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Colour temperature based colour correction for plant discrimination

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Abstract

One of the problems with machine vision based outdoor discrimination of weeds plants from crops is the varying daylight. Colours appear different when daylight conditions change. Green measured on a cloudy day is not observed as the same value green when measured on a very sunny day. One solution can be using a cover and artificial light but that is not always a desired or possible solution.

The colours observed by the camera are the result of light that is reflected by plants and depends not only on the green colour of the plant but also on the composition of the incident light. A measure for the composition of the incident light is the colour temperature and an approximation for the colour temperature is the Correlated Colour Temperature (CCT).

The objective of the research was to develop a procedure that results in that a colour in real life is projected on the same colour in an image processing system, regardless the colour (i.e. colour temperature) of the incident light. The focus was on the colour green, dominant for discrimination of weed and crop plants.

A camera was mounted perpendicular towards the ground and was observing several coloured surfaces including a ColorChecker® and green grass during several hours of a day with daylight conditions varying from a cloudy to a very sunny sky.

The reference consisted of a ColorChecker® card which was illuminated with daylight lamps with a colour temperature of 6500 K. and was used to develop a correction model that corrects the values of Red, Green and Blue based on the CCT.

The developed procedure has two steps. In the first step the colour values are normalised by dividing each R, G and B component by the average of R, G and B. In the second step the model correction is applied.

The results showed a considerable improvement of the constancy of the colours. The coefficient of variation was reduced from more than 6.5% to less than 1.0% for the ColorChecker® measurements and from more than 4.4% to less than about 1.0% for measurements on grass.

Keywords: colour constancy, machine vision, colour temperature, plant discrimination

1 Introduction

In modern weed control machine vision is an important tool to discriminate weed plants from the crop. However, this discrimination process is not as easy as it might appear on first sight. In most cases we have to deal with making a distinction between plants that are both green but differ in the green tint. An important disturbing factor is that the reflected colour observed by the camera not only depends on the colour of the object itself but also on the colour of the

environmental light that lightens the object. The consequence is that the colours of an object are not constant, making discrimination very difficult in especially daylight conditions. A measure for the composition of the incident light is the colour temperature. The colour temperature of the sun (an ideal black body radiator) is 5780 K and varies due to scattering of the light in the atmosphere. An approximation for the colour temperature is the Correlated Colour Temperature (CCT), which can be calculated from the spectrum.

Nieuwenhuizen *et al.* (2010) worked on the control of volunteer potatoes in sugar beet. In the first experiments they worked under normal daylight conditions and used only an intensity correction based on the average intensity of the image. The discrimination results were rather poor due to the continuous change in lighting conditions. For consecutive experiments they used a cover with artificial lighting which resulted in a large improvement of the discrimination results.

Marchant *et al.* (2004) studied the discrimination between soil and vegetation, independent of the illumination. Their method is not suitable for discrimination between different colours because their method is based on using an achromatic image derived from the three colour bands. In this process most of the colour information is lost.

Using artificial lighting might in some cases be a solution for dealing with varying daylight conditions. Artificial lighting requires in most cases a hood which makes working widths larger than about 2.5 m difficult to achieve. For applications with a small robot the required power for lighting will usually not be available or will reduce the operation time considerably.

At this moment the specific threshold values and other parameters of a decision system depend on the actual lighting situation resulting in poor discrimination results.

Using artificial light is not an option for operations with a large working width and applications using a small robot. For these conditions it is desired to have a robust discrimination algorithm that is independent of the continuously changing daylight conditions. The first step to achieve this is to make the values of the colours received by an image sensor independent of the colour of the incident light.

The main problem is that a procedure that can adjust colour values such that they are independent of the colour incident light and to be used for plant discrimination does not exist.

The objective of the research was to develop a procedure that results in constant values for colours independent from the colour of the incident light.

