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Mosaicing Digital Orthophotos

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Abstract:

Working with digital orthophotomaps, for instance in a Geographical Information System, means that a continous digital orthophoto covering several mapsheets has to be available. Digital mosaicing techniques capable of handling the usual poblem with greyvalue differences between adjacent photos are needed for making such coverage. This paper presents a method based on an analogy to the An-block adjustment, used in aerotriangulation. Modelling the greyvalue distortion in every photo with a polynomial distortion-surface, makes it possible to remove the greyvalue differences, thus making mosaicing possible.

Introduction

When making orthophotomaps consisting of several photos problems arise when these are to be put together. This is due to the fact that different exposures of the same object seldomly come out the same. Often a shift in greytones can be seen, along the lines that seperate the photos.

At present most orthophotos are made "the old fashioned way", that is with analogue photographic methods and normally using one photo for one map. If mosaiced the greytone shifts are handled in the darkroom, where a contrast regulation takes place in order to achieve a presentable result fit for the eye.

The use of Geographical Information Systems has created a need for capabilities of combining various information with picturelike images, such as arial photographs and satellite-imagery.

Working with it, however, means that one cannot limit oneself to information within the boundary of one photo: There is a need for continous digital image information covering several mapsheets.

As all layers within a GIS, the ortohphoto-layer must also have up-dating facilities. So, mosaicing digital orthophotos comes into focus when updated photos has to be adjusted to the existing information in order to preserve a homogenous look.

This paper documents preliminary results for a project for mosaicing digital orthophotos.

The method

An analogy to the analytical block-adjustment used in aerotriangulation is used,

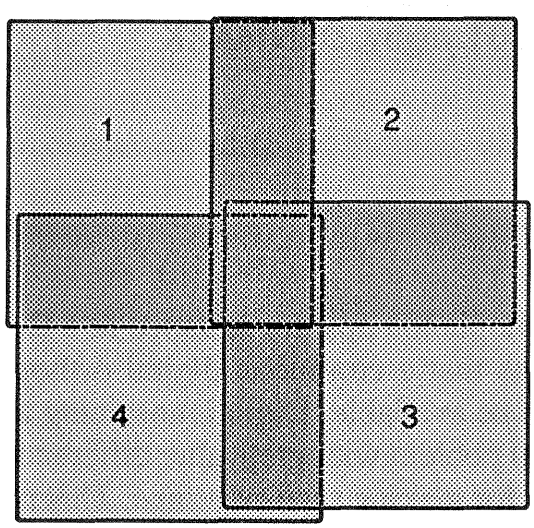

Figure 1. 4 overlapping images.

but here the plane geometry of the system is not subject to adjustment - the geometry in orthophotos is well known.

The situation with 4 adjacent and overlapping orthophotos is shown in Fig. 1.
Because of the greyvalue distortion the corresponding greyvalues are not equal and this is the backgruond for an adjustment.

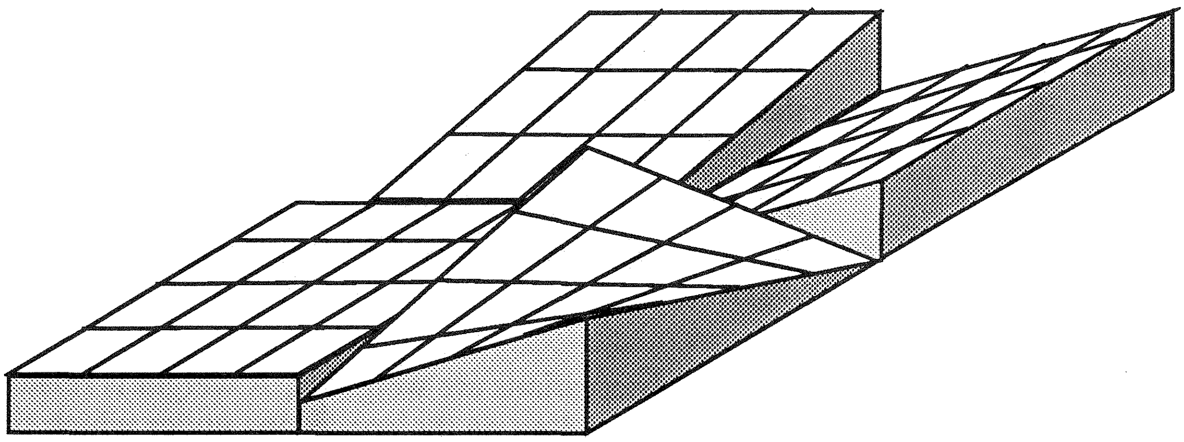

Figure 2. Example of possible distortion-surfaces in 4 overlapping images.

