Survey on Range Image Segmentation and Registration

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Second Exam, Part One
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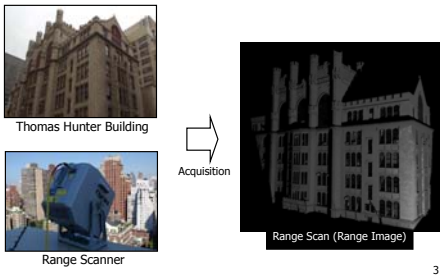
May 18, 2005

Outline

- Introduction
- Range Image Segmentation
  - Edge-based approaches
  - Range-based approaches
  - Hybrid approaches
- Range Image Registration
  - Point-based methods
  - Feature-based methods
  - Multi-view registration
- Conclusions

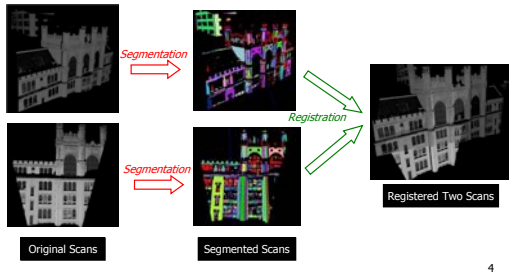
Introduction

- 3D photorealistic modeling (step 1)



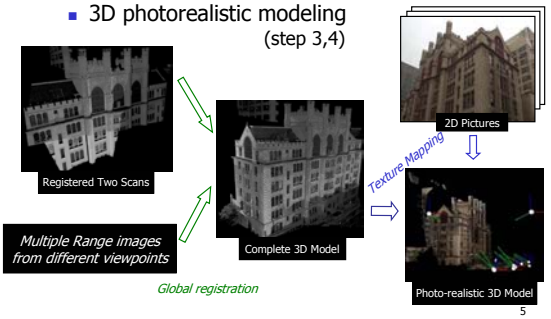
Introduction

- 3D photorealistic modeling (step 2,3)



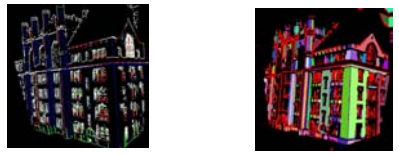
Introduction

- 3D photorealistic modeling (step 3,4)



Segmentation

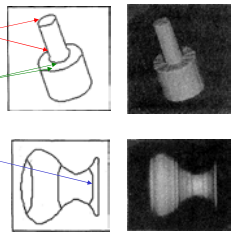
- Partition a scan into meaningful parts based on geometry
- Edge-based
- Region-based



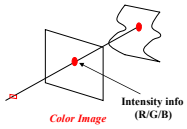
- Hybrid approaches

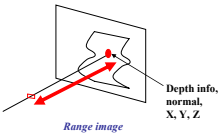
Edge-based Segmentation

- Three types of edges
  - Step/Jump edges
    - Depth discontinuity
  - Roof/Fold edges
    - Surface normal discontinuity
  - Smooth edges
    - Smooth local extrema of curvature



Edge-based Segmentation





- Adapting 2D image processing techniques
  - Edge masks [8,10,26]
  - Residue operators (erosion, dilation, opening, closing) [7]
  - Surface normal clustering [6,9]
- Edge linking and edge thinning

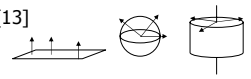
Edge-based Segmentation

- Limitations
  - ? Fragmented and discontinuous edges
  - ? Sensitive to noise
  - ? Not much information for curved surfaces
- Advantages
  - ♪ Simple to implement
  - ♪ Useful for polyhedral objects
  - ♪ Initialize segmentation for later region-based

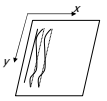
Region-based Segmentation

- Polyhedral surfaces, spheres, cylinders
  - Normal decomposition, with depth information [12]

  - Normal Analysis [13]

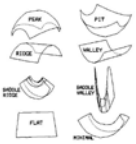


  - Scan line clustering [14]
    - Quadratic curve fitting and merging



Region-based Segmentation

- Arbitrary shapes by surface model fitting (Besl and Jain[15], etc.)
  - Point classification for an initial segmentation
  - Local least square fitting at each pixel
    - Linear; quadratic; polynomial;
  - Region growing to minimize fitting error



$$z = f(x, y)$$

$$z = g(x, y) = \sum_{i=1}^{N} f_i(x, y)\, \chi(x, y, R_i)$$

$$\epsilon_{ij} = \left\| g(i, j) - \hat{g}(x(i), y(j)) \right\|_2$$

Region-based Segmentation

- Robust estimators
  - Tolerate data from different statistical populations; estimate parameters for dominant population
  - RESC [19][20]
    - K sets of sample points for function fitting
    - Histogram on residues to determine one best inlier set
  - ALKS [21]
    - Minimizes k-th order statistics
    - Pick p(<k) random points from n points; fit model;
    - compute residuals and sort them;
    - find the shortest window that contains at least k residuals;
    - Repeat for several p-tuples; the one with shortest window provides the model estimate.
  - MUSE [22]
    - Seeks the k with the minimum k-th order statistics
  - Robust to outliers; high complexity

Region-based Segmentation

- Segmenting by partitioning [24]
  - Cluster point clouds to small clusters
  - Partition all clusters into two portions that minimizes the disassociation measure (normalized cut)
  - Disassociation determined by distance, normal, etc.
  - Iteratively repeat partitioning
- Summary on segmentation
  - ♪ General solution to surface fitting
  - ♪ Provide closed segmented regions
  - ? High time complexity
  - ? Cannot provide accurate boundary information

