RELIABLE FUSION OF TOF AND STEREO DEPTH DRIVEN BY CONFIDENCE MEASURES

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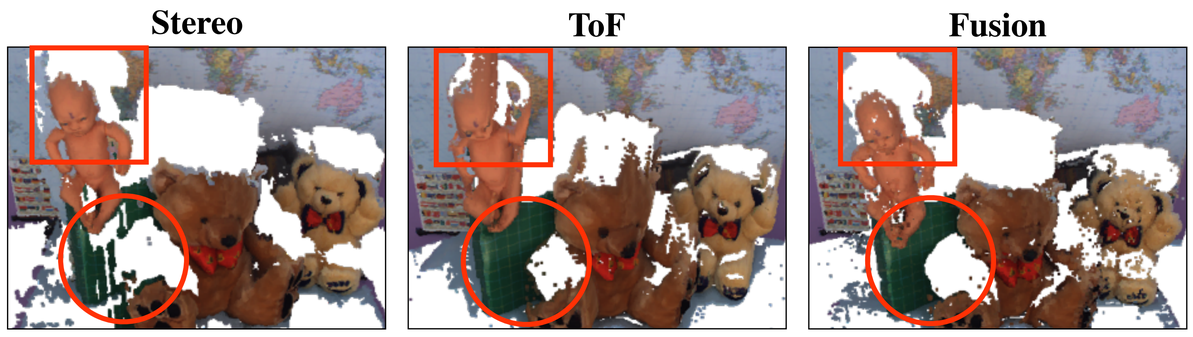
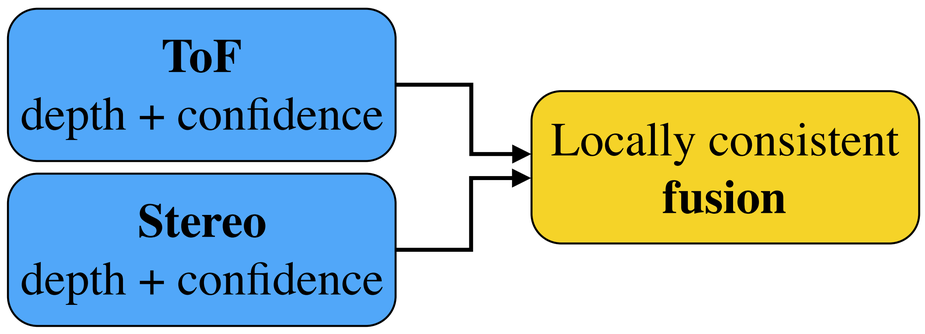
Motivation



Proposed method



ToF depth map and confidence

Depth map
ToF data are projected on the left color camera and then interpolated combining cross bilateral filtering and color segmentation.

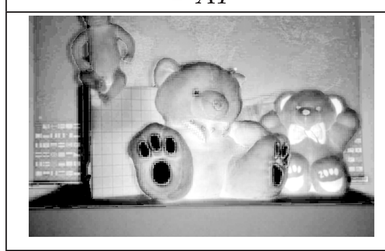
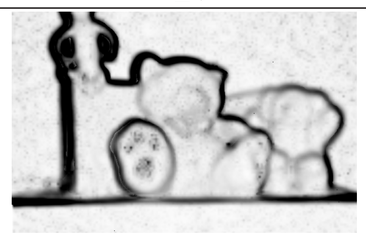
Confidence
Both geometric and photometric properties of the scene are used.

- P_{AI}: amplitude and intensity of ToF signal.

$$\sigma_z = \frac{c}{4\pi f_{mod}} \frac{\sqrt{I/2}}{A} \quad \Rightarrow \quad \sigma_d = bf \, \frac{\sigma_z}{z^2 - \sigma_z^2} \tag{1}$$

- P_{LV}: accounts for local depth variance.

$$D_l^{TOF} = \frac{1}{\left|\mathcal{N}(p_i^{TOF})\right|} \sum_{j \in \mathcal{N}(p_i^{TOF})} |z_i - z_j| \tag{2}$$

