GEOMETRICAL CLONING OF 3D OBJECTS VIA SIMULTANEOUS REGISTRATION OF MULTIPLE RANGE IMAGES

Presented by

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PRESENTATION OUTLINE

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  - Image Registration
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  - Previous Works
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  - Reconstruction and 3D Rendering
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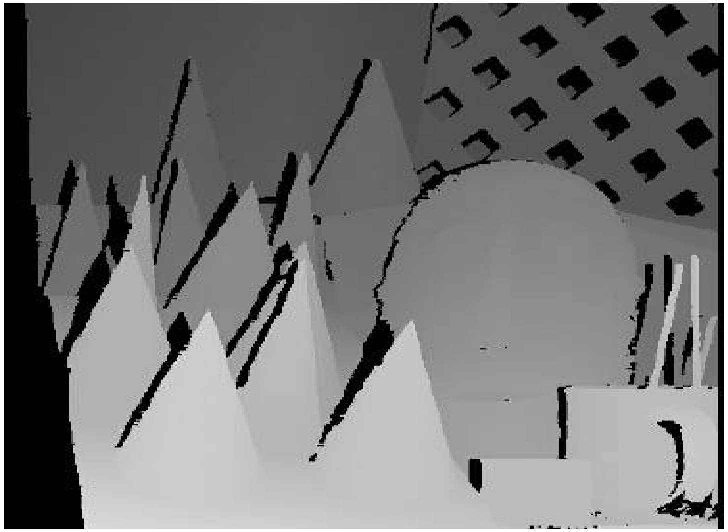
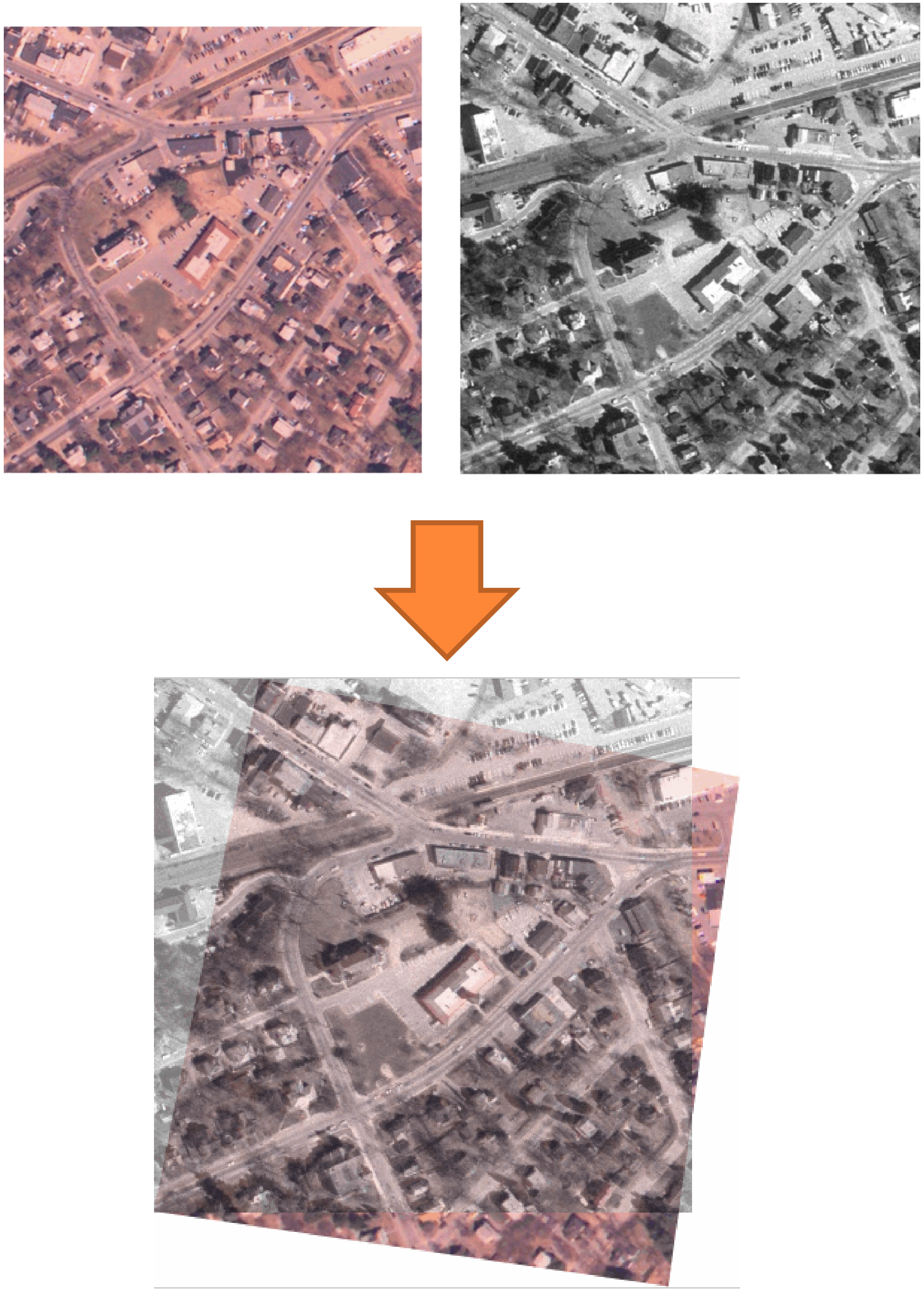
KEYWORDS
RANGE IMAGING

