Relative Pose Estimation and Fusion of Omnidirectional and Lidar Cameras

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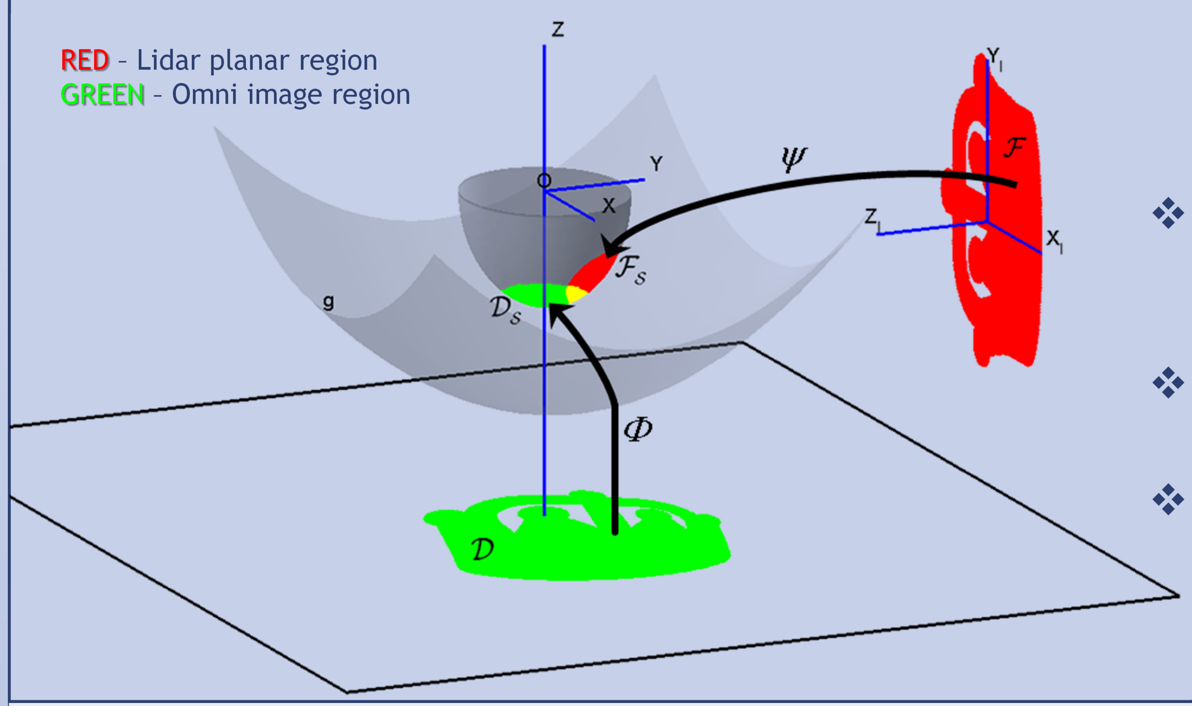
Problem Statement

- Estimate the relative pose of an omnidirectional camera with respect to a 3D Lidar coordinate frame and fuse the different sensor data.



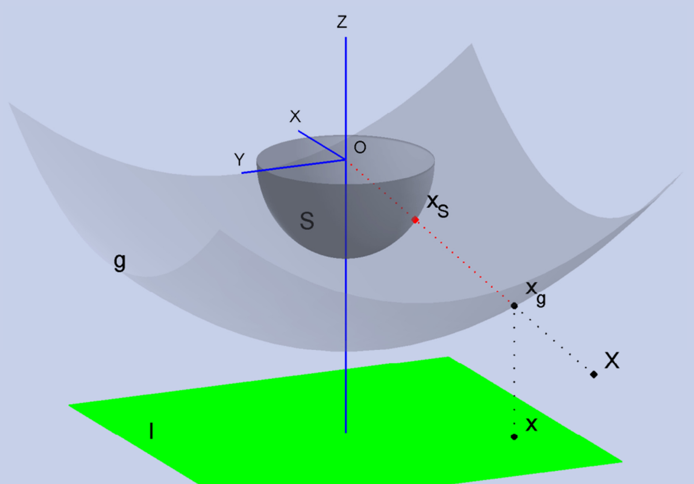
- Classical solution: point correspondence estimation
- Challenge: no radiometric information is available with the range data
- We directly work with segmented arbitrary planar regions
- Pose estimation formulated as a 2D-3D shape alignment
- Pose parameters obtained by solving a system of nonlinear equations

