Spectral Characterisation of a Digital Still Camera Through a Single Integrating Exposure.

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Abstract

In order to perform spectral characterization of a digital still camera it is necessary to know the spectral sensitivities of the camera. Methods for determining these sensitivities are generally time consuming and require costly equipment.

This paper describes the basic constructional elements, subsequent calibration and practical use of the device incorporating a trans-illuminated filter array.

The device consists of an array of 36 narrow band dichroic filters in 10nm intervals from 380nm to 730nm, each being illuminated by an individual light emitting diode and the output attenuated by a potentiometer.

The performance of the prototype filter array was evaluated against a polynomial regression technique using a 24 patch GretagMacbeth ColorChecker and was found to produce comparable results.

Introduction

Methods for characterizing digital still cameras (DSCs) include target-based and spectral methods [1]. Spectral characterization can give a good correlation to original scene colorimetry independently of the illuminant, but requires that the spectral sensitivities of the camera are known. This is generally a laboratory task requiring costly equipment and time-consuming measurements. The resulting matrix conversion produces results that are approximations of the linear original RGB colour space.

Different approaches have been taken to ascertain a cameras spectral sensitivity without using a monochromator, with Schmitt and others [2] arriving at 20 Munsell colour chips representing the principal eigenvectors for the basis functions required to spectrally characterise a device. The 20 chips equate to the lowest RMS error from optimised pairings of the spectra from 1269 Munsell chips. Finlayson and others [3] also showed that a DSC's spectral responses could be recovered from a single image of a GretagMacbeth 24 patch ColorChecker by quadratic programming and applying three constraints of being positive, of limited modality and band limited between 400nm and 700nm.

In this instance the aim is to provide a means of spectral characterization which can be used by a photographer without specialist knowledge of characterization techniques or access to laboratory equipment. This requires a simple and robust device with a minimal instruction set. The work outlined in this paper is ongoing and the device can be regarded as a prototype, demonstrating the feasibility of simple, low cost spectral characterization.

Spectral filter array

The considerations in constructing such a device surrounds four main areas of concern, namely, filter type, illuminant and diffusion, calibration and stability in use. Stability has a bearing on the selection of the preceding three, since once the device is finally calibrated its performance must be repeatable over time. The camera under test is a Canon G5 digital compact, chosen for its advanced features, small size and its ability to record RAW files and download them direct to a computer. The camera at all times was set to 50asa and the aperture to f5.6, with the zoom fully extended.

Filters

The aim was to characterize the DSC over the range of 380nm to 730nm at 10nm intervals.

To accomplish this, narrow band dichroic interference filters with centre wavelengths at 10nm intervals and a 10nm passband (full width at half maximum) were selected. The filter size is 12.5mm in diameter including mount, and when mounted in the devices faceplate in the form of a 6 by 6 array the filter aperture is reduced to 10mm in diameter. The 10mm aperture is sufficiently large enough to obtain repeatable RAW camera RGB values, while minimising the size of the source required and the overall dimensions of the device.

To confirm the passband and that no secondary passband within the spectrum of 380nm to 730nm exists, each filter is transilluminated via a diffuser with a Solux tungsten lamp and its spectral transmission measured using a Minolta CS1000A telespectroradiometer. The results are shown in Figure 1, indicating good performance in centre-wavelength transmittance and off-band rejection.

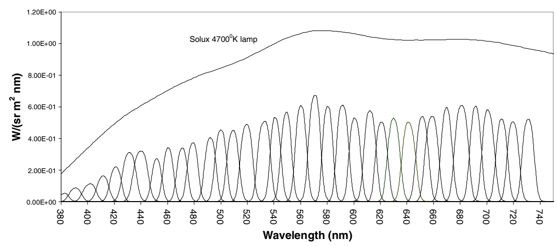

***Figure 1**. Spectral transmission of the 36 narrow band filters used in the array compared to the spectral power distribution of the Solux lamp used for illumination.*

Illuminant

Using dichroic filters requires that the illuminant be on axis and collimated to ensure maximum light transmission. A single lamp per filter is therefore decided upon to ensure on axis illumination, which also allows the luminous flux of each lamp to be discretely attenuated via a potentiometer to set the radiances equal. This is of great importance as the aim is to obtain camera RGB values for each filter simultaneously, using a single exposure.