2 Materials and methods

2.1 Measurement setup

The measurement setup (Figure 1 and Figure 2) consisted of a camera to take images and a spectrometer with an irradiance probe to measure the daylight spectrum. The camera was a Marlin F-145C2 (Allied Vision Technologies, Stadroda, Germany) with a Pentax C60607

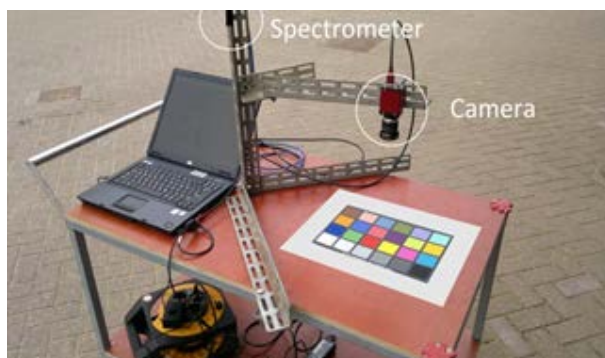


Figure 1 – Measurement setup for measuring the ColorChecker with daylight conditions (Source: Jager, M.J. de (2013)).



Figure 2 – Measurement setup for measuring a grass spot. (Source: Jager, M.J. de (2013))

6 mm lens (Pentax, Tokyo, Japan). The spectrometer was a Qwave spectrometer (RGB Lasersysteme GmbH, Kelheim, Germany). The spectrometer had a focal length of 75 mm and measures in the visible spectrum between 350 nm and 880 nm with a resolution of 0.5 nm. The irradiance probe consisted of a CC-3 cosine corrector (OceanOptics, Dunedin FL, USA)

with an opaline glass diffusor and a field of view of 180° and an optical fibre to connect it to the spectrometer.

Images were taken of a X-rite ColorChecker® colour rendition card (X-Rite, Grand Rapids MI, USA) reference card (Figure 1) and a natural grass surface (Figure 2). This ColorChecker® card contains 24 natural object, chromatic, primary, and grey scale colours.

2.2 Camera colour calibration

The camera has an adjustable white balance. This white balance was calibrated with the ColorChecker card and Megaman MM33215daylight lamps (6500 K) (Neonlite Electronic & Lighting (HK) Ltd., Hong Kong, China) in a closed image acquisition box. The white balance settings of the camera were such that the error between the measured colour values and the real colour values provided by the manufacturer of the card were minimised. The average errors over the 24 colours were -1.1% for red, 1.7% for green and -0.6% for blue.

2.3 Calculation of CCT

The Correlated Colour Temperature (CCT) was derived from the measured spectrum in the range 380 to 780 nm, in correspondence to a procedure described by (Hernández-Andrés, 1999). The sub range was used to be in line with the standard CIE observer functions.

The first step was the calculation of the CIE Tristimulus values XYZ values according to:

$$X = \int_{\lambda} \bar{x}(\lambda)P(\lambda)d\lambda ; Y = \int_{\lambda} \bar{y}(\lambda)P(\lambda)d\lambda ; Z = \int_{\lambda} \bar{z}(\lambda)P(\lambda)d\lambda \quad (1)$$

In these equations $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$ are the CIE standard observer functions and $P(\lambda)$ the measured spectrum. The standard observer functions are based on the CIE two degree observer values (Smith and Guild, 1931). Normalised values for X and Y were calculated by dividing the individual values with the sum of them and the normalised values for Z followed from that the sum of x , y , and z is equal to 1:

$$x = \frac{X}{X+Y+Z} ; y = \frac{Y}{X+Y+Z} ; z = 1 - x - y \quad (2)$$

The CCT was calculated with:

$$CCT = A_0 + A_1 \cdot \exp\left(-\frac{n}{t_1}\right) + A_2 \cdot \exp\left(-\frac{n}{t_2}\right) + A_3 \exp\left(-\frac{n}{t_3}\right) \quad (3)$$

where n is equal to:

$$n = (x - x_e)/(y - y_e) \quad (4)$$

Values for the different coefficients in Eqn (3) are specified in Table 1.

