METRIC ALIGNMENT OF LASER RANGE SCANS AND CALIBRATED IMAGES USING LINEAR STRUCTURES

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Outline

- Work goal
- Work motivation
- State of the art
- Calibration model
- Implementation details
- Results
The goal is the estimation of rigid motion transformation between a Laser Range Scanner and an Imaging System (External Calibration), which is needed to achieve the accurate alignment of the 3D range profiles on a matched video.

\[(R, t) : R \in SO(3), t \in \mathbb{R}^3\]
The accurate co-registration of heterogeneous data is a fundamental requirement for a robotic systems, performing autonomous operations:

- Object pose estimation, docking, tracking, grasping, etc.;
- Rover Autonomous Navigation, Laser aided visual SLAM;
- Geometric documentation and object inspection;
- Sensor aided exposure of imaging systems;
- ... anytime range profiles and image raster maps need to be jointly processed to gather knowledge about the surrounding environment.
!! No extensive literature is available on this topic.

I. P. Núñez and al. - *Data Fusion Calibration for a 3D Laser Range Finder and a Camera using Inertial Data.* (ECMR 2009).


- Need of a middle-man sensor (AHRS);
- Algorithm do not cope with 1D lasers scanners;
- Geometric entity used for calibration may not be easily and accurately extracted from raw data (planes);
- Not real calibration (generation of rough navigation maps);
Calibration Model

Geometric Entity

Back-projected plane

Image line

Camera

Laser Scanner

\[ [cP] = H^{s\rightarrow c} \cdot [sP] \in \Pi = [cI] \]

\[ H^{s\rightarrow c} \in SE(3) \]
Calibration Model

\[ H^{S \to C} = \min_{H \in SE(3)} \sum_{i=1}^{N} d\left( C \prod_i, H^{S \to C} \cdot S P_i \right) = \sum_{i=1}^{N} C l_i^T \cdot \left( R \cdot S P_i + t \right) \]
Implementation Details

Calibration Tool
Line Detection by Hough Transform

Line Refinement Based on GL_{10} Filtering

Bisector Segment Extraction

{C^1_i}_{i=1,...,N}

Implementation Details

Line extraction from range profiles

Spot Detection by maximum curvature

\[ k(\theta) = \frac{r'^2 + 2rr'' - rr'''}{\left( r^2 + r'^2 \right)^{\frac{3}{2}}} \]

Spot Refinement by Local Parabolic Fitting

\[ \{ s, P_i \}_{i=1,...,N} \]
External Calibration estimation

- External calibration initialization by visual inspection (easy!) 

- Implicit enforcement of SO(3) constraint in LM scheme;
- Analytical computation of error terms Jacobian.

\[
H_0 = \begin{bmatrix} R_z(\pi) & 0 \\ 0 & 1 \end{bmatrix}
\]

\[
d(C\Pi_i, H^S \rightarrow C \cdot S \cdot P_i) = C \cdot l_i^T \cdot [dR(R \cdot S \cdot P_i + t) + d\tau] \approx d_{0i} + J_{di} \cdot dp
\]

\[
\begin{align*}
&d_{0i} = C \cdot l_i^T \left( R \cdot S \cdot P_i + t \right) \\
&J_{di} = C \cdot l_i^T \cdot \left[ -\left[ R \cdot S \cdot P_i + t \right]_x \right. \cdot I_3 \\
&dp = \begin{bmatrix} d\omega^T & d\tau^T \end{bmatrix}^T
\end{align*}
\]
Results on synthetic data

- Synthetically generated scene given by 20 lines in 3D space;
- Image points corrupted by additive white Gaussian noise;
- Noise std.dev. ranging in the interval [0-10] pix;
- 100 test for each noise level.

\[
e_{\text{rot}} = \frac{\|R^T \hat{R}\|}{\pi} \cdot 180 \quad [\text{deg}]
\]

\[
e_{\text{tr}} = \frac{\|t - \hat{t}\|}{\|t\|} \cdot 100 \quad [%]
\]
Results on synthetic data

- Synthetically generated scene given by N lines in 3D space;
- Image points corrupted by additive white Gaussian noise with fixed intensity (3 pix std.dev.);
- Number of lines ranging in the interval [5-200];
- 100 test for each scene complexity level.

\[
e_{\text{rot}} = \frac{\|R^T \hat{R}\|}{\pi} \cdot 180 \quad \text{[deg]}
\]

\[
e_{\text{tr}} = \frac{\|t - \hat{t}\|}{\|t\|} \cdot 100 \quad \text{[\%]}
\]
Results on real system

- **Point Grey Chameleon**
  - 1296(H) x 964(V)
  - 6 mm lens (43° H Fov)
- **Hokuyo Scanning Range Finder UTM-30LX**
  - 30m x 270° scanning range
  - 0.25° angular resolution
  - Accuracy ±30mm [0.1m : 10 m]
Results on real system

Optimization Process

\[ \frac{|dp|}{|dp_0|} \]

\[ \frac{|Err|}{|Err_0|} \]

\( \text{it} \)

\( 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6 \)
Results on real system

Optimization Process
Results
Results
Conclusions

- A technique to estimate the **External Calibration of a Laser-Camera system** has been proposed;
- The technique uses **3D straight lines** as calibration geometrical entity;
- Support algorithms have been defined to accurately collect the calibration dataset from laser profiles and images;
- The algorithm provides a core utility for any **multisensor platform** performing some robotic operation (object tracking, pose estimation, scene exploration, geometry retrieval, etc.);
- The algorithm is suitable for offline calibration and online **calibration recovery**;
- Straightforward extension to the case of stereocamera or multicamera.
Thank you for attention!