COLOUR PHOTOMOSAICS FROM DIGITISED AERIAL PHOTOGRAPHS

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ABSTRACT

Conventional methods for the production of photomosaics generally involve manual 'cut and paste' techniques. The photos are cut , usually along some apparent boundary in the photo to reduce the visibility of the cut line, and then pasted together into strips. The strips are pasted together to form the basic photomosaic, which is then photographed to produce the photomosaic negative. This negative is then used to produce the final mosaic. Any annotation or delineation of features must be carried out separately and printed down with this negative.

The advent of image processing systems and relatively cheap colour scanning systems offer new possibilities for the creation of photomosaics and orthophotos.

This paper will discuss our experiences in creating medium scale (1:5000) photomosaics from digitised aerial photography. The mosaics were prepared for the Kingdom of Tonga and covered parts of the islands of Nuku'alofa, 'Eua, Niua Niuafo'ou, Niuatoputapu and Tafahi.

The photographs (standard 23 cm colour aerial prints) were scanned on a standard A3 colour document scanner to produce RGB images at a resolution of 300 dpi. The images were processed using an ERDAS image processing system. Each image was colour balanced using histogram techniques to a selected image of appropriate colour tone. Annotation and feature delineation were added directly to the photomosaic image. The final image files were written to film using a commercial image writing service.

Rectification of images was based on supplied maps at a scale of 1:25000. As part of this project, a method of joining the digitised photos using a least squares fit on common detail points was developed and tested. The results of this approach will be presented and evaluated in the paper.

The use of image processing systems has typically been with systems whose original product is a digital image (satellite systems, airbourne scanners). Document scanners now offer a cheap and efficient means of obtaining digital imagery for these systems. This opens the way for a broader application of image processing to traditional tasks in photogrammetry and cartography.

INTRODUCTION

Photomosaics have long been used as a means of providing cheap, highly detailed maps. Conventional methods for producing photomosaics have generally involved assembling the photos into a mosaic using 'cut and paste' techniques. Once assembled, the mosaic can be re-photographed to produce a photomosaic negative and then enlarged to the desired scale.

The advent of image processing systems and relatively cheap colour scanning systems offers new possibilities for the creation of photomosaics and orhtophotos.

This paper discusses our experiences in producing medium scale (1:5000) digital photomosaics from standard aerial photography.

PROJECT BRIEF

The most recent maps available for the major islands of the Kingdom of Tonga were published in 1971. These maps were based on 1968 aerial photography. Today these maps show gross omissions with regard to the current status of Tonga's transportation network and land use.

Colour aerial photography was flown over the Kingdom during 1991 at a scale of 1 : 10 000. The Tongan Government was interested in obtaining maps based on this photography as soon as possible. A controlled photomosaic was suggested as one of the cheapest and quickest methods of producing highly detailed maps from aerial photography. The Tongans were also keen to utilise the latest technology in the production of their image maps. After some consultation, it was requested that we produce a series of controlled, digital photomosaics at a scale of 1:5000 from the 1:10000 aerial photography. As accuracy was not of paramount importance, we were able to use detail points from old 1:25000 maps as contol points for the mosaics.

Parts of the islands of Nuku'alofa, 'Eau, Niua Niaufo'ou, Niuatoputapu and Tafahi were to be covered. These islands were most suitable for photomosaics, as they had minimal relief displacement, generally in the order of 20 metres. Displacement errors in the photography were therefore largely due to tilts of the aircraft at the time of exposure.

METHOD

During the first stage photomosaic development standard data input and image processing techniques were used. Aerial photography was scanned using a flat top colour scanner. Once in digital form as red, green and blue layers they were imported into the image analysis system for further processing. This is accomplished by converting the image data which comes from the scanner in band sequential format and placing it in band interleaved by line format with the appropriate header information.

Once in the desired format, all images were matched to a selected standard using histogram matching techniques. During this process the range and distribution of the pixel values as shown in the cumulative frequency histograms of the scanned image (slave image) are made to match, as closely as possible, the cumulative frequency histogram of the reference or master image. In this way both images exhibit a similar range of colour tones and brightnesses.

Standard image rectification routines were used to resample the image to the UTM. Image rectification involves selecting a series of ground control points which can be identified on both the image (scanned and colour matched photograph) and the map base used for ground control coordinate selection. Once these points are established a mapping polynomial can be established between the two coordinate systems such that all of the pixels from the image can be transformed into UTM coordinates via a process known as resampling. During resampling a local neighbourhood of 4 by 4 pixels from the input image are used to interpolate a "reflectance" value to be placed in the new (output) image. This process was continued one photograph at a time until a complete photomosaic was produced. Checks on pixel residuals were made during the mosaicing process to ensure a degree of geometric stability.

