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USING B-SPLINE SURFACES FOR CHROMATIC ATTACHMENT OF DIGITAL ORTHOPHOTOS

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ABSTRACT

Since the eighties, there has been a significant evolution of photogrammetric systems for the production of digital orthophotos. All the various procedures for the generation of orthophotos (for example, image orientation and the DTM generation) are completely automated now, while, in general, the mosaicking phase requires human intervention in a consistent manner.
The article suggests an original methodology which allows for the complete automation of the mosaicking procedure. It is based on two distinct phases: radiometric equalization of the images and elimination of the radiometric discontinuities by the application of B-Spline surfaces.
Finally, various numerical examples show the capability of the method proposed.

1 INTRODUCTION

The main factors which intervene during the phase of chromatic attachment amongst orthophotos include:

1. The diverse brightness amongst images.
2. The diverse reflection of the objects on the ground which are located along the cutting line.
3. The presence of objects not lying on the DTM (buildings, trees etc.)
4. The poor quality of the DTM in various areas which results in a shift on the orthophoto.
5. The printing process of the images.

These factors entail that the choice of the cutting line depends upon the experience of the operator in order to reduce the metric and radiometric effects amongst orthophotos.
As an alternative, the choice of using an algorithm of refined attachment allows for the automation of the process with great advantage in terms of time and costs.
The proposed method is characterized by two main phases.
The first consists of an equalization which reacts in a differential manner along the cutting line on the inner side of a predefined band. This requires the definition of sectors in which an algorithm is applied after the calculation of an average value of gray for each subsection, creating in this way a linear correction along the cutting line and along its orthogonal direction.
The second phase allows for the elimination of the residual radiometric discontinuity present internally at each section. This is caused by the fact that the dimensions of the last were not selected as of infinitesimal width to avoid problems of uneven appearances amongst objects present on both images.
The proposed method uses B-Spline surfaces to correct the discontinuity (Crosilla and Barbacetto 1997).
B-Spline surfaces are parametric operators which allow for a series of *X,Y,Z* coordinates to interpolate in a normal mode. Crosilla and Barbacetto (1997) have applied them to research outliers and morphological discontinuities using a control network with a number of vertices less then the points initially given. This allows for a least square fitting of the initial surface thereby highlighting the eventual presence of outliers and discontinuity.

2 EQUALIZATION OF IMAGES

Problem definitions

Given both orthophotos A and B, and defined a certain cutting line L, we will define Δb the difference of luminosity amongst the two images along L.
In general we can observe (figure 2.1.1) that Δb is not constant along the cutting line, but it may vary considerably.

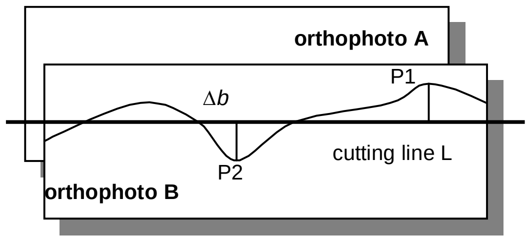

Figure 2.1.1

The causes are mainly related to the diverse reflectance of the objects present along the cutting line.
Actually, the same object (figure 2.1.2) is taken from two different positions (photograms A and B), consequently, the incidental radiation in the photogram is different, therefore, the radiometric value also differs (for example the level of gray).

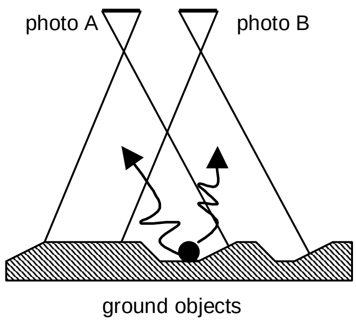

Figure 2.1.2

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It is therefore evident (figure 2.1.1 and 2.1.3) that by regulating the luminosity of either of the two orthophotos, so as to render a certain area chromatically homogenous (ex. *P1*), the opposite effect is determined in the other (ex. *P2*).

