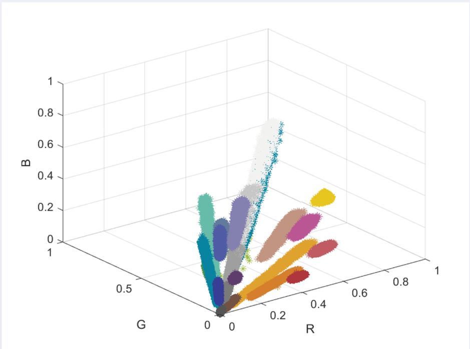
ORGB: OFFSET CORRECTION IN RGB COLOR SPACE FOR ILLUMINATION-ROBUST IMAGE PROCESSING

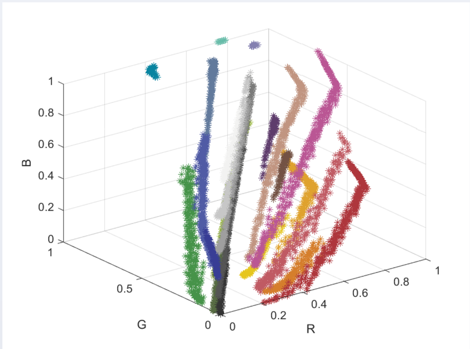
Zhenqiang Ying[1], Ge Li[1], Sixin Wen[2], Guozhen Tan[2]

[1] SECE, Shenzhen Graduate School, Peking University, Shenzhen, China [2] Electronic Information and Electrical Engineering, Dalian University of Technology, Dalian, China

ABSTRACT

Single materials have colors which form straight lines in RGB space. However, in severe shadow cases, those lines do not intersect the origin, which is inconsistent with the description of most literature.


Ideal: intersect the origin


Reality: offset from the origin

This paper is concerned with the detection and correction of the offset between the intersection and origin.

OFFSET FORMATION

$L^d(\lambda)$ - direct light

$L^e(\lambda)$ - environment light

μ - a value between [0, 1] indicating how much direct light gets to the surface

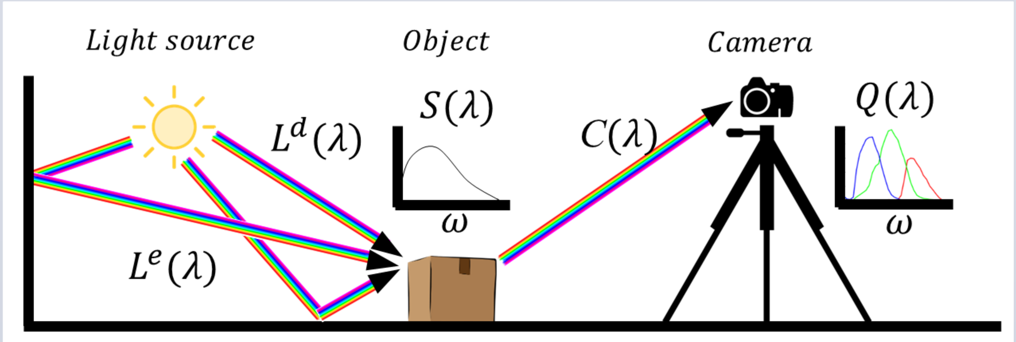
θ - the angle between the direct light and the surface norm

$Q_k(\lambda)$ - a function of wavelength λ characterizing how sensor k responds to light

$C(\lambda)$ - captured light

$S(\lambda)$ - surface reflectance function

ρ_k - the k-th sensor response



Schematic diagram of image formation

$$\rho_k = \varphi_k + \delta_k$$

$$\varphi_k = \mu \cos\theta \int_\omega L^d(\lambda) S(\lambda) Q_k(\lambda) d\lambda$$

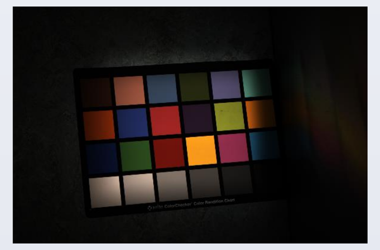
$$\delta_k = \int_\omega L^e(\lambda) S(\lambda) Q_k(\lambda)\, d\lambda$$