The completed image was then reproduced using image writing onto diapositive which was then used in standard cartographic reproduction.

PROCEDURE

In order to streamline the process of digital photomosaic production (there are eight sheets to complete all together), all the steps were listed in a flow diagram and areas standardised if possible.

The initial procedure was as follows.

1. Lay out and identify all photography for the entire study area.

2. Determine the neatlines (geographic boundary lines) for all images allowing a degree of overlap between sheets.

3. Identify and list all photographs required for each completed photomosaic. It was decided to create mosaics in pairs rather than create one large mosaic and subset it at a later date. This was done to make handling the large files easier.

4. Scan all photography for one mosaic pair using the Sharp JX 450 colour scanner. It was anticipated that the scanning would need to be done at a resolution of 300dpi but some initial evaluation revealed that 200dpi gave an acceptable visual appearance while keeping files at a manageable size. At this scanning resolution each pixel was calculated to measure approximately 1 metre on the ground. Each mosaic required data from six photographs making a total of 10 photographs (taking into consideration the overlap at the join of the two mosaics). Only the central two thirds of the photograph was scanned in order to minimise the effects of tilt and relief distortion. Scanning time for each photograph was approximately 10 minutes giving a total scanning time of 100 minutes. This was extended to approximately two hours to allow for set up and general house keeping of files. Photographs were scanned so as to be the same dimensions in terms of lines and pixels. This simplified the import process to the image processing system as batch processing could be used with only the names of the files having to be changed within the batch script. Allowing for this streamlining of the import procedure it took approximately 30 minutes to import all of the relevant files.

5. During the execution of the batch file is to control file import, ground control point selection commenced using the photographs and 1:25000 maps.

   Photographs in one of the corners of the mosaic were rectified first using approximately 15 ground control points derived from the 1:25000 topographic maps. Many of these points needed replacing as the maps were old and many features were not accurately represented. When the images had finished loading, the scanned photograph was colour matched to the master and the control point coordinates were determined using the routines of ERDAS. Balancing colour tones between images using histogram matching was difficult as many of the photographs showed a colour balance which was heavily biased towards green and the images exhibited extreme bimodal histograms.

   ERDAS allows image ground control points to be measured to the sub-pixel level. This proved to be very useful as control points could be visualised at the sub-pixel level quite easily on the scanned photography.

6. Once all points had been established a mapping polynomial was applied and residuals examined. This was an iterative process with step 5 (ground control point selection). An affine model was fitted and residuals in both x and y of less than 2 pixels were deemed acceptable (keep in mind that 1:25 000 control was being used). The image was then resampled using a bi-linear interpolation algorithm.

7. Steps 5 and 6 were then repeated on the remaining scanned photographs. In order to tie together the other photographs control was derived from the previously resampled photograph. This enabled control to be derived from both the map and along the "join" between continguous photographs. The photograph to the immediate north and then west (assuming the first photo was placed in the SE corner) of the first resampled image were sewn in next. By using this sequence, when the photograph to the NW of the first photograph was sewn in place, control could be derived along the eastern and southern edges, based on the resampled image, with additional control derived from the maps. This allowed a check to see how well each of the scanned photographs was being resampled into the overall mosaic.

8. During step 7 the edges were checked to see if features aligned correctly. e.g. if roads and coastline were continuous across borders. Occasionally edges did not match. Under these circumstances additional control was derived around the mismatched feature and the photograph resampled again.

9. At this stage a final interactive contrast stretch was applied to the whole image and it was sent for image writing.

DISCUSSION

The first attempt at creating a photomosaic digitally allowed the formulation of a streamlined procedure which could be implemented in an operational environment.

The use of digital image processing in the compilation of digital photo mosaics offered several benefits.

1. The images could be enhanced using histogram manipulation techniques. This allowed some degree of colour matching between images even though the colour of the photographs was quite variable. The digitally enhanced images actually look substantially superior to the hard copy originals.

2. The final mosaics were resampled to the UTM projection within the accuracy of the control used. This allowed easy overlay of desired vector features and update of the vector database of graphical features using the photomosaics.