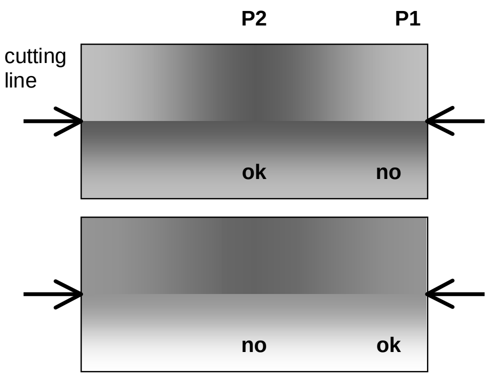

Figure 2.1.3

Solution of the problem and description of the algorithm

As mentioned in the preceeding paragraph, we decided to solve the problem locally, so that *Δb* could be considered practically constant. In this manner, it was possible to regulate a portion of the two orthophotos by calculating the respective average values of the level of gray. The adopted procedure (figure 2.2.1) consists in defining a band F in the two orthophotos which overlaps the cutting line L, and then dividing it in sections S which have the function to radiometrically correct the level of gray of the images.

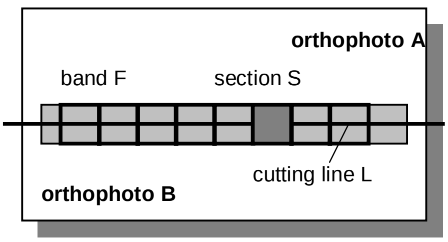

Figure 2.2.1

Every single section S is composed by two subsections Sa and Sb according to the orthophoto portion contained in it (figure 2.2.2).

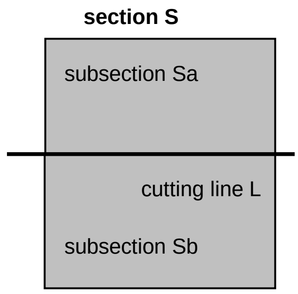

Figure 2.2.2

Once the section S is defined, the average value is calculated according to the levels of gray of the two subsections $\overline{g}_a$ *and* $\overline{g}_b$:

$$\overline{g}_a = \frac{1}{n_i^a n_j^b} \sum_i \sum_j g_{i,j}^a$$

where:
n_i^b is the number of rows of Sa
n_j^a is the number of colums of Sa
$g_{i,j}^a$ is the value (0..255) of the pixel gray-level

thus: $\overline{g}_b = \frac{1}{n_i^b n_j^b} \sum_i \sum_j g_{i,j}^b$

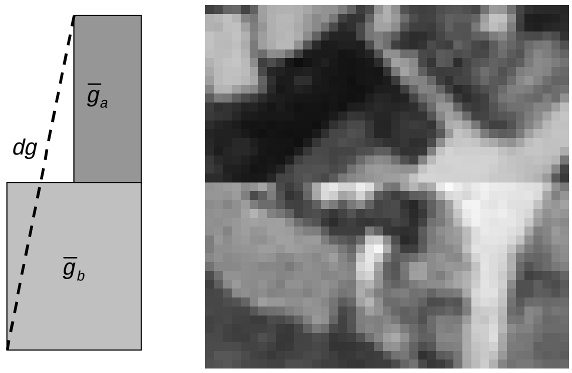

Figure 2.2.3

Therefore, the value of the correction to report at the generic level of gray $g_{i,j}^*$ of the subsection Sa will be:

$$g_{i,j}^{a*} = g_{i,j}^a + dg = g_{i,j}^a + \Delta g\left(\frac{i}{n_i^a}\right) \text{ where: } \Delta g = \frac{\overline{g}_b - \overline{g}_a}{2}$$

thus: $g_{i,j}^{b*} = g_{i,j}^b - \Delta g\left(\frac{i}{n_i^b}\right)$

This procedure allows for the elimination of a large part of the radiometric discrepancies amongst the two subsections, even if (figure 2.2.4b) a residual effect persists, due to the fact that the intervention section is not infinitesimal, and therefore we cannot consider *Δb* constant.

