# Modeling Rugged 3D Terrain from a Long Sequence of Range Images for Outdoor Mobile Robots

Takeo Kanade and In So Kweon

The Robotics Institute
Carnegie Mellon University

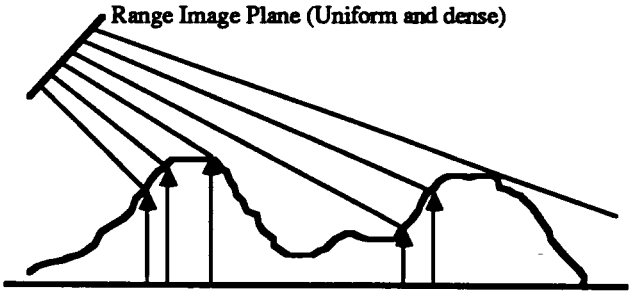
October 16, 1989

# From Range Image to Elevation Map

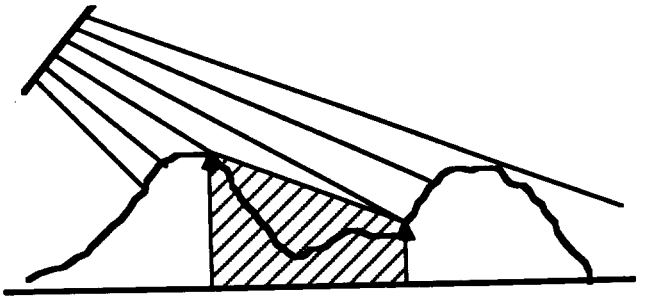