3. The photomosaics could be zoomed on screen to ascertain the most appropriate enlargement for hard copy products.

4. The effects of reflectance on water features and darkening at the edges of photographs was a problem. It is possible to digitally cut out these parts of the image very accurately by zooming and cutting on screen. Areas of water that do suffer from extreme glint can be replaced by a continuous tone of blue designed to match the areas of surrounding water. It is recommended that in the future production of photomosaics, this capability should be utilised.

5. The photomosaic can be used as a backdrop for other mapping products or for GIS/LIS activities.

One problem encountered when using digital methods was the edges between adjacent photographs did not always meet correctly. This required deriving extra ground control and re-running the resampling of that photograph. This proved to be a bottle neck in the production process. Consequently, a technique has been derived to edge-match raster images such that a series of points can be specified along the boundary between them. During resampling, the technique ensures that these features align in the output image. When fully implemented, this technique will ensure a seamless join between two images and remove the bottle neck from the compilation procedure.

The theory behind this technique is given below.

EDGE MATCHING OF SCANNED PHOTOGRAPHS

Consider two scanned images with a common boundary as shown in Figure 1 below. Each image has a number of control points (Δ) , which have image coordinates as well as ground coordinates, and common points (•), which have image coordinates only. The control points are used to rectify the image to the existing ground control and the common points in each image define the boundary between the images. Due to distortions it is unlikely that the common points will match, either before or after rectification based on the control points and a combined image will have a "fuzzy" join. To remove this problem the following technique can be employed to rectify the images using the control points as well as ensuring that the common points along the image boundaries have the same unique coordinates. This method has been employed by Shmutter and Doytsher (1991) to match the edges of digitized cadastral maps and a similar technique known as the ANBLOCK method by Van den Hout (1966) is used in photogrammetric block adjustments.

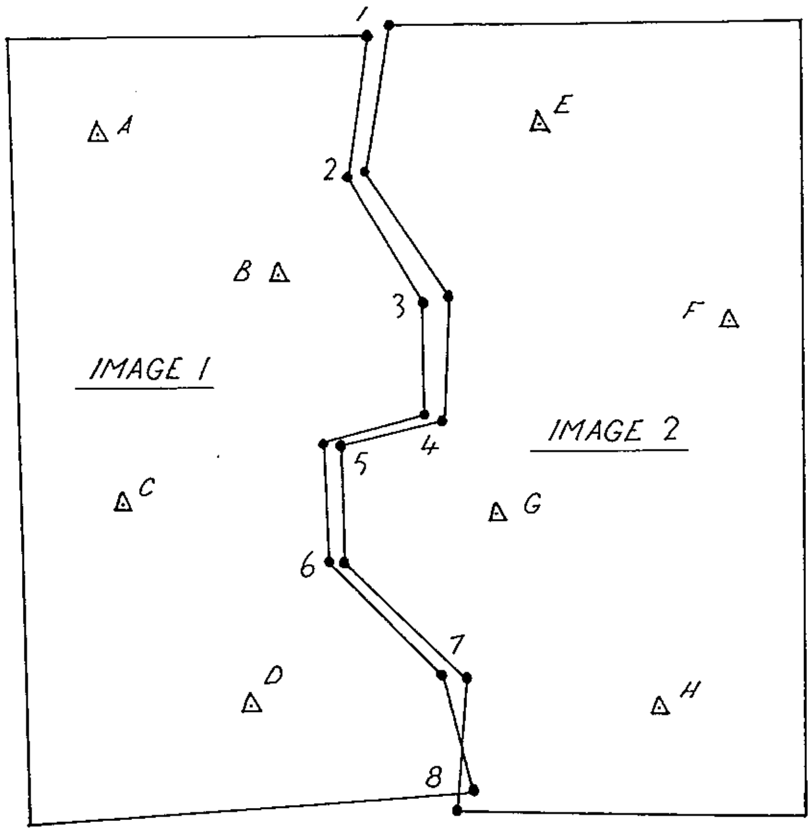
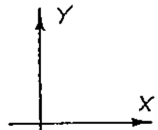


Figure 1. Images with control and a common boundary

DERIVATION OF FORMULAE

Referring to figure 1 above; Image 1 has m control points (m = 4 = A,B,C,D) and Image 2 has n control points (n = 4 = E,F,G,H). There are p common points along the boundary of Images 1 and 2 (p = 8).

Let X,Y be the final ground coordinates of a point resulting from the rectification (or transformation) of the initial image coordinates x,y.