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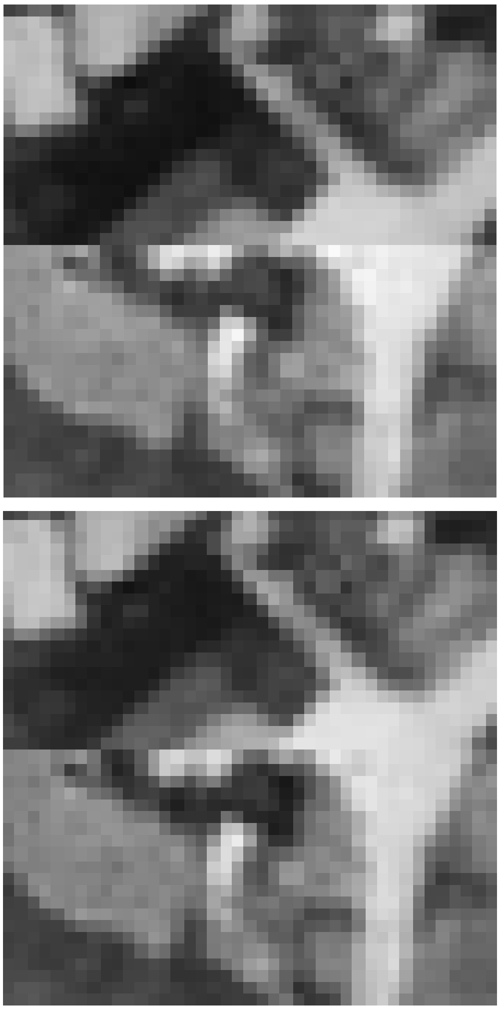

Figure 2.2.4a, b

The methodology to eliminate this residual effect will be described in paragraph 3.
It is important to note that the process of equalization of the images even if, in general, eliminates the radiometric differences orthogonally to the cutting line, also introduces new ones in the longitudinal sense. As a matter of fact, as evident in figure 2.2.5, the radiometric continuity is less evident amongst the contiguous sections (ex. S1 and S2).

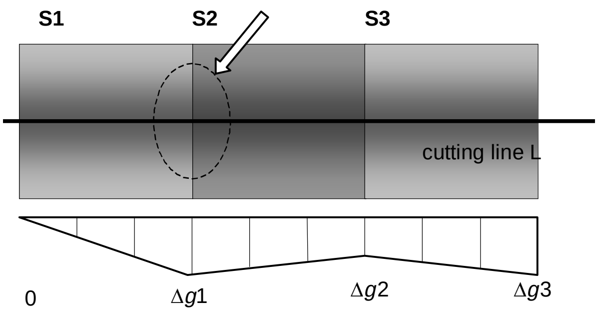

Figure 2.2.5

To eliminate this inconvenience we proceed to another correction of the linear luminosity in the longitudinal sense along all the sections which consist of the intervention phase.

The values of these corrections are: initially 0, and therefore the variation of the level of average gray of the preceeding subsection Δg_{i-1} (figure 2.2.5).

3 ELIMINATION OF THE DISCONTINUITY

3.1 Description of the problem

At the end of the process of transversal and longitudinal compensation, the majority of the radiometric differences amongst the orthophotos are eliminated along the cutting line.
Since the corrections are not of local nature, all those discontinuities present internally at each single section remain unsolved (the left side may be seen in figure 2.2.4b).
Another possibility is evident when the DTM is not reliable, therefore those objects along the cutting line present internally on the orthophotos are not congruent (for example, the road in figure 3.1):

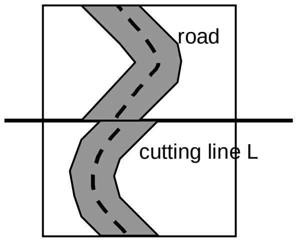

Figure 3.1

If a raster image is considered as a three dimensional surface, where the pixel position *i,j* corresponds to the planimetric coordinates *x,y* and the level of gray *g* of the pixel is represented by the elevation *z,* therefore any type of radiometric discontinuity may be considered as a morphological discontinuity.
Consequently, a method used to eliminate morphological discontinuity can be applied to eliminate radiometric discontinuities.
As previously mentioned, a very flexible method already tested by the authors consists in using the B-Spline surfaces.
These operators must closely smooth the surface only in correspondance to strong gradients, which are the cases where the chromatic attachment intervenes in the presence of significant variations in the level of gray.

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3.2 B-Spline surfaces

The fundamental equation of the B-Spline surfaces is:

$$P(u,w) = \sum_{i=1}^{n+1}\sum_{j=1}^{m+1} B_{i,j} N_{i,k}(u) M_{j,l}(w) \qquad [1]$$

where: $B_{i,j}$ coordinates of the vertices of the control network

$N_{i,k}$ e $M_{j,l}$ base functions of the B-Spline

u, w parametric dimensions

with : $\begin{cases} u_{\min} \le u \le u_{\max} \\ w_{\min} \le w \le w_{\max} \end{cases}$ e $\begin{cases} 2 \le k \le n+1 \\ 2 \le l \le m+1 \end{cases}$

Figure 3.2.1 illustrates in a simple way the significance of the B-Spline surfaces. Given a series of *D* points (which represent in figure 3.2.1 the hull of a ship) we initially calculate a control network *B* which allows for the generation of the B-Spline surface *S*.
It is important to note that the surface does not exactly pass along the points *D(r,s)*, since the number of vertices *B(n,m)* is not sufficient to completely describe them. This characteristic is the base of the method used which applies the least squares principle for the elimination of radiometric discontinuities.