The use of a high intensity light emitting diode (LED) to discretely illuminate each filter provides a better alternative to incandescent sources, since they are small, robust, and stable in use and have greater power in the blue region. An additional advantage is that through careful selection from commercially available LEDs the spectral power distribution (SPD) of the LED can be specifically tailored to the filter's passband ensuring a high level of efficiency.

White 5mm 1800mcd, 6800mcd and 12000mcd LEDs are therefore chosen to illuminate the filters over the range of 430nm to 730nm. In addition, high intensity violet and ultraviolet 5mm LEDs were selected to illuminate the filter values of 380nm to 420nm. (The relatively low SPD offered by the white LEDs in the region 670nm to 730nm will require LEDs with greater output in this region in order to complete full equal-radiance calibration.) Once selected, each LED, resistor and potentiometer was placed in position on a purpose made printed circuit board which maintains accurate spacing.

Diffusion

A bare LED will cause the diode chip to be imaged by the DSC unless a form of diffusion is introduced between the LED and dichroic filter. The diffuser also ensures even light distribution over the entire filter surface at the expense of some light loss due to the illumination not being collimated. Traditional opal diffusers are of little value as they will not pass the short wavelengths of the visible spectrum required in this application, so a diffuser made from ultra violet transmitting Perspex was used instead.

As all images are captured on axis where the diffuser acts solely to even out the light distribution across the filter surface, the bidirectional reflectance distribution function (BRDF) of the diffuser was not measured. However one aspect of using dichroic filters is that if imaged at an oblique angle, the transmission of the centre wavelength can be shifted to one of a shorter wavelength. If the camera is set close to the filter array to fill the frame by using a short focal length lens, a correspondingly large angle is subtended for the peripheral incident rays and these shifts are maximised, by using a medium telephoto lens, the angle subtended is far smaller, thus minimising the wavelength shift.

To determine the degree to which the captured RGB value varies with the position within the array and to establish the repeatability of data captured off axis at differing angles of the combined filter, diffuser and illuminant, a simple test was performed. The target array is imaged by the camera and lens combination whereby a single filter within the array was chosen and placed at the centre of frame. A series of 9 images at a constant exposure were then taken, the procedure being repeated without altering exposure but with the filter placed diagonally at the frame periphery. The 590nm filter was selected and the $L^*a^*b^*$ values for each series of 9 exposures was averaged, the resulting difference in readings varied by only 1 Δa^* unit.

Final construction

The diffuser and a clear sheet of Perspex are mounted in a solid block with 36 pre drilled chambers coated in titanium oxide to form a discrete mixing chamber for each LED and filter combination. This ensures no cross contamination or spill of light from one LED position to another. Each mixing chamber is akin to that found in a photographic colour enlarger.

The individual elements of the device are now assembled, the mixing chamber being sandwiched between the filter array face plate and the PCB, as shown in Figure 2. The final device is mounted in a housing with 12v DC electrical supply.

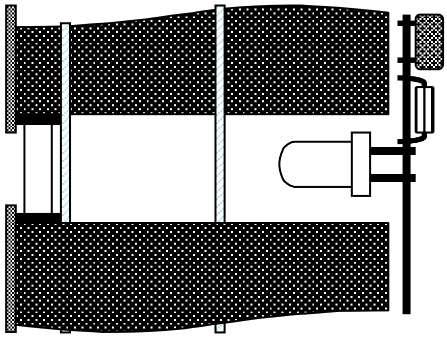

***Figure 2**. Cross sectional view of a single filter position showing from left to right the filter faceplate, filter, diffusers bounding the mixing chamber, LED, PCB, resistor and potentiometer.*

***Figure 3.** View of the assembled components after rear cowling removed with the filter array faceplate at bottom then the mixing chamber and PCB uppermost.*

Calibration

Equal-radiance calibration of the filter array was attained by attenuating the luminous flux of each LED through its potentiometer. The array was bench mounted and levelled, and measurements taken from the face of the illuminated filter with a tripod mounted Minolta CS1000A telespectroradiometer (TSR) with a 50mm macro lens. Care was taken to ensure that the filter array and objective lens of the TSR were as near to parallel as possible by levelling the tripod mounted TSR with the filter ring of the objective lens placed flat and in direct contact with the filter array face plate. The filter array was then moved back against a rest and all measurements are then taken at a distance of 300mm.

Using this procedure, calibration consisted of a series of iterations of measurement and potentiometer adjustment for each LED until the peak outputs from each filter and the LED combination are approximately equal, as shown in Figure 4.