The coordinates are assumed to be linked by a six parameter linear transformation (or *affine transformation*) of the form

$$X = ax + by + c$$

$$Y = dx + ey + f \qquad \ldots (1)$$

The parameters c and f are translations between the origins of the X,Y and x,y systems. If coordinates of a *centroid* are calculated for the control points in both systems and subtracted from the original coordinates to produce *centroidal coordinates* then the new coordinate origins are coincident and the parameters c and f will be zero. Equations (1) may be written as

$$\bar{X} = a\bar{x} + b\bar{y}$$
$$\bar{Y} = d\bar{x} + e\bar{y} \qquad \ldots (2)$$

where $\bar{X},\bar{Y}$ and $\bar{x},\bar{y}$ are *centroidal* coordinates.

Equations of this form can be written for each control point. Two points are sufficient to determine the parameters; more than two points will lead to an "over determined" system of equations which can be solved by the *Least Squares* technique.

Let approximate values of the parameters be a', b', d' and e' such that $a = a' + \Delta a$, $b = b' + \Delta b$, $d = d' + \Delta d$, $e = e' + \Delta e$ and Δa, Δb, Δd and Δe are small unknown corrections to the approximate values.

Also, let "observed quantities" be the image centroidal coordinates $\bar{x},\bar{y}$ with residuals (or small corrections) v_x and v_y. Equations (2) can be expressed as

$$\bar{X} = (a' + \Delta a)(\bar{x} + v_x) + (b' + \Delta b)(\bar{y} + v_y)$$
$$\bar{Y} = (d' + \Delta d)(\bar{x} + v_x) + (e' + \Delta e)(\bar{y} + v_y) \qquad \ldots (3)$$

Now since Δa, Δb, Δd, Δe and v_x and v_y are small, any products of these quantities will be exceedingly small and may be disregarded. Hence if equations (3) are multiplied and products of small quantities neglected the following simplification arises

$$\bar{X} = a'v_x + b'v_y + \bar{x}\Delta a + \bar{y}\Delta b + (a'\bar{x} + b'\bar{y})$$
$$\bar{Y} = d'v_x + e'v_y + \bar{x}\Delta a + \bar{y}\Delta b + (d'\bar{x} + e'\bar{y}) \qquad \ldots (5)$$

Inspection of equations (2) shows that the terms in parenthesis are expressions for the approximate centroidal coordinates $\bar{X}'$ and $\bar{Y}'$ and equations (5) may be written in the following form for the m control points of Image 1 and the n control points of Image 2

$$a'_1 v_{x_{i,1}} + b'_1 v_{y_{i,1}} + \bar{x}_{i,1} \Delta a_1 + \bar{y}_{i,1} \Delta b_1 = \bar{X}_{i,1} - \bar{X}'_{i,1}$$

$$d'_1 v_{x_{i,1}} + e'_1 v_{y_{i,1}} + \bar{x}_{i,1} \Delta d_1 + \bar{y}_{i,1} \Delta e_1 = \bar{Y}_{i,1} - \bar{Y}'_{i,1}$$

... (6a)

where

the subscript $i,1$ refers to the control point number

$i = 1, 2, 3, \ldots, m$ and the Image number 1

and

$$a'_2 v_{x_{j,2}} + b'_2 v_{y_{j,2}} + \bar{x}_{j,2} \Delta a_2 + \bar{y}_{j,2} \Delta b_2 = \bar{X}_{j,2} - \bar{X}'_{j,2}$$

$$d'_2 v_{x_{j,2}} + e'_2 v_{y_{j,2}} + \bar{x}_{j,2} \Delta d_2 + \bar{y}_{j,2} \Delta e_2 = \bar{Y}_{j,2} - \bar{Y}'_{j,2}$$

... (6b)

where

the subscript $j,2$ refers to the control point number

$j = 1, 2, 3, \ldots, n$ and the Image number 2.

In addition to equations (6a) and (6b) above that can be written for each of the $(m + n)$ control points, equations may be derived for each of the p common points on Images 1 and 2. Using the general transformation equations in centroidal form (equations (2)), the following relationships express the fact that the final coordinates of a common point on Image 1 must be the same as the final coordinates for the same point on Image 2.

$$a_1 \bar{x}_{k,1} + b_1 \bar{y}_{k,1} = a_2 \bar{x}_{k,2} + b_2 \bar{y}_{k,2}$$

$$d_1 \bar{x}_{k,1} + e_1 \bar{y}_{k,1} = d_2 \bar{x}_{k,2} + e_2 \bar{y}_{k,2}$$ ... (7)