Camera Model

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

The image plane $\mathbf{I}$ maps to the surface of sphere $\mathbb{S}$ by Φ:

- lifting the image point $\mathbf{x}$ onto the g surface
- centrally projecting $\mathbf{x}_g$ onto the sphere $\mathbb{S}$



A 3D world point $\mathbf{X}$ projects onto $\mathbb{S}$ considering the extrinsic pose parameters $\mathbf{R}$,$\mathbf{t}$:

$$\Phi(\mathbf{x}) = \mathbf{x}_{\mathcal{S}} = \Psi(\mathbf{X}) = \frac{\mathbf{R}\mathbf{X}+\mathbf{t}}{\|\mathbf{R}\mathbf{X}+\mathbf{t}\|}$$

Proposed Solution

Point matches not available ➡ Integrate out individual point pairs over spherical surface patches $\mathcal{D}_S$ and $\mathcal{F}_S$

$$\boxed{\begin{aligned}\mathbf{x}_{\mathcal{S}} &= \Phi(\mathbf{x})\\ \mathbf{z}_{\mathcal{S}} &= \Psi(\mathbf{X})\end{aligned}} \qquad \iint_{\mathcal{D}_{\mathcal{S}}} \mathbf{x}_{\mathcal{S}}\, \mathrm{d}\mathcal{D}_{\mathcal{S}} = \iint_{\mathcal{F}_{\mathcal{S}}} \mathbf{z}_{\mathcal{S}}\, \mathrm{d}\mathcal{F}_{\mathcal{S}}$$

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

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

$$\iint_{\mathcal{D}_{\mathcal{S}}} \omega(\mathbf{x}_{\mathcal{S}})\, \mathrm{d}\mathcal{D}_{\mathcal{S}} = \iint_{\mathcal{F}_{\mathcal{S}}} \omega(\mathbf{z}_{\mathcal{S}})\, \mathrm{d}\mathcal{F}_{\mathcal{S}}$$

- We can generate independent equations by applying a set of nonlinear $\omega_i(\mathbf{x}_{\mathcal{S}}) = x_1^{l_i} x_2^{m_i} x_3^{n_i}$ functions[2].
- Using $0 \le l_i, m_i, n_i \le 2$ and $l_i + m_i + n_i \le 3$ we obtain an overdetermined system of 15 equations.
- The explicit form of the equation is obtained by parameterizing the surface patches $\mathcal{D}_S$ and $\mathcal{F}_S$ via Φ and Ψ over the planar regions $\mathcal{D}$ and $\mathcal{F}$:

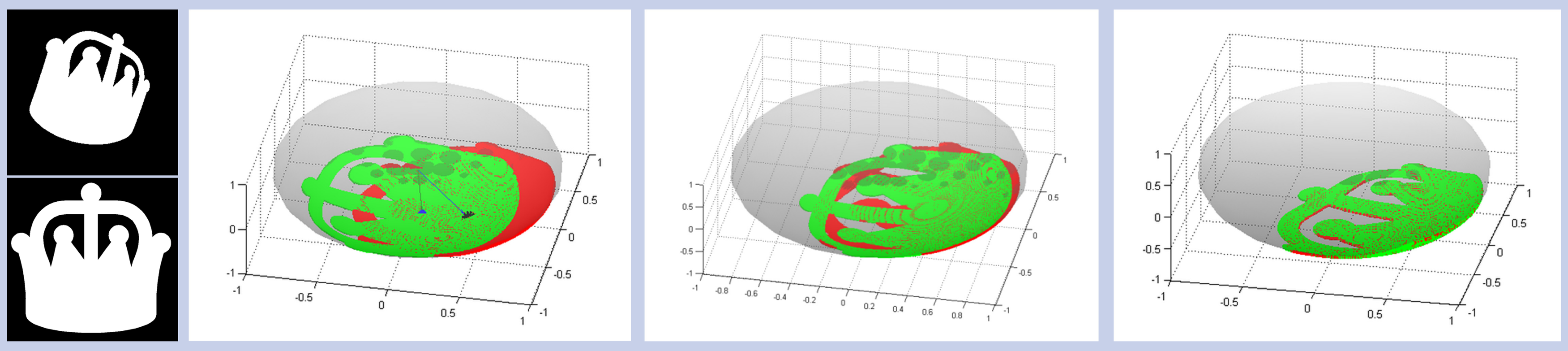
$$\iint_{\mathcal{D}} \omega_i(\Phi(\mathbf{x})) \left\| \frac{\partial \Phi}{\partial x_1} \times \frac{\partial \Phi}{\partial x_2} \right\| \mathrm{d}x_1\, \mathrm{d}x_2 = \iint_{\mathcal{F}} \omega_i(\Psi(\mathbf{X})) \left\| \frac{\partial \Psi}{\partial X_1} \times \frac{\partial \Psi}{\partial X_2} \right\| \mathrm{d}X_1\, \mathrm{d}X_2$$