- Collection of techniques used to produce a 2D image that provide depth information
- Range images are also referred to as “depth maps,” or “xyz maps”
- Typically, light intensity used to represent depth



KEYWORDS
IMAGE REGISTRATION

- Process of *aligning* two or more images of the same scene
  - Use one image as a reference (model), and align target (scene) images
  - Rigid (translation, rotation, scaling) and non-rigid (elastic) transformations
  - Curves, edges, points used as correspondences
- Applications:
  - Medical Imaging – combining CT and NMR data (multi-modal analysis)
  - Cartography – Map updating (multi-temporal analysis)



KEYWORDS
IMAGE REGISTRATION

- Range Image, or “Surface”, Registration
  - Matching or aligning points for 3D surfaces
- In mathematical terms:

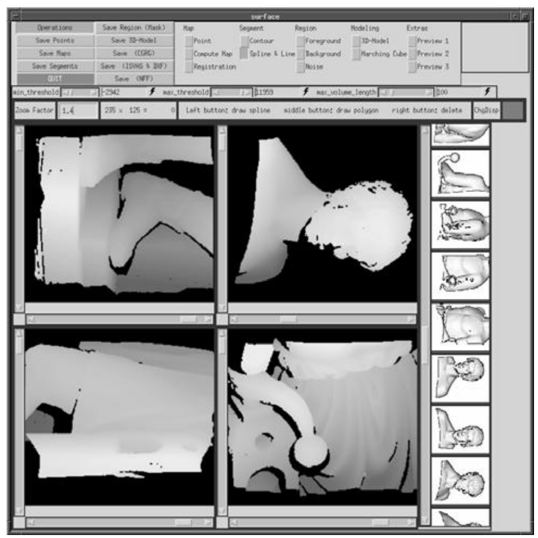
Let X, Y represent two surfaces; for $x \in X$, $y \in Y$ and for some rigid transformation T,

$$\forall x_i \in X, \exists y_i \in Y, \text{s.t. } \|T(x_i) - y_i\| = 0$$

$$x_i = x_i(a, b, f(a, b)),\ y_i = y_i(c, d, g(c, d))$$

INTRODUCTION
MOTIVATION

- Reconstruction/3D rendering of real world objects from the Registration of multiple Range Images



