Dense Accurate Urban Mapping from Spherical RGB-D Images

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Urban mapping from spherical stereo

Our goal: build compact maps for a posteriori localization

Urban mapping from spherical stereo

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Urban mapping from spherical stereo

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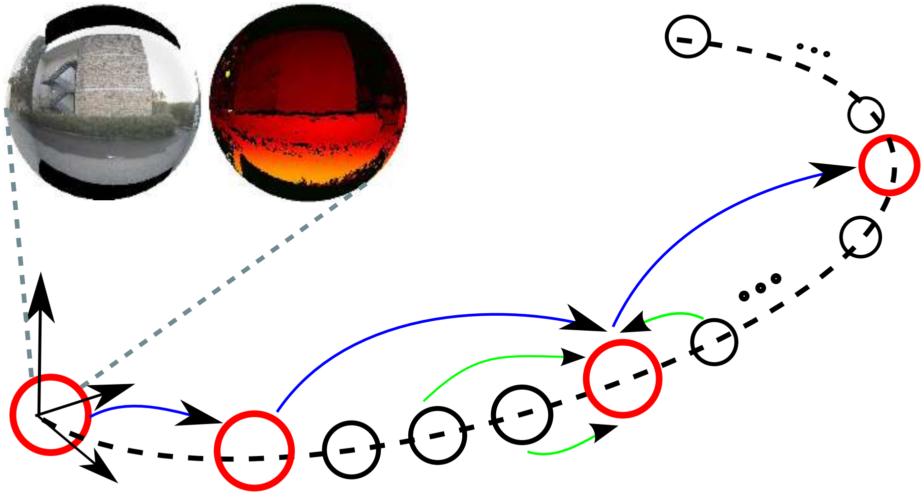
Spherical RGB-D sequence

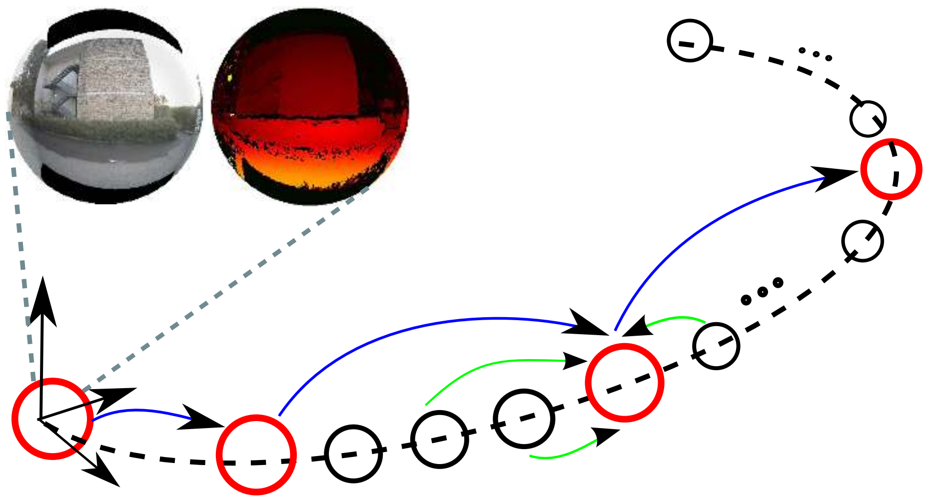
Data acquisition

Garbejaire. Sophia-Antipolis. France

Keyframe-based solution



Keyframe-based solution

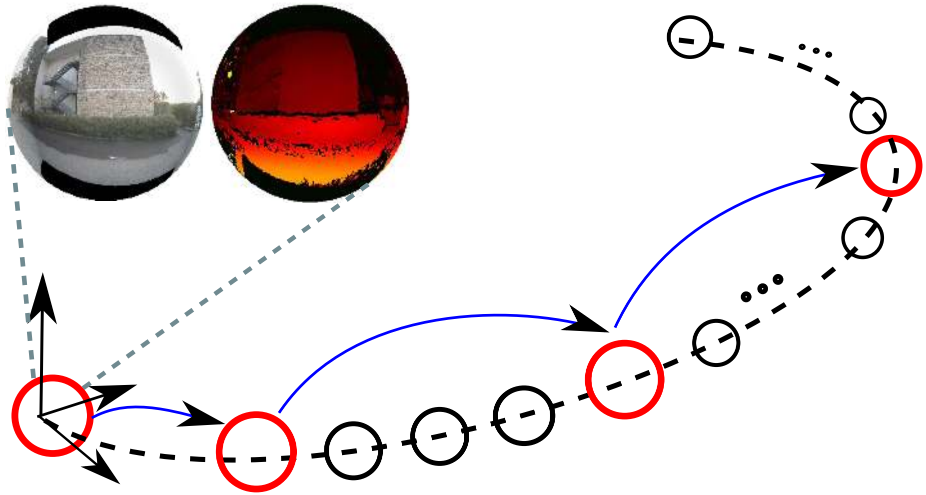


Dense registration:

Minimize the photometric error:

$$\mathfrak{F}_S = \frac{1}{2}\sum_{\mathbf{p}^*} W^I(\mathbf{p}^*) \left\| \mathcal{I}\left(w(\mathbf{p}^*, \widehat{\mathbf{T}}\mathbf{T}(\mathbf{x}))\right) - \mathcal{I}^*(\mathbf{p}^*) \right\|^2$$

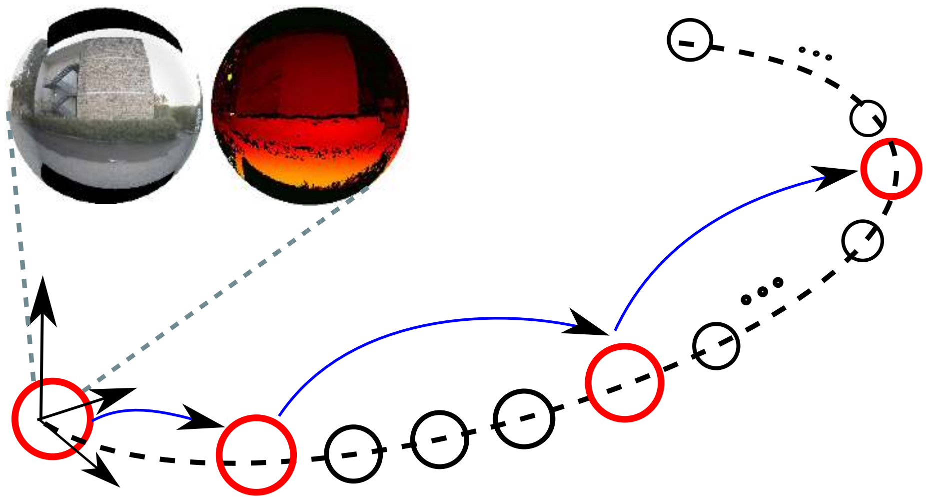
Keyframe-based solution



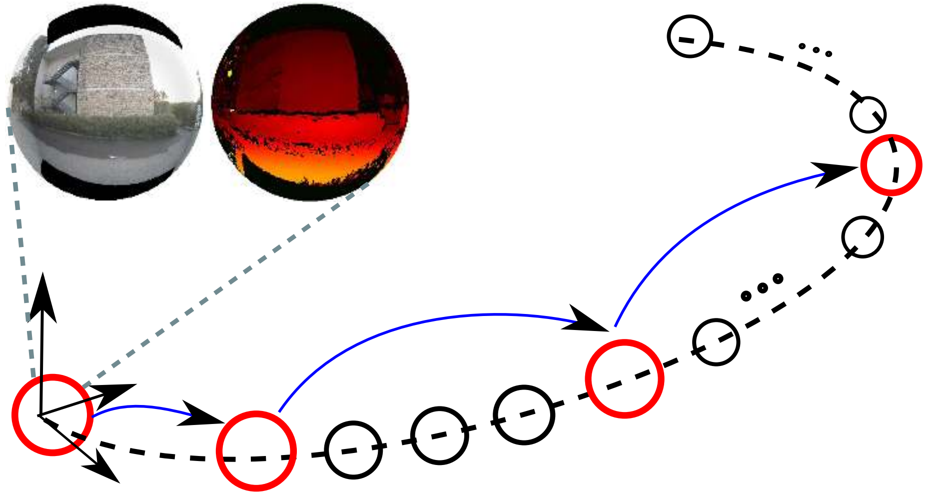
Previous works:

- Meilland, M., Comport, A. I., Rives, P. *A spherical robot-centered representation for urban navigation*, (IROS) 2010.
- Meilland, M., Comport, A. I., Rives, P. *Dense Omnidirectional RGB-D Mapping of Large-scale Outdoor Environments for Real-time Localization and Autonomous Navigation*. Journal of Field Robotics 2015.