## Traditional Method

1. Convert a range image to cartesian elevation map by coordinate transform.
2. Smooth and interpolate elevation map.

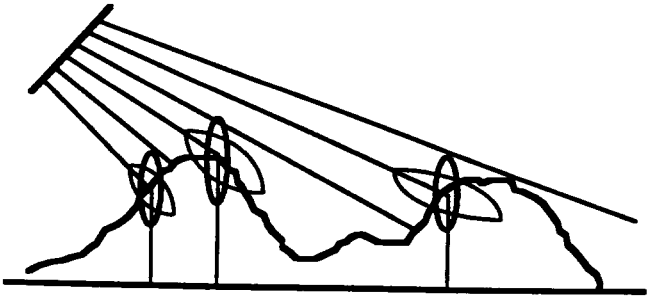
Sparse and non-uniform data



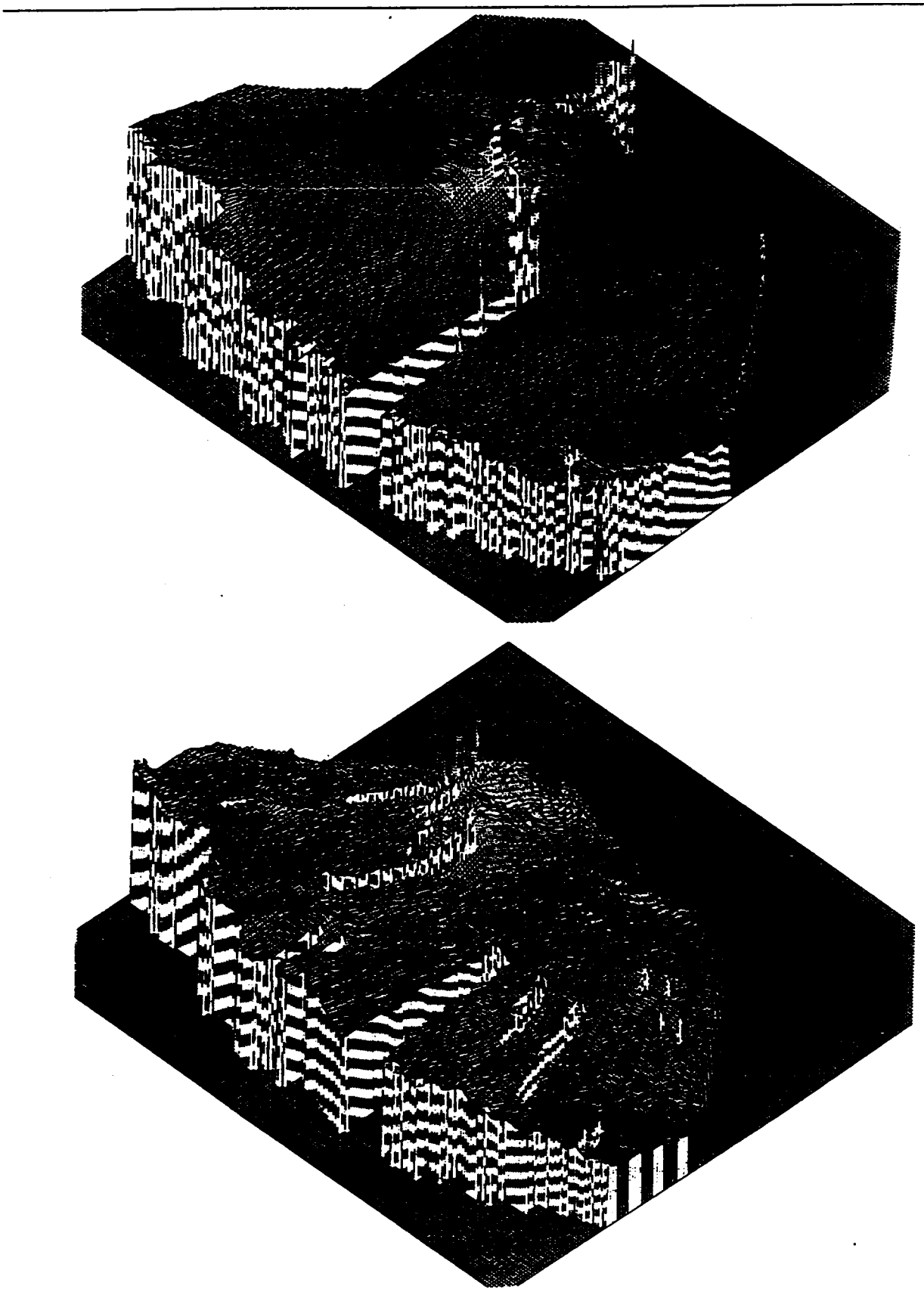