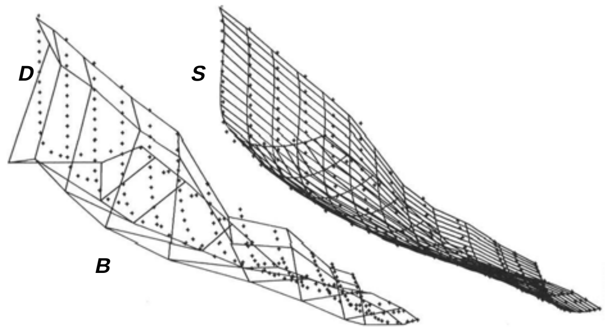

Figure 3.2.1

The most important properties of these surfaces are the following:
- the function *P(u,w)* is a polynomial of degree *k-1, l-1* at every interval $x_i \le t \le x_{i+1}$, $y_j \le t \le y_{j+1}$

- *P(u,w)* and its derivatives of order *1,2, …, k-2, 1, 2, …, l-2* are all continuous along the surface
- the maximum order is the same the number of vertices of the polygon defined by the respective parametric dimensions
- the surface may not vary around a plane which is greater than what is allowed by the polygon (minimium variation)
- in general the surface follows the form of the vertices of the control network
- the surface is always found internally in the convex area of the defined polygons (convex-hull)

The base functions on the other hand are defined in the following manner:

$$N_{i,1}(u) = \begin{cases} 1 & x_i \le u \le x_{i+1} \\ 0 & otherwise \end{cases}$$

$$N_{i,k}(u) = \frac{u - x_i}{x_{i+k-1} - x_i} N_{i,k-1}(u) + \frac{x_{i+k} - u}{x_{i+k} - x_{i+1}} N_{i+1,k-1}(u)$$

$$M_{j,1}(w) = \begin{cases} 1 & y_j \le w \le y_{j+1} \\ 0 & otherwise \end{cases}$$

$$M_{j,l}(w) = \frac{w - y_j}{y_{j+l-1} - y_j} M_{j,l-1}(w) + \frac{y_{j+l} - w}{y_{j+l} - y_{j+1}} M_{j+1,l-1}(w)$$

where u,w are the values along the two parametric directions

$x_i \le u \le x_{i+k} \qquad y_j \le w \le y_{j+l}$

while x_i, y_i are the elements of the vector-nodes: $\begin{cases} x_i \le x_{i+1} \\ y_j \le y_{j+1} \end{cases}$

Figure 3.2.2 shows the typical shape of the basic function of the B-spline of the 4[th] order.

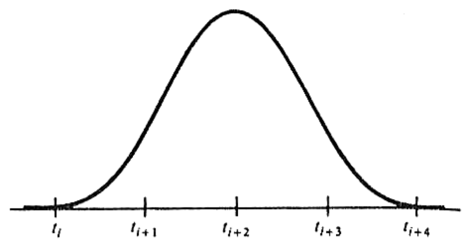

Figure 3.2.2

By developing formula (1) in matrix form it is possible to define a new *C* matrix as:

$$C = \begin{vmatrix}
M_{1,l}(w_1)\sum_{i=1}^{n+1} N_{i,k}(u_1) & M_{2,l}(w_1)\sum_{i=1}^{n+1} N_{i,k}(u_1) & .. & M_{m+1,l}(w_1)\sum_{i=1}^{n+1} N_{i,k}(u_1) \\
M_{1,l}(w_1)\sum_{i=1}^{n+1} N_{i,k}(u_2) & M_{2,l}(w_1)\sum_{i=1}^{n+1} N_{i,k}(u_2) & .. & M_{m+1,l}(w_1)\sum_{i=1}^{n+1} N_{i,k}(u_2) \\
.... & .... & .. & .... \\
M_{1,l}(w_1)\sum_{i=1}^{n+1} N_{i,k}(u_r) & M_{2,l}(w_1)\sum_{i=1}^{n+1} N_{i,k}(u_r) & .. & M_{m+1,l}(w_1)\sum_{i=1}^{n+1} N_{i,k}(u_r) \\
 & & & \\
M_{1,l}(w_s)\sum_{i=1}^{n+1} N_{i,k}(u_1) & M_{2,l}(w_s)\sum_{i=1}^{n+1} N_{i,k}(u_1) & .. & M_{m+1,l}(w_s)\sum_{i=1}^{n+1} N_{i,k}(u_1) \\
M_{1,l}(w_s)\sum_{i=1}^{n+1} N_{i,k}(u_2) & M_{2,l}(w_s)\sum_{i=1}^{n+1} N_{i,k}(u_2) & .. & M_{m+1,l}(w_s)\sum_{i=1}^{n+1} N_{i,k}(u_2) \\
.... & .... & .. & .... \\
M_{1,l}(w_s)\sum_{i=1}^{n+1} N_{i,k}(u_r) & M_{2,l}(w_s)\sum_{i=1}^{n+1} N_{i,k}(u_r) & .. & M_{m+1,l}(w_s)\sum_{i=1}^{n+1} N_{i,k}(u_r)
\end{vmatrix}$$

Therefore formula (1) can be rewritten as:

$$D \doteq CB \qquad [2]$$

where: *D* = matrix of the data points with dimensions *[k, l]*

C = matrix of the basic B-Spline functions with dimensions *[rs, nm]*

B = matrix of the vertices of the control network with dimensions *[nm, 3]*

In the case that the number *nm* of the vertices of the polygon network defined is less than the number *rs* of the data points, the system [2] is inconsistent.

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A possible solution is given by applying the least squares principle:

$$\hat{B} = \left(C^T C\right)^{-1} C^T D$$

$$\Rightarrow \quad \hat{D} = C\hat{B} = C\left(C^T C\right)^{-1} C^T D$$

3.2.1 Research and elimination of the discontinuity

As discussed in the previous paragraph, if the number of vertices of the control network is less than the number of data points, a surface is obtained which does not exactly pass through the initial points but approximates them in the least squares sense. A major deviation will present in correspondance to the points characterized by outliers and by discontinuity. This important property is schematically represented in figures 3.2.1.1 and 3.2.1.2.

If the surface is characterized by an outlyer (D_3) and the number of vertices of the control network is equal to the number of data points (in this case 5) the final surface passes exactly through all the sampled points (figure 3.2.1.1).

If the number of vertices of the control network is less than the number of data points (for ex. 4) the influence on the outlayer (D_3) on the final surface is significantly streamlined.

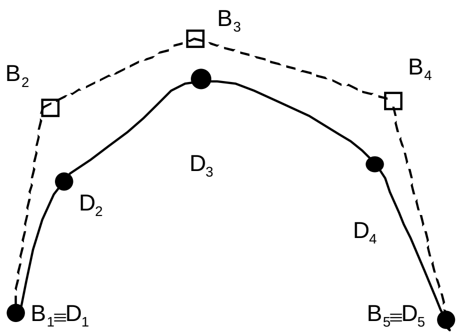

Figure3.2.1.1

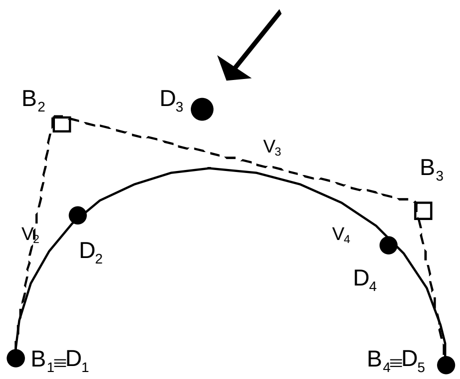

Figure 3.2.1.2

This method may be considered substantially robust in that the local control of the *B*-spine surface, contrary to what occurs by exclusively applying the least squares principle, does not allow these points to influence the others over a certain distance (Rogers and Adams, 1990).

3.3 Using B-Spline for the elimination of radiometric discontinuities

The basic principle of the method consists in considering a raster image as a tridimensional surface where *x, y* define the position of the pixel in the image while z is the radiometric value of the same pixel (figure 3.3.1).

