A COLOUR-BALANCING METHOD AND ITS APPLICATIONS

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Abstract

Efficiently forming seamless mosaics from multiple overlapping images becomes an important issue for many large-scale projects, especially for making visual products from massively large numbers of overlapping images. It is desirable that the manual-editing work involved in such a mosaicking process should be minimised. A statistical technique of colour-balancing, especially for remotely sensed imagery and aerial photography, has been developed.

The basic idea of this method is to equalise the colours at edges by applying appropriate kinds of kernels so that the colour differences between the overlaps are minimised, while the dynamic range of the data is substantially retained. Some constraints are applied to enable the algorithm to converge and to maintain the original colour information; it is important that real differences are not lost in colour-balancing.

This method has been applied to colour-balance the Landsat panchromatic imagery covering the Australian continent as a part of the Australian Greenhouse Office (AGO)'s National Carbon Accounting System (NCAS) project. This colour-balancing task involves 188 Landsat images (mixed standard, double and triple scenes from ACRES) for a single-date mosaic. The results from NCAS and other applications are presented. The promising results suggest that this method can be regarded as a generalised tool for automatic image colour-balancing.

Introduction

With the rapid development of digital imaging and high-resolution satellite technologies, there is great demand for colour-balancing to form seamless mosaics in photogrammetry, remote sensing and geographical information systems (GIS) applications. Satellite or aerial image data may be affected by the solar incidence, azimuth and image viewing angle; atmospheric effects; the effect of the bi-directional reflectance distribution function (BRDF) of the surface sensed; and sensor band spectral response functions. If an analogue camera is used to capture the photos, some image processing adjustments are usually applied during the scanning of the photos to digital format. The scanning adjustment may change the colours from photo to photo and make the radiometric calibration more complicated and difficult. These combine to produce significant radiometric differences, confounding the interpretation of both temporal and spatial data sets. When using such images to make a broadarea seamless mosaic, it is desirable to remove these effects by implementing a method which can produce a radiometrically consistent set of images.

Much research effort has been expended on the image radiometric calibration problem (Vermote *et al.*, 1994, Furby and Campbell, 2001), and some BRDF calibration procedures are already in common use (Wu *et al.*, 2001). In this paper, a colour-balancing method is presented which aims to balance the colour differences among adjacent images. The reason for developing such a method is purely for the purpose of producing seamless visual mosaics. Any images regardless what kind of pre-processing has been applied can be considered in our method.

Colour-balancing belongs to an important class of image enhancement algorithms that are useful for reducing colour differences between images. Colour-balancing is often referred as “white point” correction in digital imaging (Hasler and Susstrunk, 2004, Mitsunaga and Nayar, 1999). In this paper, colour-balancing has a slightly different meaning: it means to reduce and balance the colour differences between images in order to make seamless mosaics from multiple images, where the images are usually already geometrically rectified into a common geometric coordinate system such as a map projection, or they are already registered into a common coordinate system, so that no alignment is required while performing the colour-balancing.

The Residual Method for Colour-Balancing

The traditional colour-balancing techniques commonly used in photogrammetry and remote sensing fields are either time consuming (require lots of manual editing work and therefore are labour intensive) or could not retain detailed original visual information (often seen when using some histogram equalisation algorithms). An automatic colour-balancing method was developed through statistically minimising the residuals between images while retaining the original visual information as much as possible. The proposed method is called the “residual method” since its nature is to deal with residuals among adjacent images. It is recommended (but not essential) that a BRDF calibration is applied prior to colour-balancing. The main reason for requiring a BRDF calibration is that enough geometric and radiometric information can be obtained from most aerial photography, satellite imagery and their ancillary metadata to allow BRDF calibration to be easily applied.

The proposed residual method was developed based on the assumption that there are enough overlapping regions among adjacent images, which can be easily met in most mosaic applications. The colour differences among the images are modelled using some kinds of kernels and the kernel coefficients are estimated using the samples collected from entire individual images (image samples) and the samples collected from the overlap regions (overlap samples). The goal of the residual method is to reduce the majority of colour differences dramatically by applying certain kind of kernel, while some localised colour differences may still remain due to various effects. So it is an approach to balance the colours globally, and it is beyond the current capability of the suggested kernels to equalise the colour differences locally. The following paragraphs explain the residual method in detail.