- The above equation can be solved by LM algorithm.

Algorithm

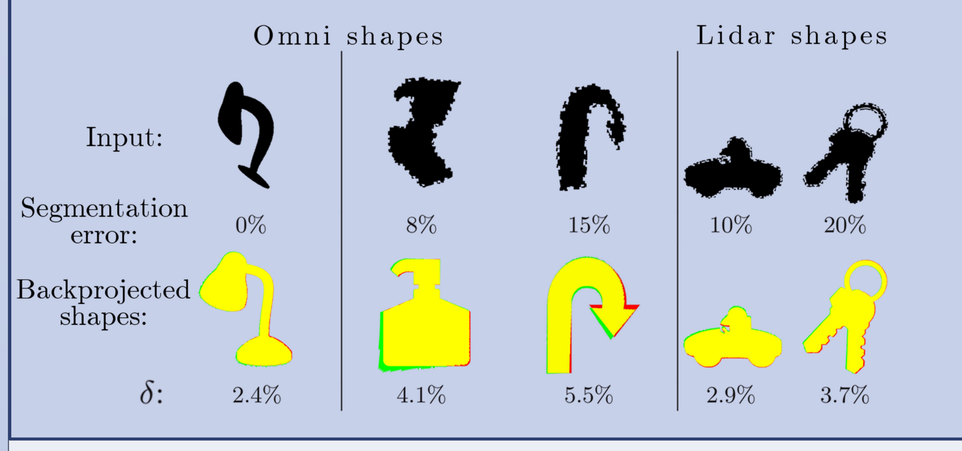
Good initialization of $\mathbf{R}$,$\mathbf{t}$ parameters is crucial for optimal results

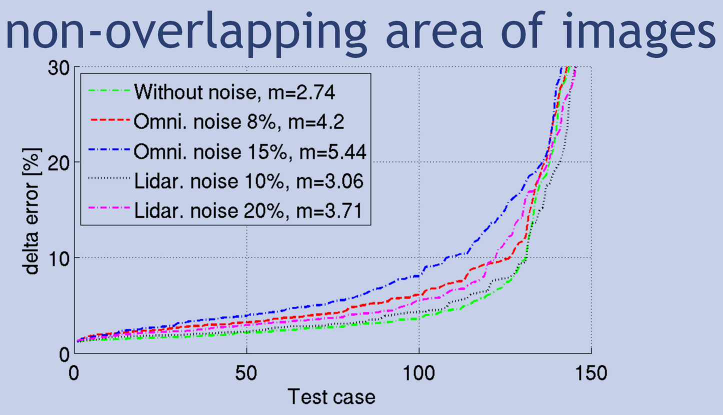
1. project both data on the unit sphere, calculate centroid of shapes
2. Initialize $\mathbf{R}$ as the rotation between the centroids, $\mathbf{t}$ as the distance from where the area of the projected patches is equal
3. Solve the system using LM algorithm