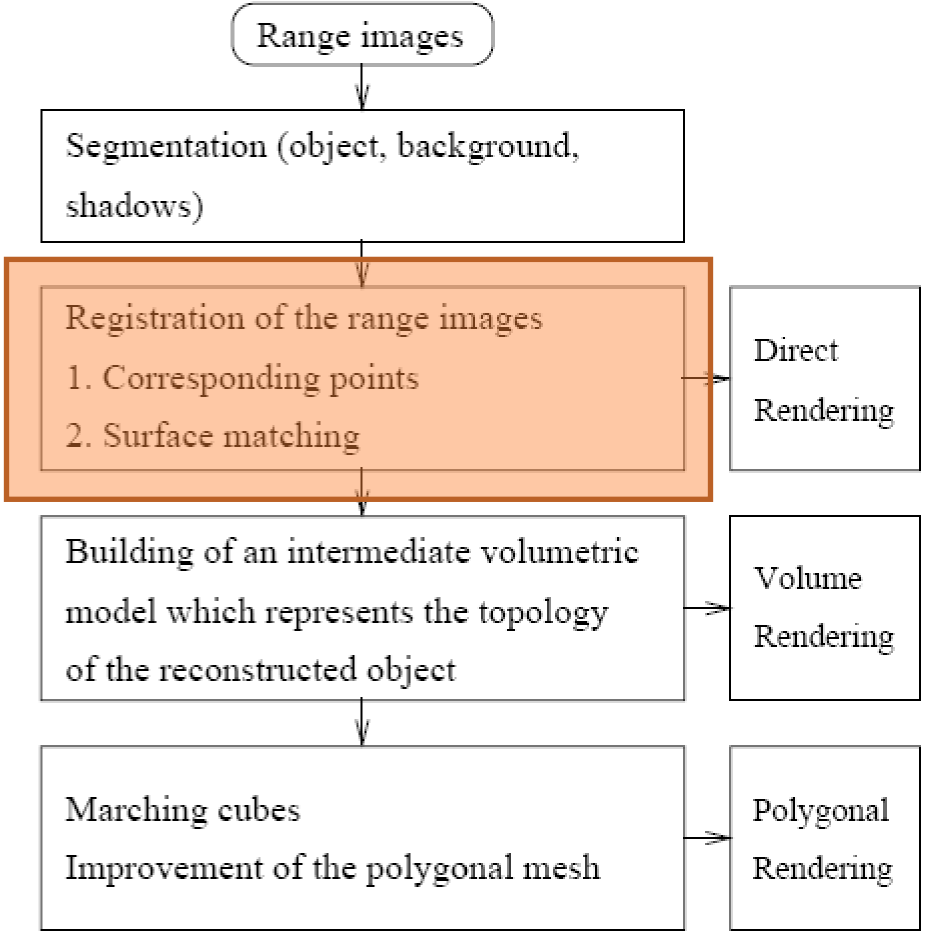
INTRODUCTION
PREVIOUS WORKS

- Turk and Levoy
  - Registration of range images through a modified ICP (iterative closest point) algorithm
- Bergevin, Laurendeau, and Poussart
  - Partial range views represented as triangulated meshes, used as features for registrations
- Higuchi, Herbert, and Ikeuchi
  - Feature-based approach using curvature for registration
- Curless and Levoy
  - Reconstructed complete objects through a volumetric approach, given registered range images

INTRODUCTION
MAJOR CONTRIBUTIONS

- Simultaneous Registration
  - Iteratively align all range images simultaneously
- Resolution Hierarchy
  - Cuts down on runtime of convergence
- Visibility Criteria
  - Ensures that points not belonging to the object are not inadvertently incorporated into the 3D image

