ARTIGO TÉCNICO

ÁREA: PROCESSAMENTO DE IMAGENS: SENSORIAMENTO REMOTO

MORPHOLOGICAL FILTERING FOR STRIPPING CORRECTION OF SPOT IMAGES

Gerald Jean Francis Banon
Junior Barrera

Ministério da Ciência e Tecnologia - MCT
Instituto de Pesquisas Espaciais - INPE
Caixa Postal 515 - 12201 - São José dos Campos - SP - Brasil

ABSTRACT

The objective of this paper is to show how a sequence of elementary morphological filtering operations can lead to the correction of the stripping effect present on some level 2B SPOT images.

The basic idea employed is to design the morphological filter using as a priori modeling of the stripes. The overall algorithm is divided in three steps. A binary image showing the high frequencies in the vertical direction is first obtained. Another binary image is then deduced which indicates the location of the stripes. Finally, the corrected image is obtained by morphological interpolation.

The effect of each processing step is illustrated from an original image of the Porto Alegre city corrupted by the stripes.

1 - INTRODUCTION

The panchromatic band and the spectral band 2 from the HRV2 ("Haute Resolution Visible") instrument of the "Satellite Pour l'Observation de la Terre" (SPOT) present some stripping effects. On the level 1A images this stripping effect is precisely vertical. On the level 2B images (see photo 1) this effect produces almost vertical straight lines, because of geometric correction.

The objective of this paper is to propose an algorithm to eliminate the stripping effect without changing the relevant information of the image. To reach this goal we have chosen a nonlinear approach: Mathematical Morphology. Traditionally restoration has been performed using linear approaches, like filtering in the Fourier Transform domain, or linear optimization by vector space methods (Andrews & Hunt, 1977).

Mathematical Morphology is a tool to deal with signal processing that explores the geometrical properties of the signals. It was created originally to extract morphological parameters from binary images (Serra, 1982) and since then its scope has grown. The theory has been extended to deal with gray scale images (Sternberg, 1986) and several applications in image enhancement, edge detection and coding have been proposed (Maragos & Schafer, 1986). New results (Maragos, 1987) show that morphological filters (i.e functionals) form a general class which includes linear and some well-known nonlinear filters as special cases (Maragos & Schafer, 1987 a-b).

The beauty and the simplicity of Mathematical Morphology approach come from the fact that a large class of filters can be represented as the combination of two simple operations on functions: erosion and dilation (Matheron, 1975; Maragos, 1987).

Let F the set of the real valued functions of Z^2 with range [0,1] and $f \in F$. Let B be a finite subset of Z^2, called structural element, and let B_x represent the translation of B by the vector x of Z^2, then the operation of erosion of f by B is the new function of F denoted by $f \ominus B^s$ and defined for any x of Z^2 as:

$$(f \ominus B^s)(x) = \min_{y \in B_x}\{f(y)\}.$$

In the same way, the operation of dilation of f by B is the new function of F denoted by $F \oplus B^s$ and defined for any x of Z^2 as:

$$(f \oplus B^s)(x) = \max_{y \in B_x}\{f(y)\}.$$

Actually $\ominus$ and $\oplus$ are the Minkowski subtraction and addition (Minkowski, 1903), and B^s is the set $\{x \in Z^2 : -x \in B\}$.

The elements of F will be seen as images formed along raws and columns, where the point $x = (x_1,x_2) \in Z^2$ is localized at column x_1 and raw x_2. The set Z^2 is chosen as domain for the images to avoid the problem of defining the local behavior of the filters at the image frontiers.

In this paper the structural element B will always be a subset of the set:

$\{(-1,1),(0,1),(1,1),(-1,0),(0,0),(1,0),(-1,-1),(0,-1),(1,-1)\}$ i.e., the 3x3 "square" centred at the origin.

Such a subset will be denoted in the form of a 3x3 matrix whose elements are "." or "1".

For example the structural element $B = \{(0,0),(-1,-1),(0,-1),(1,-1)\}$ will be written in the form $\begin{matrix}\cdot\cdot\cdot\\ \cdot 1 \cdot\\ 111\end{matrix}$ and the result of erosion and dilation of f by B written:

$$f \ominus \begin{matrix}\cdot 1 \cdot\\ 111\\ \cdot\cdot\cdot\end{matrix} \qquad \text{and} \qquad f \oplus \begin{matrix}\cdot 1 \cdot\\ 111\\ \cdot\cdot\cdot\end{matrix},$$

respectively.

