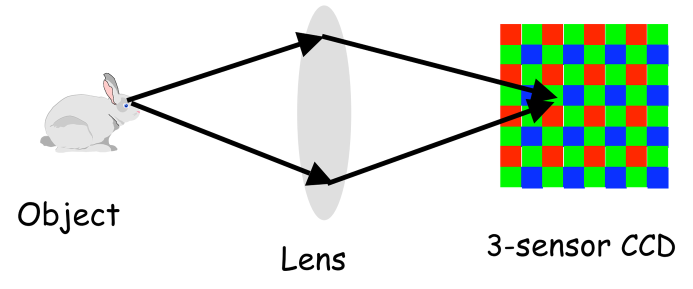
Chromagenic Digital Photography

P. Morovic (in collaboration with Prof. G. Finlayson and Dr. S. Hordley)

School of Computing Sciences, University of East Anglia, United Kingdom.

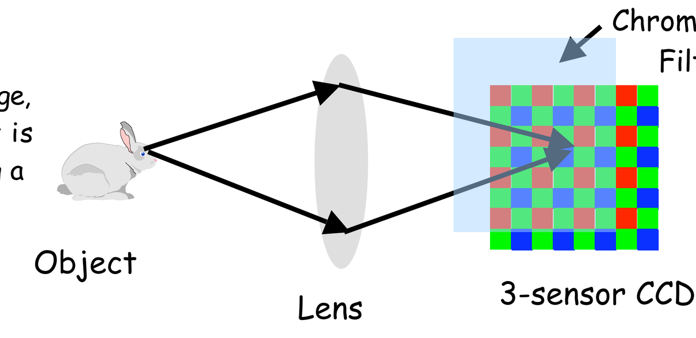
(Supported by the EPSRC and the Leverhulme Trust)

The Chromagenic Camera



A conventional digital camera records an image on a 3-sensor CCD array

A Chromagenic Camera captures a conventional image, and an additional image that is optically pre-filtered using a chromagenic filter



So, the chromagenic camera gives us two pairs of 3 measurements at each pixel: a conventional measurement: (R, G, B) and a filtered measurement: (R_f, G_f, B_f).

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} \xrightarrow[\text{Filter } F_c(\lambda)]{\text{Related by}} \begin{pmatrix} R_f \\ G_f \\ B_f \end{pmatrix}$$

Importantly, these pairs of measurements are related to one another in a well defined way: they are related by a known filter.

Relating Filtered and Unfiltered Responses

For a wide class of surfaces, the relationship between un-filtered and filtered RGBs is linear:

$$\begin{pmatrix} R^i \\ G^i \\ B^i \end{pmatrix} = M^i_f \begin{pmatrix} R^i_f \\ G^i_f \\ B^i_f \end{pmatrix}$$

Unfiltered response to a surface under a given illuminant

3x3 linear transform dependent on illuminant and filter

Filtered response to same surface under same light

For a fixed illuminant, the linear transform M^i_f depends on the chromagenic filter $F_c(\lambda)$ and the illuminant (i) under which the RGBs are recorded

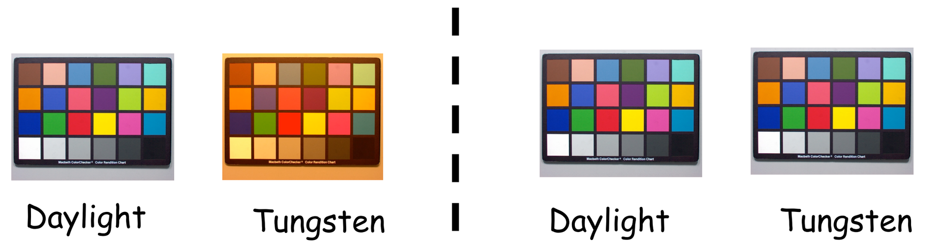
Importantly, the transforms M^i_f are different for different illuminants i

We can use this property of chromagenic camera responses to identify the illuminant in a scene: that is, to solve the **Colour Constancy Problem**.

