RADIOMETRIC NORMALISATION AND COLOUR COMPOSITE GENERATION OF THE DMC

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ABSTRACT

This paper describes the aspects of data processing from the raw image to the colour composite of the Digital Modular Camera (DMC) of Z/I Imaging. Since photogrammetric applications demand high precision inside the images, a radiometric normalisation has to be done with the raw image data.

To normalise CCD line-arrays look up tables are stored during the calibration procedure. Looking at CCD matrix-arrays with high resolution and to a principle used in DMC with a couple of CCD matrix-arrays, the necessary storage for look up tables increases dramatically.

Therefore one has to determine functional coherence between the radiometric behaviour of the CCD and the influencing factors. This paper describes which influences are expected and how to store the resulting parameters and look up tables (LUT).

The images taken by the 4 panchromatic cameras have to be transformed into a single mosaiced image. This mosaic covers the same area on the ground as the multi-spectral cameras do, but the resolution is four times higher.

Our aim was to generate a colour image with the geometrical accuracy of the mosaic image, i.e. a colour composite. Therefore we fused the colour information of the 3 multi-spectral images with the luminance data of the mosaic. The main task is to separate the luminance from the colour information so that it is possible to replace it. This paper describes the used workflow, the investigations about several colour space transformations and their results to select the best practice.

1 INTRODUCTION

The Digital Modular Camera (DMC) is the new digital aerial camera system of Z/I Imaging. With this system the last lack of the digital chain in aerial photogrammetry is closed. The key issue of the whole photogrammetric workflow is the geometric image accuracy, which is mostly defined by the camera sensor itself. In order to fulfil the high requirements of mapping applications, Z/I Imaging has decided to base the new DMC on a CCD-matrix sensor, because of its stable geometry.

According to its modular design, more than one individual camera module can be tied together, resulting in a large field of view of the camera. The full equipped configuration of the DMC is composed of four panchromatic modules and up to four multi-spectral channels. The four panchromatic modules have their optical axes looking downwards in a slightly divergent set up to reach a large ground coverage. A post-processing procedure (“mosaicing”) serves to transform the four individual images into one virtual image which can be considered as normal central projection. The multi-spectral modules are arranged along the flight direction and acquire nadir looking views. The colour imagery has the same ground coverage as the panchromatic one but only the sixteenth part of the number of pixels [Hinz2000]. This leads to a footprint as shown in figure 1.

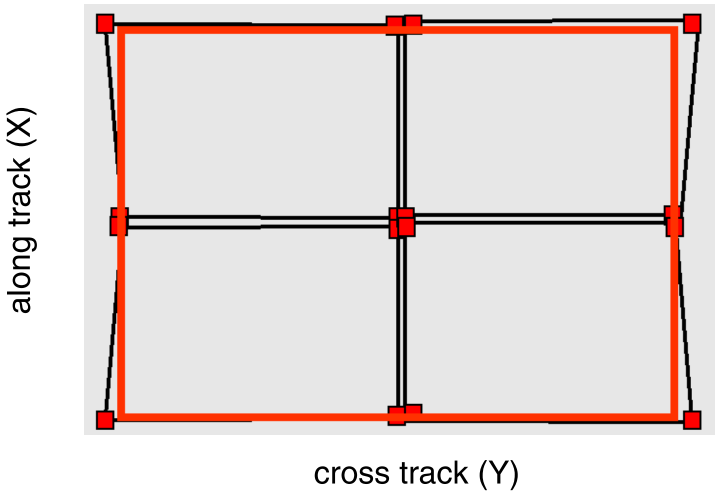

Figure 1. Sensor footprint on ground.

black quadrangles: panchromatic, grey rectangle: multispectral

2 RADIOMETRIC NORMALISATION OF THE DMC

Even though Charge-Coupled Devices (CCD) have a sensitivity which is quite equably for the whole area of the CCD plane there is still the need of a radiometric normalisation. The reason for this stems from the accuracy requirement for photogrammetric applications. Since local changes in radiometry can take effect on the result of an automatic measurement one has to correct the differences of the sensitivity of single pixels inside a CCD.

But the differences of the resulting gray values do not only stem from the different sensitivities of single pixels. They also result from other influences like lenses and aperture. And there are more forces left. The DMC has the ability to compensate the forward motion during an exposure and therefore we have to correct the influences of this TDI (time delayed integration). Another well known influence on the resulting values of CCD images is the dark current. The longer the image data stays on the CCD the more this value increases. Thus one has to use the shortest read out time as possible and one has to correct the influence of this time on the data.

2.1 Classical Normalisation Approach

Many studies on CCD behaviour have shown that the voltage output of a CCD increases linear with the integration time [Theuwissen95]. Therefore one can use a linear approach to correct the influences shown above.

