Registration of Colored 3D Point Clouds with a Kernel-based Extension to the Normal Distributions Transform

**Benjamin Huhle**¹, Martin Magnusson², Wolfgang Straßer¹, Achim J. Lilienthal²

¹ WSI/GRIS, University of Tübingen, Germany
² AASS, Dept. of Technology, Örebro University, Sweden
Motivation

- point cloud registration for Localization & Mapping

- Problems
  - geometric features (structure) required
  - small field-of-view
  - noise

- additional color data available!
Outline of the talk

- Related Work
  - Normal Distributions Transform (NDT)
  - Vision-aided registration (SIFT-Features)
  - Combined approach (SIFT-Features+NDT)

- Color-NDT
  - straightforward approach fails
  - Kernel-based Color-NDT

- Experiments
  - mobile robot with time-of-flight camera
Normal Distributions Transform (NDT)

- Biber & Straßer, 2003
  - cell grid
  - approximate point distributions
  - optimization using analytical (2\textsuperscript{nd} order) derivatives

(from: Biber, 2003)
3D Normal Distributions Transform

- in 3D

- comparison with ICP: Magnusson et al., 2007
Vision-Aided Registration

- robust registration with image features (SIFT)
  - feature detection in images
  - lookup of 3D coordinates
- challenges:
  - noise
  - dynamic environments

from: Andreasson et al., 2007
Combined Energy Approach

- Sum of NDT score and feature distances

\[ E = \alpha E_{NDT} + (1 - \alpha) E_F \]

- must favor features (small $\alpha$)
Ad-hoc approach to using color with NDT

- colored point cloud: \([x, y, z, r, g, b]\)
- 6D color–space distribution

**toy example:**

- 2D position
- 1 color-dimension (hue)

- model is 3D normal distribution
Single-Mode Color–Space Distribution

- conditional distributions of 2 test-points
Single-Mode Color–Space Distribution

- ... for a test-point with different color
Kernel-Based Color-NDT

- mixture-model in **color-space**
- use components as weighting kernels for point distributions

- *for each kernel:* compute **spatial** Normal Distribution using
  - weighted mean
  - weighted covariance
Modeling the Color-Distribution

• Gaussian Mixture Model
  – number of components?
    • no expensive testing (Bayesian Information Criterion...)
    • 3 components suffice for 3D registration

• Expectation Maximization
  – k-Means for initialization
    (starting from random samples of the data)
Toy Example revisited

- perfect match of model and data
Toy Example revisited

• ... test point with different color
Registration with Color-NDT

- optimize score (mixture model of normal distributions)
- Newton's method
- translation + rotation vector (6D parameters)
Experiments

- Time-of-flight camera
  - *PMDTec 19k*
  - 160x120 pixels
  - 30° fov
  - significant noise level
- additional color camera
Results

- 21 incrementally registered frames
- odometry as initial poses
Results

- 21 incrementally registered frames
- odometry as initial poses
Results using combined approach

- 11 frames
Results using combined approach

- 11 frames
Results using combined approach

- 11 frame

SIFT only
combined SIFT+NDT
combined SIFT+Color-NDT
Results using combined approach

- 11 frames

SIFT only

combined SIFT+NDT

combined SIFT+Color-NDT
Results using combined approach

- 11 frame
Results using combined approach

- 11 frame
Conclusion

• Color-NDT:
  – more robust/stable
  – more weight on Color-NDT score in combined approach
  – can fix inaccuracies of SIFT registration

• towards registration of low-end sensor data with integrated use of color and depth data
Thanks for your attention!


