Real-Time High-Quality Specular Highlight Removal using Efficient Pixel Clustering

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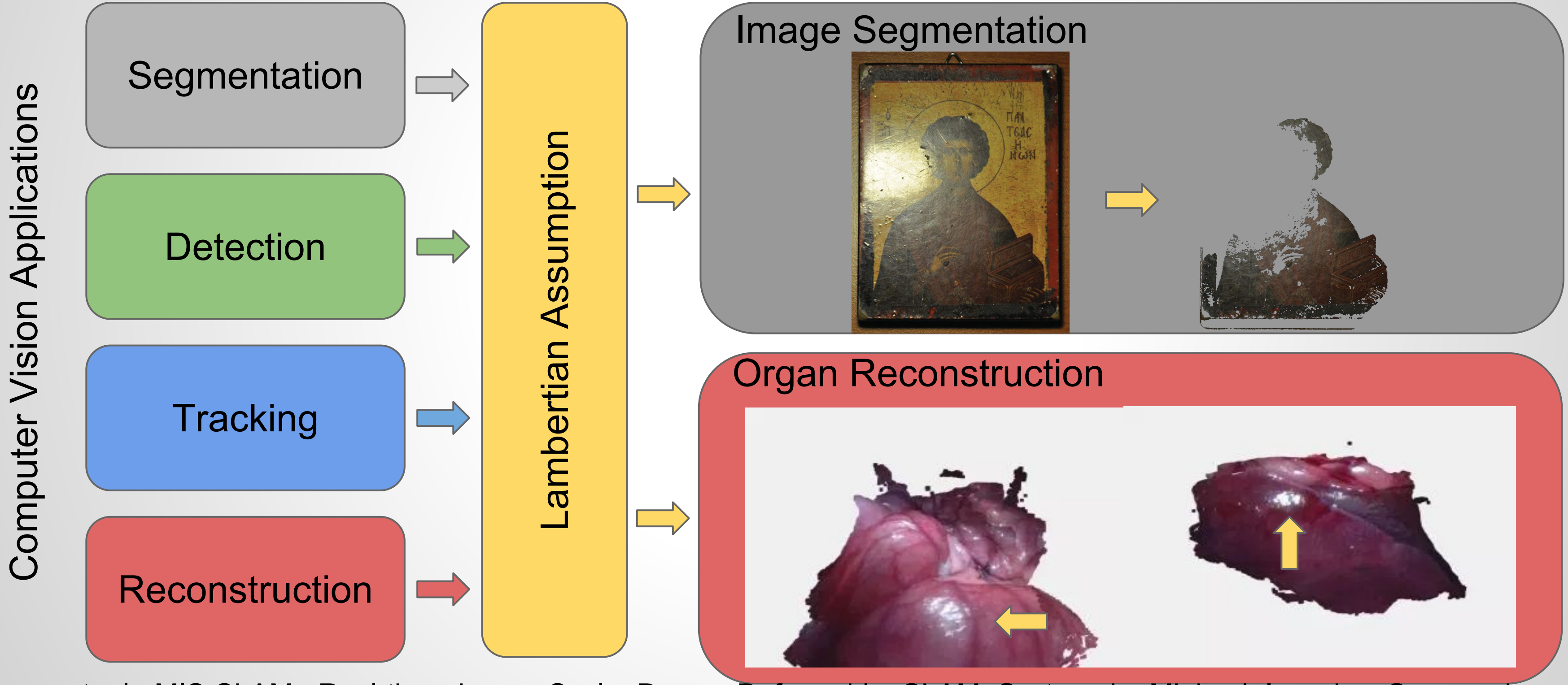
Agenda

- Introduction;
- Real-Time Specular Highlight Removal;
- Results and Discussion;
- Conclusion and Future Work;

Introduction

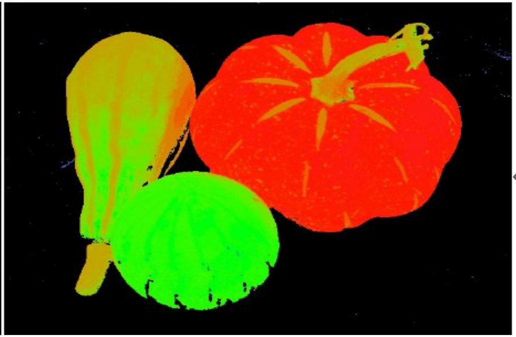
Context



J. Song et al. MIS-SLAM: Real-time Large Scale Dense Deformable SLAM System in Minimal Invasive Surgery based on Heterogeneous Computing. Proceedings of the IEEE IROS, 2018.