The Colour Constancy Problem

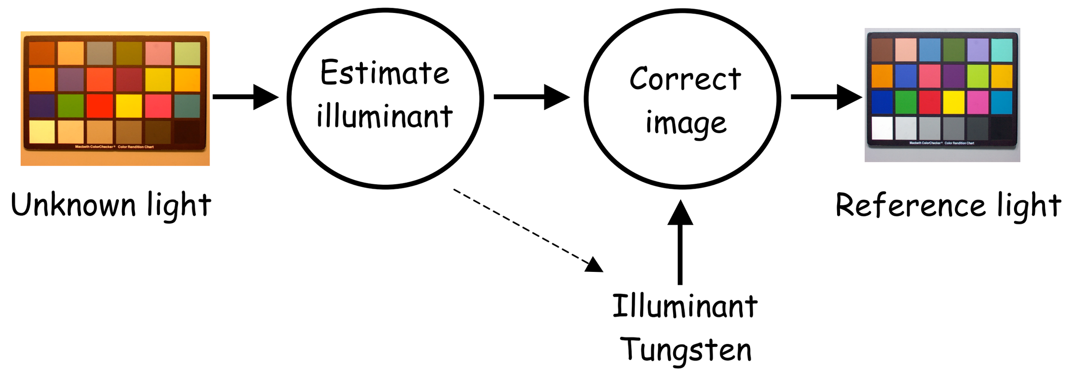
Cameras "see" illuminant dependent colours:

We would like them to see the same colours independent of the illumination



Solving the Problem

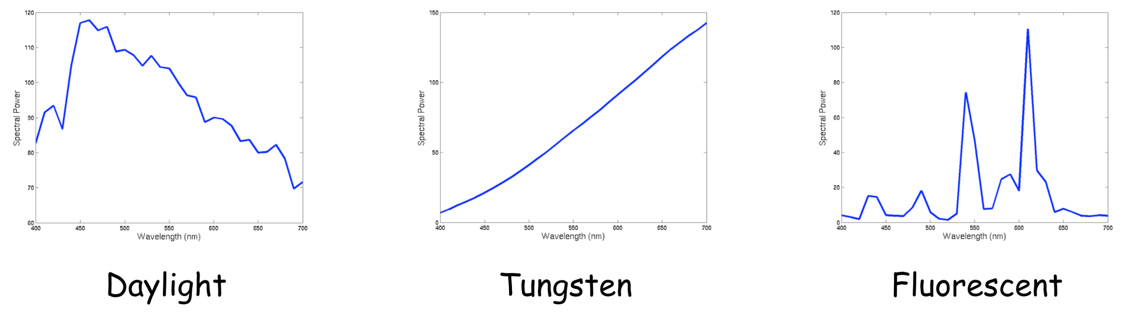
Achieving colour constancy is a two stage process ...



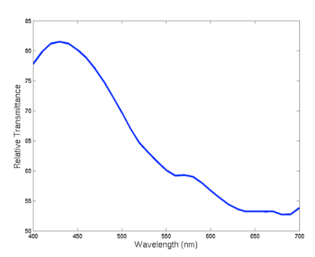
Estimating the Illuminant with the Chromagenic Camera

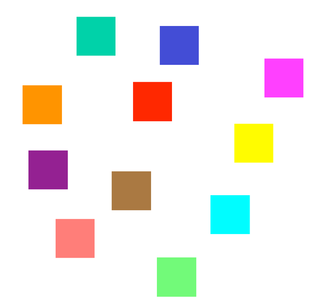
Pre-Processing

1. Choose a set of plausible scene illuminants:



2. Choose a chromagenic filter, and a representative set of surface reflectances





3. Represent each light by the linear transform that best maps the RGBs of surfaces viewed under that light, to the corresponding filtered RGBs:

Daylight:
$$\begin{pmatrix} 1.82 & -0.06 & -0.09 \\ 0.15 & 1.54 & -0.05 \\ -0.03 & 0.04 & 1.26 \end{pmatrix}$$

Tungsten:
$$\begin{pmatrix} 1.90 & -0.11 & -0.06 \\ 0.13 & 1.56 & -0.06 \\ -0.02 & 0.05 & 1.27 \end{pmatrix}$$

Fluorescent:
$$\begin{pmatrix} 1.85 & -0.10 & -0.09 \\ 0.12 & 1.58 & -0.05 \\ -0.01 & 0.02 & 1.26 \end{pmatrix}$$

Operation

1. Use the transform for each plausible light in turn to map the unfiltered image responses to their corresponding filtered responses.

Unfiltered responses under unknown light

$$\begin{pmatrix} 1.82 & -0.06 & -0.09 \\ 0.15 & 1.54 & -0.05 \\ -0.03 & 0.04 & 1.26 \end{pmatrix}$$

$$\begin{pmatrix} 1.90 & -0.11 & -0.06 \\ 0.13 & 1.56 & -0.06 \\ -0.02 & 0.05 & 1.27 \end{pmatrix}$$

$$\begin{pmatrix} 1.85 & -0.10 & -0.09 \\ 0.12 & 1.58 & -0.05 \\ -0.01 & 0.02 & 1.26 \end{pmatrix}$$

Filtered responses under same unknown light

2. Choose the plausible light which best maps responses as the estimate of the scene illuminant.

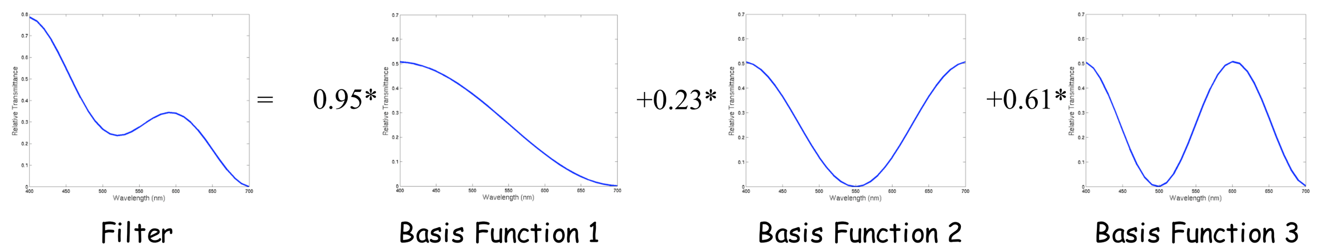
Choosing a Chromagenic Filter

In theory, any transmittance function $F_c(\lambda)$ is a possible chromagenic filter

In practice, it is useful to restrict $F_c(\lambda)$ to be a linear combination of a set of basis functions.:

$$F_c(\lambda) = c_1 b_1(\lambda) + c_2 b_2(\lambda) + \ldots + c_m b_m(\lambda) = B\underline{c}_F$$

For example, a 3-d Cosine Basis:



Note: in practice, we can choose a filter basis of arbitrary dimension and having arbitrary basis functions. So, restricting a filter in this way is a weak constraint.

Useful Properties of a Chromagenic Filter

An inspection of the chromagenic algorithm suggests two useful properties that a chromagenic filter should satisfy:

1. The transforms M^i_f for different plausible scene illuminants should be as different to one another as possible.

2. The transforms for a given filter and scene illuminant, should map unfiltered RGB values to filtered RGB values with as small an error as possible.