Hybrid approaches

- Edges first, then regions [25][26]
  - Curvature sign map separates regions
  - Edge-based methods to detect edges
  - Each patch fitted to certain surface model
- Regions first, then edges [27]
  - Plane fitting and clustering
  - Contour extraction and classification
  - Computing parameters for linear edges
  - Refine step edges based on plane information
  - Polyhedral only; can extend to curved surfaces

Summary on Segmentation

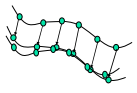
- Edge-based methods
  - ♪ Precise border locations, simple operations
  - ? Unstable, fail for curved surface
- Region-based methods
  - ♪ Explicit descriptions on surface shapes, closed regions
  - ? Time consuming, no accurate boundary information
- Hybrid methods
  - ♪ Efficient, expressive
  - Edge maps restricting ranges, enable parallel computing
  - Region growth joins fragmented edge points and provide surface descriptions

Registration

- Transform a set of partially overlapped range scans into a common coordinate system
- Pair-wise registration
  - Point-based (ICP)
    - Iteratively match two point clouds
  - Feature-based
    - Feature extraction
    - Finding transformation by matching features
- Multi-view registration

Point-based Registration

- ICP algorithm
  - Assume a close initial alignment
  - Compute the closest point
  - Compute the transformation from error metric
  - Apply the transformation
  - Next iteration

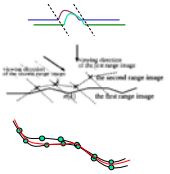


Point-based Registration

- Variations (high speed variants are underlined [36])
  - Point sampling
    - All points; uniform sampling; random sampling; those with high intensity gradient
  - Finding closest point
    - Closest distance; normal shooting; projection to plane; projection along viewing direction
  - Weighting of pairs
    - Constant weight; based on compatibility of normal; based on point-to-point distance;
  - Error metric
    - Point-to-point; point-to-plane; point-to-plane along viewing direction; distance as well as color or laser intensity
  - Acceleration and noise handle
    - K-d tree structure; distance threshold for rejecting pairs

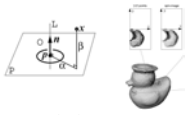
Point-based Registration

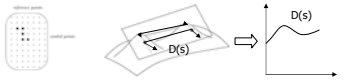
- Improving alignment accuracy
  - Prevent unstable sliding [37]
    - Determine stable areas on two meshes to register
    - Select sample points from stable areas
  - Considers the measurement error [38]
    - Corresponding points found along viewing direction
  - Non-rigid scan alignment using thin-plate splines [39]
    - Hierarchical ICP for feature correspondence
    - Use thin-plate spline to warp points to a smooth surface
- Summary
  - Slow convergence
  - Finds local minima
  - Performs well with good initialization
  - Initial alignment may come from manual or feature-based registration



Feature-based Registration

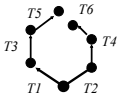
- Point-based features
  - Spin images [40,41]
- Line-based features [47][60]
- DARCES
  - Point groups sliding [46]
- Bitangent curves matching [48]





Multi-view Registration

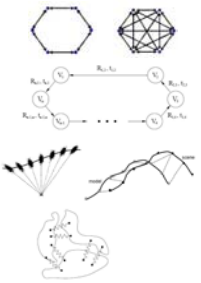
- Problem of error accumulation



- Sequential Optimization
  - Add a view to current registered view sets at each step [29]
  - Add a view at each step while satisfying pair-wise constraints [49,50]

Multi-view Registration

- Simultaneous Optimization
  - Minimize the composite transformation errors [51,52]
  - Distribute error along cycles [53,54,55]
  - Robust methods
    - Statistical estimation on points' true positions [56]
    - M-estimation; distance + reflectance strength as error metric [57]
  - Force-based optimization methods [58,59]

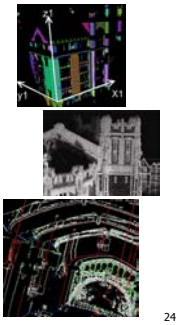


Summary on Registration

- Point-based methods (fine registration)
  - Iteratively registration with high accuracy
  - Requires good initial alignment
  - Time consuming
  - Easy to get stuck in local minima
- Feature-based methods (coarse registration)
  - Based on extracted features
  - More errors occur at feature extraction
  - Usually requires point-based methods to refine registration
- Multi-view registration
  - Usually point-based
  - Time consuming
  - Hard to find optimal solution

For Urban Scenes

- Segmentation
  - Edge features: lines, circles
  - Region features: planes, spheres, cylinders
- Registration
  - Existing problems: time-consuming, symmetry, error accumulation
  - Proposed solutions: feature-based, user guidance, coarse-to-fine registration, global optimization



Conclusions

- Segmentation and registration techniques applied to large variety of object shapes and surfaces; from lab controlled small objects to large outdoor scenes
- Segmentation and Registration
  - Segmentation results can be useful for feature-based registration
  - Registration transforms can be used to combine and refine segmentations
  - Registered 3D points, segmented edges and regions used for object modeling and recognition
  - Segmentation provides local geometric information; registration provides global structure
  - Incorporate both techniques into an interactive system of urban scene 3D modeling

Thanks !

Questions ?