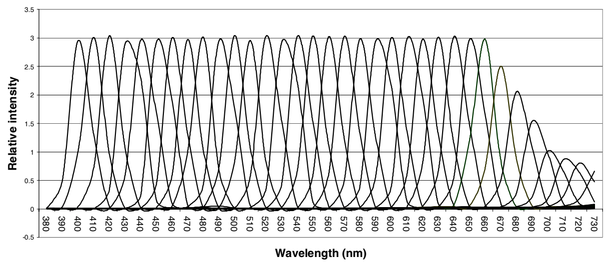

Figure 4. *Final equal-radiance calibration showing lack of luminous flux for the filter values of 380 and 390nm along with decreasing luminous flux from 670nm onwards.*

Camera characterisation using the filter array

The camera's opto-electronic conversion function (OECF) is required to linearise the RAW camera RGB values prior to spectral characterization. The OECF is evaluated in this case by presenting the camera to an even diffused illumination across its entire field of view via an illuminator in accordance with ISO 14524 Alternative focal plane (method B) [4]. A series of 9 exposures were averaged per 1 stop increment covering the camera's dynamic range. The resulting OECF calculated for each of the three channels has a slope of .87 indicating accurate white balance.

To obtain the RAW camera RGB values the filter array was imaged with a digital camera firmly mounted on a tripod and set parallel and on axis to the array, Figure 5. The optimum exposure was arrived at by altering the shutter speed over a series of images while keeping the lens at a mid range aperture to achieve a RAW RGB image file value in the region of, but not exceeding 250 for the peak transmitting wavelength. This allows for the full dynamic range of the camera to be utilised without the saturation of pixel wells leading to bleed and flare.

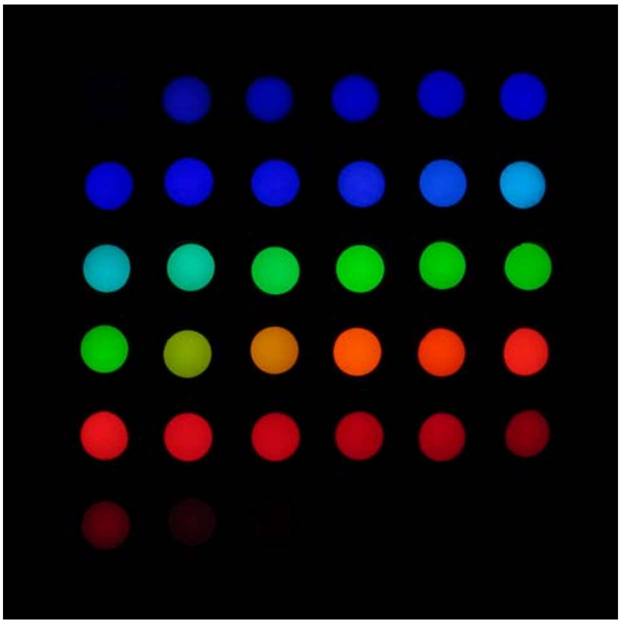

Figure 5. *Filter array as imaged by the camera (cropped).*

To achieve this, a non matrixed RAW image file was obtained through 3rd party software with the image being saved as a 16bit TIFF file. A mild median filter was applied to smooth out any noise in the image and a smaller 40 by 40 pixel area is sampled to gain RAW camera RGB values from the very centre of each filter image. The resulting camera spectral sensitivity is shown in Figure 6.

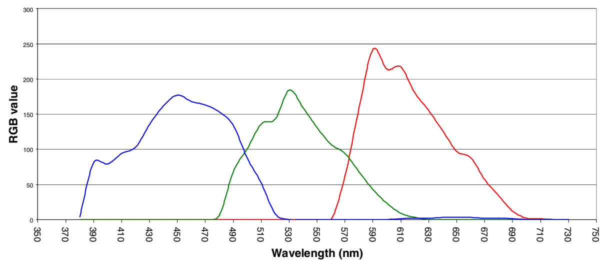

Figure 6. *RAW camera RGB values obtained through a single exposure to the filter array.*

From these sensitivities the linear RAW camera RGB values were calculated by applying the inverse of the cameras OECF and normalising. Interpolation was then applied to produce data at 5nm intervals and the range extended down to 360nm and up to 830nm by taking the nearest measured value and replicating for each missing wavelength.