Evaluation on Synthetic Data

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

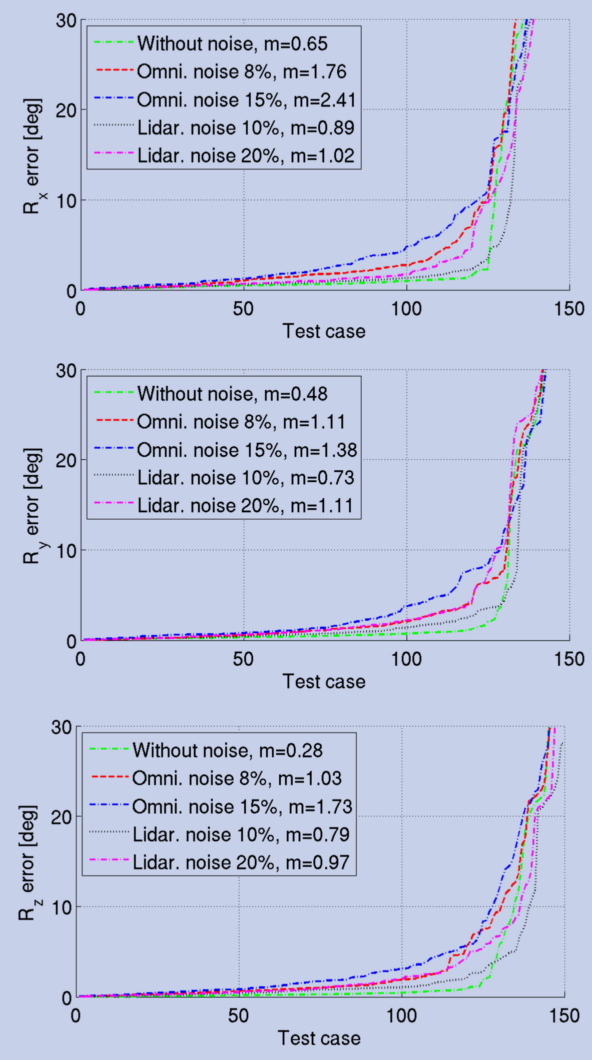




Alignment error plot for different segmentation errors. The method proves to be robust for errors up to 15%.

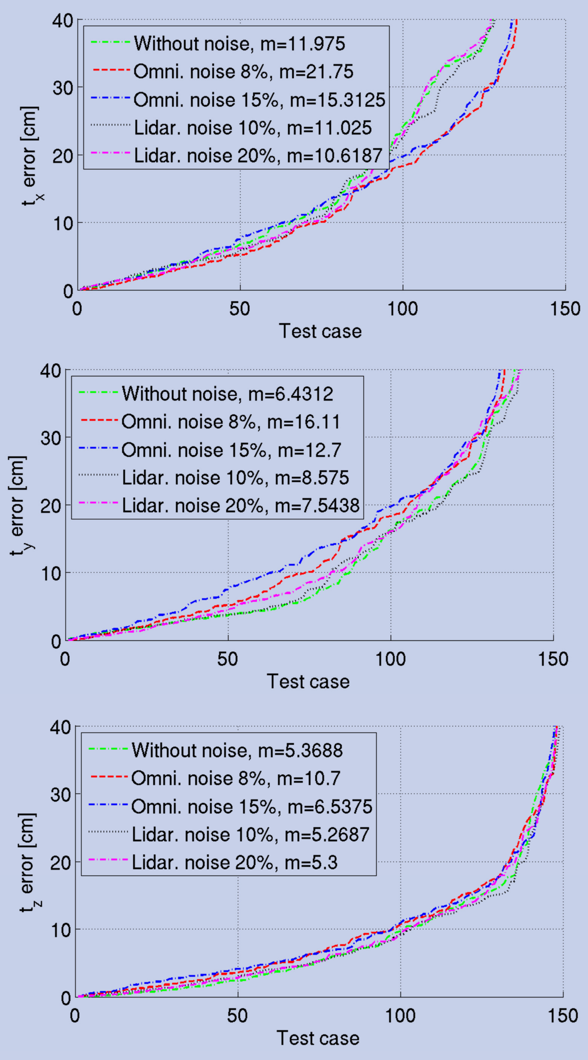
Rotation error

Rotation errors in degrees along the 3 axis.