P_{AI}	P_{LV}	$P_T = P_{AI} P_{LV}$
		

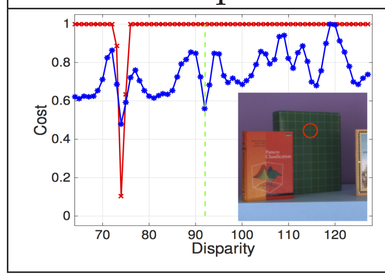
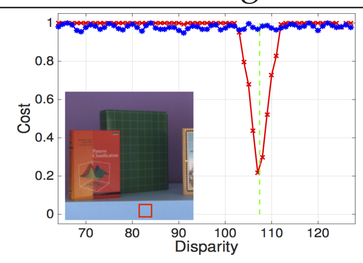
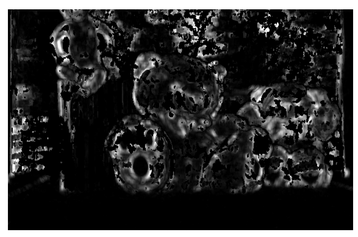
Stereo depth map and confidence

Depth map
A high resolution disparity map is inferred by global or semi-global stereo vision algorithms.

Confidence
Point-wise matching cost is compared with the globally optimized cost.

$$P_S = \frac{\Delta C^l}{C_1^l} \left(1 - \frac{\min\{\Delta d^l, \gamma\}}{\gamma}\right) \left(1 - \frac{\min\{\Delta d^{lg}, \gamma\}}{\gamma}\right) \tag{3}$$

- $C_1 = C(d_1) = \min_d C(d)$, $\quad C_2$ s.t. $|d_2 - d_1| \leq 1$
- l: local, g: global
- $\Delta C^l = C_2^l - C_1^l$, $\quad \Delta d^l = |d_2^l - d_1^l|$, $\quad \Delta d^{lg} = |d_1^l - d_1^g|$

Periodic pattern	Uniform region	P_S
		

Local cost, Global cost, Ground truth

Data fusion

Enforce local consistency and weight contribution with confidence.

$$\Omega'_f(d) = \sum_{g \in \mathcal{A}} \Big(P_T(g) \mathcal{P}_{f,g,T}(d) \; + \; P_S(g) \mathcal{P}_{f,g,S}(d) \Big) \tag{4}$$

where $\mathcal{P}_{f,g}(d) = e^{-\frac{\Delta_{f,g}}{\gamma_s}} \cdot e^{-\frac{\Delta^{\psi}_{f,g}}{\gamma_c}} \cdot e^{-\frac{\Delta^{\psi}_{f',g'}}{\gamma_c}} \cdot e^{-\frac{\Delta^{\omega}_{g,g'}}{\gamma_t}}$

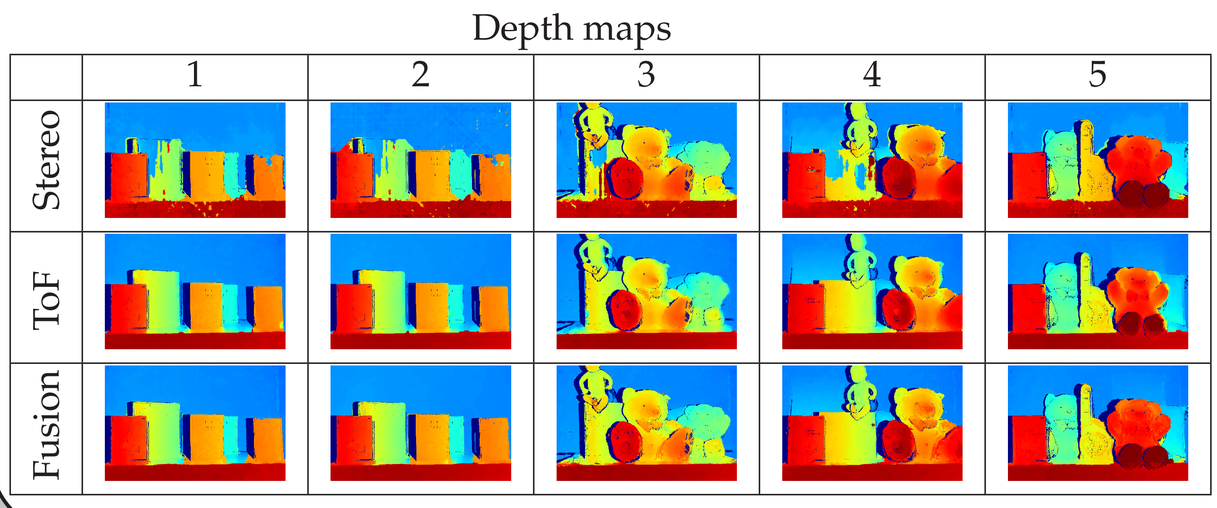
- f, g and f', g': points in the left and right image
- Δ: spatial proximity; $\quad \Delta^{\psi}$, Δ^{ω}: color similarity