Table 1 - Overview of coefficients for the calculation of the CCT from the measured spectrum based on the CIE 1931 two degree observer functions .(Source: Hernández-Andrés, 1999)

Coefficient	Value	Coefficient	Value
A_0	-949.86315	x_e	0.3366
A_1	6253.80338	y_e	0.1735
A_2	28.70599	t_1	0.92159
A_3	0.00004	t_2	0.20039
		t_3	0.07125

2.4 ColorChecker® measurements

Images of the colour checker card were taken outside on five days in March 2013. 76 Images from all measurements, distributed over all days, were randomly selected and used for further model development and analysis. To remove intensity information and keep only the colour values, the measured RGB values were normalised by:

$$r = \frac{R}{R+G+B}, g = \frac{G}{R+G+B}, b = \frac{B}{R+G+B} \quad (5)$$

Linear regression was used to determine a relation between the CCT and different colours of the colour checker. For each square and for each colour band, the following relation was determined:

$$color_{r,g,b} = a \cdot CCT + c \quad (6)$$

And resulted in the following individual model for the colour correction of each surface of the ColorChecker® card:

$$color_{r,g,b \text{ corrected}} = color_{r,g,b} - a \cdot (CCT - 3700) \quad (7)$$

In the research 3700 K was chosen as a zero level for the colour correction.

2.5 Grass measurements

Measurements on grass were done on four different days in March and April 2013. These consisted of only one sample area and the whole image was used. Measurements were done with time intervals of 10 s and 20 s. Conditions of the measurements are presented in Table 2.

Table 2 - Overview of characteristics of the measurements performed on grass on four different days.

Measuring characteristic	Measuring day			
	14-Mar-13	27-Mar-13	16-Apr-13	17-Apr-13
Start time	14:15	16:50	13:50	13:57
Number of images	232	75	329	266
Time interval (s)	10	20	10	10
Min CCT (K)	3788	3853	3762	3780
Max CCT (K)	4444	3950	3945	3950
Weather	Sunny with clouds in between	Sunny at sunset	Cloudy with a bit sun	Cloudy with a bit sun

The measurements on grass were analysed in a similar way as the ColorChecker® measurements. For each day an individual model was developed and the best of these four models was applied to the data of the other three days to test whether the model was generic or not.

3 Results

3.1 Individual correction ColorChecker®

Figure 3 shows the values of the Correlated Colour Temperature of the 76 selected images made in March 2013. The figure shows a variation in CCT between about 3700 K and 4350 K. The values for Red, Green and Blue of square 19 (white) of the ColorChecker Card are shown in Figure 4. The figure shows for the same colour white a wide variation in the corresponding values for Red, Green and Blue. The corresponding coefficients of variation are shown in Table 3. There is some relation visible between the variation in CCT and the corresponding values for Red, Green and Blue. Figure 5 shows the normalised values. It can be seen that the values for Green become more constant after normalisation. The values for Red and Blue show much more variation after normalisation. From this figure it becomes clear that the normalised value for Blue has a positive correlation with the CCT and the normalised value for Red a negative correlation. After applying the individual correction model for square 19 (White), the values for Red, Green, and Blue are almost constant. The corresponding values for the CV are less or equal to 1.0.

The values for a were also averaged over all 24 surfaces for each of the three colour bands and this resulted in a more general colour correction model for each of the three colour bands:

$$r_{corrected} = r_{normalised} + 9.60 \cdot 10^{-5} \cdot (CCT - 3700) \quad (8)$$

$$g_{corrected} = g_{normalised} - 0.77 \cdot 10^{-5} \cdot (CCT - 3700) \quad (9)$$

$$b_{corrected} = b_{normalised} - 8.83 \cdot 10^{-5} \cdot (CCT - 3700) \quad (10)$$

For each of the squares the Coefficient of Variation (CV) was determined over the time series of images. The last column of Table 3 shows the resulting values for the CV. In the most ideal case the CV is equal to zero after application of the correction. In that case the colour is constant under varying lighting conditions. Other squares show for the general correction a slightly larger CV compared to the individual correction; results are not shown.

Table 3 - Original, normalised, and corrected (individual and general) values for Red, Green and Blue of square 19 (white) of ColorChecker® Card.

	Original RGB values		Normalised RGB values		Corrected RGB values (indiv. correction)		Corrected RGB values (gen. corr.)
	Mean	CV	Mean	CV	Mean	CV	CV
Red	171	7.3	0.38	4.6	0.41	0.9	0.9
Green	138	6.5	0.31	0.5	0.31	0.4	0.4
Blue	139	9.2	0.31	5.2	0.28	1.0	1.0