The classical way to compute the coefficients of the linear model is to take the so called dark and bright image. The dark image is taken to get the dark current of each pixel of the CCD. Without exposure of the CCD the whole CCD values are read out and stored in an image. One expects a totally dark image with zeros. Since a CCD has the dark current we get a dark image but the values inside are not really zero but close to. And the values between the pixels vary too. The bright image is the second image which is used for the normalisation. For this image one needs a homogenous source light. That means the light at each pixel of the CCD has the same brightness. This is done by using an Ulbricht sphere. With these two images one can now compute the linear coefficients (gain and offset) of each pixel using the following equation:

$$gain_{rc} = \frac{res}{bright_{rc} - dark_{rc}}$$

$$offset_{rc} = \frac{res * dark_{rc}}{bright_{rc} - dark_{rc}} \qquad (2.1)$$

with

res	: range of gray values
$bright_{rc}$	: gray value of bright image at position *rc* (row, column)
$dark_{rc}$	: gray value of dark image at position *rc*
$gray_{rc_{original}}$	: gray value at position *rc* of the original image data, which has to be corrected
$gray_{rc_{corrected}}$	: gray value at position *rc* of the corrected image data

Applying the respective gain and offset to each pixel leads to the corrected gray value:

$$gray_{rc_{corrected}} = gain_{rc} * gray_{rc_{original}} - offset_{rc} \tag{2.2}$$

With one set of gain and offset values there is the possibility to correct images of one state of the system. This means if one of the above mentioned influences changes the set of gain and offset values changes too. Therefore one has to store a set of gain and offset values for each state of the system. This means for every temperature step (e.g. in steps of 5 degrees from –20°C to + 20°C), each used aperture (e.g. 4, 5.6, 8, 11) and each used TDI (e.g. 0 to 7) and especially each combination of these states one has to store the gain and offset values.

Using a simple method to store one look up table (LUT) for gain and offset respectively we get the following needed storage capacity assuming that gain and offset are stored with 2 bytes. Using e.g. a CCD array with 4k by 4k pixels the following space would be needed:

4096 * 4096 * (2 Bytes) * 9 * 5 * 8 = 11.25 GByte

One can easily see that using the classical LUT method the needed storage for the normalisation data explodes. Thus we need an alternative method.

2.2 DMC Normalisation Approach

Since the DMC camera has not only one CCD array this topic becomes more critical. With increasing number of cameras the amount of normalisation data increases too. Each CCD has an own behaviour with regard to the sensitivity of each pixel. Using LUTs there is no way to store the influences.

Thus we develop another strategy for the radiometric normalisation. The main purpose of this strategy is to use only one LUT for each camera. That way one can inhibit the strong increase of the needed storage. But this results in a new problem. We work out the coherence between the changes of the CCD values and the current examined influence. At the end we get a function which delivers the correct gain and offset value for a given input state. For each of the shown influences one function is computed.

Instead of examining the gain and offset values it is also possible to look at the changes of the dark and bright image. There is no difference in the needed amount of storage if the gain and offset values are stored instead of the dark and bright image. From the latter one can compute gain and offset. The reason for this is situated in the fact that more easily a functional model can be found if the modifications in the light or dark image are taken.

Then if these functions are determined, one has simply to transform the original gray value at certain position in the dark and bright image with these functions sequentially to get the correct gray values of dark and bright image. With these transformed dark and bright image one can compute the gain and offset of the current state. With equation 2.2 the correct gray value of a given image can be computed afterwards.

3 COLOUR COMPOSITE GENERATION

3.1 Workflow

The generation of the colour composite can be divided into five steps as shown in figure 2. At first the offsets of the multi-spectral cameras have to be corrected. These offsets were estimated during the calibration of the DMC and result in parameters for affine transformations. Furthermore the individual multi-spectral channels have to match the mosaic image, so another affine transformation is necessary. The post-processing software will combine the parameters of both transformations to perform only one affine transformation (and interpolation).

After the orientation of all separate colour channels to the mosaic image a single RGB image can be created. The low resolution RGB image and the high resolution mosaic image are covering the same area on the ground.

To prepare the colour image for the pixel-wise colour space transformation the image has to be scaled up to the size of the mosaic image. We investigated the bilinear and bicubic interpolation methods.

To make an objective comparison we scaled down an image (to 1/4 of width and height), scale up the intermediate image to the original size and calculated the difference between the start image and the down-up-scaled image. This was done with a couple of images. We compared the resulting unbiased RMSE and the required time for scaling up for both bilinear and bicubic interpolation.

The RMSE of the bicubic interpolated images is 2-4% less, but the algorithm is 15-30% slower than the bilinear interpolation. Remembering the significant better visual results for a few sample images the smaller RMSE becomes more important than the 2-4% ratio implies. We will use the bicubic and bilinear interpolation method for a high quality image processing (i.e. for scaling and affine transformations).