Firstly, the colour value differences in the overlap regions are modeled using some kind of kernel. The following criterion is chosen, which can be explained as that once the kernel components are taken out from the observed colour values of an identical point in the overlap region, the residual colour values of the point in both images should be identical. That is,

$$g_1 - K_1 = g_2 - K_2 \tag{1}$$

where g_1, g_2 are the image values for two adjacent images, and K_1, K_2 are the corresponding kernel components.

Secondly, a constraint is applied in order to guarantee the coefficient estimation will converge and meanwhile retain the original colour information. The following proposed constraint is applied to each image:

$$\begin{cases} K_1 = g_1 - \bar{g} \\ K_2 = g_2 - \bar{g} \end{cases} \tag{2}$$

where $\bar{g}$ is the averaged image mean values for two images which can be calculated prior to the coefficient estimation.

The choice of kernel is dependent on image content and imaging conditions. Since the more complicated atmospheric and solar-view angle affect components of the colour differences can be calibrated during the BRDF calibration process phase, the remaining colour differences can be modeled using basic linear or quadratic models. The following are three proposed kernels which will be used to for K_1, K_2 in Equation 1 in the practical implementation:

Two-coefficient kernel: $\begin{cases} K_1 = a_1 X_1 + a_2 Y_1 \\ K_2 = b_1 X_2 + b_2 Y_2 \end{cases}$

Three-coefficient kernel: $\begin{cases} K_1 = a_1 X_1 + a_2 Y_1 + a_3 X_1 Y_1 \\ K_2 = b_1 X_2 + b_2 Y_2 + b_3 X_2 Y_2 \end{cases}$

Five-coefficient kernel: $\begin{cases} K_1 = a_1 X_1 + a_2 Y_1 + a_3 X_1{}^2 + a_4 X_1 Y_1 + a_5 Y_1^2 \\ K_2 = b_1 X_2 + b_2 Y_2 + b_3 X_2{}^2 + b_4 X_2 Y_2 + b_5 Y_2^2 \end{cases}$

where

(X_i, Y_i) are the geometric coordinates of the samples and a_i, b_i are the kernel coefficients, respectively.

$(g_1 - \bar{g}) - K_1$, $(g_2 - \bar{g}) - K_2$ and $(g_1 - g_2) - K_1 + K_2$ are the residuals for image one, image two and their overlap region, respectively. The final adjusted colour values are $g_1 - K_1$ and $g_2 - K_2$ for image one and image two, respectively.

The kernel coefficients are estimated by minimising the combined residual sum of squares (SSQ) for observations in both the individual images and the overlap region:

$$R = \sum_{1}^{n_1}((g_1 - \bar{g}) - K_1)^2 + \sum_{1}^{n_2}((g_2 - \bar{g}) - K_2)^2 + \sum_{1}^{n_3}((g_1 - g_2) - K_1 + K_2)^2 \rightarrow \min \qquad (3)$$

where n_1, n_2 and n_3 are the numbers of observation samples collected from image one, image two and their overlap region, respectively.

Differentiating R with respect to a_i, b_i gives

$$\begin{cases} \dfrac{\partial R}{\partial a_i} = \sum_{1}^{n_1} 2((g_1 - \bar{g}) - K_1)\dfrac{\partial K_1}{\partial a_i} + \sum_{1}^{n_3} 2((g_1 - g_2) - K_1 + K_2)\dfrac{\partial K_1}{\partial a_i} \\ \dfrac{\partial R}{\partial b_i} = \sum_{1}^{n_2} 2((g_2 - \bar{g}) - K_2)\dfrac{\partial K_2}{\partial b_i} - \sum_{1}^{n_3} 2((g_1 - g_2) - K_1 + K_2)\dfrac{\partial K_2}{\partial b_i} \end{cases} \qquad (4)$$

where $\dfrac{\partial K_1}{\partial a_i}, \dfrac{\partial K_2}{\partial b_i}$ are the gradients of K_1, K_2 with respect to a_i, b_i, respectively, which can be easily derived from the kernels.