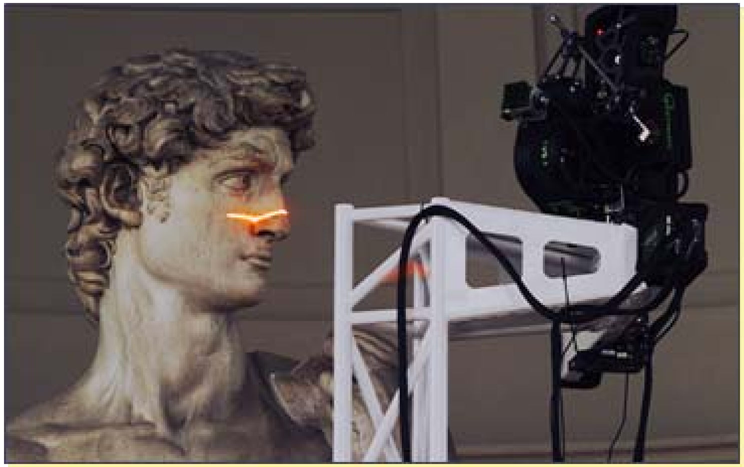
METHODOLOGIES
PROCESS "PIPELINE"



METHODOLOGIES
3D SCANNING

- Range Images acquired through 3D Scanners
- 3D Scanning Issues
  - Not possible to scan the shape of an object entirely in one view – topological/geometrical limitations
  - Need to have ~20-50% overlap in images for correspondence
- Application of Registration for Rendering
  - Reconstruction of a 3D scene entirely from partial views
  - Connecting surface pieces of a puzzle in 3D.

METHODOLOGIES
3D SCANNING



METHODOLOGIES
IMAGE REGISTRATION

- Initial Estimates
  - Manual selection of corresponding points in each image (need at least 3 points)
  - Serves to provide an initial relative orientation estimate

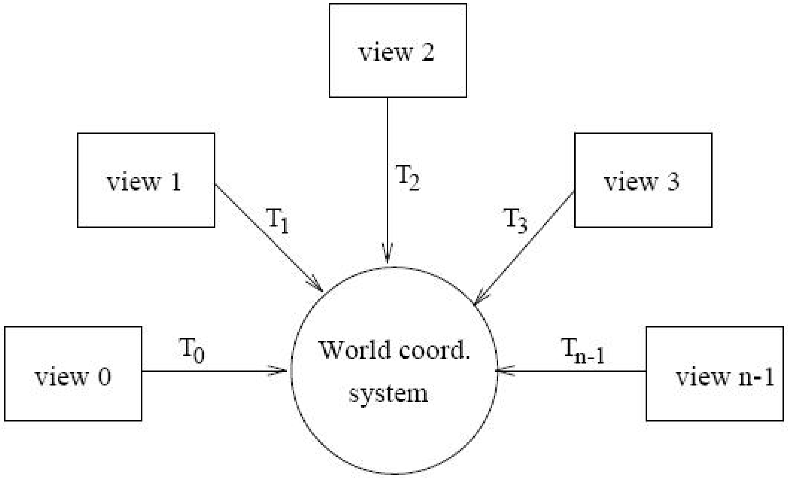


Fig. 2. The relative orientation for each range image with respect to a world coordinate system.

METHODOLOGIES
IMAGE REGISTRATION

- Simultaneous Registration
  - Use the initial relative orientation estimate and iteratively optimize the transformation parameters over *all range images*
  - Advantages
    - Global error minimization – spread/diffuse error over all range images
  - Disadvantages
    - Large computational cost, since each iteration must compute error between each range image and reference

METHODOLOGIES
NONLINEAR LEAST SQUARES

- Notation

  $S = \{S_0, S_1, \ldots, S_N\}$: Set of range images/surfaces

  $\underline{\theta}_{\mathrm{i}}$: Relative orientation w.r.t. world coordinates

  $R_i^{(\theta)}$: Rotation matrix, dependent on $\underline{\theta}_{\mathrm{i}}$

  $\underline{t}_i^{(\theta)}$: Translation parameters, dependent on $\underline{\theta}_{\mathrm{i}}$

  $T_i^{(\theta)}$: Transformation matrix Range image $\Rightarrow$ World coord.