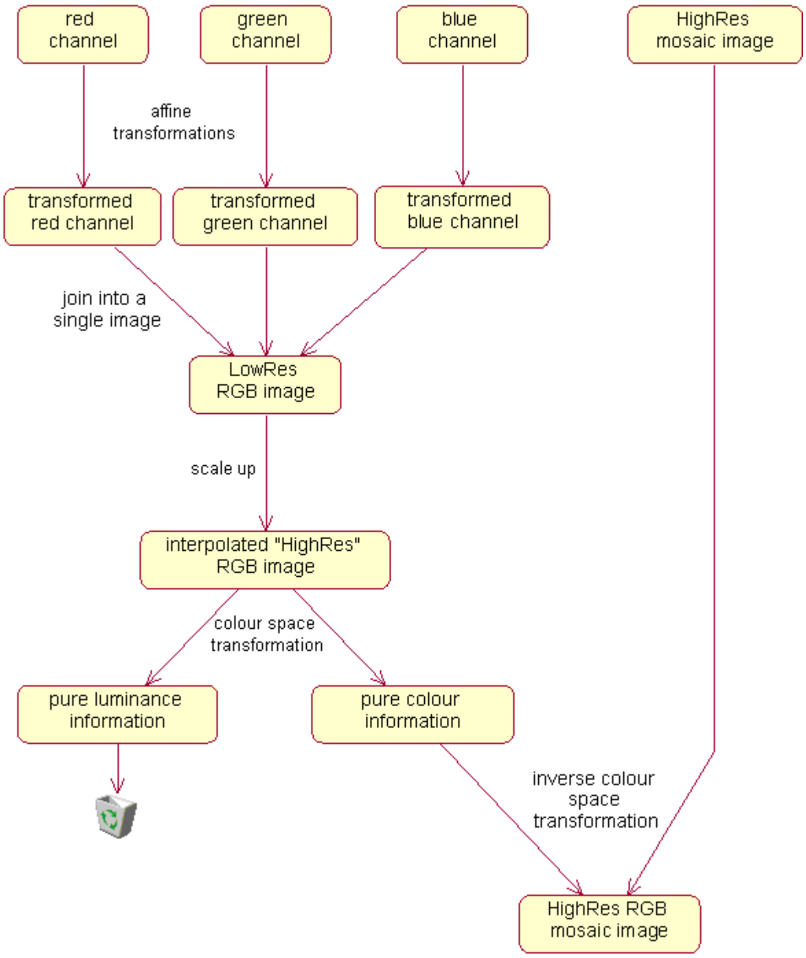

Figure 2. Principal workflow of the colour composite generation.

After scaling up the RGB image to the size of the mosaic image one has to separate the luminance and the pure colour information. This is done by transforming the image from the RGB colour space into another suitable colour space as described in the following section.

Now the fusion can be performed: The extracted luminance from the interpolated RGB image has to be replaced by the mosaic image. To complete the workflow the inverse colour space transformation is necessary. The resulting image is the desired high resolution RGB mosaic image, which is ready for further processing steps.

3.2 Comparison of colour space transformations

We compared the following colour spaces and their belonging transformations from and to RGB:

a) CIE XYZ (linear transformation, [Fairchild98])

b) CIE Lab (non-linear, [Fairchild98])

c) CIE Luv (non-linear, [Fairchild98])

d) $I_1I_2I_3$ (linear, [Kao97])

e) HSI (non-linear, [Kender76])

f) YC_bC_r (linear, [Bourgin95])

We produced a couple of colour composites for test purposes. From a high resolution colour image we created a low resolution colour image (1/4 of width and height) and a high resolution panchromatic image to meet the requirements of the colour composite generation as described in section 3.1. We used the original image as a loss less reference for later comparisons.

At first human observers took a look at the computed composite images. The results from the CIE XYZ transformation were a disappointment, because especially the green channel of the composites showed a big difference to the original image. This is only a consequence of the back transformation from CIE XYZ to RGB:

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 1{,}9104 & -0{,}5338 & -0{,}2891 \\ -0{,}9844 & 1{,}9985 & -0{,}0279 \\ 0{,}0585 & -0{,}1187 & 0{,}9017 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \tag{3.1}$$

with X and Z as the colour valences and Y as the exchanged luminance.

One can see that a change in Y is always doubled in the green channel of the composite. So this colour space transformation is not stable for variations in the high resolution panchromatic image.

With this fact in mind it is surprising that the derived colour spaces CIE Lab and CIE Luv produce much less visible adulterations. This is caused by the additional non-linear transformation steps. CIE Lab and CIE Luv are quite stable and the resulting composites show a very good quality.