$|\longleftarrow$ *Image 1* $\longrightarrow|$ $|\longleftarrow$ *Image 2* $\longrightarrow|$

Using approximate values for the parameters; residuals related to the observed coordinates; and ignoring products of small quantities; equations of the following form may be derived from equations (7) above.

$$\begin{aligned} & a'_1 v_{x_{k,1}} + b'_1 v_{y_{k,1}} + \bar{x}_{k,1}\,\Delta a_1 + \bar{y}_{k,1}\,\Delta b_1 \\ - & a'_2 v_{x_{k,2}} + b'_2 v_{y_{k,2}} + \bar{x}_{k,2}\,\Delta a_2 + \bar{y}_{k,2}\,\Delta b_2 = \bar{X}'_{k,2} - \bar{X}'_{k,1} \\ & d'_1 v_{x_{k,1}} + e'_1 v_{y_{k,1}} + \bar{x}_{k,1}\,\Delta d_1 + \bar{y}_{k,1}\,\Delta e_1 \\ - & d'_2 v_{x_{k,2}} + e'_2 v_{y_{k,2}} + \bar{x}_{k,2}\,\Delta d_2 + \bar{y}_{k,2}\,\Delta e_2 = \bar{Y}'_{k,2} - \bar{Y}'_{k,1} \end{aligned} \qquad \ldots (8)$$

where

the subscripts k,1 and k,2 refer to the common point number $k = 1, 2, 3, \ldots, p$ and the Image numbers 1 or 2.

Equations can be written in matrix form for the *m* control points on Image 1 (equations 6a); the *n* control points of Image 2 (equations 6b); and the *p* common points (equations 8) as:

$\mathbf{A}_1\mathbf{v}_1 + \mathbf{B}_1\boldsymbol{\Delta} = \mathbf{f}_1$ *(Image 1)*

$\mathbf{A}_2\mathbf{v}_2 + \mathbf{B}_2\boldsymbol{\Delta} = \mathbf{f}_2$ *(Image 2)*

$\mathbf{A}_3\mathbf{v}_3 + \mathbf{B}_3\boldsymbol{\Delta} = \mathbf{f}_3$ *(Common Points on Images 1 and 2)* and represented as a partitioned matrix of the form

$$\begin{bmatrix} A_1 & 0 & 0 \\ 0 & A_2 & 0 \\ 0 & 0 & A_3 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} + \begin{bmatrix} B_1 \\ B_2 \\ B_3 \end{bmatrix} \Delta = \begin{bmatrix} f_1 \\ f_2 \\ f_3 \end{bmatrix}$$

or

$$\mathbf{Av} + \mathbf{B\Delta} = \mathbf{f} \qquad \ldots (9)$$

where

$\mathbf{A}(c,q)$ and $\mathbf{B}(c,u)$ are coefficient matrices

$\mathbf{v}(q,1)$ is a column vector of residuals

$\mathbf{\Delta}(u,1)$ is a column vector of unknown parameters

$\mathbf{f}(c,1)$ is a column vector of numeric terms

q is the number of observations

u is the number of unknown parameters

c is the number of equations

Equation (9) above is the fundamental form of equations for the adjustment of observations and parameters combined and represents c linear equations in $(q + u)$ unknowns which are the elements of the two vectors $\mathbf{v}$ and $\mathbf{\Delta}$.

Mikhail (1976, pp.110-135 and pp.184-212) shows how the *Least Squares* principle can be employed to solve for the unknown parameters a_1, b_1, d_1, e_1 and a_2, b_2, d_2, e_2 in vector $\mathbf{\Delta}$ for an *Affine* transformation from image coordinates to ground coordinates with common boundary points.

The solution has the general form

$$\mathbf{\Delta} = \mathbf{N}^{-1}\mathbf{t}$$

where

$$\mathbf{N} = \mathbf{B}^T(\mathbf{AQA}^T)^{-1}\mathbf{B}$$
$$\mathbf{t} = \mathbf{B}^T(\mathbf{AQA}^T)^{-1}\mathbf{f}$$

and

$\mathbf{Q}$ is a cofactor matrix containing estimates of the variances and covariances of the observations.

The formation of the coefficient matrix $\mathbf{N}$ and the vector $\mathbf{t}$ can be accomplished as a series of summation processes for equations related to each control point in Images 1 and 2 together with the common points. The whole process is iterative due to the assumptions made in developing the equations which means that an initial set of coefficients must be computed and both Images approximately rectified to ground control.

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