In perspective the distortion surfaces of the 4 photos might look as shown in Fig. 2. Since the distortion-surfaces are not known the following model for the system is made:

The model:
A digital orthophoto concists of picture elements - pixels. To every pixel a greyvalue is attached - the pixelvalue. Normally this value is in the range 0-255 (= one 8-bit byte in a computer) covering a greyscale from black to white. The pixelvalue represents the amount of reflected light, from the area on the ground covered by the pixel.

The thesis is that the greytones in every photo is distorted systematically as a result of the sun-angle (time of day and year), flight-direction, atmosphere, etc. This means that every pixelvalue in the orthophoto can be described as a "true" value S, related to the reflection of the groundsurface, plus a contribution from the distortion-surface.

If all the types of variations were to be modelled the distortion-surface would be very complex and difficult to describe. This method implies that a simple polynomial surface-function might be enough to describe the necessary corrections to be made in every image in order to produce a homogeneous image covering several photos.

There are two kinds of condition equations in the system:

$$l_i = S_p + F_k(X_{p,k}, Y_{p,k}) \qquad (1)$$

$$l_j = E_m \qquad (2)$$

where l_i, l_j : the i'th and j'th adjusted observation,
S_p : the greyvalue of pixel p,
$X_{p,k}$, $Y_{p,k}$: the pixel,line coordinate of pixel p in image k,
F_k : the distortion-surface function in image k,
E_m : the m'th unknown (pixelvalue or surface parameter)

Weights:
In a least squares adjustment the observations are weighted. A weight is related to the observations of the type (1), depending on the conditions under which the pixelvalue is observed.
Observations of type (2) are assigned any large weight (this is done interactively in the computer-program). The corresponding elements in the normal equations then become numerically dominant, thus ensuring the wanted solution for these elements. In this way observations of type (2) can be used to control the solution. This is both suitable and necessary, as several of the unknown parameters are highly correlated - depending on the geometrical distribution of the observations (1) within the image .
A distortion-surface can be controlled directly by "observing" the parameters or indirectly by observing a number of pixelvalues within the image, and the problem with higly correlated unknown parameters (due to the model and distribution of observations) destroying the solution ,can be dealt with. At least the level for the distortion-surface and a number of pixelvalues along the boundary of the block of images have to be known, and thus being observations of type (2), to ensure a moderat solution, fit for the physical problem.

Distortion surface model:
So far a bi-linear surface model is used. This means the distortion surface in image k is given by

$$F_k(X_{p,k}, Y_{p,k}) = A_k \cdot X_{p,k} + B_k \cdot Y_{p,k} + C_k \cdot X_{p,k} \cdot Y_{p,k} + D \qquad (3)$$

where A_k, B_k, C_k, D_k : bi-linear surface parameters,
$X_{p,k}$, $Y_{p,k}$: the pixel,line coordinate of point p in image k

The number of unknown parameters in the least squares adjustment is the equal to the number of observed pixels plus 4 times the number of distortion surfaces.

This is also the minimum of observations needed to make the system redundant. In practice this is done by primarilly observing corresponding pixels in the overlaps between the images.

Experiments with synthetic data.

The method has been tested, so far in synthetic images, in which the functions describing the greyvalue-distortion are well known.

A block of 4 overlapping images, each 256 x 256 pixels is used. By limiting the images to this size, it is possible to display all four at the same time on our image processing system.

Two tests have been carried out and in both cases the procedure was as follows:

A greyvalue distortion-surface is added to each image. Corresponding points in the 4 models are measured and a least squares adjustment is performed. The resulting parameters for the distortion-surfaces are compared with the ones originally imposed on the images.

In both cases the pattern of the measured pixels was as shown in Fig. 3.