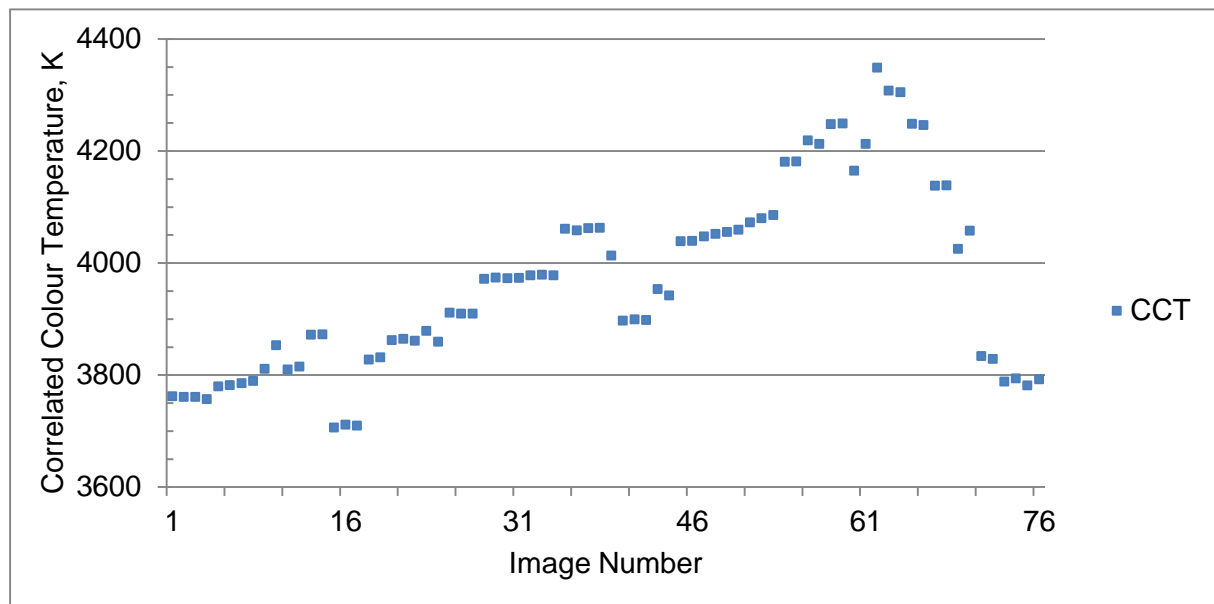


Figure 3 – Values of the Correlated Colour Temperature corresponding with the 76 randomly selected images in Figure 4 and Figure 5. The sequence of the images is random.

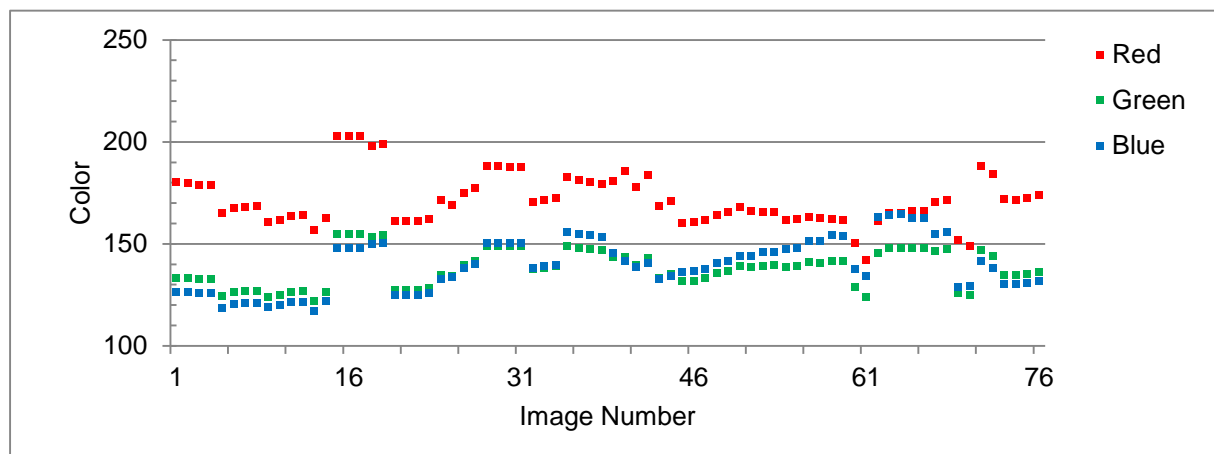


Figure 4 – Values of Red, Green and Blue of a random selection of 76 images of square 19 (white) of a ColorChecker Card on different days.