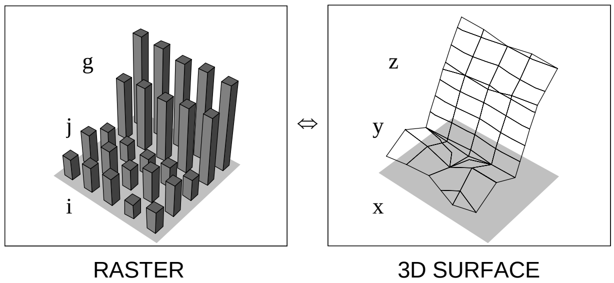

Figure 3.3.1

In this manner, considering the analogy *raster–3D surface* it is possible to correct the radiometric discontinuities of an image via the B-Spline surface (figure 3.3.2).

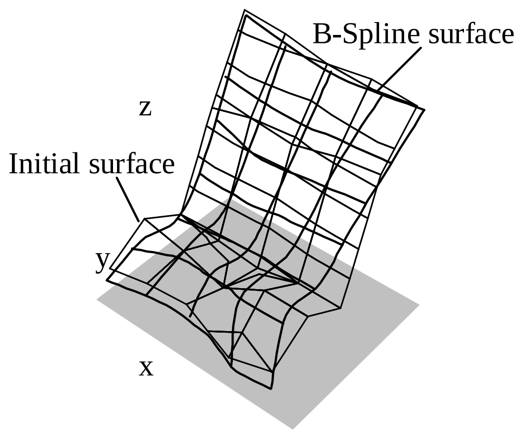

Figure 3.3.2

An analogy which allows one to understand the principle behind the method is to consider the B-Spline surface as a low-pass filter, in which all the higher frequencies (variations of gray in the image) are eliminated.

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3.4 Description of the algorithm

Initially the intervention band is subdivided into areas in which the image is regulated via B-Spline surfaces (figure 3.4.1). Different from the previous phase, this area will have a fewer number of pixels since the generation of B-Spline surfaces requires the inversion of a matrix (it is very costly at the computational level). Furthermore, this type of operation must intervene only in proximity of the cutting line.

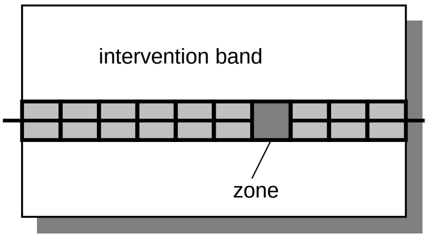

Figure 3.4.1

Once the areas requiring intervention are defined, one may proceed to the elimination of the radiometric discontinuity via B-Spline surfaces. In order to further refine this phase it was decided to introduce the following conditions:

1. Weigh those areas closest to the cutting line in an inversely proportional mode to the distance (figure 3.4.2).

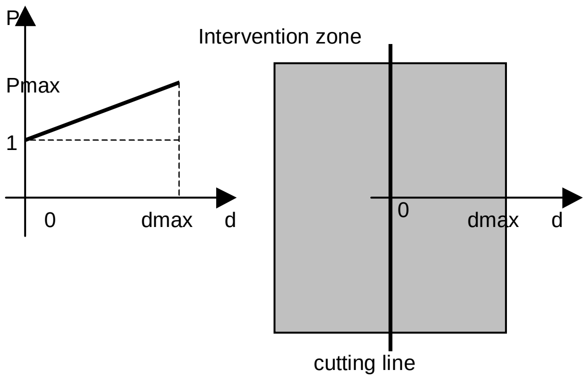

Figure 3.4.2

2. Use along the direction of the cutting line a number of vertices for the control network (*n, m)* equal to the number of data points (*r, s).* In this manner the “fitting” occurs exclusively in the orthogonal direction to the cutting line, consequently only those discontinuities lying perpendicular are eliminated.
 Therefore if:
 n, m are the vertices of the control network of the B-Spline surface and *r, s* are the numbers of data points (number of pixels in the image).
 Then:

$$\begin{cases} n = r \\ m = c \cdot s \end{cases}$$

where the coefficient *c=0.5÷0.7*
This assumption is outlined in figure 3.4.3:

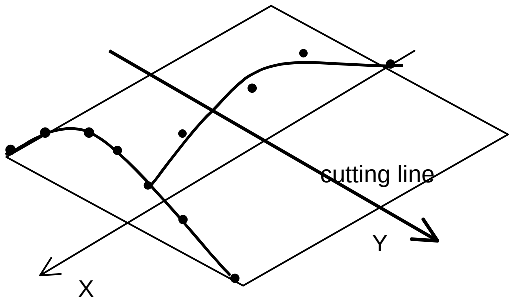

Figure 3.4.3

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4 SOME EXAMPLES

The following illustrates various results obtained using the algorithms previously discussed.
Figure 4.1 represents the initial condition of a portion of the area of attachment amongst two orthophotos.
It is important to note how the radiometric differences along the cutting line are not uniform, but vary from area to area. For example it is simple to dispute how the extreme ends present a difference in luminosity Δb less than the central area.

