On the Accuracy of the 3D Normal Distributions Transform as a Tool for Spatial Representation

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Metric models of the robot’s workspace are commonly used. Comparing the accuracy of metric maps is a difficult problem.
Metric Environment Representations

- Metric models of the robot’s workspace are commonly used
- Comparing the accuracy of metric maps is a difficult problem
Outline

1. Spatial Representations in Robotics
2. Accuracy Evaluation
3. 3D-NDT / Occupancy Map Comparative Evaluation
4. Conclusions and Future Work
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Evaluation of the accuracy of maps built by robots is a challenging problem.

Often a critical concern, due to safety reasons.

Approached as evaluating localization system accuracy.
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Evaluation of the accuracy of maps built by robots is a challenging problem. Often a critical concern, due to safety reasons. Approached as evaluating localization system accuracy. Underlying spatial representation usually not discussed.
Spatial Modeling Overview

- What spatial representations are employed for 3D environment modeling?

  - Point Cloud — large size and difficult to manipulate
  - Occupancy Grid — large size
  - Triangle Mesh — difficult to construct
  - Elevation Grid — low expressive power
  - Multilevel Surface Map — Ad-hoc discretisation based on robot size
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Motivation: Develop an approach to quantitatively evaluate the accuracy with which the spatial representation explains the observations
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Evaluation Methodology

- A simple 2D example will be used to illustrate the evaluation procedure
  - Given a set of points collected by a range device
  - Perform k-fold cross validation — split into $k$ random subsets
  - Use $k - 1$ subsets to construct a model
  - Generate positive and negative examples from the remaining subset
  - Evaluate occupancy probability, classify based on threshold
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- Varying the threshold produces a curve on a Receiver Operating Characteristic (ROC) plot
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The Normal Distributions Transform

- The Normal Distributions Transform originally developed for 2D scan registration
- Points grouped into cells
- Several possible ways to discretise space:
  - Regular cell grid (3D-NDT Grid)
  - OcTree with fixed leaf size
  - OcTree with leaf-splitting heuristic (3D-NDT Tree)
- A Gaussian pdf used to represent space in each cell
- Extension to 3D is expressive and space efficient
- Each cell represented by Covariance matrix $\mathbf{C}$ and mean $\mu$
3D-NDT has already been used in a variety of applications:

- 3D scan registration
- place recognition
- change detection
- path planning
The 3D Normal Distributions Transform - Applications

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Accuracy Evaluation — Tests

- Tests were performed on several input 3D scans
- Three versions of the 3D-NDT were evaluated: Tree, Grid and Interpolated
- An Occupancy grid map was used as a reference
Accuracy Evaluation — Results

ROC curves at Resolution 0.2 meters

Grid NDT
Interpolated NDT
Tree NDT
Occupancy Map

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Accuracy Evaluation — Results

ROC curves at Resolution 0.8 meters

- Grid NDT
- Interpolated NDT
- Tree NDT
- Occupancy Map
Accuracy Evaluation — Results

ROC curves at Resolution 1.6 meters

True Positives Ratio

False Positives Ratio

Grid NDT
Interpolated NDT
Tree NDT
Occupancy Map

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Accuracy Evaluation — Results

Figure: Left: 3DNDT-Tree. Right: Occupancy Map

- Evaluate at what probability threshold the best performance occurs
- For all 3D-NDT implementations — very close to zero
A threshold of 0.1 was set for all 3D-NDT classifiers

Average performance over all test scans:

Average Accuracy

![Average Accuracy Chart]

Average Precision

![Average Precision Chart]
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Conclusions and Future Work

Summary

Proposed a method to evaluate spatial representation accuracy.

Demonstrated that 3D-NDT is an accurate environment modeling technique, with a lower importance of discretisation parameters.

**work in progress**

- Perform an evaluation on larger test sets and simulated data.
- Compare performance under varying degrees of sensing noise.
Thank You!

Thank you for your attention.

Questions?