We can formulate these properties (see paper for details) into a closed form mathematical optimisation where our measure of filter goodness is defined as:

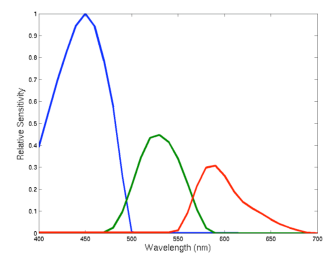
$$\text{Filter Goodness} = \underline{c}^T V^T V \underline{c} + \lambda\left(1 - \underline{c}^T G^T G \underline{c}\right)$$

Term controlling inter-transform variance

Term controlling transform error

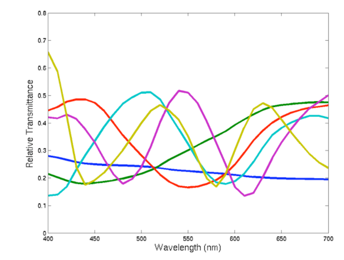
We can determine the best filter according to this measure of goodness by solving an eigenvector problem.

An Example

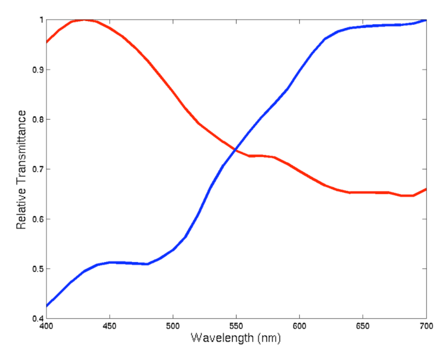


Sensors of a Sony Digital Camera

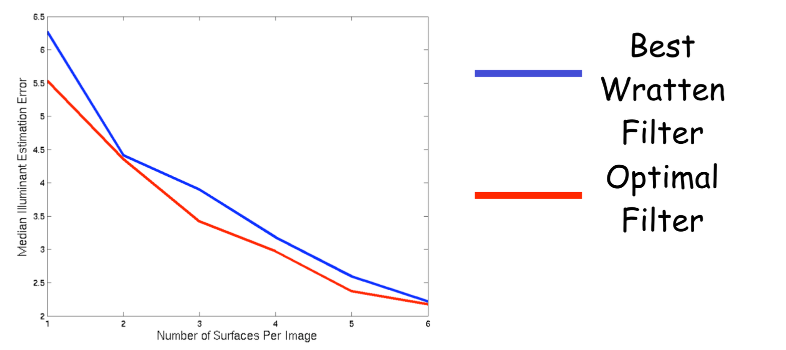
\+ 87 plausible scene lights, and 1995 possible surface reflectances +



6-d Filter Basis derived from a PCA of 53 Wratten Filters



Recovered Optimal filter



Summary of Colour Constancy Performance

·Colour Constancy performance is based on 6000 images containing between 2 and 64 surfaces. Each image is lit by one of 287 possible scene lights

·The optimal filter gives better colour constancy performance than can be achieved using a standard Wratten transmittance filter

Performance evaluation

There are many ways to solve the colour constancy problem: such as assuming a white patch in the scene (Max RGB), assuming the average of a scene is a grey (Grey World), constraining the set of possible lights based on the likelihood of surfaces under particular lights (linear programming gamut mapping, colour by correlation), and many others, ranging in complexity and performance.

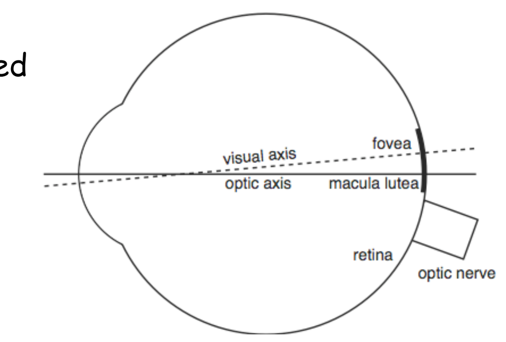
	MxRGB	GW	DBGW	LPGM	CbyC	CGenic
MxRGB		+	-	-	-	-
GW	-		-	-	-	-
DBGW	+	+		-		-
LPGM	+	+			-	-
CbyC	+	+	+	+		
CGenic	+	+	+	+		