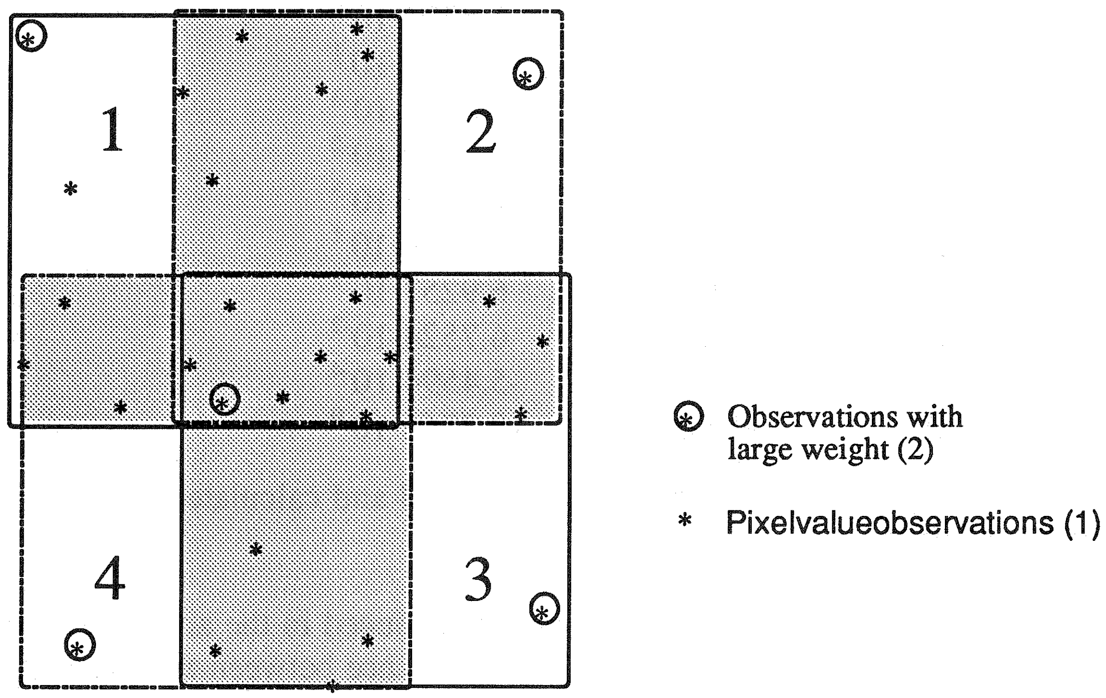

Figure 3. The pattern of observations in the 4 overlapping images. The overlaps are hatched.

Pixels in the overlaps are measured 2 or 4 times, depending on how many images in which they appear.

Tests with different combinations of observations of type (2) were conducted. Here only the simplest is mentioned. 5 pixelvalues were observed and given a large weight.

Test 1:

The 4 photos were distorted by bi-linear surfaces.

5 pixels situated in the boundary region and in the center of the block of images, were constrained with observations of the type (2) applying a very large weight.

The result of the adjustment is showed in Table 1.

		Applied surface	Calculated surface
image 1,	A	0.0	$1.3058 \cdot 10^{-3}$
	B	0.0	$2.0309 \cdot 10^{-3}$
	C	0.0	$-1.0118 \cdot 10^{-5}$
	D	0.0	$-2.8300 \cdot 10^{-1}$
image 2,	A	$7.058824 \cdot 10^{-2}$	$7.2210 \cdot 10^{-2}$
	B	0.0	$-3.1620 \cdot 10^{-4}$
	C	0.0	$1.3204 \cdot 10^{-6}$
	D	-10.0	$-1.0131 \cdot 10^{1}$
image 3,	A	0.0	$1.6144 \cdot 10^{-3}$
	B	$7.058824 \cdot 10^{-2}$	$6.7445 \cdot 10^{-2}$
	C	0.0	$2.0585 \cdot 10^{-5}$
	D	-10.0	$-1.0429 \cdot 10^{1}$
image 4,	A	$7.058824 \cdot 10^{-2}$	$6.9257 \cdot 10^{-2}$
	B	$7.058824 \cdot 10^{-2}$	$6.7524 \cdot 10^{-2}$
	C	$-5.536300 \cdot 10^{-4}$	$-5.4594 \cdot 10^{-4}$
	D	-10.0	$-9.7766 \cdot 10^{0}$

Table 1. The parameters describing the applied and calculated bi-linear surfaces in test 1.

As the distortions are similar to the model introduced in the adjustment program, an almost exact solution is found. The difference between the two sets of parameters is mainly due to the conflict between the continous surface in the theoretical continous model and the discreet digital image. This can be seen when looking at the differences between the two surfaces, as they appear on a screen, see Fig 4.