Shadow (visibility) — occlusion



Uncertainty — from sensor to map



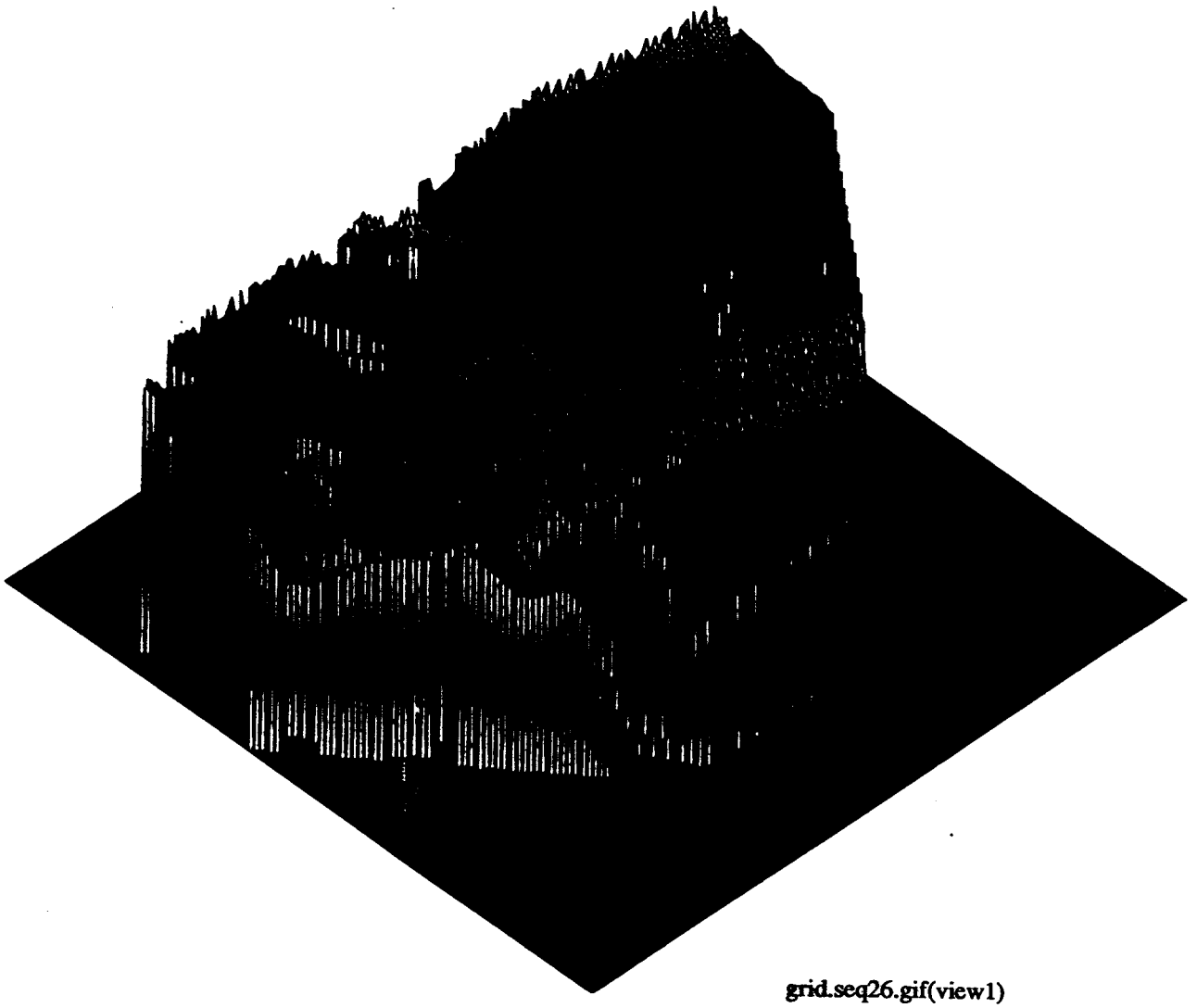
# Elevation Maps by Locus Method and Traditional Method



TRN

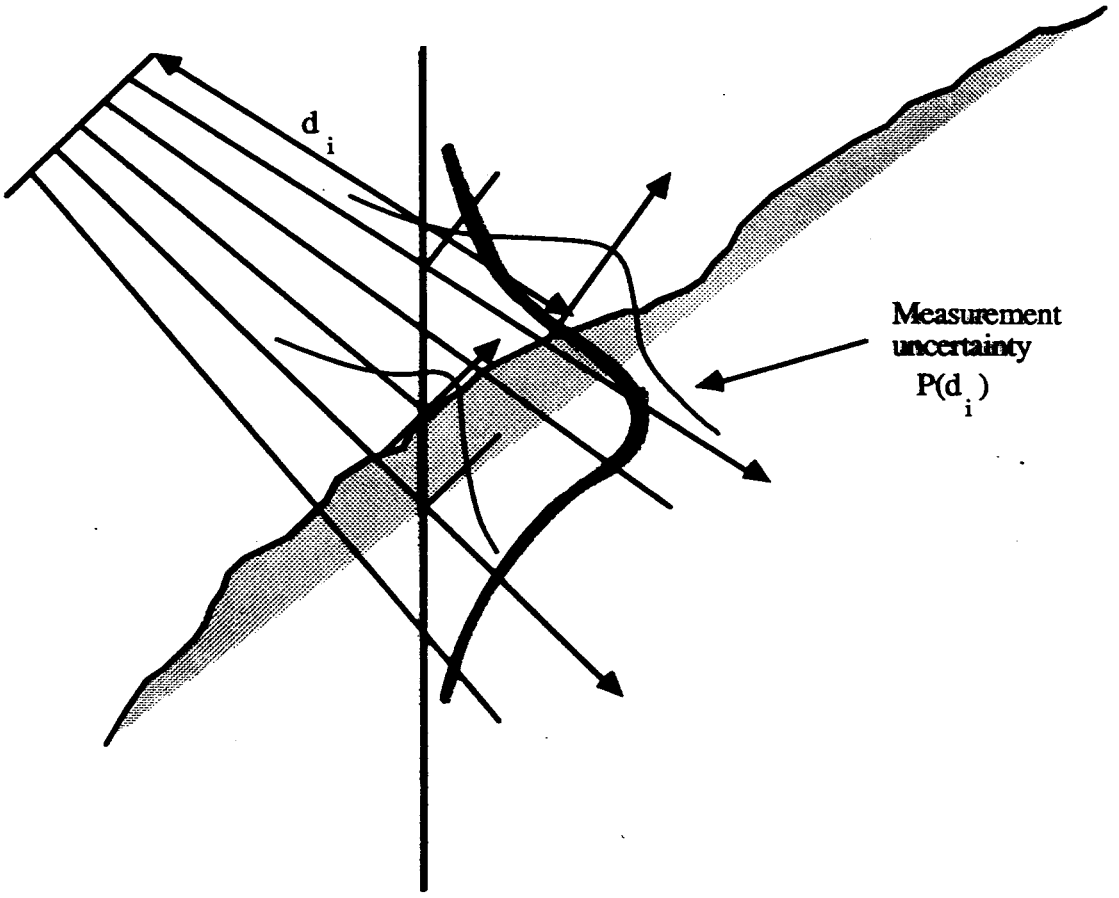
# Elevation Map by Locus Method on Range Images

