smart engines™

Whitepaper

ProLAB:

Perceptually Uniform
Projective Colour Coordinates System

Aiming at advancing the fundamental science, Smart Engines R&D team is closely working with the research group from the Russian Academy of Sciences — specifically the Institute for Information Transmission Problems. Our collaborative research has recently resulted in the development of the new colour coordinate system. The system, in our view, is the most suitable framework for linear colour analysis, and is given further elaboration below.

Recently, Smart Engines researchers together with the team from the Institute for Information Transmission Problems RAS, in the scientific collaboration devoted to the advancement of colour vision science have developed the new colour coordinate system. That system is claimed to be the best suitable framework for linear color analysis. The results of the research have been presented by Smart Engines at the 25th Symposium of the International Color Vision Society (ICVS). Established in 1969 in Sweden, ICVS is a large R&D group of physiologists, psychologists, physicists, geneticists, optometrists, ophthalmologists and visual scientists, which studies various aspects of colour vision and colour vision deficiencies. Held in Riga, Latvia, earlier this summer, the event brought together 167 participants from 19 countries.

Below, you will find some details of the invention, including the poster which was presented at the conference.

Aiming at advancing the fundamental science, Smart Engines R&D team is closely working with the research group from the Russian Academy of Sciences — specifically the Institute for Information Transmission Problems. Our collaborative research has recently resulted in the development of the new colour coordinate system. The system, in our view, is the most suitable framework for linear colour analysis, and is given further elaboration below.

Various algorithms of technical colour vision (mostly related to colour constancy problem) operate in so called linear colour spaces which are obtained by linear mappings of the spectral power distribution space. This practice is motivated by the linearity of the underlying optical image formation model. However, requirement of mapping linearity is redundant since affine properties of manifolds are preserved not only by linear transformations. On the other hand, linear regression in linear colour spaces (hardware RGB or CIE XYZ) is unreasonable, because euclidean distance in such spaces does not approximate the colour difference well. This holds both for perceptual difference and deviations caused by heteroscedastic optical noise.

The researchers from Smart Engines and IITP RAS have proposed the ProLAB colour space obtained as a projective mapping of the spectral power distribution space which is more adequate for colour image analysis algorithms. The Euclidean distance in the ProLAB coordinate space provides a closer approximation of perceptual differences between colours in comparison with the widely used CIE LAB. Also, the transition into ProLAB coordinates makes image noise more homoscedastic. For now it looks to be the best suitable framework for linear colour analysis in computer vision.

ProLAB: perceptually uniform projective colour coordinates system

ICVS 2019

Algorithms of technical colour vision (mostly for colour constancy) operate in linear colour spaces obtained by linear mapping of the spectral power distribution space. This practice is motivated by the linearity of the underlying optical image formation model. We find that the mapping linearity is not required to preserve the submanifolds affine properties.

I. A. Konovalenko, V. V. Kohan, A. A. Smagina, D. P. Nikolaev

Institute for Information Transmission Problems (Kharkevich Institute) RAS, Russia

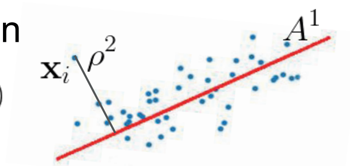
Институт проблем передачи информации им. А. А. Харкевича Российской академии наук

SMART ENGINES QUALITY MATTERS.

VISILLECT

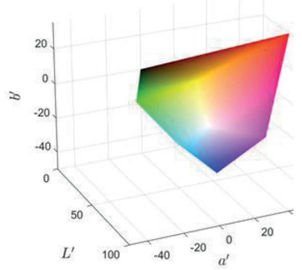
Linear regression

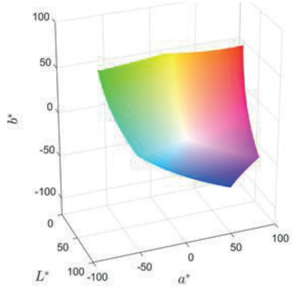
$$\underset{A^r}{\operatorname{argmin}} \sum_{i=1}^{n} \rho^2(A^r, \mathbf{x}_i)$$

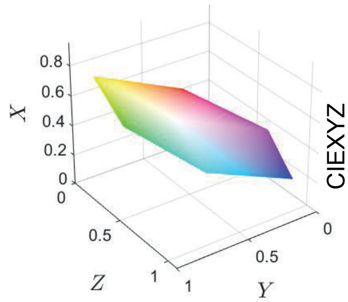


In linear colour space Euclidean distance correlates poorly with the perceptual colour difference, which is approximated best by CIEDE2000 [1]

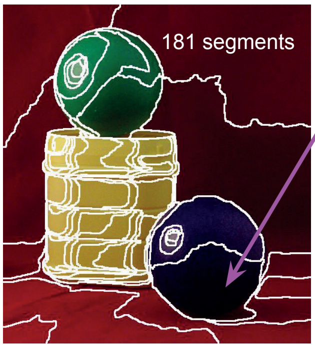
The sRGB gamut in:







in linear colour space **vs** in projective colour space [3]

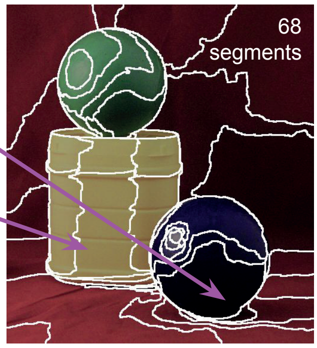


the shadow is wrongly merged with the object

the darker regions are distinguishable better

the lighter regions appear more homogenous

The sum of squared deviations from the image model is equal in both cases (according to a reference colour space).