Under the Mathematical Morphology point of view, to build a specific filter consists of finding an adequate combination of erosions and dilations. The problem is that there is no a priori technique to find a good combination of elementar operations.

What we have done here is to design a morphological filter (a sequence of erosions and dilations) in order to eliminate the stripping effect on SPOT images. The basic idea employed has been to design the morphological filter using a priori modeling of this effect. The overall algorithm is divided into three steps:

a) extraction of high frequencies in the vertical direction;

b) filtering of the detected high frequencies in order to identify the stripes;

c) morphological interpolation at the points identified as part of the stripes.

2 - MORPHOLOGICAL MODEL OF THE STRIPPING EFFECT

From the original 1B level SPOT image (see photo 1) one can extract some elementary properties of the stripping effect. In terms of radiometric aspects, the stripping effect appears as a positive variation of brightness superposed upon the scene details.

In terms of geometrical aspects the stripes are one pixel large, almost vertical straight lines, which slope lightly smaller than 90^{o}. Because of the digital nature of the image, these lines are represented as short adjacent vertical segments, which are formed by more than six pixels. More precisely, let f_1 be the binary function, with range $\{0,1\}$, indicating the presence of stripes in the image, then the lower (respectively upper) extremities of those adjacent segments are the points for which the binary function $f_1 - f_1 \ominus \begin{smallmatrix} \cdot & \cdot & \cdot \\ \cdot & 1 & \cdot \\ 1 & \cdot & \cdot \end{smallmatrix}$ (respectively $f_1 - f_1 \ominus \begin{smallmatrix} \cdot & \cdot & 1 \\ \cdot & 1 & \cdot \\ \cdot & \cdot & \cdot \end{smallmatrix}$) are one.

Finally, from the original image (see photo 1) one can observe that, neglecting noise effect, the stripes differ from each other by a translation of an almost constant vector.

Due to the presence of noise, some of these segments may appear subdivided into shorter segments with less than six pixels.

3 - MORPHOLOGICAL FILTERING

Let $\sim$ be the complementary operation on functions of F: $\forall\ f \in F$ and $x \in Z^2$:

$$(\sim f)(x) = 1 - f(x).$$

Let $-$, $\circeq$, $\not\circeq$, $\wedge$ e $\vee$ be the following binary operations on functions of F: $\forall\ f_1, f_2 \in F$ and $x \in Z^2$:

$$(f_1 - f_2)(x) = f_1(x) - f_2(x)\ ,$$

$$(f_1 \circeq f_2)(x) = \begin{cases} 1 \text{ if } f_1(x) = f_2(x), \\ 0 \text{ if not} \end{cases}$$

$$(f_1 \not\circeq f_2)(x) = (\sim f_1 \circeq f_2)\ (x)\ ,$$

$$(f_1 \wedge f_2)(x) = \min(f_1(x), f_2(x)),$$

$$(f_1 \vee f_2)(x) = \max(f_1(x), f_2(x)).$$

Let denote by the function f the original image presenting the stripping effect (see photo 1).

The overall filtering algorithm is devided into the following three steps.

Step one consists of transforming the original gray scale image into a binary image, showing the nonhorizontal edges. The horizontal high frequencies are first extracted from the original image f, leading to the gray scaled image g_1 (see photo 2):

$$g_1 = f - f \ominus \begin{smallmatrix} \cdot & \cdot & \cdot \\ 1 & 1 & 1 \\ \cdot & \cdot & \cdot \end{smallmatrix} .$$

Positive one pixel large horizontal peaks in g_1 are then selected to form the binary image g_1 (see photo 3):

$$g_2 = ((g_1 \oplus \begin{smallmatrix} \cdot & \cdot & \cdot \\ 1 & 1 & 1 \\ \cdot & \cdot & \cdot \end{smallmatrix}) \mathbin{\text{⊜}} g_1) \wedge ((g_1 \ominus \begin{smallmatrix} \cdot & \cdot & \cdot \\ 1 & \cdot & \cdot \\ \cdot & \cdot & \cdot \end{smallmatrix}) \mathbin{\not\text{⊜}} g_1) \wedge ((g_1 \ominus \begin{smallmatrix} \cdot & \cdot & \cdot \\ \cdot & \cdot & 1 \\ \cdot & \cdot & \cdot \end{smallmatrix}) \mathbin{\not\text{⊜}} g_1).$$

In other terms $\forall\ x = (x_1,x_2) \in Z^2$:

$$g_2(x) = g_2(x_1,x_2) = \begin{cases} 1 \text{ if } g_1(x_1+1, x_2) \text{ and } g(x_1-1, x_2) \text{ are } < g_1(x_1,x_2) \\ 0 \text{ if not} \end{cases}$$

The above filtering guarantees that g_2 does not contain any horizontal segment.