Current Scenario

Original Image



Clustered Image

Bad initialization of cluster seeds

Diffuse Image

Specular Image

Interactive performance

J. Suo et al. Fast and High Quality Highlight Removal from a Single Image. IEEE Transactions on Image Processing, vol. 25, no. 11, pp. 5441-5454, 2016.

Contributions

- Our main contributions are:
  - An efficient pixel clustering scheme that provides improved initialization of cluster seeds and **higher accuracy** than related work;
  - A pipeline that supports efficient **real-time** implementations for both CPU and GPU architectures;

Real-Time Specular Highlight Removal

Algorithm

- Step 1 - Pseudo Specular-Free Image Computation:

Input Image

Minimum Image

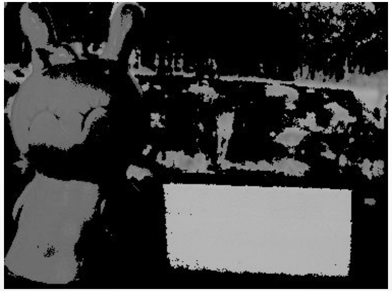
Pseudo Specular-Free Image

Algorithm

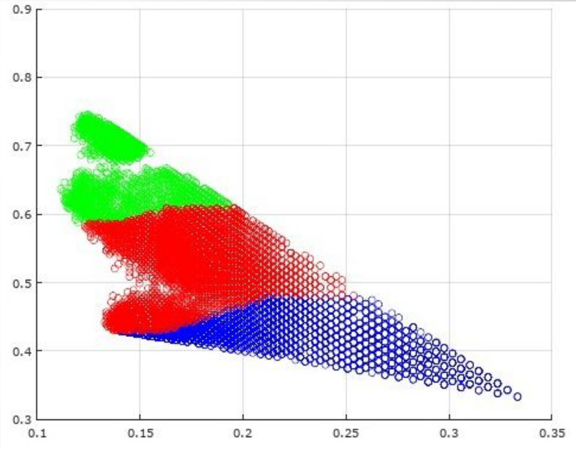
- Step 2 - Min-Max Chromaticity Space Estimation:

Pseudo Specular-Free Image

Min. Chromaticity Image (D_{min}^{psf})



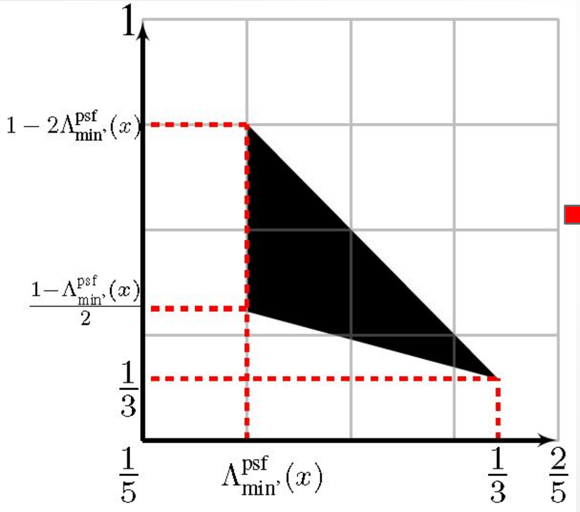
Max. Chromaticity Image (D_{max}^{psf})