  $D(\cdot,\cdot)$: Distance between points

- Numerically optimize θ in order to estimate:

$$T_i^{(\theta)}(\underline{x_i}) = R_i^{(\theta)}(\underline{x_i}) + t_i^{(\theta)},\ \underline{x_i} \in S_i$$

METHODOLOGIES NONLINEAR LEAST SQUARES (CONT'D)

- Least Squares Problem
  - Estimate the values of the relative coordinate parameters, θ, such that:

$$D(T_i^{(\theta)}(S_i), T_j^{(\theta)}(S_j))$$

is minimized in the least-squares sense; i.e.,

$$\varepsilon^2 = \min_{\underline{\theta}} \sum_{i \neq j} \left[D(T_i^{(\theta)}(S_i), T_j^{(\theta)}(S_j)) \right]^2$$

METHODOLOGIES
NONLINEAR LEAST SQUARES (CONT'D)

- Iterative algorithm registers all images at once
  - Split the transformation operator into "known" and "correction" operators:

$$T_i^{(\theta)} = T_i^{(\tau)} T_i^{(\delta)}$$

  - New distance to minimize:

$$\varepsilon^2 = \min_{\underline{\delta}} \sum_{i \neq j} \left[D(T_i^{(\tau)} T_i^{(\delta)}(S_i), T_j^{(\tau)} T_j^{(\delta)}(S_j)) \right]^2$$

  - Discretize the model/reference image, approximating a region around each model point as a plane:

$$S_i = \{ \underline{n}_{ik} (\underline{x} - \underline{x}_{ik}) = 0 \}, k = 1,2,....$$

METHODOLOGIES
NONLINEAR LEAST SQUARES (CONT'D)

- The correction vector, δ is derived from simplifying the least squares expression:

$$\underline{\delta} = \left(\sum_{i \neq j,k} A_{ijk}^T A_{ijk} \right)^{-1} \sum_{i \neq j,k} A_{ijk}^T s_{ijk}$$

i, j : Indices of range images from the set S

k : index representing available model points

- The iterative step:

$$T_i^{(\tau_{n+1})} = T_i^{(\tau_n)} T_i^{(\delta_n)}$$

METHODOLOGIES NONLINEAR LEAST SQUARES (CONT'D)

- Resolution Hierarchy
  - Choose only a few model points for the first iteration, and successively increase the number of model points each iterative step
  - Run-time depends mainly on how registration algorithm is iterated in the highest resolution
    - 20-100 times faster as a result of implementing hierarchy

METHODOLOGIES
VISIBILITY CRITERION

- "Visible" objects are defined as lying between the scanner and the surface.
- A point x given in the world coordinates does not belong to a particular object if:

$$P_z T_i^{-1}(\underline{x}) > f_i\left(P_x T_i^{-1}(\underline{x}), P_y T_i^{-1}(\underline{x})\right)$$

where:

$$P_x = \langle 1, 0, 0 \rangle^T \underline{x}$$

$$P_y = \langle 0, 1, 0 \rangle^T \underline{x}$$

$$P_z = \langle 0, 0, 1 \rangle^T \underline{x}$$

$$f : \text{Interpolated depth at coordinates of } S_i$$

METHODOLOGIES RECONSTRUCTION AND 3D RENDERING

- Intermediate Volume
  - Construction of a topological model from registered partial views (under the world coordinate system)
- Volume Rendering
  - 3D rendering of the Intermediate Volume
  - For each point, requires an opacity and color
- Polygonal Rendering
  - Resample the object in 3D space using the Marching Cubes Algorithm
    - scheme for extracting a polygonal mesh of an isosurface

SUMMARY OVERVIEW

3D Scanning

Multiple views with 20-50% overlap

Segmentation (usually automatic)

Range Images

2D images with embedded 3D depth information

Image Registration

1.Roughly estimate relative orientations w.r.t. world coordinates

2.Numerically optimize orientation parameters (by minimizing error in a least-square sense)

Visibility Criterion

Detection of occluded surfaces

Reconstruction/3D Rendering

1.Intermediate Vol.
2.Volume Rendering
3.Polygonal Rendering