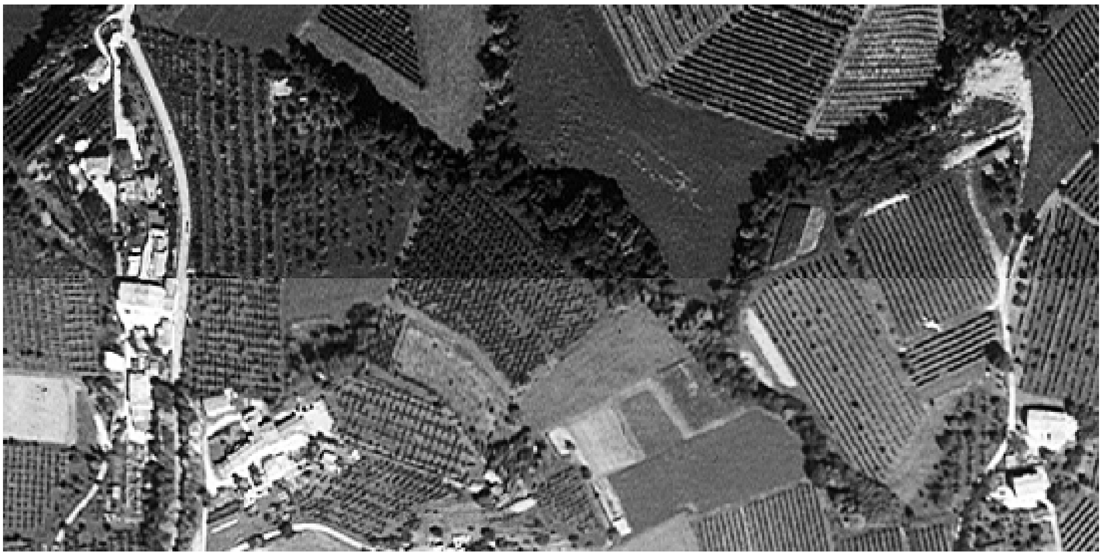

Figure 4.1

Figure 4.2 represents the final result, obtained initially along the adjusting phase of the images, followed by the elimination of the radiometric discontinuities.

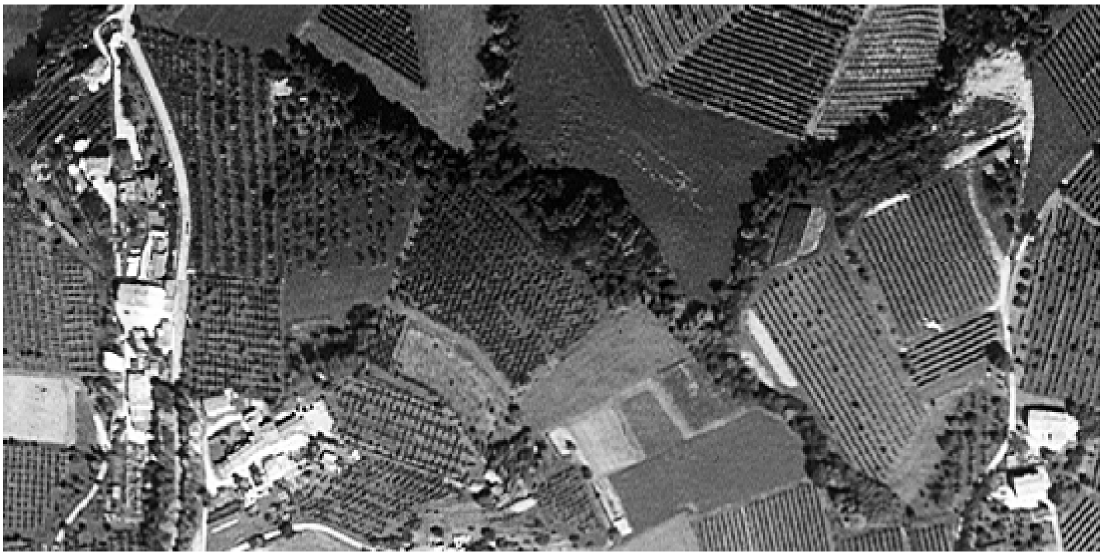

Figure 4.2

These images are characterized by : photogram scale 1:18000 and resolution 1200 dpi (pixel $\cong$ 21μm)
The test characteristics are:
1. Section size (see fig. 2.2.1): height =200, width =20 pixels
2. Zone size (see figure 3.4.1): height =20, width =20 pixels
3. B-Spline parameters (see paragraph 3.2.1): k=3, l=2, n=m=14, r=s=20 pixels