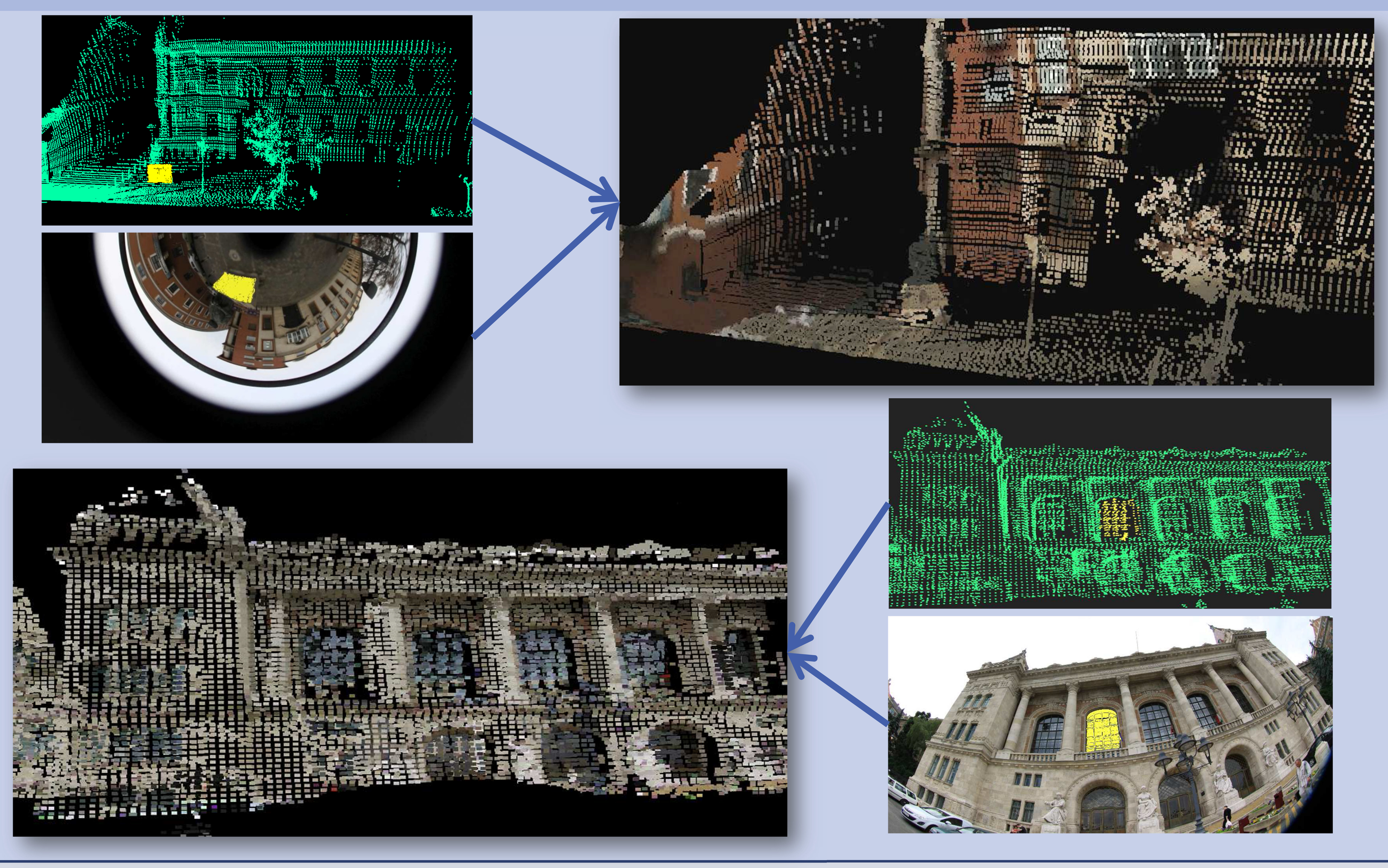


Translation error

Translation errors in cm along the 3 axis.



Evaluation on Real Data



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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2. Domokos, C., Nemeth, J., Kato, Z.: Nonlinear Shape Registration without Correspondences. IEEE Transactions on Pattern Analysis and Machine Intelligence 34(5) (2012) 943–958

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