Step two consists of isolating the stripping effect from the binary image obtained in step one. The linear segments with slope at 45^o and 135^o in g are first delect, leaging to the binary image g_3 (see photo 4):

$$g_3 = g_2 - ((g_2 \ominus \begin{smallmatrix} \cdot & \cdot & 1 \\ \cdot & 1 & \cdot \\ \cdot & \cdot & \cdot \end{smallmatrix}) \vee (g_2 \ominus \begin{smallmatrix} \cdot & \cdot & \cdot \\ \cdot & 1 & \cdot \\ 1 & \cdot & \cdot \end{smallmatrix}) \vee (g_2 \ominus \begin{smallmatrix} 1 & \cdot & \cdot \\ \cdot & 1 & \cdot \\ \cdot & \cdot & \cdot \end{smallmatrix}) \vee (g_2 \ominus \begin{smallmatrix} \cdot & \cdot & \cdot \\ \cdot & 1 & \cdot \\ \cdot & \cdot & 1 \end{smallmatrix})).$$

With this procedure the vertical segments in g_2 are preserved in g_3. However the extremities of adjacent segments are last.

The isolated points and the extremity points of vertical segments not far from the others by more then two pixels in g_3 are then joined together to form the binary image g_4:

$$g_4 = (g_3 \oplus \begin{smallmatrix} \cdot & 1 & \cdot \\ \cdot & 1 & \cdot \\ \cdot & 1 & \cdot \end{smallmatrix}) \ominus \begin{smallmatrix} \cdot & 1 & \cdot \\ \cdot & 1 & \cdot \\ \cdot & 1 & \cdot \end{smallmatrix} .$$

The image g_4 is called the "closing" of g_5.

The short (formed by less then 7 pixels) vertical segments are then eliminated from g_4, leading to the binary image g_5 (see photo 5):

$$g_5 = (g_4 \ominus 3 \begin{smallmatrix} \cdot & 1 & \cdot \\ \cdot & 1 & \cdot \\ \cdot & 1 & \cdot \end{smallmatrix}) \oplus 3 \begin{smallmatrix} \cdot & 1 & \cdot \\ \cdot & 1 & \cdot \\ \cdot & 1 & \cdot \end{smallmatrix} .$$

The image g_5 is called the "opening" of g_4. The previous operation eliminates the short small segments that do not belong to the stripes, but also eliminates the stripe segments corrupted by noise, those which are subdivided into segments with less than six pixels. These segments are recovered by a sequence of dilations and an intersection with g_3, leading to g_6:

$$g_6 = (g_3 \wedge ((g_5 \oplus 5 \begin{matrix} \cdot 1 \cdot \\ \cdot 1 \cdot \\ \cdot 1 \cdot \end{matrix}) \oplus \begin{matrix} 111 \\ 111 \\ 111 \end{matrix}).$$

The last dilation by $\begin{matrix} 111 \\ 111 \\ 111 \end{matrix}$ is necessary to recover these segments which are totally lost in g_5, but have adjacent segments preserved.

To recover the extremities points of the segments lost in g_3, one more dilation is done, leading to g_7 (see photo 6):

$$g_7 = g_6 \oplus \begin{matrix} \cdot 1 \cdot \\ \cdot 1 \cdot \\ \cdot 1 \cdot \end{matrix} \quad .$$

At this stage the points x, such that $g_7(x)$, is one, should be points of the stripes only. On the other hand, all the points x belonging to the stripes should be such that $g_7(x)$ is one. In other words g_7 can be seen as a binary mask that identifies the pixels of the original image that must be corrected.

In step three a radiometric correction procedure is applied to the points of the binary mask g_7. This procedure consists of a morphological interpolation from the radiometric values of the original image f. The interpolated image f' (see photo 7) is given by:

$$f' = (f \wedge \sim g_7) \vee ((f \ominus \begin{matrix} \cdots \\ 111 \\ \cdots \end{matrix}) \wedge g_7).$$

In other terms $\forall\ x = (x_1, x_2) \in Z^2$:

$$f'(x) = \begin{cases} f(x) \text{ if } g_7(x) = 0 \\ \min(f(x_1-1,x_2),\ f(x_1,x_2),\ f(x_1+1,x_2) \text{ if } g_7(x) = 1, \\ \quad \text{if } g_7(x) = 1, \end{cases}$$

i.e., the minimum radiometric value of the immediately left and right points is used to correct the image at a stripe point.