This paper



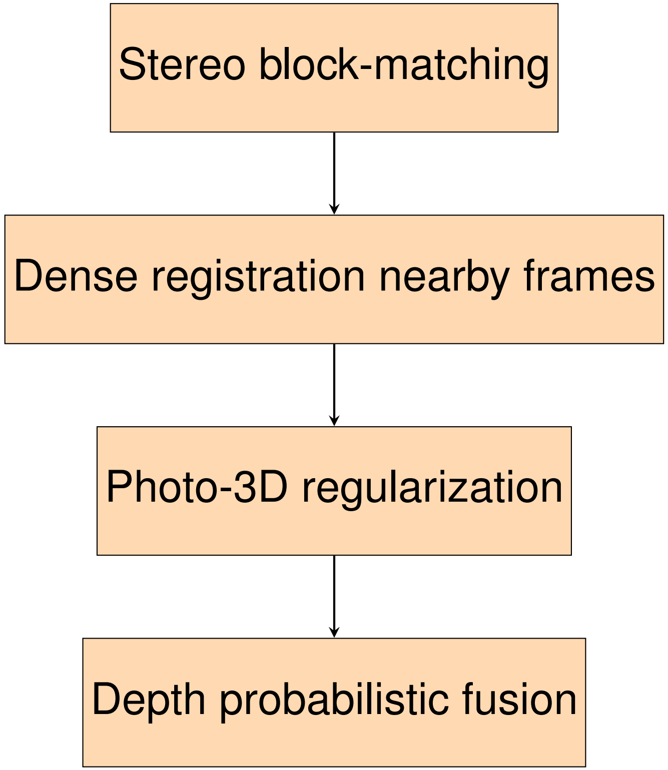
This paper



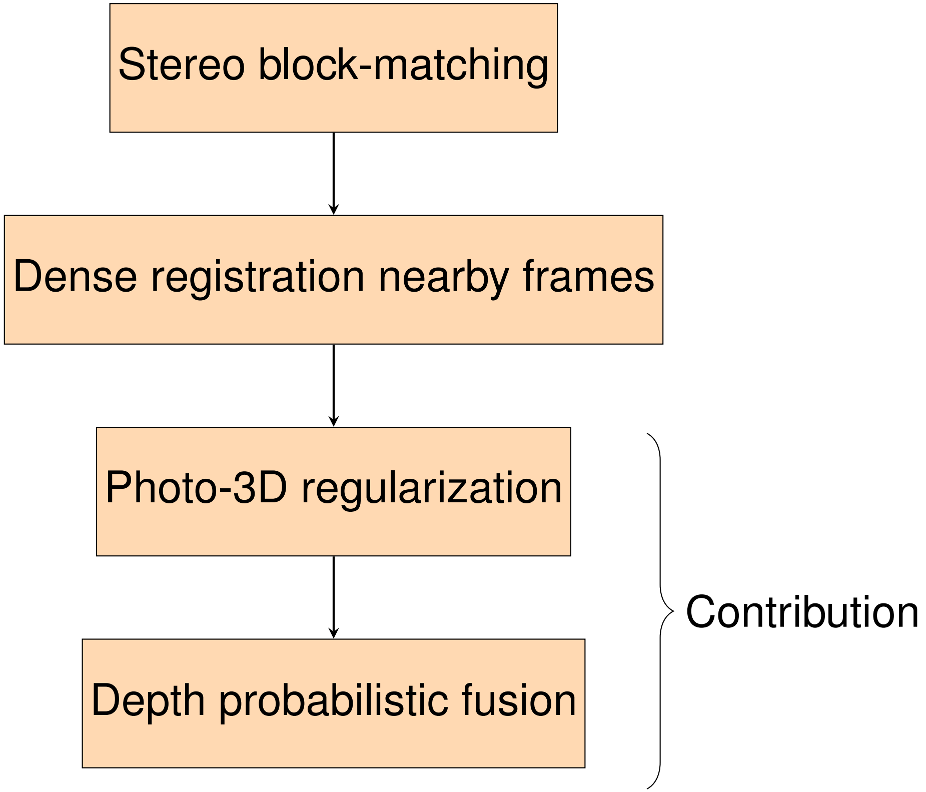
Improve keyframes by merging information of nearby frames

