Quality-driven autonomous scanning of complex objects

Minglun Gong
Department of Computer Science, Memorial University

In collaboration with: Shihao Wu, Wei Sun, Pinxin Long, Hui Huang, Daniel Cohen-Or, Oliver Deussen, Baoquan Chen
Introduction

https://www.youtube.com/watch?v=BLX4LbiUtSQ
Next Best View Problem

- Next sensor position to maximize information gain [Connolly 1985]
- Unknown object
- NBV computed on-the-fly
Related Work

[Analyse boundaries] [Next-Best-Scans]

[Kriegel et al. 2013] (state-of-the-art)

Completed?

No

Yes

End
Related Work

Tentative watertight reconstruction

Next-Best-Scans

Sufficient quality?

No

Yes

End

Our approach

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Related Work

[Pauly et al. 2004]

Focus on density, regularity and curvature
Do not account for geometric completeness and topology
Related Work

Conventional NBV method: Boundary-driven

Our method: Quality-driven
Key Idea

Tentative watertight surface confidence map

Ambient viewing field next-best-scans

High confidence

Low confidence

High suitability

Low suitability

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Algorithm Overview

Initial scan
Initial Blind Scan

Start with an initial blind, all-around scanning
Algorithm Overview

Confidence map of iso-surface
Confidence Map

$ f(s_k) = f_g(s_k, n_k) f_s(s_k, n_k) $
Completeness Confidence

Directional gradient of the Poisson scalar field

Poisson Scalar field of incomplete point cloud

Poisson Scalar field of completed point cloud
Smoothness Confidence

Bilateral weighted sum: \( f_s(s_k, n_k) = \sum_{j \in \Omega_k} \theta(\|s_k - q_j\|) \phi(n_k, q_j - s_k) \)

A synthetic model, One scan, Five scans, Ten scans
Combination: \( f(s_k) = f_g(s_k, n_k) f_s(s_k, n_k) \)
Algorithm Overview

View selection using Ambient viewing field
Next Best View Selection

Iso-points

Ambient viewing field

Search in 5D space
Viewing Vector Field Generation

**NBV score:**

\[ g(v_i) = \max_{s_k} \{ w(v_i, s_k)(1 - f(s_k)) \} \]

\[ w(v_i, s_k) = w_d(s_k, v_i)w_o(s_k, v_i)w_v(s_k, v_i) \]

Distance  Orientation  Visibility

Confidence propagation on \( S_k \)

Confidence score
Field-guided View Selection

Local maxima

Non-adjacent maxima (Optimal positions)

Next-Best-Views (Optimal directions)
Ambient Viewing Field in 3D
Ambient Viewing Field in 3D
Algorithm Overview

Scan at NBVs till converge
Result Evaluation

Visibility
[Khalifaoui et al. 2013]

Boundary
[Kriegel et al. 2013]

Ours
Quantitative Evaluation

Low amplitude noise

Noticeable errors

Quantitative error evaluation
More Comparison

Sphere-based NBV
[V’asquez-G’omez et al. 2009]

Ours
Confidence Measure Selection

- Local curvature
- Local point density
- Ours
Compare with Manual Scan
With Texture Mapping
Outdoor Scan Simulation

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Future Work

- Incorporating more advanced sensor models and searching in 6D pose space.
- Semi-automatic interactive scanning: provide visual feedback for user-operated capturing systems.
- Proactive scanning: avoid self-occlusion by introducing interaction with the scanned object.
- Optimize the scanning path, rather than frame by frame.
- Automatic scan for large-scale outdoor scenes.
Thank you!

Source codes and data are available at the project page.
Welcome to visit our PR2 robot.
A quality-driven, Poisson-guided autonomous scanning method is discussed in this talk. Unlike previous scan planning techniques, the presented method does not aim to minimize the number of scans needed to cover the object’s surface, but rather to ensure the high quality scanning of the model. This goal is achieved by placing the scanner at strategically selected Next-Best-Views (NBVs) to ensure progressively capturing the geometric details of the object, until both completeness and high fidelity are reached. The technique is based on the analysis of a Poisson field and its geometric relation with an input scan. A confidence map that reflects the quality/fidelity of the estimated Poisson iso-surface is computed, which guides the generation of a viewing vector field, as well as the selection of a set of NBVs. The algorithm is tested on two different robotic platforms, a PR2 mobile robot and a one-arm industry robot. We demonstrated the advantages of our method through a number of autonomous high quality scannings of complex physical objects, as well as performance comparisons against state-of-the-art methods.
### Time Table

<table>
<thead>
<tr>
<th>Operation</th>
<th>Time (sec)</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Robot motion/capture</td>
<td>463</td>
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<tr>
<td>Scan consolidation/registration</td>
<td>178</td>
<td>25%</td>
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<tr>
<td>NBV computation</td>
<td>71</td>
<td>10%</td>
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<th>#Pt</th>
<th>#Iter</th>
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<th>Time (min)</th>
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</table>
Combination: \( f(s_k) = f_g(s_k, n_k) f_s(s_k, n_k) \)
Combination: $f(s_k) = f_g(s_k, n_k)f_s(s_k, n_k)$
Iso-points extraction

Scanned input

\[ Q = \{ q_j \}_{j \in J} \subset \mathbb{R}^3 \]

Tentative iso-surface

Iso-points

\[ S = \{ (s_k, n_k) \}_{k \in K} \subset \mathbb{R}^6 \]

Screened Poisson Reconstruction

[Kazhdan and Hoppe 2013]

Poisson-disk Sampling

[Corsini et al. 2012]
Why maximum instead of sum?

\[ g(v_i) = \max_{s_k} \{ w(v_i, s_k)(1 - f(s_k)) \} \]
Different grid resolution

Resolution: 62X62X62  
Time: 0.001 sec

Resolution: 125X125X125  
Time: 0.01 sec