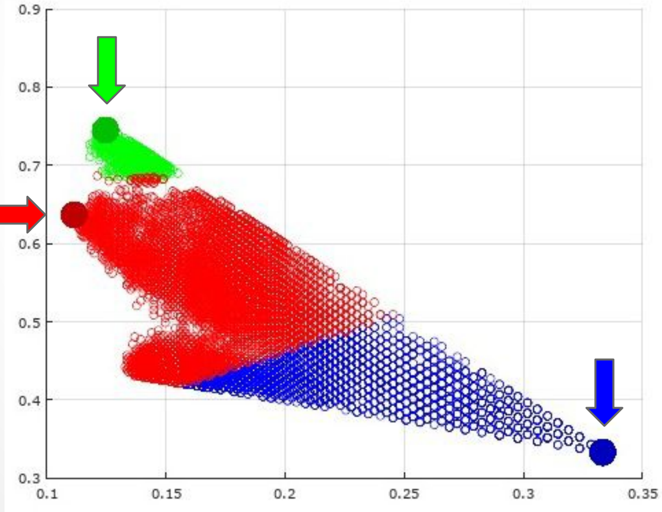
D_{min}^{psf}, D_{max}^{psf} space

Algorithm

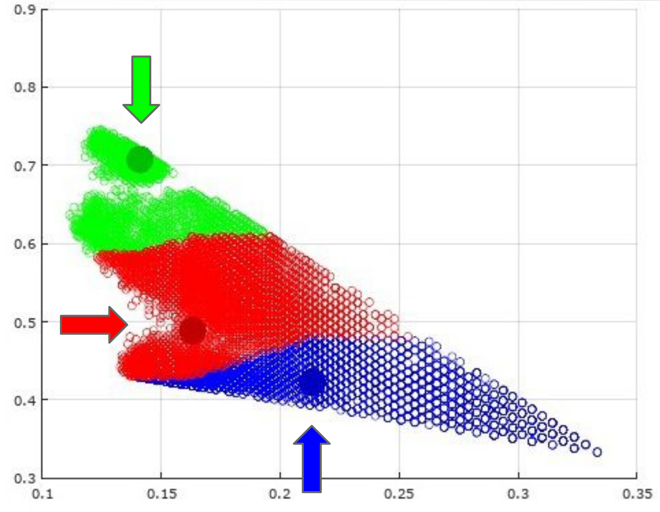
- Step 3 - Pixel Clustering:



D_{min}^{psf}, D_{max}^{psf} space



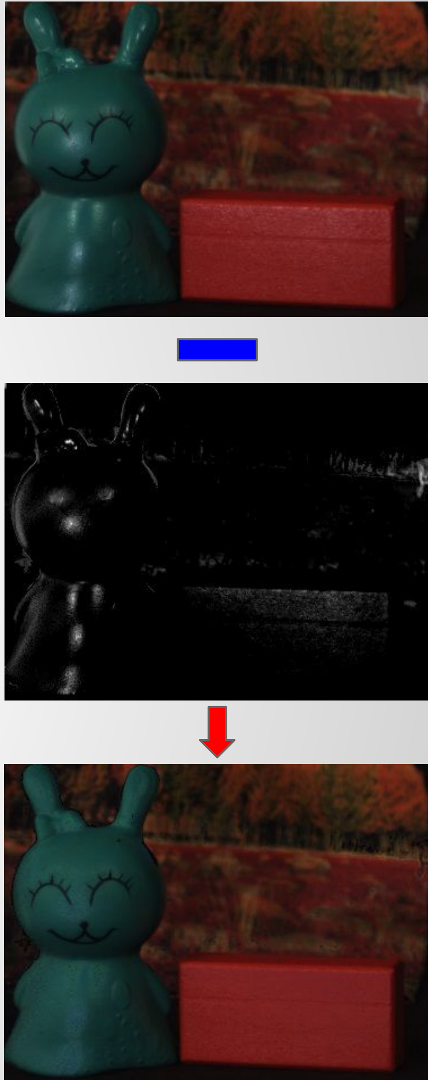
Initialization of cluster seeds



Updating cluster seeds with 2 iterations of K-Means

Algorithm

- Step 4 - Specular Highlight Removal:
  - Compute an intensity ratio $\mathbf{I^{ratio}}$ per pixel:
    - $I^{ratio} = I^{max} / (I^{max} - I^{min})$
  - Select a single intensity ratio **r** per cluster that divides diffuse and specular pixels;
  - Compute the specular term **S**:
    - $\mathbf{S} = I^{max} - r * (I^{max} - I^{min})$