The gradients lead to matrix equations of the Gauss-Newton solution which can be solved explicitly for a_i and b_i.

Kernel Coefficient Estimates

Due to the large amount of samples collected and available for kernel coefficient estimation, some statistical techniques were employed in order to make the residual method more practical and computationally efficient: 1) the number of samples are carefully chosen to avoid some overlap regions being over-sampled and others being under-sampled; 2) coefficients are estimated in an iterative fashion and residuals are analysed after each iteration, samples with “very big” residuals are considered as real changes in the images (say because of different dates of acquisition, assuming there is no mis-registration problem) and therefore discarded.

In summary, the residual method consists of three steps: 1) collecting the observation samples (both image samples and overlap samples); 2) estimating the kernel coefficients; and 3) computing the colour-balanced images using the estimated kernel coefficients.

Assuming the colour differences among adjacent images are significantly reduced by applying the residual method, and a new set of images are generated, the mosaic image can be formed by simply laying them according to their coordinates.

Colour-Balancing Results

The residual method was implemented in a computer program and the program runs fully automatically once the images are provided. Some results from different projects are presented as follows.

Figure 1 shows the application of the residual method on the AGO's NCAS project. The year 2002 panchromatic-band mosaic image (Figure 1(a)) was formed from 188 Landsat 7 ETM+ scenes (some scenes are standard scene, some are double or triple scenes from ACRES), and all images have already had a BRDF calibration applied (Wu *et al.*, 2001). Figure 1(b) shows the colour-balanced mosaic image. Figure 1(c) shows the colour differences between un-balanced and balanced images (the darker the colour, the bigger the difference), using a three-coefficient kernel as the kernel. As shown in Figure 1(b), the majority of colour differences has been significantly reduced. Some local differences still remain due to the different dates of acquisition (the TM scenes were acquired from the period of November 2001 to October 2002).

The residual method also has been applied to form an aerial orthoimage mosaic. Four enlarged image windows were extracted from a big mosaic and they are used to illustrate the detailed balanced colours (Figures 2-5). There are three images in each figure: the left one is the mosaic using original orthoimages; the middle one is the mosaic colour-balanced using a common histogram equalisation method (the histogram equalising was conducted using ER Mapper software); and the right one is the mosaic colour-balanced using the residual method. As mentioned previously, the registration among adjacent images plays an important role in the proposed colour-balancing method, Figures 2,3 and 4 show three examples where the registration among images are very accurate and the resultant images are well colour-balanced, while Figure 5 shows how a bad registration among images can influence colour-balancing.

(a) (b) (c)

Figure 1: Year 2002 Panchromatic-band mosaic image (pixel size: 12.5 metres). This mosaic image was formed from 188 Landsat 7 TM scenes (some scenes are standard scene, some are double and triple scenes from ACRES). (a): The mosaic before colour-balancing (individual images have been BRDF calibrated); (b): The mosaic after applying the proposed residual method to the individual images (BRDF calibrated); and (c): The differences between un-balanced and balanced images (the darker the colour, the bigger the difference).