Experimental results - Comparison

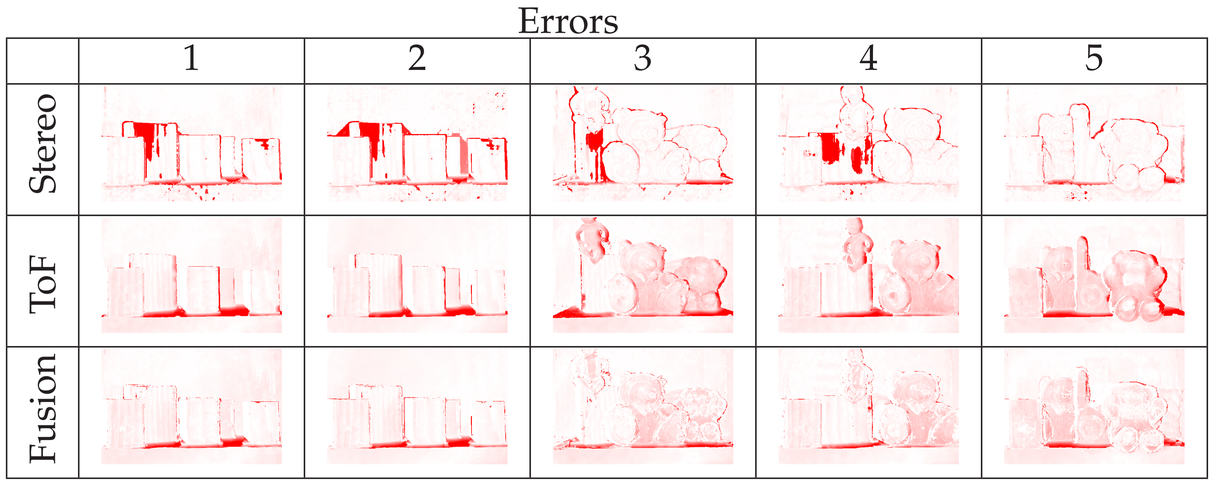
Scene	1	2	3	4	5	Avg.
ToF Int.	9.83	10.33	14.43	8.68	15.12	11.67
Stereo	19.17	27.83	18.06	25.52	11.49	20.42
Fusion	**7.40**	9.33	**6.92**	**6.30**	**8.39**	**7.67**
[1]	7.43	**9.27**	12.60	7.99	13.01	10.06
[2]	8.49	9.92	11.44	9.88	15.19	10.98
[3]	9.04	10.04	13.04	9.52	14.03	11.13
[4]	10.98	13.19	9.83	13.93	13.10	12.21
Ideal	2.50	2.60	3.22	2.42	3.16	2.78

Experimental results - Images

Depth maps



Errors



[1] Dal Mutto, C., Zanuttigh, P., Mattoccia, S., Cortelazzo, G.M.: Locally consistent tof and stereo data fusion. In: Workshop on Consumer Depth Cameras for Computer Vision (ECCV Workshop), 2012.
[2] Yang, Q., Yang, R., Davis, J., Nister, D.: Spatial-depth super resolution for range images. In: Proceedings of IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2007.
[3] Zhu, J., Wang, L., Yang, R., Davis, J.: Fusion of time-of-flight depth and stereo for high accuracy depth maps. In: Proceedings of IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2008.
[4] Dal Mutto, C., Zanuttigh, P., Cortelazzo, G.M.: Probabilistic tof and stereo data fusion based on mixed pixels measurement models. IEEE Transactions on Pattern Analysis and Machine Intelligence (TPAMI), 2015.

http://lttm.dei.unipd.it/paper_data/eccv16