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

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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

Range Image Plane (Uniform and dense)

Shadow (visibility) — occlusion

Uncertainty — from sensor to map
Elevation Maps by Locus Method and Traditional Method
Elevation Map by Locus Method on Range Images

Single Frame
Scanner: ERIM laser range finder: 30 deg × 80 deg field of view
(64 rows × 256 cols)
Uncertainty — from Sensor to Map
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 (e.g. 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: \( f(\text{roughness, slope, material, ...}) \)

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

\[ \sigma \] (cm)

\[ \text{depth} \] (bits)

for flat. one
(real data)

for real scene.