Relative Pose Estimation and Fusion of Omnidirectional and Lidar Cameras

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Problem Statement

- Estimate the relative pose of an omnidirectional camera with respect to a 3D Lidar coordinate frame and fuse the different sensor data.
- Classical solution: point correspondence estimation
- Challenge: no radiometric information is available with the range data
- We directly work with segmented arbitrary planar regions
- Pose estimation formulated as a 2D-3D shape alignment
- Pose parameters obtained by solving a system of nonlinear equations

Camera Model

The omnidirectional camera is represented as a projection onto the surface of a unit sphere[1].

The image plane maps to the surface of sphere by:

\[ \Phi(x) = x_S = \Psi(X) = \frac{RX + t}{||RX + t||} \]

A 3D world point \( X \) projects onto \( S \) considering the extrinsic pose parameters \( R, t \):

\[ \Phi(x) = x_S = \Psi(X) = \frac{RX + t}{||RX + t||} \]

Proposed Solution

Point matches not available → Integrate out individual point pairs over spherical surface patches \( D_x \) and \( F_x \)

\[ \int_{D_x} x_S \ dD_S = \int_{F_x} z_S \ dF_S \]

This gives us 2 equations only, but pose has 6 parameters

The integral is still valid if a function \( \omega : \mathbb{R}^3 \rightarrow \mathbb{R} \) acting on both sides.

\[ \int_{D_x} \omega(x_S) \ dD_S = \int_{F_x} \omega(z_S) \ dF_S \]

We can generate independent equations by applying a set of nonlinear functions\[2\].

Using \( 0 \leq i, j, k, n \leq 2 \) and \( i + j + k + n \leq 3 \) we obtain an overdetermined system of 15 equations.

The explicit form of the equation is obtained by parameterizing the surface patches \( D_x \) and \( F_x \) via \( \Phi \) and \( \Psi \) over the planar regions \( D \) and \( F \):

\[ \int_{D_x} \omega(\Phi(x)) \left| \frac{\partial \Phi}{\partial x_1} \times \frac{\partial \Phi}{\partial x_2} \right| \ dx_1 \ dx_2 = \int_{F_x} \omega(\Psi(X)) \left| \frac{\partial \Psi}{\partial X_1} \times \frac{\partial \Psi}{\partial X_2} \right| \ dX_1 \ dX_2 \]

The above equation can be solved by LM algorithm.

Evaluation on Synthetic Data

- benchmark dataset of 2500 2D-3D synthetic image pairs
- simulating segmentation errors around the contour
- alignment error \((\delta)\) measured as the % of non-overlapping area of images

Evaluation on Real Data

- Rotation errors in degrees along the 3 axis.
- Translation errors in cm along the 3 axis.

Conclusion

- Instead of estimating point matches or using artificial markers we work on segmented planar patches.
- Pose estimation is formulated as a 2D-3D nonlinear shape alignment, pose parameters are obtained by solving a small system of nonlinear equations.
- The method proved to be robust against segmentation errors.

References


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