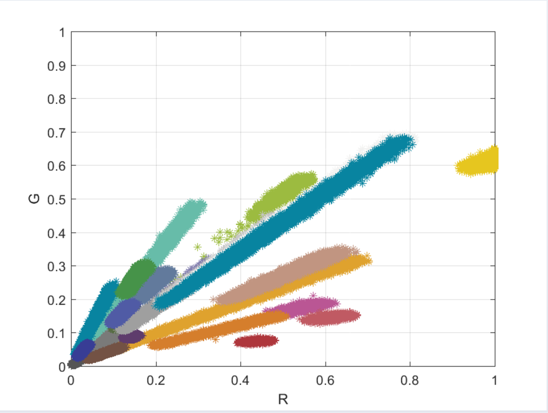
EXPERIMENTAL VERIFICATION

To verify the proposed model, we took pictures of a *ColorChecker* exposed to different light conditions.

The image only exposed to direct light I_φ meets color constancy. For the same material pixels captured by different color sensors, their responses have a proportional relationship

$$\frac{\rho_i}{\rho_j} = \frac{\varphi_i}{\varphi_j} = \frac{\cancel{\mu \cos\theta} \int_\omega L^d(\lambda) S(\lambda) Q_k(\lambda) d\lambda}{\cancel{\mu \cos\theta} \int_\omega L^d(\lambda) S(\lambda) Q_k(\lambda) d\lambda}$$

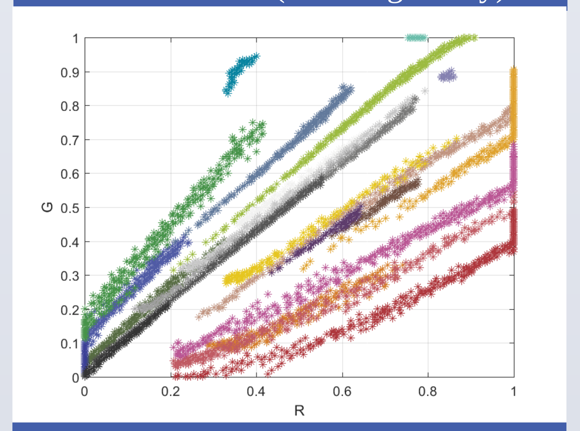

I_φ


Case 1: indoor (direct light only)

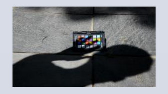

$I_{\varphi+\delta}$

Sunlight: direct light

Skylight: environment light

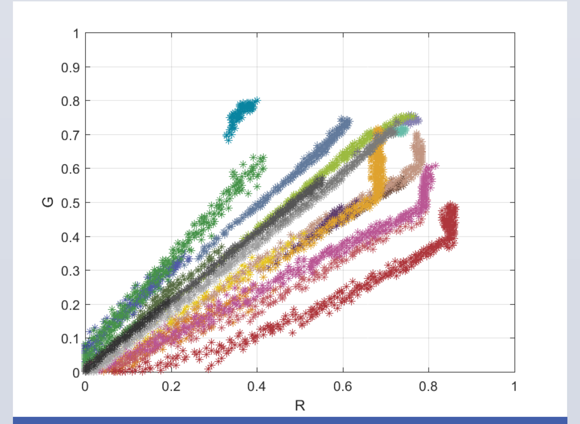

Case 2: outdoor (sunlight and skylight)


$I_{\varphi+\delta}$ - I_δ



$I_{\varphi+\delta}$ I_δ

Remove the skylight by image subtraction

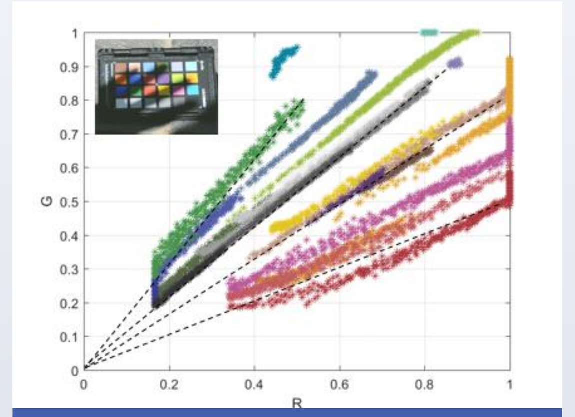

Case 3: synthetic image (sunlight only)

Color consistency is established only in the case of no environment light (I_φ). As the presence of environment light undermines the color consistency, lines consisted of pixels from the same material do not intersect the origin ($I_{\varphi+\delta}$). By removing the contribution from environment light, those lines will intersect at the origin again ($I_{\varphi+\delta}$ - I_δ).