4 - ILLUSTRATIVE EXAMPLE

The original image f (see photo 1) shows a small part of Porto Alegre (Rio Grande do Sul State - Brazil) obtained from the HRV2 instrument of the SPOT. This digital image is a 256x256 gray scale representation of band 2 level 2B. One can observe in it the stripping effect.

The g_1 image (see photo 2) shows the horizontal high frequencies contained in f. The vertical edges, and in particular the stripes, are enhanced.

The g_2 binary image (see photo 3) shows the positive one pixel large horizontal peaks contained in g_1. One can observe the great density of such peaks in all image and in particular above the city.

The g_3 binary image (see photo 4) shows the result of the nonvertical segments elimination in g_2. One can observe that g_3 contains only vertical segments. The greater segments are part of the stripes.

The g_5 binary image (see photo 5) shows the greater segments contained in the closing of g_3.

The g_7 binary image (see photo 6) shows the final stage of the binary mask creation. One can recognize the geometric aspects of the stripe described in Section 2.

The f' gray scale image (see photo 7) which is the result of a morphological interpolation, of f at the pixels given in g_7, shows how the stripping effect has been reduced.

In order to visually evaluate the performances obtained by using the previous sequences of morphological operations, the original image f has also been filtered by a simple opening procedure, leading to the gray scale image f" (see photo 8):

$$f'' = \left(f \ominus \begin{matrix}\cdots\\ 111\\ \cdots\end{matrix}\right) \oplus \begin{matrix}\cdots\\ 111\\ \cdots\end{matrix} \quad .$$

The opening procedure acts as an oriented low pass filter. Similar behavior could also be obtained by other linear or nonlinear filters, such as the mean or median filters.

Looking at photos 7 and 8, one can observe that in spite of not reducing so well the stripping effect, a lot of small details on the original scene lost in f" are still present in f' (see for example the city part of the image, or the bright pixel appearing at the lower right part of the small island close to the Porto Alegre harbour).

All the above morphological filters have been run using the ANIMA system developped at INPE (Dutra et alii, 1987).

5 - CONCLUSION

The correction of the stripping effect in 2B level SPOT image as it has been done here is certainly much more complicated than it would be in the case of the correction of 1A level SPOT image. In the latter case the stripes are strictly vertical, i.e. take place along column, and the resulting procedure to correct the image should be simpler and consequently will lend to better results. In the proposed filter, the a priori information that the stripes differ from each other by translation has not been used. Taking this property into account will probably improves the quality of the resulting image.

All the elementary steps used here to correct the stripping effect are based on nonlinear operations. Actually, other traditional approaches could be used to solve the same problem. For example, the stripping effect could be corrected by removing typical peaks in the Fourier transform module image

(Moik, 1980). The originality of the morphological approach comes from the fact that a unified tool is used to solve a large class of problems, just by combining simple operations that are well-adapted to be implemented on parallel processors.

At the present time the main difficulty is to find the right way to combine those simple operations. This work, based on a goal oriented design method, is an example of how to design morphological filters.

In the interpolation procedure the minimum value between the left and right neighbour of a point at a stripe location is used to correct the image. This choice guarantees that repeating the filtering scheme, no more stripes will be found where they were corrected. Another kind of interpolation as the mean on the median will not guarantee this property.

Another interesting feature of the proposed filter is that it appears as an adaptative filter, which has been built through elementary filters that do not have this property.

6 - REFERENCES

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AGRADECIMENTOS

Este trabalho teve o apoio financeiro da Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) e da SID Informática através do projeto ESTRA.