Results and Discussion

Experimental Setup

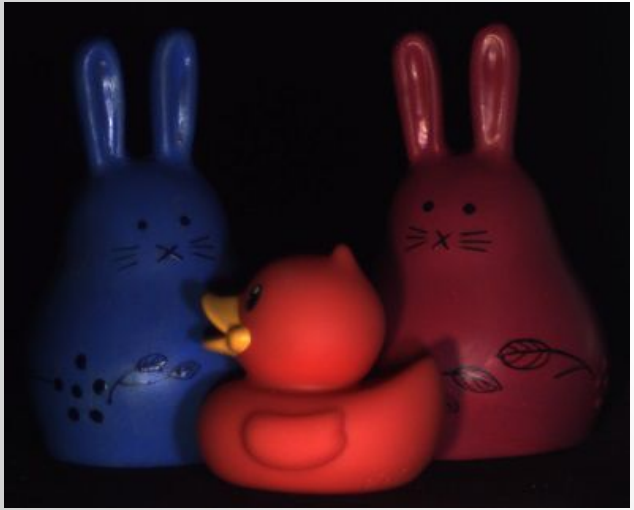
- For all tests, we used an Intel® Core™ i7-3770K, CPU @3.50GHZ, 8GB RAM, NVIDIA GeForce GTX Titan X;
- Our approach was implemented using OpenCV 2.3.1 and CUDA 8.0;
- Our final source code is open and available for free[1];
- We evaluate our approach using a standard dataset[2];

[2] H. Shen and Z. Zheng. Real-Time Highlight Removal using Intensity Ratio. Applied Optics, vol. 52, no. 19, pp. 4483-4493, 2013.

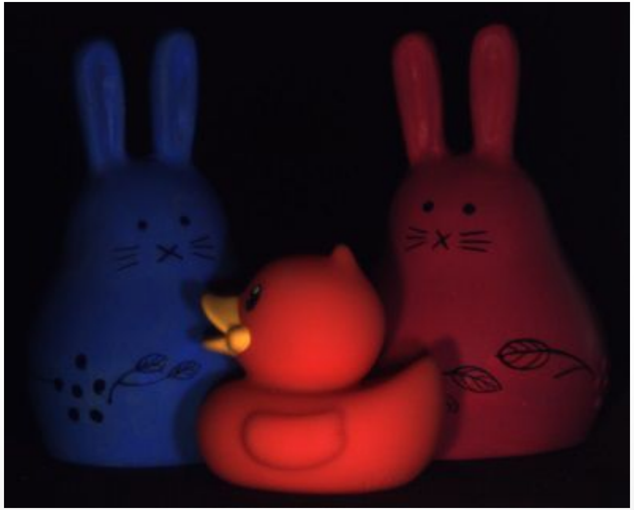
[1] https://github.com/MarcioCerqueira/RealTimeSpecularHighlightRemoval

Accuracy

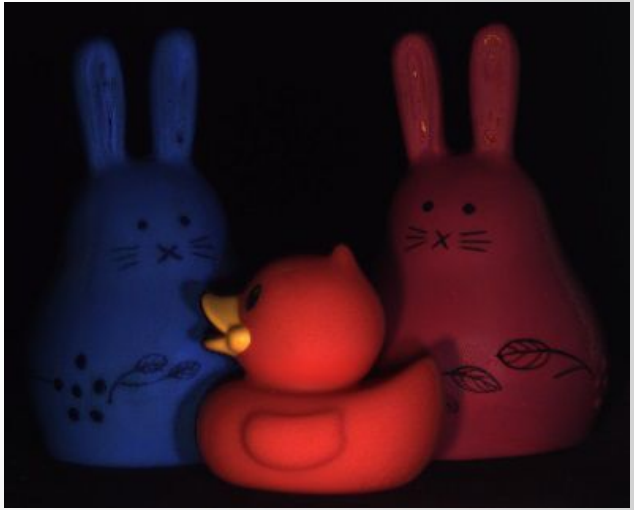
- Qualitative Evaluation (Animals):



Original



Ground-Truth



Our Result

Accuracy

- Qualitative Evaluation (Cups):

Original

Ground-Truth

Our Result

Accuracy

- Quantitative Evaluation (PNSR metric):

Method	Masks	Cups	Fruits	Animals
Shen *et al.* 2008	32.2	37.5	38.0	34.2
Shen and Cai 2009	34.0	37.6	36.9	34.8
Q. Yang *et al.* 2015	32.2	38.0	35.6	37.2
Shen and Zheng 2013	34.1	39.3	38.9	37.3
Suo *et al.* 2016	34.2	NRA	**40.4**	NRA
Ren *et al.* 2017	34.5	38.0	37.7	NRA
Our approach	**34.9**	**39.5**	39.4	**37.5**