- More accurate depth images
- Reduce uncertainty
- Keyframe completeness (gap filling)

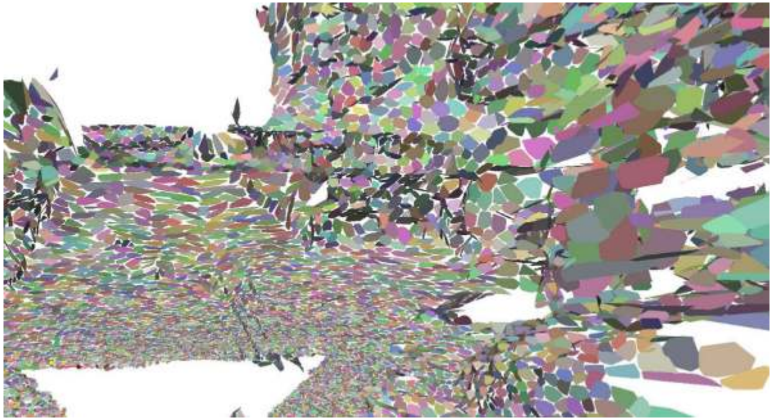
Our approach



Our approach



Regularization



"Superpatches" for photo-geometric regularization

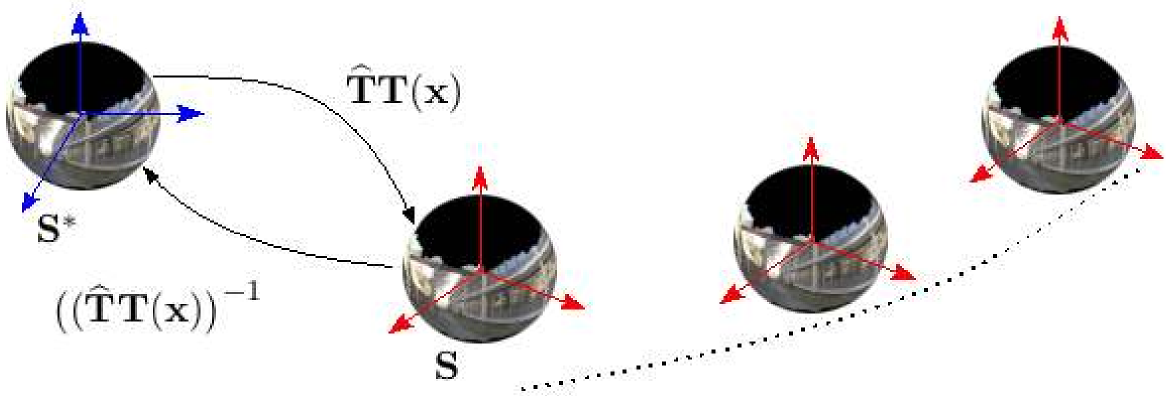
- Region growing enforcing isotropic 3D planar patches (same area)
- Superpixel colour segmentation: are combined in $\mathcal{P}_f(d_f, \mathbf{n}_f)$.

Patches geometrically and photometrically consistent are merged:

$$\|d_i\mathbf{n}_i - d_s\mathbf{n}_s\|_2 < \epsilon_1$$

$$\|\mathbf{n}_i^T\mathbf{n}_s\|_1 - 1 < \epsilon_2$$

Fusion



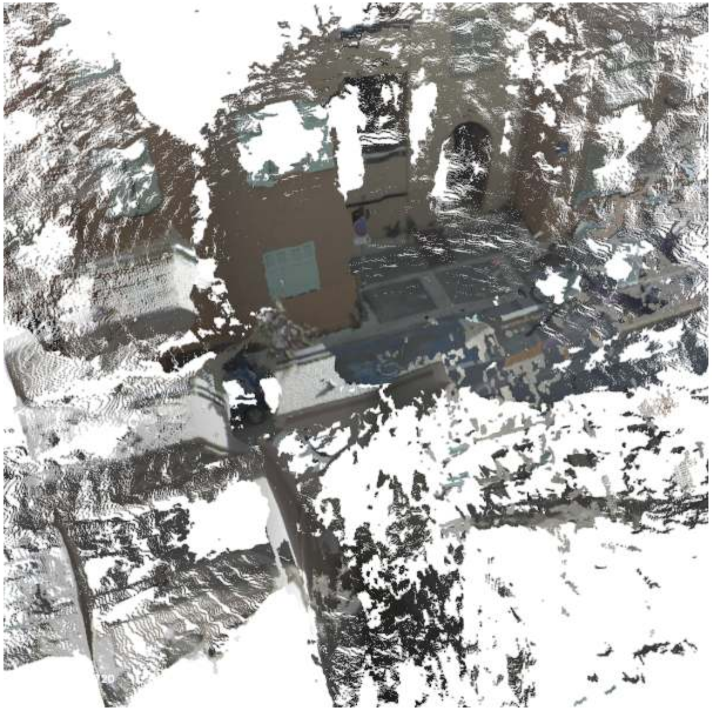
Probabilistic depth averaging

- Sliding window:

$$\begin{cases} \mathcal{D}_F^*(\mathbf{p}) = \dfrac{W^*(\mathbf{p})\mathcal{D}^*(\mathbf{p}) + W_w(\mathbf{p})\mathcal{D}_w(\mathbf{p})}{W^*(\mathbf{p}) + W_w(\mathbf{p})} \\ W_F^*(\mathbf{p}) = W^*(\mathbf{p}) + W_w(\mathbf{p}) \end{cases}$$

Results

- Improved consistency



Results

We obtain a full sequence with improved depth images

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Localization methods

- Photo-consistency

$$\mathfrak{F}_S = \tfrac{1}{2}\sum_{\mathbf{p}^*} W^I(\mathbf{p}^*)\left\|\mathcal{I}\left(w(\mathbf{p}^*,\widehat{\mathbf{T}}\mathbf{T}(\mathbf{x}))\right)-\mathcal{I}^*(\mathbf{p}^*)\right\|^2$$

- Dense RGB-D

$$\begin{aligned}\mathfrak{F}_S =& \frac{1}{2}\sum_{\mathbf{p}^*} W^I(\mathbf{p}^*)\left\|\mathcal{I}\left(w(\mathbf{p}^*,\widehat{\mathbf{T}}\mathbf{T}(\mathbf{x}))\right)-\mathcal{I}^*(\mathbf{p}^*)\right\|^2 + \\ & \frac{\lambda^2}{2}\sum_{\mathbf{p}^*} W^D(\mathbf{p}^*)\left\|\mathbf{n}^T\left(g(w(\mathbf{p}^*,\widehat{\mathbf{T}}\mathbf{T}(\mathbf{x})))-\widehat{\mathbf{T}}\mathbf{T}(\mathbf{x})g^*(\mathbf{p}^*)\right)\right\|^2\end{aligned}$$

Results

We obtain a full sequence with improved depth images

Localization methods

- Photo-consistency

$$\mathfrak{F}_S = \frac{1}{2}\sum_{\mathbf{p}^*} W^I(\mathbf{p}^*)\left\|\mathcal{I}\left(w(\mathbf{p}^*,\widehat{\mathbf{T}}\mathbf{T}(\mathbf{x}))\right) - \mathcal{I}^*(\mathbf{p}^*)\right\|^2$$

- Dense RGB-D

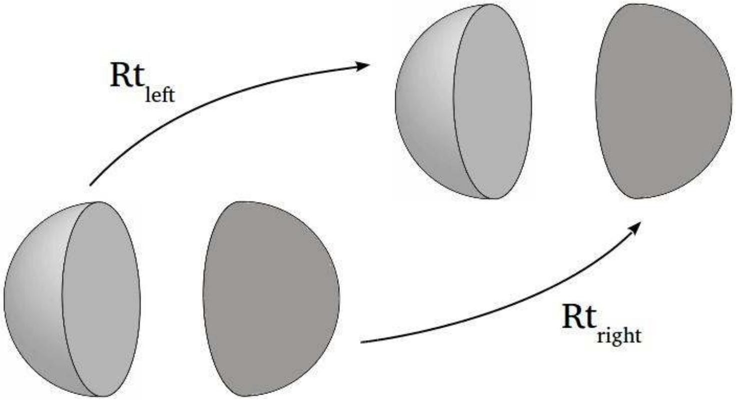
$$\mathfrak{F}_S = \frac{1}{2}\sum_{\mathbf{p}^*} W^I(\mathbf{p}^*)\left\|\mathcal{I}\left(w(\mathbf{p}^*,\widehat{\mathbf{T}}\mathbf{T}(\mathbf{x}))\right) - \mathcal{I}^*(\mathbf{p}^*)\right\|^2 + \frac{\lambda^2}{2}\sum_{\mathbf{p}^*} W^D(\mathbf{p}^*)\left\|\mathbf{n}^T\left(g(w(\mathbf{p}^*,\widehat{\mathbf{T}}\mathbf{T}(\mathbf{x}))) - \widehat{\mathbf{T}}\mathbf{T}(\mathbf{x})g^*(\mathbf{p}^*)\right)\right\|^2$$