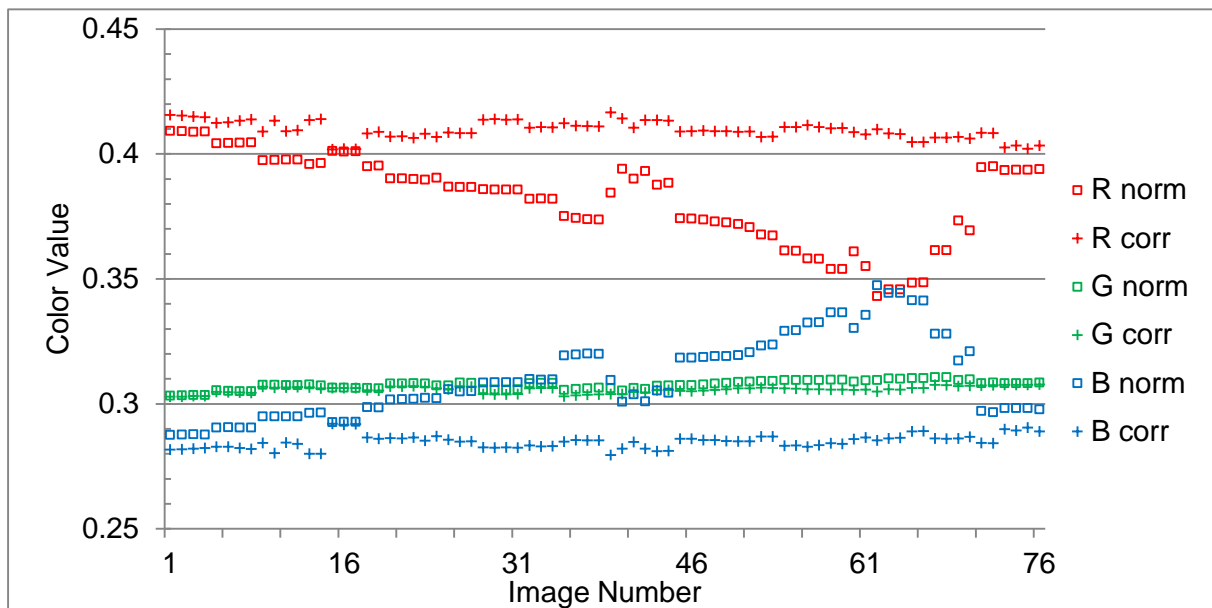


Figure 5 – Normalised values and values after correction with the model of a random selection of 76 images of square 19 (white) of the ColorChecker® Card on different days.

3.2 Grass correction

The values for the CCT measured on March 14, 2013 during about 2200 s are shown in Figure 6. The values vary between about 3800 K and 4450 K. There are some rather steep changes in CCT during this time span. The corresponding values for Red, Green and Blue of a grass spot are shown in Figure 7. The figure shows that the change in values for Red, Green and Blue corresponds with the change in values of the CCT. The corresponding values of the normalised colours are shown in Figure 8.

For grass models were developed for each of the four days measurements were done. The data of March 14 showed the largest variation and the model for this day performed the best and is described by the following set of equations:

$$r_{corrected} = r_{normalised} + 8.60 \cdot 10^{-5} \cdot (CCT - 3700) \quad (11)$$

$$g_{corrected} = g_{normalised} - 1.86 \cdot 10^{-5} \cdot (CCT - 3700) \quad (12)$$

$$b_{corrected} = b_{normalised} - 6.74 \cdot 10^{-5} \cdot (CCT - 3700) \quad (13)$$

The result of applying this model to the data is shown in Figure 8. The same model was applied to the data of the measurements of the other three dates too. The results are presented in Table 4 together with the CV's for the correction with the model developed for that specific day.