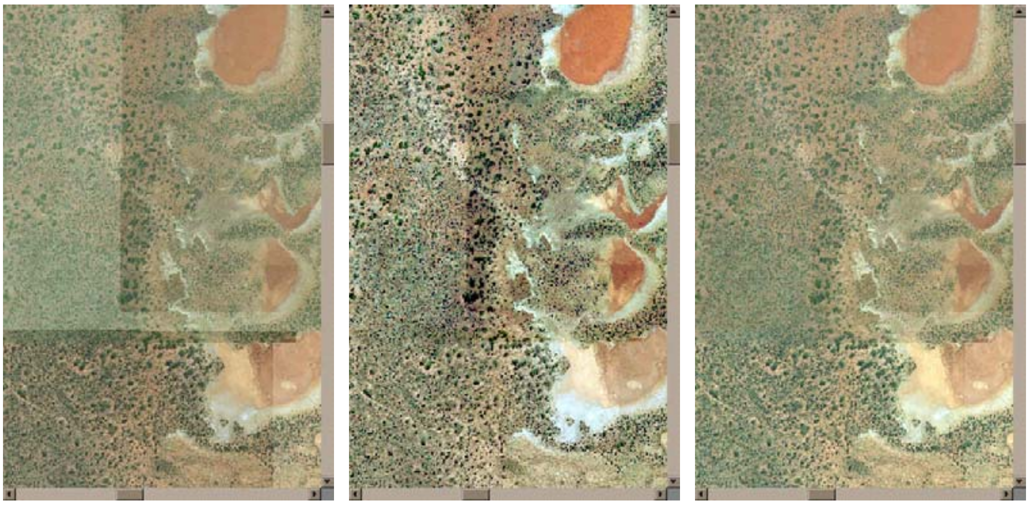

Figure 2: Example One: colour-balancing of aerial orthoimages. (a): The mosaic of original orthoimages; (b): The mosaic after applying a commonly used colour-balancing method (histogram equalisation method); and (c): The mosaic after applying the residual method.

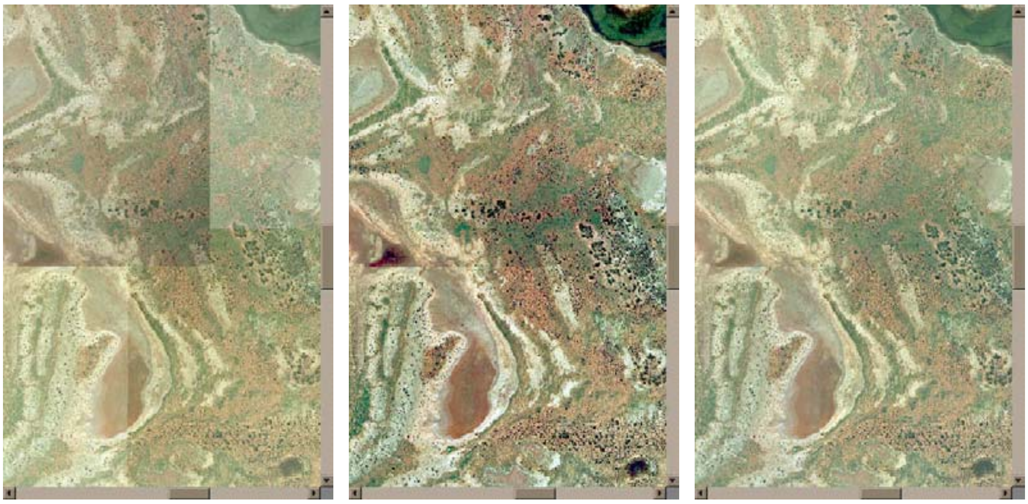

Figure 3: Example Two: colour-balancing of aerial orthoimages. (a): The mosaic of original orthoimages; (b): The mosaic after applying a commonly used colour-balancing method (histogram equalisation method); and (c): The mosaic after applying the residual method.