Homography matrix H_{4x4} [2] is obtained by optimizing

$$\left| F^2 \|\mathrm{H}(\mathbf{x}) - \mathrm{H}(\mathbf{y})\|_2^2 - \mathrm{CIEDE2000}^2(\mathbf{x}, \mathbf{y}) \right|$$

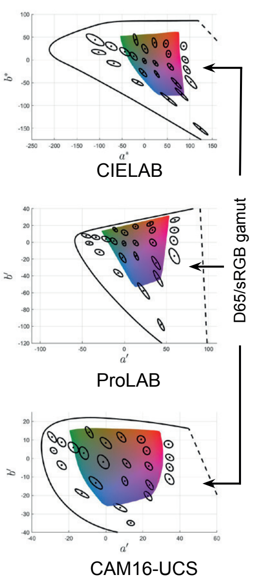
for (x, y) pairs over the gamut, where F is the scaling coefficient, and H is projective transform.

$$H = \begin{pmatrix} 72.9 & 367 & 52 & 0 \\ 480 & -478 & -1.87 & 0 \\ 116 & 81.4 & -197 & 0 \\ 0.751 & 2.29 & 0.881 & 1 \end{pmatrix}$$

$$\mathbf{x} \in XYZ \implies H(\mathbf{x}) \in ProLAB$$

MacAdam ellipses

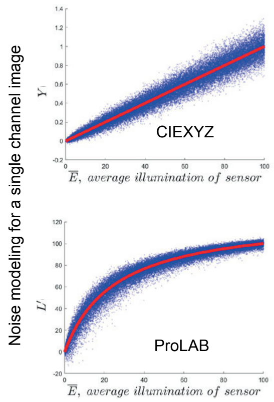
for L*=50



Optical image noise

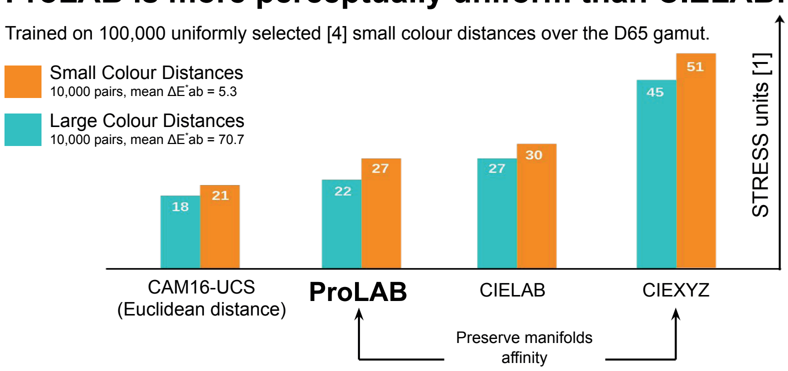
Linear regression assumes that noise is homoscedastic. But the optical image noise is heteroscedastic due to the underlying quantum noise, which is modeled with a Poisson distribution [5].

The transition into ProLAB leads to more homoscedastic noise.



ProLAB is more perceptually uniform than CIELAB!

Trained on 100,000 uniformly selected [4] small colour distances over the D65 gamut.



We might also introduce a measure of projectivity of a colour coordinates. By adding such a term in the optimization criteria, we could construct a colour space that balances preserving the submanifolds affine properties and the perceptual uniformity.

Acknowledgements

This work is partially supported with by the Russian Foundation of Basic Research (projects 17-29-03297 and 17-29-03370).

References

[1] P. A. Garcia et al. "Measurement of the relationship between perceived and computed color differences". JOSA A 24.7 (2007), p. 1823—1829.
[2] G. Finlayson, H. Gong, R. Fisher. "Color homography: theory and applications". IEEE TPAMI 41.1 (2019), p. 20—33.
[3] A. Smagina et al. Linear colour segmentation revisited." (ICMV 2018). Vol. 11041. International Society for Optics and Photonics, 2019.
[4] P. Urban et al. "Embedding non-Euclidean color spaces into Euclidean color spaces with minimal isometric disagreement". JOSA A 24.6 (2007), p. 1516—1528.
[5] B. Jahne. Digital image processing: concepts, algorithms, and scientific applications. T. 6. Springer Heidelberg, 1997.