Towards Semantic 3D Maps

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Contents

• Introduction
• 3D Robotic Mapping / 6D SLAM
• Interpretation of Point Clouds
• Semantic Maps
• Conclusion
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Simultaneous Localization and Mapping

- If one knows the pose (position and orientation) of a mobile robot precisely, then the sensor readings can be used to build a map.
- Unfortunately, pose measurements are always imprecise 😞

The chicken and egg dilemma…
State of the Art in Robotic Mapping (1)

• Laser scanner are the state of the art sensors for metrical environment mapping
• Mapping based on scan matching (Lu, Milios)
• Probabilistic theory of mapping using uncertain motion and sensor models (Kalman-Filter, Maximum Likelihood Estimation, Expectation Maximisation)

Here: Here: 3D-Data, 6D-Poses

2D-Data, 3D-Poses

⇒ Here: 3D-Data, 6D-Poses
## State of the Art in Robotic Mapping (2)

<table>
<thead>
<tr>
<th>Sensor data</th>
<th>Dimensionality of pose representation</th>
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<tbody>
<tr>
<td>2D</td>
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<td>3D</td>
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The Mobile Robot Kurt3D

- Kurt3D is a lightweight (25 kg)
- Two 90W (200W) motors, 48 NiMH a 4500mAh, C167 Microcontroller, CAN Controller, Centrino Notebook

- Indoor/Outdoor versions available
- main Sensor: 3D scanner \(\Rightarrow\) 3D data, 6D poses

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The ICP Algorithm

**Scan registration** Put two independent scans into one frame of reference

**Iterative Closest Point** algorithm [Besl/McKay 1992]

For prior point set $M$ (“model set”) and data set $D$

1. Select point correspondences $w_{i,j}$ in $\{0,1\}$
2. Minimize for rotation $R$, translation $t$

$$E(R, t) = \sum_{i=1}^{N_m} \sum_{j=1}^{N_d} w_{i,j} \| m_i - (Rd_j + t) \|^2$$

3. Iterate 1. and 2.

SVD-based calculation of rotation
- works in 3 translation plus 3 rotation dimensions
  $\Rightarrow$ 6D SLAM with closed loop detection and global relaxation.
3D Mapping with ICP – Examples

CMU Mine Mapping

RoboCup Rescue

3D Outdoor Mapping
3D Mapping with ICP – Examples
Closed Loop Detection and Global Relaxation

3D data acquisition
GraphSLAM – Examples

- Leibniz University Hannover

  ![Image](image1)

- Riegl Laser Measurement GmbH

  (Video courtesy Riegl)

  (Video 1)  (Video 2)  (Video 3)

- We need some performance measure ⇒ Semantic Information
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Semantics by Point Labeling (1)

- Classification of 3D points \( p_{i,j} = (\varphi_i, z_{i,j}, y_{i,j}) \) is in the \( i \)-th vertical scan the \( j \)-th point (start counting from the bottom).

Angle between point \((j-1)\) and \(j\)

- "floor points" Flat angle in scanning order
- \( |\alpha_{i,j}| < \tau \)

- "ceiling points" Large angle counter-clockwise to the scanning order
- \( |\alpha_{i,j}| > \pi - \tau \)
Semantics by Point Labeling (2)

- **blue:** floor points
- **red:** ceiling points
- **yellow:** everything else
- **green:** artifacts / negative objects (robot)

Five 3D scans registered
Point Semantic for Object Detection

• Task: Detect Objects in depth images

• Point labeling removes the ground
• Extract contour features
• Learning
• Detect objects
⇒ Map building with labeled objects
Object Detection in Range & Reflectance Images

Object detection

3D Scan

Off-Screen rendering

Class

depth
refl.

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Object Detection

- Use the cascade for detection in the depth and reflectance image
- Logical AND yields reliable detection (false detection ~ 0%)
Localize the Objects

- Fit objects in point cloud using an ICP variant

For prior point set $M$ (“model set”) and data set $D$

1. Select point correspondences $w_{i,j}$ in $\{0,1\}$
2. Minimize for rotation $R$, translation $t$
   \[
   E(R, t) = \sum_{i=1}^{N_m} \sum_{j=1}^{N_d} w_{i,j} ||m_i - (Rd_j + t)||^2
   \]
3. Iterate 1. and 2.
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Semantic Maps – A Definition

• A semantic 3D map is a metrical map that contains in addition to geometrical information semantic label of the data points.

• Presentation as video

(Video)
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Semantic Maps – Status Quo?

- A typical map content is in harmony with today’s typical purpose of maps for mobile robots, namely, navigation.
- A semantic map augments that by information about entities, i.e., objects, functionalities, or events, which are located in space.
- Currently labeled point clouds
- Semantic information should not be contained in the map itself, but in some form of background theory about the concepts, of which instances are labeled in the map ⇒ open issue
Contributions

• Practical (on-line, on-board) variant of ICP for high-resolution point sets due to
  – point reduction and
  – efficient representation (Cached k-D-trees)
• Generating overall consistent 3D maps with global error minimization
• Assessing map quality by comparing trajectories
• Tested on various data sets (including borrowed ones, e.g., CMU mine mapping)
• Interpretation of 3D maps resulting in 3D object maps
• Integrated into robot controller for 3D environment mapping
• RoboCup Rescue as evaluation for our mapping approach
  – 2004 second place, SSRR 2005 best paper award, 2005 6th place
Questions? – Thank you for your attention!