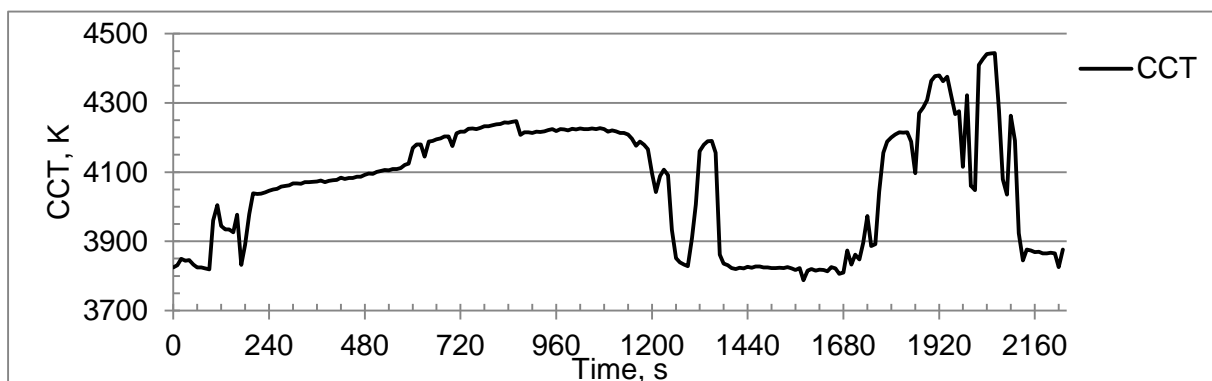


Figure 6 - Value of the CCT for the measurements of March 14, 2013 during about 2200 s with an interval of 10 s.

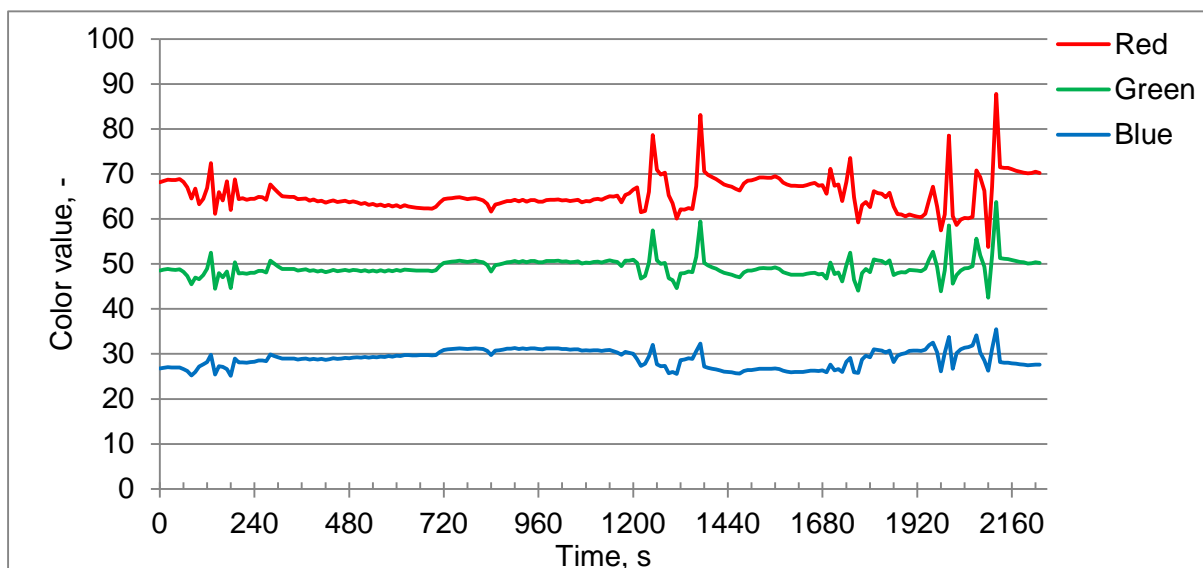


Figure 7 - Values for Red, Green and Blue measured on March 14, 2013 during about 2200 s with an interval of 10 s.

