IROS 2009 Workshop

Network Robot Systems: Network Robot Systems: Network Robot Services for the Elderly

October 15, 2009
St. Louis, USA

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Combination of Distributed Camera Network and Laser-based 3D Mapping for Urban Service Robotics

IROS’09 Workshop on Network Robot Systems
St. Louis, Missouri

October 2009

Outline

- Introduction
- Laser-based 6DOF SLAM
- From range maps to traversability maps
- From range maps to camera network calibration
Introduction

- A much needed step, usually neglected in SLAM implementations, is to compute maps useful for robot path planning and navigation.
- In this presentation we show how SLAM results are used to create useful maps for the URUS project.

Introduction: Overview

Data acquisition

- ICP alignment
- 6DOF SLAM
  - Traversability map
  - Camera network calibration
Scan matching

- Iterative Closest Point over consecutive range scans
  - ANN: Approximated Nearest Neighbor Search (Mount and Arya, 1997)
    - Euclidian space
    - Very efficient (divides the space using kd-trees)
  - NNSS: Nearest Neighbor Search in Spherical Space (Minguez et al., 2006)
    - Divide the space using spherical coordinates.
    - Gives more weight to the rotation.
    - Higher computational cost

- Biota et al. Proposed a metric for the registration step which compensate translation and rotation.

\[
    d^{icp}_{p_1,p_2} = \sqrt{||\delta||^2 - \frac{||p_1 \times \delta||^2}{k}}
\]

\[
    k = ||p_1||^2 + L^2
\]

- We combined Biota's icra06 metric with a correspondence search on the Euclidean space.

- We proposed a hierarchical new correspondence search strategy:
  - Using a point-to-plane strategy at the highest level and a point-to-point metric at finer levels.
6DOF SLAM

- Pose SLAM: *Eustice06, Ila09*
  - Delayed-State Extended Information Filter.
  - Estimates a state vector containing the history of poses.

\[ p(x) \sim \mathcal{N}(x : \mu, \Sigma) \sim \mathcal{N}^{-1}(x : \eta, \Lambda) \]

State augmentation:

\[
\begin{bmatrix}
Q^{-1} & Q^{-1}F \\
Q^{-1}F^T & \Lambda_{t-1} + F^TQ^{-1}F
\end{bmatrix}
\begin{bmatrix}
\delta \eta_t \\
\delta \Lambda_t
\end{bmatrix}
\]

Loop closure:

\[
\begin{bmatrix}
\delta x \\
\delta \Sigma_d
\end{bmatrix} \begin{bmatrix}
S & \Sigma_d \\
\Sigma_d & R
\end{bmatrix}^{-1} \begin{bmatrix}
\delta x \\
\delta \Sigma_d
\end{bmatrix} \leq \chi^2_{m,0}
\]
Experimental Site

- Over 15,000 sq. meters
- Several levels and underpasses
- Poor GPS coverage
- Sunlight exposure severely subject to shadows
- Moderate vegetation
- Several points with aliasing
- Large amount of regularity from building structures

Experimental setup: Laser 3D

- 3D point clouds with ranges up to 30 meters
- 76,000 points per cloud
- Sensor noise level is ±5 cm in depth estimation
Experimental setup: Robotic platform

- Pioneer 3AT robot
- Other sensors: GPS, INS

3D Mapping results
3D Mapping results

- Results are compared to manually built CAD model.
- The CAD model was made using geo-referenced information.

Traversability maps

- 2D grid layer. Each cell indicates maximum linear velocity.
  1. Horizontal cut at robot laser height to create 2D layer.
  2. Morphological operations to enlarge obstacles to produce a binary grid map.
Traversability maps

- 2D grid layer. Each cell indicates maximum linear velocity.
  1. Horizontal cut at robot laser height to create 2D layer.
  2. Morphological operations to enlarge obstacles to produce a binary grid map.
  3. For each robot configuration in the grid, compute the set of admissible actions that do not produce a collision.
  4. And select the minimum for all orientations of the maximum linear velocities at each xy location.

Camera Network Calibration

Coarse estimation of camera parameters

3D to 2D feature matching with nonlinear optimization of camera parameters

Plane and line segmentation

Computation of homographies of the walking areas

LRF Data
A very efficient graph-based region growing algorithm is used to segment planes from the range map.

- Planes are intersected to extract line segments.
Coarse calibration

- User interaction with a GUI:
- Select initial camera location, viewing direction and field of view.

\[ P(\theta_j) = K[R \tau] \]
Nonlinear optimization

- 3D to 2D line matching with nonlinear optimization
- Iterate over each of the camera parameters
- Minimize distance between laser projected points and image points on the matching lines

\[ \hat{\theta}_j = \arg \min_{\theta_j} \sum_i \left\| m_i - h(\theta_j \cdot M_i) \right\|^2 \]
Homographies of the walking areas

- Use the calibration results to compute homographies of the walking areas
- These can be used to measure traveling distances or traveling speed of robots and people