3-D PHOTOGRAPHY, Fall 2002

NOTES ON ZIPPERED POLYGON MESHES BY G. TURK AND M. LEVOY

1. **Problem Description**
   - Collect a set of range images into a single polygonal mesh that completely describes an object as a solid.
   - Applications:
     - Digitization of objects for animation and visual simulation
     - Reverse Engineering of parts
     - Modeling and building anatomical parts for prostheses and surgical planning
     - Recreating artifacts
   - Two main problems need to be addressed:
     - Registration of images from different viewpoints
     - Integration of models into a complete solid.
   - A single range image is insufficient - it usually requires quite a few images.
   - Two interesting research questions are how many views of an object are sufficient, and how to plan the next view to decrease model uncertainty.

2. Desirable properties for surface reconstruction:

- No restriction on topological type
- Representation of range uncertainty
- Utilization of all range data
- Incremental and order independent updating
- Time and space efficiency
- Robustness
- Ability to fill holes in the reconstruction

3. CREATING THE MESH

- Structured light scanner used to get full range image. Cyberware scanner used. Laser beam with cylindrical lens, creating plane of light 2mm wide and 30 cm high.
- Raw range image data my be filtered before creating a mesh
- Range points have a number of sources of error
  - Beam resolution and sensing grid resolution
  - Depth discontinuities
  - Baseline separation from light source and camera
  - Grazing angle of laser
  - "Curling" of edges can result from some configurations
- Confidence measures can be associated with each range point.
- Given a range image, triangular meshes are created.
- 4 adjacent points form 2 triangles - use diagonals to choose most robust triangles.
- No triangle vertices joined if separated by depth discontinuity threshold (some multiple of sensing resolution).
- If points are not joined, then other scans will hopefully fill in the data better. Strategy is to use high quality data as much as possible and discard data that is questionable.

4. **REGISTRATION OF IMAGES**

- In typical sensing situation, motorized control is used to move either the object or the scanner for each scan. If this motion is known and quantified, a simple rigid transformation can be used to bring the scans into full registration. However, if we need to move the object on the rotation table to scan top or bottom, we lose the ability to compute the transform directly.
- The approach in Zipper is to do on screen interactive registration where the user can control the placement of each set of scan points.
- Once the user has brought the points into "close" or approximate registration the system can begin to refine the fit.
- An Iterated Closest Point algorithm is used to refine the registration.

  - Find the nearest position on Mesh A to each vertex of Mesh B. Note that the point on A can be anywhere on or inside a triangle.
  - Discard points that are two far way from each other
  - Eliminate pairs with points on a Mesh Boundary
  - Find the rigid transformation (translation and rotation) that minimizes a weighted least-squares distance between pairs of points
  - Iterate until convergence
  - Once registration is done at one Mesh level, do it at the next highest level of resolution to refine the fit

- Horn's procedure is used to minimize the distance between all candidate pairs of points by finding the translation and rotation matrix that will transform one point set into the other.
- The translation vector is found by taking the difference in point set's centroids
- Rotation matrix is found by finding eigenvector of cross-covariance matrix.
- If confidence values can be assigned to points, then a weighted least squares algorithm can be used. Boundary points and facets with near-grazing angle normals can be weighted less than other points.
- Hierarchical approach allows trade off between speed and accuracy

5. **INTEGRATION: MESH ZIPPERING**

- General Procedure:
  - Remove overlapping portions of meshes
  - Clip one mesh against the other
  - Remove the small triangles introduced during clipping
- Clipping involves intersecting boundaries and deleting facets caused by the intersection to leave a clean boundary
- Clipping uses a hack to extend the target mesh in depth to guarantee intersection with other mesh and approximate intersection point
- Removing a triangle on Mesh A if its vertices all are within a tolerance distance d of the target mesh.
- Skinny triangles are merged with neighbor vertices
- Small holes may result that need to be taken care of in a post-processing step.

6. CONSENSUS GEOMETRY

- Once the merged object is created, we can refine the geometry of the object by using the original range scans.
- Each vertex of the Zippered polygon mesh is moved along the surface normal a distance to bring it into better registration with the existing range data.
- This is an attempt to recapture object fidelity that may have been compromised during zippering.