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In the following figures 4.3 and 4.4 the same details of both figures are reported (scale factor 4:1), in order to highlight the potentiality of the method proposed.

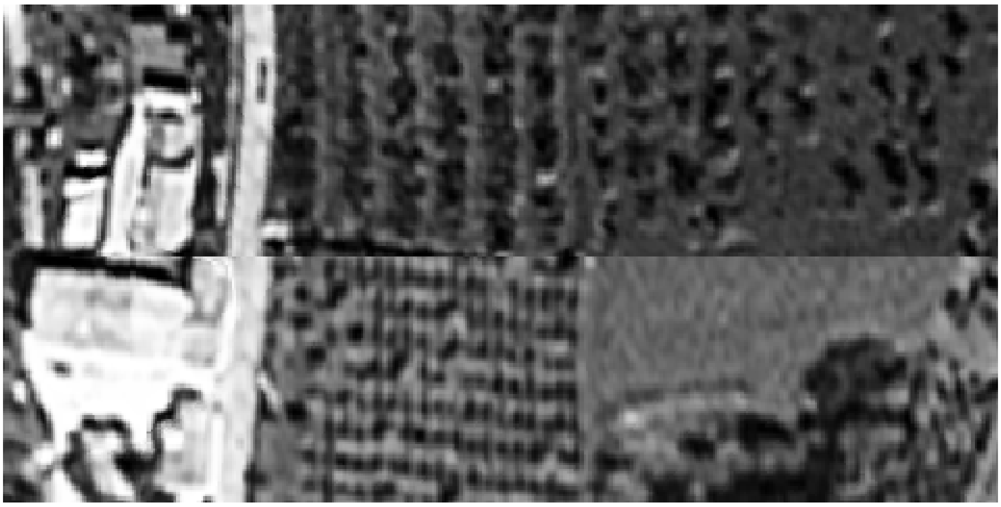

Figure 4.3

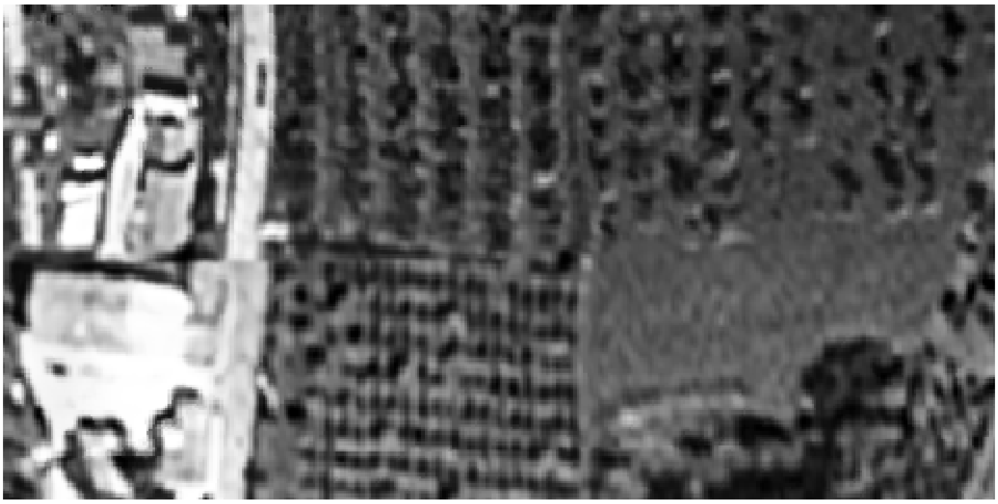

Figure 4.4

4 CONCLUSIONS

The method discussed in this paper proves to be particularly useful to solve those problems associated with the chromatic attachment of the orthophotos. The procedure foresees the use of two intervention phases for the elimination of the differences in luminosity amongst the images followed by radiometric regulation of the same. The examples reveals the potentiality of the proposed method.

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