Acquisition of Dense 3D Model Database for Robotic Vision

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Problem Statement

Q. How to detect and localize ‘unseen’ objects?
Q. How to perform vision based manipulation of such objects?
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Q. How to perform vision based manipulation of such objects?

Our answer: Utilize huge amount of data available on internet.
Challenges

• Internet database:
  – Google’s 3D Warehouse

• Problems:
  – Outliers
  – Insufficient number of models
  – Scaling and localization
  – Speed
Contributions

• Automatic rejection of irrelevant models
• Creation of new models
• Setup for scale and location estimation
• Speeding up matching against images
Related Work

- Learning Object Categories from Google’s Image Search (R. Fergus et al. ICCV’05)
Related Work

- Learning **Grasp Strategies** with Partial Shape Information (Saxena et al. IJRR’08)
Related Work

- Recognition and Tracking of 3D Objects (Steger et al. DAGM’08)
Related Work

- Morphing of 3D triangulated models (Kraevoy et al. SIGGRAPH’04)
Outline

• Steps
  1. Internet Search
  2. Model Selection
  3. Model Specialization
  4. Visual Search
  5. Learning Step

• System Evaluation
Model Selection

- Clustering (k-means, k=4),
- Distance measurements: $\chi^2$ - distance over Shape distribution function (Osada et al. TOG’02):
  - Histogram of distances between randomly selected points
- Tested Alternatives: Rusu et. al. ICARCV’08
Model Selection : Results

(a) (b) (c) (d) (e)

(f) (g) (h) (i)

(j) (k) (l)
Model Selection: Results
Model Selection : Results

- Inliers classification for 10 different searches: knife, spoon, fork, mug, cup, cooking pot, pan, plate, oven, milk

System output

<table>
<thead>
<tr>
<th>Manually assigned errors for the search results</th>
<th>Result inlier</th>
<th>Result outlier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inliers</td>
<td>52</td>
<td>20</td>
</tr>
<tr>
<td>Wrong object</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Scene</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Similar</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>
Automatic Alignment and Morphing

• Before morphing:
  – Initial Alignment:
    • Translation and scaling using the Shape Distribution Function used for selection (peak of histogram).
    • Pose aligned by sampling in rotation space (+/- 90° in x,y and z)
  – Optimized Alignment: **Volumetric ICP** (Dense point cloud needed => Add Points)
Automatic Alignment and Morphing

- Before morphing: Obtain the axis of rotational symmetry (Sherrah et al., PAMI98).
Automatic Alignment and Morphing

• Morphing:
  – Corresponding points are added on an orthogonal plane of axis of rotational symmetry to the opposite models.
  – Linear Interpolation between corresponding points
Automatic Alignment and Morphing

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- Morphing: Significant increase of matching edges
Matching

• 3D Shape Based Matching (Wiedemann et al. DAGM’08, Ulrich et al. ICRA’09)
  – Create a tree of projected models in the search space (offline)
  – Exhaustive search
  – Available in the software package HALCON

• For larger 3D models, pyramid building phase can be prohibitively slow (hours per model)
Matching

- Search space restrictions important
  - Model generation time
  - Memory usage of search tree

- Necessary to have an environment model
Search Space Restriction, Optimizations

- Transform 3D Euclidean Gaussian covariance ellipsoid to a spherical search space (Tavcar ‘09)

- Reason about the correctness of the results (Pangercic et al. ICAR’09)

- Backface Culling of larger 3D models to speed up the pyramid building phase in HALCON.
Backface Culling

• Utilize the technique of backface culling to simplify larger models.
• Cast a ray from the camera to every face.
• If the angle between this ray and the face normal is greater than $\beta$, delete it from the model (nominally $\beta = 120$ deg)
Backface Culling

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- Cast a ray from the camera to every face.
- If the angle between this ray and the face normal is greater than \( \beta \), delete it from the model (nominally \( \beta = 120 \) deg)
<table>
<thead>
<tr>
<th>Model</th>
<th>Original Model</th>
<th>Model after Culling</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Model" /></td>
<td>904 faces, 113.7s</td>
<td>447 faces, 29.5s</td>
</tr>
<tr>
<td><img src="image2" alt="Model" /></td>
<td>1892 faces, 87.48s</td>
<td>844 faces, 25.5s</td>
</tr>
<tr>
<td><img src="image3" alt="Model" /></td>
<td>344 faces, 33.74s</td>
<td>179 faces, 10.14s</td>
</tr>
<tr>
<td><img src="image4" alt="Model" /></td>
<td>1534 faces, 60.393s</td>
<td>791 faces, 38.924s</td>
</tr>
<tr>
<td><img src="image5" alt="Model" /></td>
<td>3552 faces, 794.5s</td>
<td>1786 faces, 188.2s</td>
</tr>
</tbody>
</table>
Scaling correction

- Solution: Stereo setup, Triangulate Model
System Results

- Manipulating two objects, locating three
- Give user the mug, pour ice tea into it, put the ice-tea-box on the plate
## System Results

- **Finding the Plate Model:**

<table>
<thead>
<tr>
<th>Model (Faces)</th>
<th>Time Model</th>
<th>Time Search</th>
<th>Matches/Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate 0(188)</td>
<td>201 s</td>
<td>0.65s</td>
<td>1/0.98</td>
</tr>
<tr>
<td>Plate 10(22)</td>
<td>76 s</td>
<td>0.20s</td>
<td>1/0.97</td>
</tr>
<tr>
<td>Plate 9(258)</td>
<td>296 s</td>
<td>1.89s</td>
<td>1/0.86</td>
</tr>
<tr>
<td>Plate 4(332)</td>
<td>112 s</td>
<td>0.67s</td>
<td>1/0.83</td>
</tr>
<tr>
<td>Plate 7(120)</td>
<td>223 s</td>
<td>1.09s</td>
<td>1/0.78</td>
</tr>
<tr>
<td>Plate 3(118)</td>
<td>80 s</td>
<td>0.32s</td>
<td>1/0.76</td>
</tr>
<tr>
<td>Plate 8(626)</td>
<td>326 s</td>
<td>1.24s</td>
<td>0/0.70</td>
</tr>
</tbody>
</table>
Discussion

- **Drawbacks:**
  - Calculation time for model generation
  - Incompleteness of databases
  - Ambiguities of Shape

- **Advantages**
  - Complete reconstruction, simulation of the object possible
  - High probability of available models in kitchen environment
  - Little prerequisites: only a search string and a environment model
Future Work

- Optimize the 3D object detection system for inexact models, anisotropic scaling, and occlusion.
- Improve the morphing and automatically detect for ‘unrealistic’ newly created models.
- Train for manipulating ‘unseen’ objects.
Thank you for your attention!

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