Single Frame
Scanner: ERIM laser range finder: 30 deg $\times$ 80 deg field of view
(64*rows* $\times$ 256*cols*)



grid.seq26.gif(view1)

# Uncertainty — from Sensor to Map






TRN

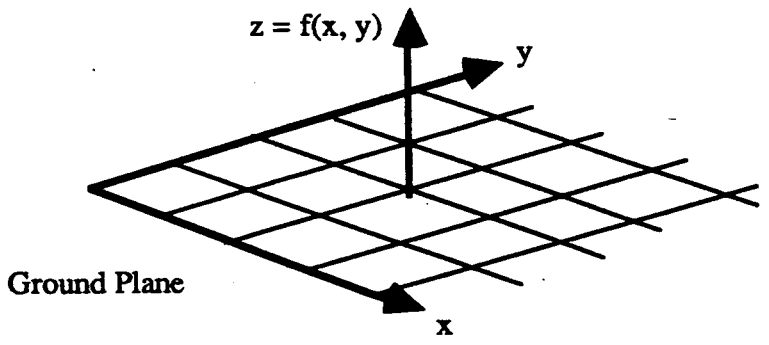
# Terrain Feature Extraction

- Height and Orientation Discontinuities in Elevation Map
- Region Growing into Primitive Surfaces Using Smoothness Constraints
- 3D Polygon Mesh Representation
- Grouping Primitive Features into Higher-Level Features (eg. ditch, slope, etc)

# Representation of Terrain Maps

Elevation Map

| | |
|---|---|
| elevation | $z = f(x, y)$ |
| uncertainty | $\sigma^2 = E[Z^2] - E^2[Z]$ |
| visibility | known, occluded, unknown |
| topography | peak, pit, ridge, ravine, saddle, ... |
| slope | |
| roughness | amplitude, spatial frequency, ... |
| material properties | friction, composition, ... |
| traversability | $f$ ( roughness, slope, material, ... ) |




Discrete Object Description

size, shape, location, material properties

paths, viewpoints

# Iconic Matching

- Initial estimation from Feature matching

- Given a map and a new frame, find $T$ to minimize:

$$E = \sum \|h_1(u, v) - g(u, v, T)\|^2$$
$$g(u, v, T) = T^{-1}(h_2(u', v')) = R' h_2(u', v') + t'$$