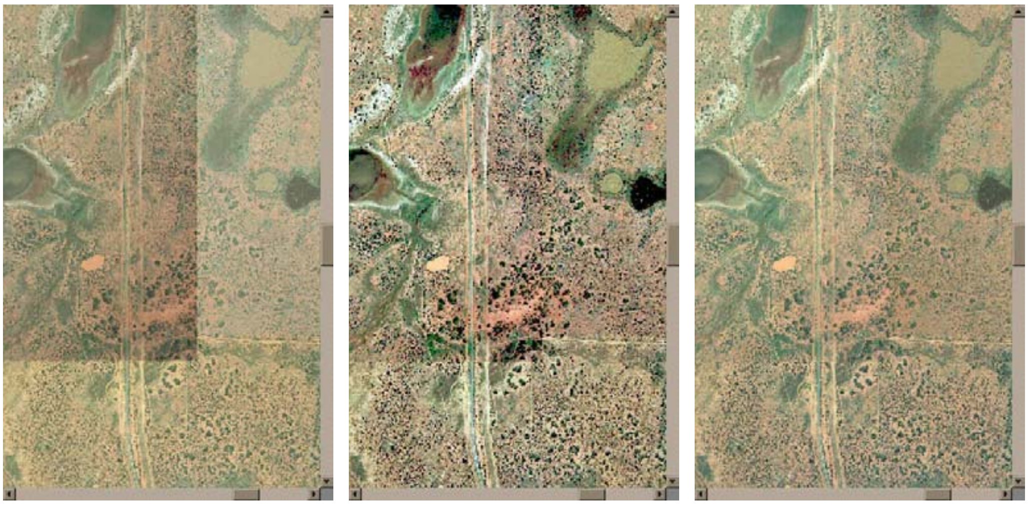

Figure 4: Example Three: colour-balancing of aerial orthoimages. (a): The mosaic of original orthoimages; (b): The mosaic after applying a commonly used colour-balancing method (histogram equalisation method); and (c): The mosaic after applying the residual method.

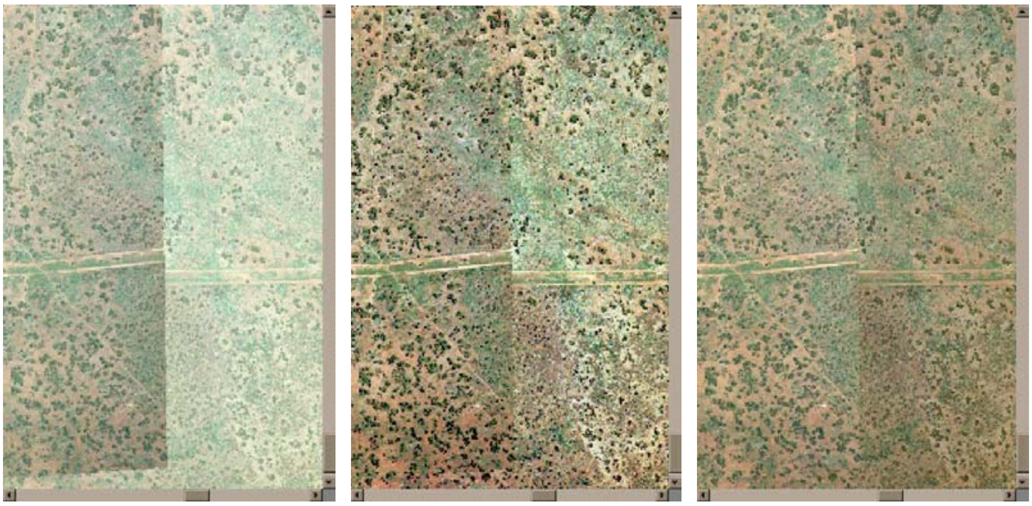

Figure 5: Example Four: colour-balancing of aerial orthoimages with some bad registration. (a): The mosaic of original orthoimages; (b): The mosaic after applying a commonly used colour-balancing method (histogram equalisation method); and (c): The mosaic after applying the residual method.

Discussions and Further Work

The proposed residual method shows the possibility to automate the colour-balancing processing and obtain reasonable results. Since the nature of the residual method relies on the overlapped image regions, it is necessary to have accurately registered images and sufficient overlap among the images.

Although the residual method works well for moderate colour-balancing applications, some potential investigations are worth exploring in order to improve the results:

- Robust estimation for kernel coefficients, which can discard the outliers and only fit the majority of samples. In some situations, the actual colour differences due to real changes may be treated as “outliers”, therefore, they will not influence the coefficient estimates and real colour differences will be maintained;

- Dealing with multiple bands simultaneously (such as orthogonal decomposition analysis). So far, the same process is repeated for each band if multiple-band images are involved;
- Kernels choice. The suggested kernels are very basic (only geometric location dependent) and work well for certain applications; however, it is desirable to have more rigorous kernels which are suitable for general colour-balancing purposes;
- The constraint used to maintain the original colours may not be efficient. For example, if two adjacent images have totally different colours, the proposed method will try to blend the image edges while the colours in the middle of images may still be maintained. A better way to deal with such an issue is desirable; and
- Integrating with radiometric calibration (e.g. BRDF, terrain illumination). With modern imaging technologies, the detailed imaging information can be easily obtained from the imaging systems; colour-balancing should use the information to adjust the radiometric component.

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