The camera RGB-to-XYZ transform matrix is then calculated by a non-linear optimization minimizing the sum of the squared ΔE errors between measured and predicted values for the 24 patch GretagMacbeth ColorChecker® target.

For comparison, characterisation was also performed by 1st order polynomial regression using the same 24 patch GretagMacbeth ColorChecker®. The target was imaged by the camera mounted on a copy stand and illuminated by 2 fluorescent D50 simulators. Each patch was presented normal to the optical axis of the camera in a completely dark room, and a RAW image file captured. The RGB values were extracted from the central portion of each image for conversion to linear RAW camera RGB values and characterization as described above.

Results & Discussion

The mean ΔE of 2.85 for the filter array is reasonable when compared to the mean ΔE of 2.8 for polynomial regression, likewise the maximum ΔE of 7.79 for red compared to the maximum polynomial regression ΔE of 4.37 for yellow is also acceptable when the lack of specific high intensity LED's to illuminate the filters in this region of the spectrum is taken in to account.

The cameras RGB response produced blue and green channel responses significantly lower than the red channel response with errors in the curves at 390nm, 520nm and 600nm, these may well be indicative of inaccurate calibration.

The transform matrix predicted co-ordinates which show a shift in hue to yellow, orange or red with the neutral patches shifting predominantly towards yellow, Figure 7.

The correlation of predicted L^* values to measured L^* is very good, patches 2, 7, 8, and 13 differ by up to ±1.52 L^* units from the aim values, whereas patches 9, 15 and 16 which are moderate red, red and magenta produce the highest differences to the measured values of -2.89, -4.84 and -3.08 respectively. The remaining patches differ by less than ±1 unit of L^* in comparison to the measured values with the highest being patch 2, dark skin at -0.77.

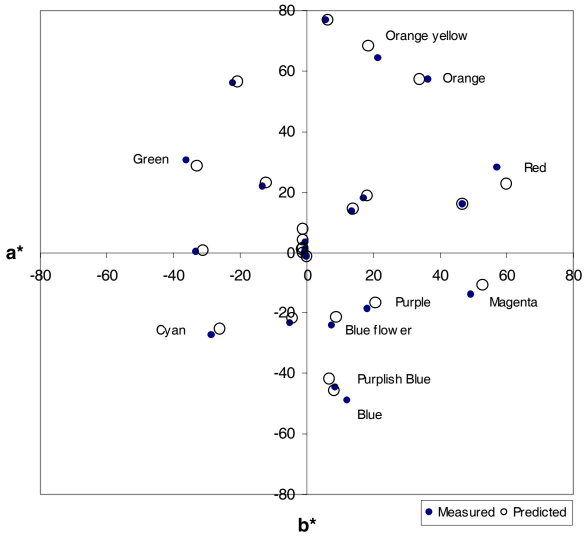

Figure 7. *Measured and predicted a*b* co-ordinates*

The errors correspond to colour patches with a high compliment of yellow, orange and red. The errors seen in the purple, purplish-blue, blue and green patches may also arise from the amounts of orange and red in the spectral reflectances of these patches from 650nm onwards.

Overall these errors point to the problem of incomplete equal-radiance calibration above 670nm. Despite this, the results of the filter array compare very favourably to other work such as Pointer and others [5] who report their best result for polynomial regression as a median ΔE of 1.9 and maximum ΔE of 6.1.

Conclusions

The performance of the array at this initial prototype stage is very encouraging. From the results so far obtained along with practical observations it can be seen that there are several limiting factors affecting performance. These encompass the necessity to incorporate specific LED's for the wavelengths of 670nm onwards to allow for full equal-radiance calibration of the array, a better integrated form of diffusion and a precise means of calibration.

These are easily remedied and current work is focussing on increasing the accuracy of the array in its reproduction of camera spectral sensitivities relative to those obtained using a monochromator.

The next version of the device will also incorporate filter wavelengths from 360nm up to 830nm. Whilst in the vast majority of cases this will have little effect on final characterisation results, a characterisation of higher accuracy should result for digital cameras without an infra red barrier filter incorporated within their design, such as the Leica M8.

Comparing the results of the array to those obtained through the polynomial regression technique of characterisation, the array has performed extremely well. The results indicate that a device allowing single-shot spectral characterisation of a DSC is indeed possible, and work to further refine the device is being undertaken.

Acknowledgements

The authors gratefully acknowledge Eric Walowit's helpful suggestions on the project and his assistance in the calculation and optimisation of the transfer matrix.

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