Processing Time

- Varying Image Resolution (seconds):

Method	480p	720p	1080p	2160p
Shen *et al.* 2008	7.96	26.04	70.68	267.55
Q. Yang *et al.* 2015	0.11	0.29	0.63	2.48
Shen and Cai 2009	0.055	0.15	0.34	1.44
Shen and Zheng 2013	0.023	0.066	0.14	0.54
Our CPU approach	**0.011**	**0.030**	**0.068**	**0.26**
Our GPU approach	**0.013**	**0.015**	**0.017**	**0.024**

Conclusion and Future Work

Final Considerations

- Conclusion:
  - Our approach is two times (CPU) to one order of magnitude (GPU) faster than related work for high-resolution images;
  - Our approach is more accurate than related work for most of the tested images;
  - Hence, our approach is suitable for applications that require real-time specular highlight removal;

Final Considerations

- Future Work:
  - Larger specular highlight removal dataset;
  - Better handling of specular highlights;

Original

Ours

Shen/Zheng 2013

Shen and Cai 2009

Acknowledgments

- We are grateful to:
  - The authors of related work, for sharing their source codes for processing time evaluation;
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Thank You!

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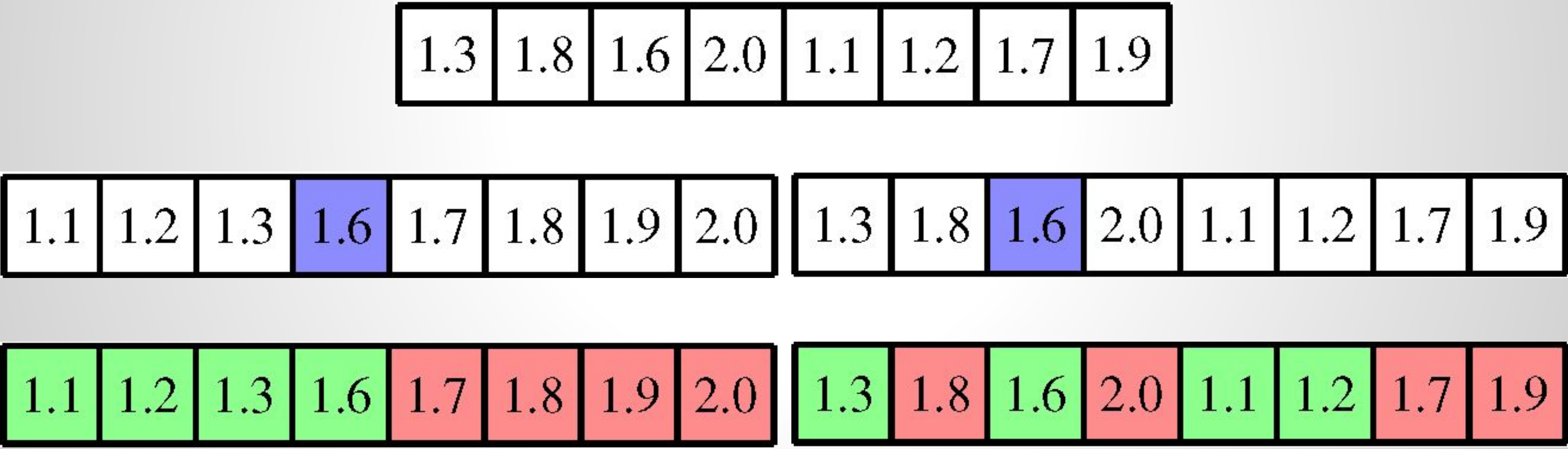
Algorithm

- Step 5 - (Per Cluster) Pixel Labelling:



Algorithm

- Step 4 - Intensity Ratio Estimation:

Maximum Image (I^{max})

Minimum Image (I^{min})

Range Image (I^{range})

$$I^{ratio} = I^{max} / I^{range}$$

$$I_D^{ratio} < I_{D+S}^{ratio}$$

Algorithm

- Step 6 - Specular Highlight Removal:

Input Image

Specular Image

Diffuse Image

$$S = I^{max} - r * I^{range}$$