The three other colour space transformations are stable too, but especially HSI showed noticeable differences in some cases. All computed colour composites were viewed by several observers but an objective comparison is needed.

For a mathematical approach we computed the difference images between the composites and the original images. Then we calculated the RMSE for each colour channel from the difference images. As expected the RMSE produced by CIE XYZ was very high compared to the other transformations and CIE Lab and CIE Luv are very close to each other. Figure 3 shows the computed RMSE's relative to CIE Lab for all investigated colour space transformations.

channel	CIE XYZ	CIE Luv	CIE Lab	$I_1I_2I_3$	HSI	YC_bC_r
red	5.541	1.027	1.000	1.153	1.148	1.074
green	7.058	1.004	1.000	1.382	1.446	1.040
blue	2.939	1.062	1.000	1.188	1.124	1.119

Figure 3. Mean above all sample images of the RMSE of the differences

between original images and computed colour composites. All values are relative to CIE Lab.

One might choose CIE Lab as the favourite transformation because it causes the smallest errors and the composite images look very well. But another important item is the achievable matching accuracy.

The matching on colour images does not use all colour channels. Most applications pick a single channel, preferable the green one. We applied an affine transformation to the extracted green channel of the original images. The least squares matching algorithm had to match these images against the green channel from all the colour composites. The resulting affine transformation parameters were used to do the inverse transformation of the modified green channel of the original images. To compare the quality the difference between the back-transformed results and the original images were computed and afterwards the RMSE. The RMSE relative to the mean occurred error is shown is figure 4.

image	CIE XYZ	CIE Luv	CIE Lab	$I_1I_2I_3$	HSI	YC_bC_r
1	1.436	0.950	0.965	0.850	0.822	0.978
2	1.076	0.982	0.984	0.960	0.968	1.031
3	1.124	0.890	0.997	1.017	0.984	0.987
4	1.026	0.936	0.893	1.127	1.106	0.912
5	1.107	0.971	1.024	0.965	0.976	0.957
6	1.302	0.939	0.952	0.856	1.015	0.937
7	1.274	0.961	0.954	0.951	0.917	0.943
8	0.797	1.030	1.029	1.056	1.036	1.052
9	0.816	0.944	0.942	1.178	0.964	1.155
mean	1.106	0.956	0.971	0.996	0.976	0.995
RMSE	0.213	0.038	0.043	0.112	0.079	0.075

Figure 4. RMSE of the grey values representing the matching accuracy relative to the mean occurred errors.

It seams that CIE Luv provides the best matching accuracy due to the smallest mean RMSE (0.956) and the smallest divergence from that value (0.038). Second best is CIE Lab. $I_1I_2I_3$, HSI and YC_bC_r are in the midfield, but CIE XYZ is the most inaccurate method.

The performance of the colour space transformations is very important for daily work. Figure 5 shows the mean computation times for an 1024x1024 pixels composite in seconds relative to CIE XYZ.

	CIE XYZ	CIE Luv	CIE Lab	$I_1I_2I_3$	HSI	YC_bC_r
rel. to CIE XYZ	1.000	1.439	1.992	0.999	1.298	1.001

Figure 5. Computation time relative to CIE XYZ for a complete 1024x1024 pixels colour composite

from a 256x256 pixels colour image and a 1024x1024 pixels panchromatic image.

As expected the three linear colour space transformations are the fastest. HSI is almost 30% slower, CIE Luv 44% and CIE Lab consumes the double time of CIE XYZ. All transformations are implemented using floating-point operations, so it is surely possible to speed up the current computation time.

4 CONCLUSIONS

In section 2 we discussed that one has to determine functional coherence between the radiometric behaviour of the CCD and all influencing factors for the DMC normalisation approach. To get these functional coherences we carried out several tests at Z/I Imaging to qualify functions and parameters for each covered characteristic. We investigated the behaviour due to temperature changes, properties of lens and aperture, influences by TDI shifting and the special sensivity of each CCD element itself. It is shown that one has only to store one normalisation look up table which consists of a dark and a bright image.

Section 3 introduces the common workflow for the colour composite generation. The short discussion about the interpolation methods showed why bicubic interpolation is used in necessary all interpolation steps.

Thereafter six wide-spread colour space transformations were compared. A first ranking was made after the optical inspection of generated composite images, although this wasn't an easy task for the observers. The RMSE of the difference images and the achievable matching accuracy gave a second objective ranking. Last but not least the required computation times were compared.

So the CIE Lab colour space transformation produces high quality composites, but the required computation time doesn't fit our requirements. The related CIE Luv is faster and reserves the quality. So we suggest to use this colour space transformation because it's a good compromise between image quality and computation time. If the latter is the most important item YC_bC_r will be the best choice.

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