The size of the difference is seen to be not more than 3 greyvalues, and in a digital image this is hardly visible.

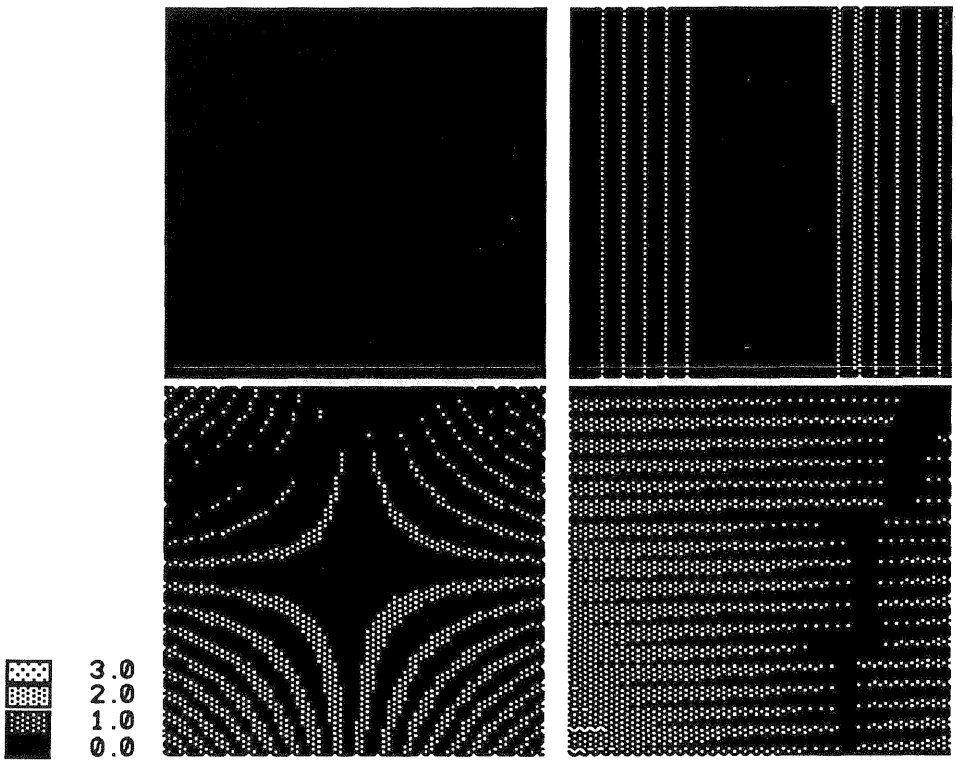

Figure 4. The absolute difference between the applied surfaces and the calculated surfaces as seen in greyvalues on a screen. The surface-parameters are listed in Table 1.

Test 2:

In the second test, a distortion-surface in image 4 is introduced as a parabolic surface. The result is seen in Table 2. As in the first test, the difference between the two sets of parameters is visualized by subtracting the two (Fig. 5).

Again the absolute difference between the applied surface and the result of the adjustment overall is not more than 5 greytones.

Problems

Not all the requirements to make the method work have been mapped. Several questions are still unanswered:

The observations and their distribution within an image: As in the An-block adjustment the solution is sensible to the number of fixed pixels along the boundary of the block of images, an to the distribution of pixels within the images. In order to insure a solution that is not too influenced by highly correlated parameters, it is necessary to create a strategy for the observation distribution.

Weights: As mentioned earlier the weights of observations of type (1) depend on the conditions under which the pixelvalues are measured. In the experiments

		Applied surface	Calculated surface
image 1,	A	0.0	$5.6252 \cdot 10^{-3}$
	B	0.0	$6.9433 \cdot 10^{-3}$
	C	0.0	$6.2521 \cdot 10^{-5}$
	D	0.0	$-4.1444 \cdot 10^{-1}$
image 2,	A	$7.058824 \cdot 10^{-2}$	$7.1076 \cdot 10^{-2}$
	B	0.0	$-2.1598 \cdot 10^{-3}$
	C	0.0	$-3.0537 \cdot 10^{-5}$
	D	-10.0	$-9.4123 \cdot 10^{0}$
image 3,	A	0.0	$1.2832 \cdot 10^{-2}$
	B	$7.058824 \cdot 10^{-2}$	$5.0526 \cdot 10^{-2}$
	C	0.0	$1.4795 \cdot 10^{-4}$
	D	-10.0	$-9.2986 \cdot 10^{0}$
image 4,	A	*	$1.3329 \cdot 10^{4}$
	B	*	$8.7280 \cdot 10^{-4}$
	C	*	$-2.7634 \cdot 10^{-4}$
	D	*	$9.3762 \cdot 10^{0}$