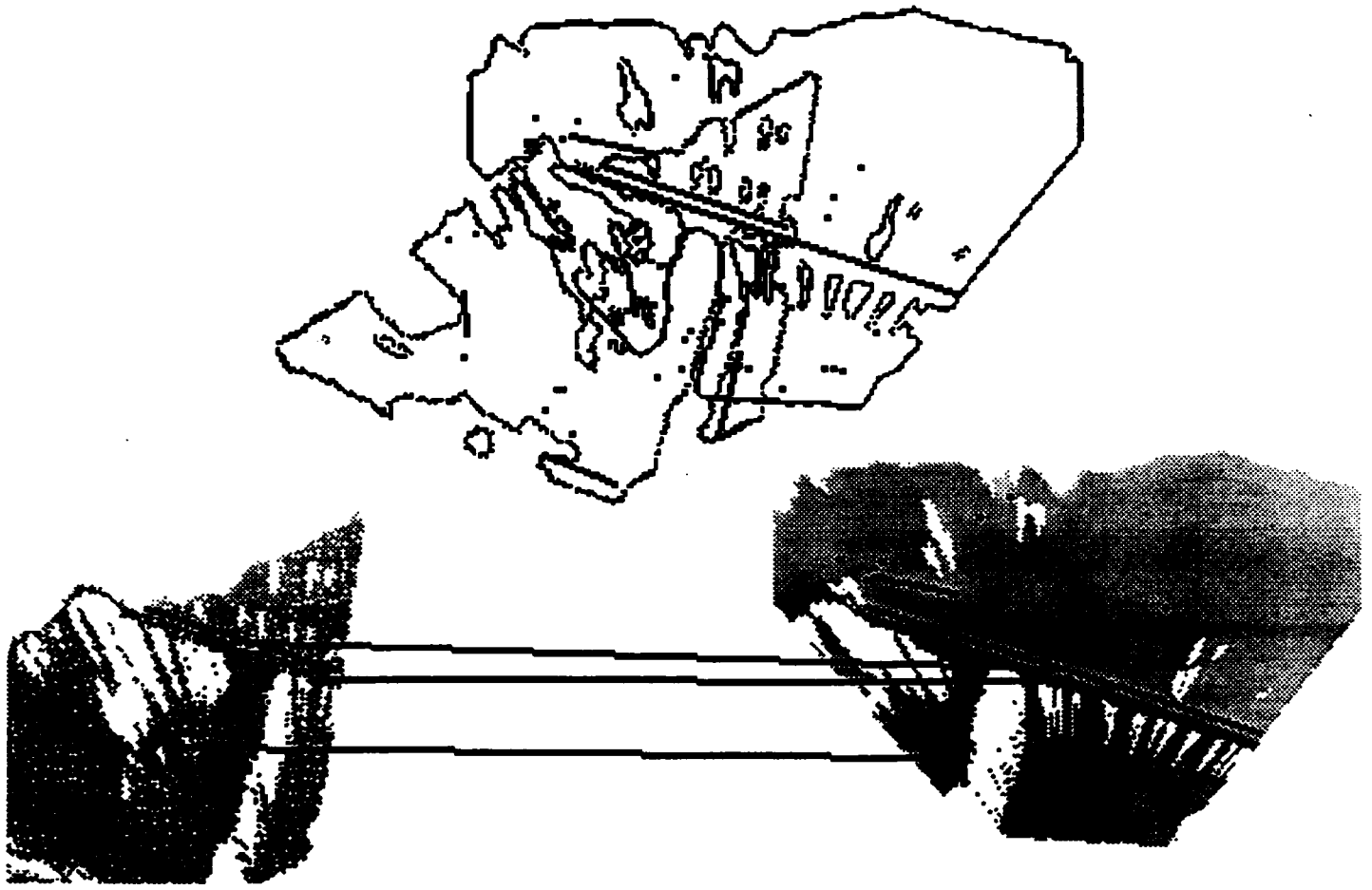
$(u, v)$: A 3D line in space.
$(u', v')$: The transformed line by $T$.

- NO correspondences (Generic Locus Method)