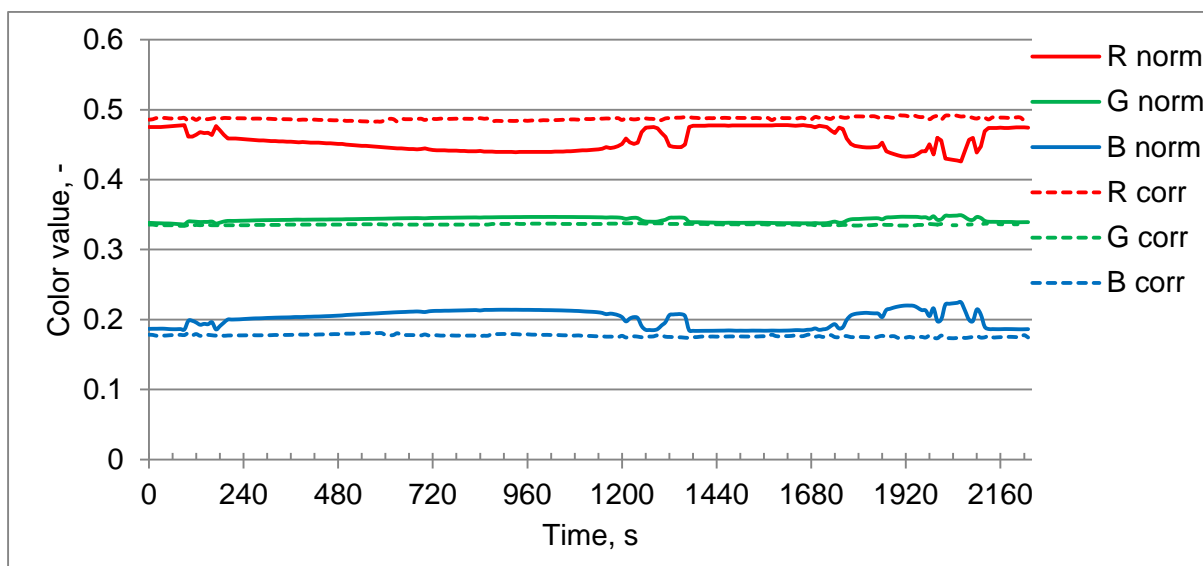


Figure 8 - Values for normalised Red, Green and Blue measured on March 14, 2013 and the model corrected values for Red, Green and Blue during about 2200 s with an interval of 10 s.

Table 4 – Values for the CV of a grass spot measured on four different days in 2013. For March 14 the values for Red, Green and Blue without correction, after normalisation and after model correction are shown. For the other days the CV's are given for the uncorrected situation, the day specific model correction, and the correction with the model developed for March 14.

Date	Correction method	Red	Green	Blue
14-03-13	Uncorrected	5.8	4.4	6.8
	Normalised	3.3	1.0	5.9
	Model corrected	0.40	0.24	0.97
27-03-13	Original	0.1	0.0	0.1
	Optimal model 27-03	0.05	0.03	0.09
	Model 14-03	0.37	0.13	0.87
16-04-13	Original	0.5	0.4	0.3
	Optimal model 16-04	0.25	0.26	0.41
	Model 14-03	0.27	0.28	0.64
17-04-13	Original	0.4	0.3	0.6
	Optimal model 17-04	0.22	0.16	0.36
	Model 14-03	0.26	0.17	0.62

4 Discussion

The results presented before show that the intensity plays an important role in colour variation. Normalisation corrects for intensity effects and CV's are smaller after normalisation. For the ColorChecker measurements the best results are obtained when for each colour on the card an individual model is developed. However, the results do not deteriorate when a correction model based on all 24 squares is used. Having one model for all colour situations is from a practical point of view preferred. For measurements of green vegetation it can be desirable to develop a model based on a set of standardised green surfaces instead of a whole range of colours. This is not investigated yet.

A problem with the grass measurements was that on several measuring days there was not much variation in colour of the incident light. This resulted in small variations of the Red, Green and Blue values and as result also a small effect of applying a correction model. In practice a general model is desired. A general model however, will in most situations be at the cost of less performance. The results showed that a general model performs less than a day specific model but the CV's are still smaller than the CV's of the uncorrected measurements were.

5 Conclusions

The research shows that the colours can be made almost independent of the colour of the incident light when the CCT is used to correct the colours. For a pure white square the CV's were reduced for Red, Green and Blue from respectively 7.3, 6.5, and 9.2 to 0.9, 0.4, and 1.0. For a green grass spot the CV's for Red, Green and Blue were reduced from respectively 5.8, 4.4, and 6.8 to 0.40, 0.24, and 0.97 for the day with the largest variation in values of the CCT. Other days showed less or no improvement due to almost no variation in CCT and consequently the resulting values for Red, Green and Blue and the correction of the model.

6 Acknowledgement

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7 References

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