OFFSET CORRECTION

In most cases, the image of corresponding environment light I_δ is not available, so we need to find another way to perform offset correction. Noticing that the straight lines in $I_{\varphi+\delta}$ are about to converge at one point, a simple and straight-forward way is to perform a linear transform. Denote the location of that convergence point as $\boldsymbol{\varepsilon} = [\varepsilon_1, \varepsilon_2, \varepsilon_3]$, the offset-corrected sensor response $\tilde{\boldsymbol{\rho}}$ is defined as

$$\tilde{\boldsymbol{\rho}} = \frac{\boldsymbol{\rho} - \boldsymbol{\varepsilon}}{\mathbf{1} - \boldsymbol{\varepsilon}}$$


Case 4: offset-corrected image

The resulting images, named ORGB (offset-corrected RGB), have almost the same appearance as the original RGB images while are more illumination-robust for color-based image processing.

Offset estimation

$$\frac{\rho_j - \varepsilon_j}{\sum_{i=1}^{3} \rho_i} \approx \frac{\rho_j - \varepsilon_j}{\sum_{i=1}^{3} (\rho_i - \varepsilon_i)} = \sum_{i=1}^{3} \frac{\rho_j - \varepsilon_j}{\rho_i - \varepsilon_i}$$

$$= \sum_{i=1}^{3} \frac{\tilde{\rho}_j (1 - \varepsilon_j)}{\tilde{\rho}_i (1 - \varepsilon_i)}$$

$$= \sum_{i=1}^{3} \frac{\tilde{\rho}_j}{\tilde{\rho}_i} \times \frac{1 - \varepsilon_j}{1 - \varepsilon_i} = Constant$$

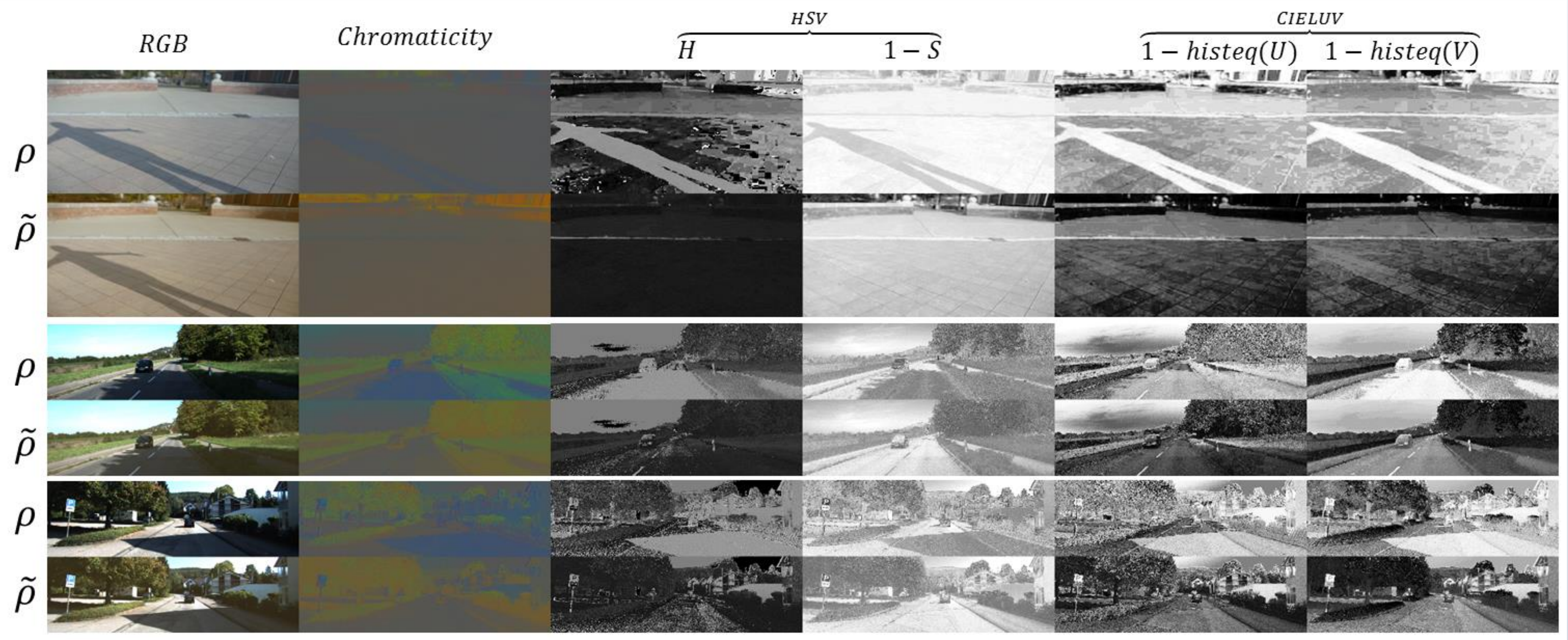
$$\Rightarrow \quad \rho_j \approx Constant \times \sum_{i=1}^{3} \rho_i + \varepsilon_j$$

