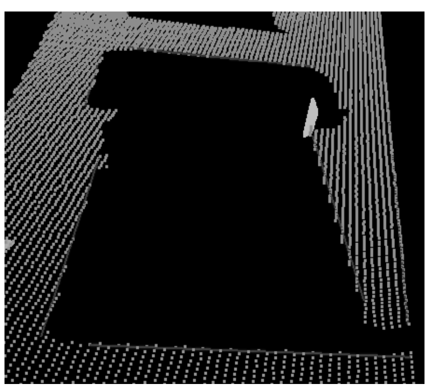


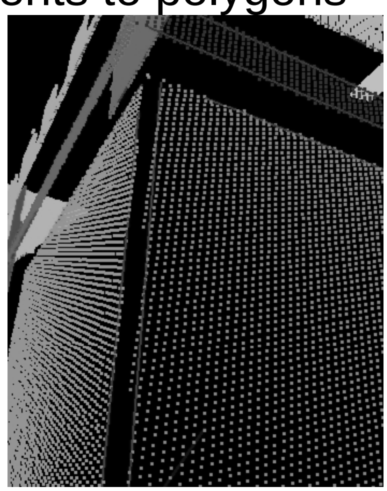


Two outer boundaries | One inner boundary

The boundaries are 3D planar polygons projected on the fitted plane of each segmented planar area.

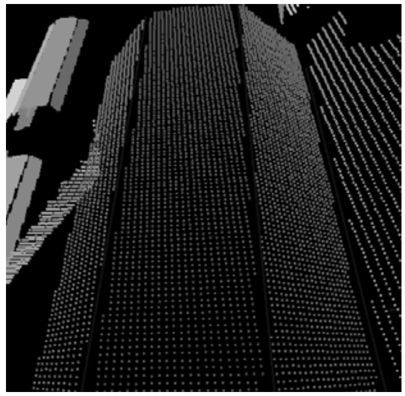
Computing Boundaries: Fitting linear segments to polygons





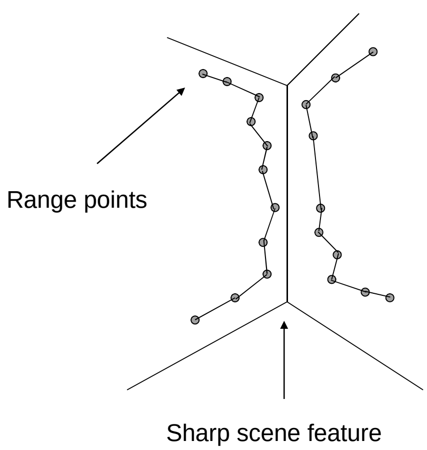
3D linear segments are fit to the outer and inner boundaries.
The boundary lines are used for automated range-range registration.

Computing Boundaries: Intersection Lines



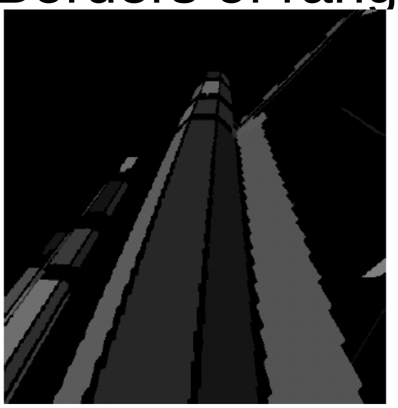
- 3D lines of intersection between neighboring planes are computed.
- The intersection lines are used for
  1. Automated range-range registration.
  2. Building topological hierarchy.
  3. Straighten borders at intersections of planar regions.

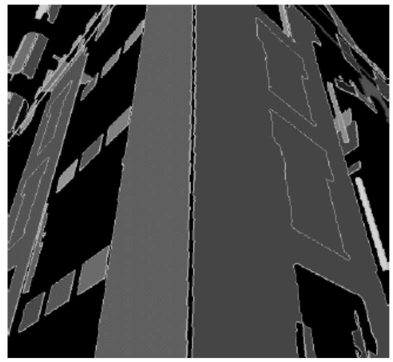
Borders of range scans



- Inherent inability to capture sharp corners due to finite sampling.
- Problem exists in any sampling rate.
- Challenge for man-made objects.

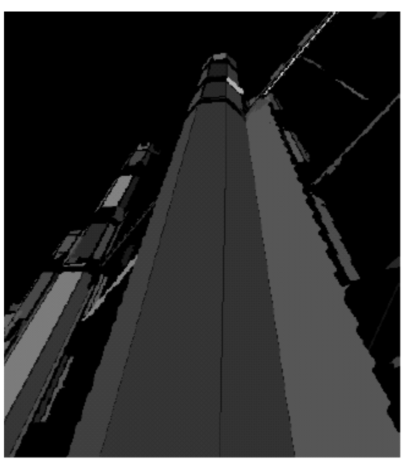
Borders of range scans





Inherent problem at borders

Borders of range scans



Our solution

1. Compute lines of intersection between neighboring SPAs.
2. Build topology graph.
3. Replace jagged boundaries with sharp intersection lines.

Planar Segmentation Result: From Points to 3D Planar Polygons

More Segmentation Results

Two segmented range scans of building