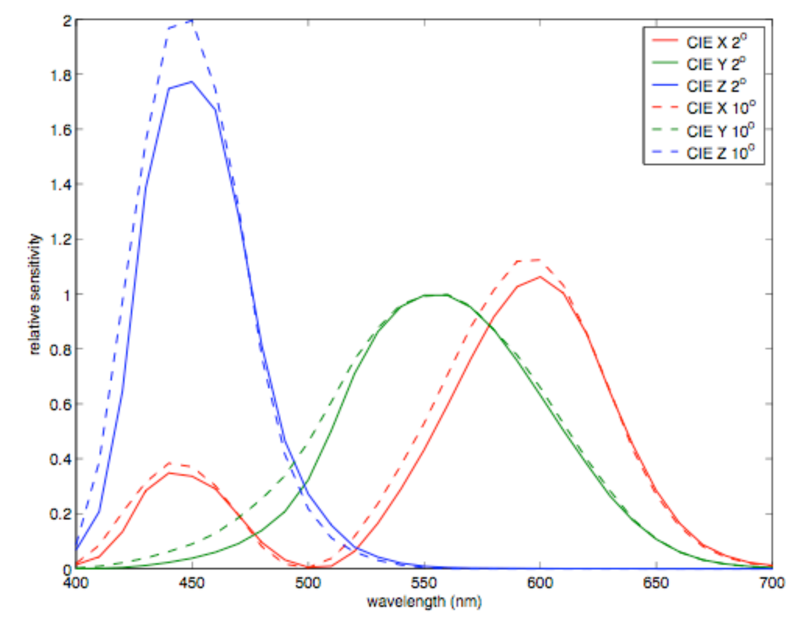
Wilcoxon Sign Test (0.01 significance level). A plus sign (+) in the *ij*th entry implies that the algorithm in row *i* is better than the algorithm in column *j*. A minus (-) means it's worse and no sign means that the two algorithms are statistically equivalent.

Chromagenic Colour Constancy is extremely simple and fast and outperforms other algorithms substantially in particular for small numbers of surfaces and hence small scene colour complexity. All algorithms plateau for large numbers of surfaces (64+) to the same level of performance.

Human visual system

The central area of the human retina - called the fovea - also uses a filter, the macular pigment. This is the reason why there are two standard colorimetric observers - 10° and 2°, depending on the field of vision.





It turns out that the 10° and 2° observer spectral sensitivities are a chromagenic pair - simulating the human visual system and using these two observers for the unfiltered RGB and filtered counterpart, we achieve good illuminant estimation (significantly better than using other methods)

Originally, the *Chromagen* idea comes from research into colour deficiency - using different coloured filters put in front of each eye, it is allegedly possible to increase the gamut of discriminable colours for colour deficient people.

A Summary

·Chromagenic Colour Constancy is a very promising solution to the illuminant estimation problem

·The choice of chromagenic filter has a significant effect on algorithm performance

·The idea may have a foundation in the human visual system and could be an explanation as to why humans have good illuminant estimation ability

References

G. D. Finlayson, S. D. Hordley, P. Morovic, "Gamut constrained chromagenic colour constancy," in Proceedings of IEEE Internat. Pattern Recognition, San Diego (USA), June 2005

G. D. Finlayson, S. D. Hordley, P. Morovic, "Chromagenic colour constancy," in Proceceing of 10th Congress of the Internat. Colour Assoc., Granada (Spain), May 2005

G. D. Finlayson, S. D. Hordley, P. Morovic, "Chromagenic filter design," in Proceedings of 10th Congress of the Inernat. Colour Assoc., Granada (Spain), May 2005

G. D. Finlayson, P. Morovic, "Human visual system: beyond three sensors," in Proceedings of IEE Internat. Conf. on Visual Image Engineering, Glasgow (Scotland), April 2005