Since there is an approximate linear relation between ρ_j and $\sum_{i=0}^{3} \rho_i$ among pixels from the same material, we can calculate $\boldsymbol{\varepsilon}$ by following steps:

1. Manually select an area of interested material.
2. Repeat 3-4 for each color channel (j = 1, 2, 3).
3. Fit a straight line to approximate the relationship between ρ_j and $\sum_{i=0}^{3} \rho_i$.
4. Take the intercept of the line as an estimation of ε_j .

RESULTS 1: COLOR SPACE CONVERSION

While existing color spaces address a range of needs, none of them can free from the interference of severe shadows. Fortunately, the shadows in extracted color components are greatly attenuated after offset correction.



Color Space Conversion using ρ (raw) and $\tilde{\boldsymbol{\rho}}$ (offset-corrected).

RESULTS 2: IMAGE PROCESSING

As color components become more illumination-robust after offset correction, color-based image processing can be improved using ORGB instead of RGB.

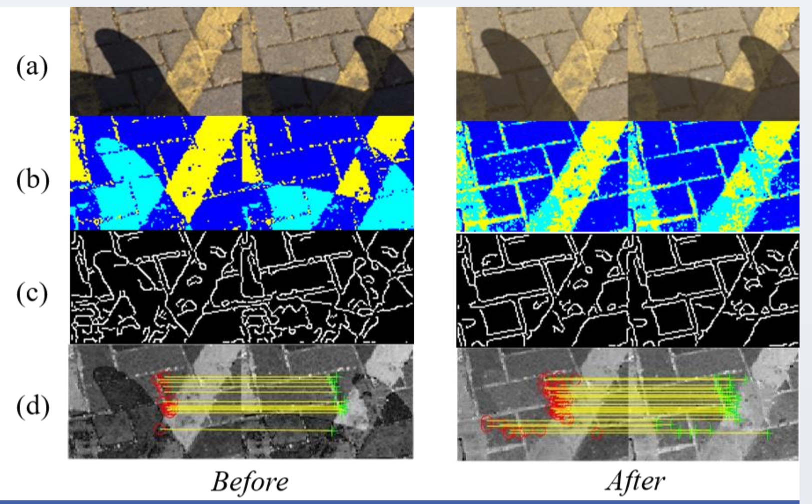


Image processing before and after offset-correction.

RESULTS 3: IMAGE ANALYSIS

As a key technique of automatic driving, road detection algorithms suffer from the shadows on road surfaces. We take road detection as an example to demonstrate the benefit of offset correction to image analysis. Experimental results show that the performance of road detection is improved after offset correction in both quantitative and qualitative measurements, especially in severe shadow cases.

Road detection performance on ROMA dataset

	Complete dataset				
	g	DR	DA	F	V RI
RGB	.80 ± .23	.84 ± .22	.91 ± .20	.87 ± .20	81%
ORGB	.83 ± .18	.87 ± .19	.94 ± .14	.89 ± .15	84%
	Severe shadow cases				
	g	DR	DA	F	V RI
RGB	.75 ± .26	.79 ± .26	.88 ± .24	.82 ± .23	73%
ORGB	.83 ± .19	.87 ± .20	.93 ± .16	.89 ± .16	88%

CONCLUSIONS

- We provide an explanation of why traditional techniques fail in severe shadow cases.
- We present a new aspect of dealing with severe shadow.
- We propose an approach to produce images that are more illumination-robust for color-based image processing.

This work was supported by the grant of National Science Foundation of China (No.U1611461), Shenzhen Peacock Plan (20130408-183003656), and Science and Technology Planning Project of Guangdong Province, China (No. 2014B090910001). Open Source https://baidut.github.io/ORGB/