Table 2. The parameters describing the applied and calculated surfaces of test 2. The * indicates that surface 4 is a parabolic surface given by distortion= $-4.257079{:}10^{-9} \cdot x^2 \cdot y^2 + 8$

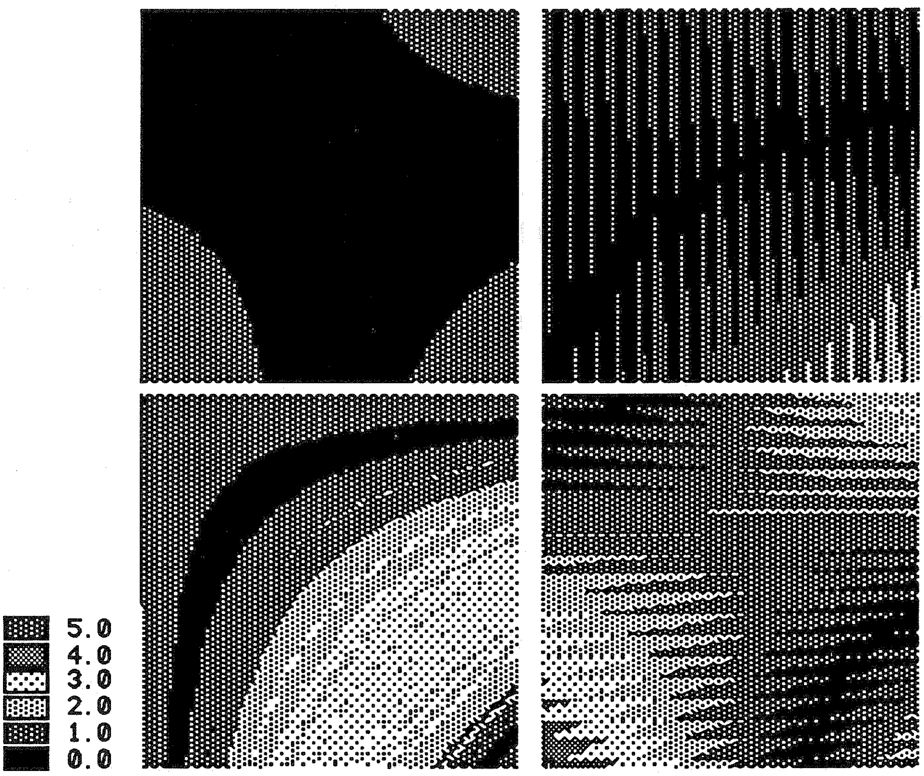

Figure 5. Absolute difference between applied and calculated surfaces in test 2.

the weights on the observations are are all set to one, since all observations are alike - the greyvalue of one pixel is measured. However, an average of the greyvalues within an area around the measured pixel might be a better representation of the reflectance. How the weight function for these observations look, is not yet described.

Highly correlated parameters: A bad distribution of observations within the block of images may result in highly correlated parameters and a bad solution. This can be dealt with in several ways. One can add highly weighted observations of some of the unknown parameters, thus constraining them to a certain value, or one can insure a "proper" distribution of corresponding pixels observated in several models - it also minimizes the correlation between parameters.

Actual mosaicing: Points having the same coordinates in different orthophotos might not look alike, i.e. houses, masts, trees which are seen under different angels in the original photos, and therefore mosaicing the greyvalue correted images properly has to be supervised to a certain degree, due to the these problems.

Outlook

Using the concept of this method offers the opportunity for modelling various kinds of distortions, thus making it possible to correct the greyvalues in the images in accordance with the physics of the problem, rather than "just" as a statistical correction.

Furthermore different kinds of distortion-surfaces for different images, can be used in the same adjustment.

A way for handling the problems with the distribution of the observations within the images, might be solved with a systematic and regular distribution, thus enabling automatic observation-routines.

So far the work has been concentrated on developing the model and testing it with synthetic data. Further studies with real data, will show how effective this model is.