- Accuracy: average trajectory error (with/without motion model)

	Av. Rot. Error (deg)			Av. Trans. Error (mm)		
	Raw	*RF*	**Improv.**	*Raw*	*RF*	**Improv.**
Dense RGB-D	0.51	0.12	**86 %**	3.4	1.1	**67 %**
Photo-consistency	0.47	0.12	**74 %**	2.9	1.3	**55 %**

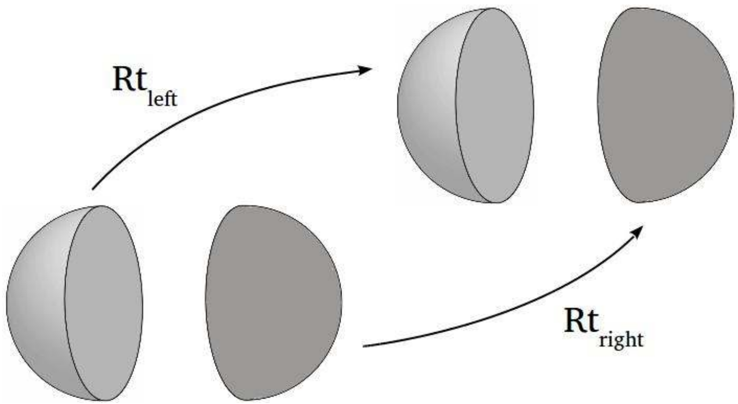
Results

- Accuracy: average deviations of half-sphere registration



Results

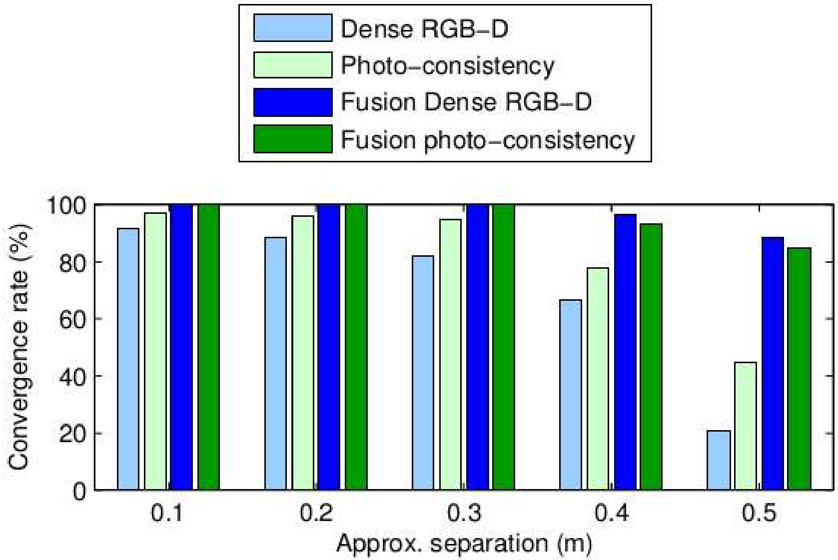
- Accuracy: average deviations of half-sphere registration



	Av. Rot. Deviation (deg)			Av. Trans. Deviation (mm)		
	Raw	*RF*	**Improv.**	*Raw*	*RF*	**Improv.**
Dense RGB-D	0.87	0.16	**80 %**	2.3	0.89	**61 %**
Photo-consistency	0.55	0.18	**67 %**	1.8	0.88	**51 %**

Results

- Dense registration convergence



Summary

Exploit the information of the sequence to improve depth images

Conclusions

- More robust and accurate a posteriori localization
- Applicable to any kind of Depth or RGB-D sequence
  (eg. 3D-LIDAR, ToF, Kinect, etc.)
- More consistent and compact maps (~20% less keyframes)

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