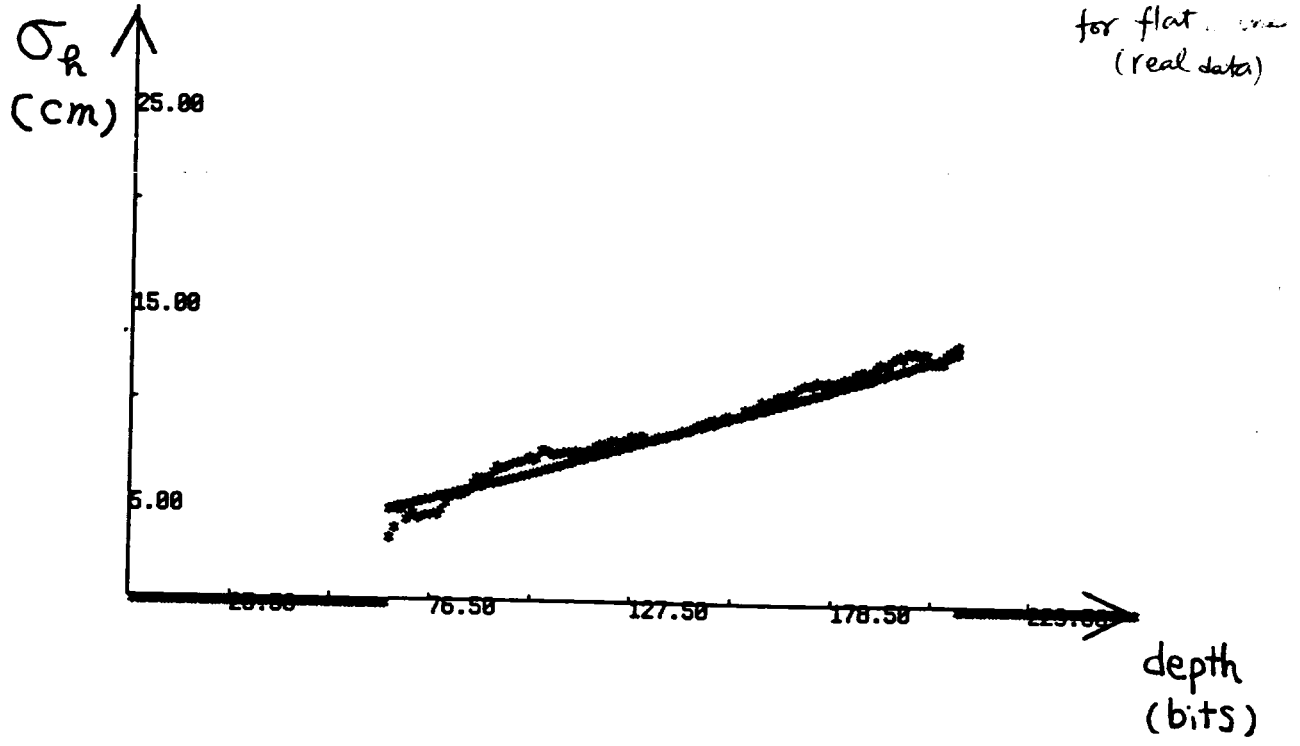
- Computational complexity
  - Coarse to fine approach.
  - Rough terrain areas - peaks, pits.

# Result of Feature-Based Matching

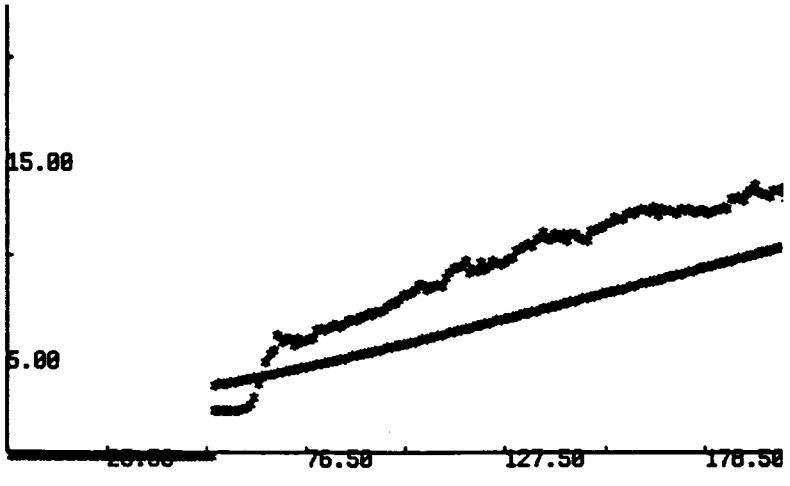
Features: high curvatures points and lines.



# Experimental Result for Uncertainty Model of Elevation Map




for flat ... (real data)




for real scene.