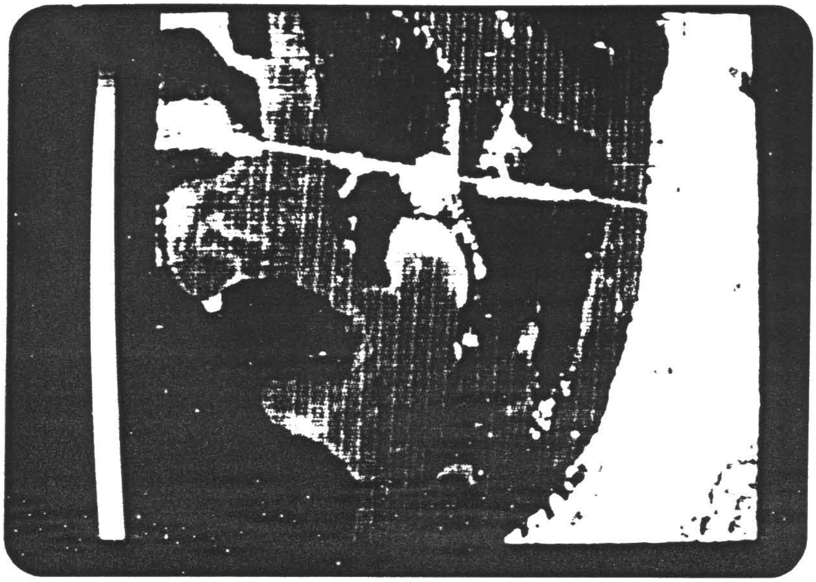

Photo 1 - Gray scale original image (f) of Porto Alegre City (Brazil) obtained from the HRV2 instrument of the SPOT (Band 2 level 2B).

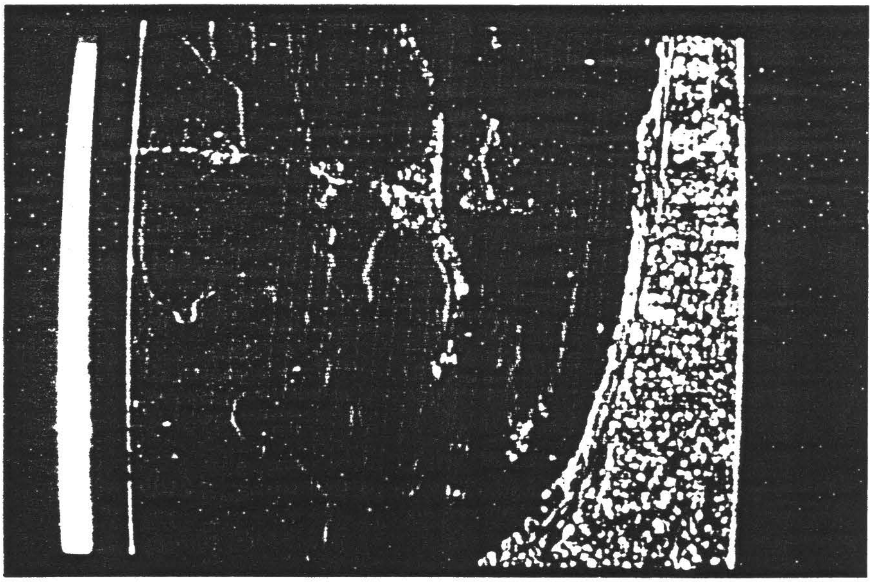

Photo 2 - Gray scale image (g_1) showing the horizontal high frequencies extraction from the original image.

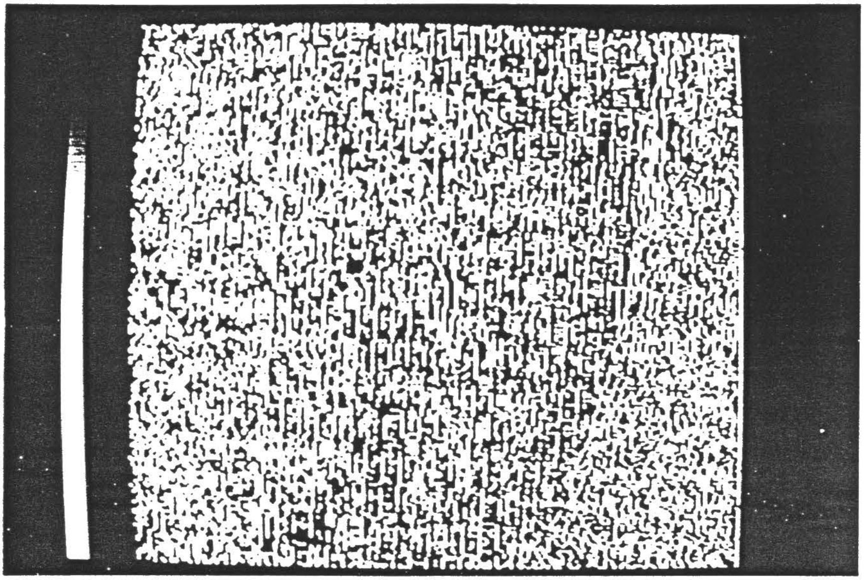

Photo 3 - Binary image (g_2) formed by the one pixel large horizontal peaks detected in the image of photo 2.

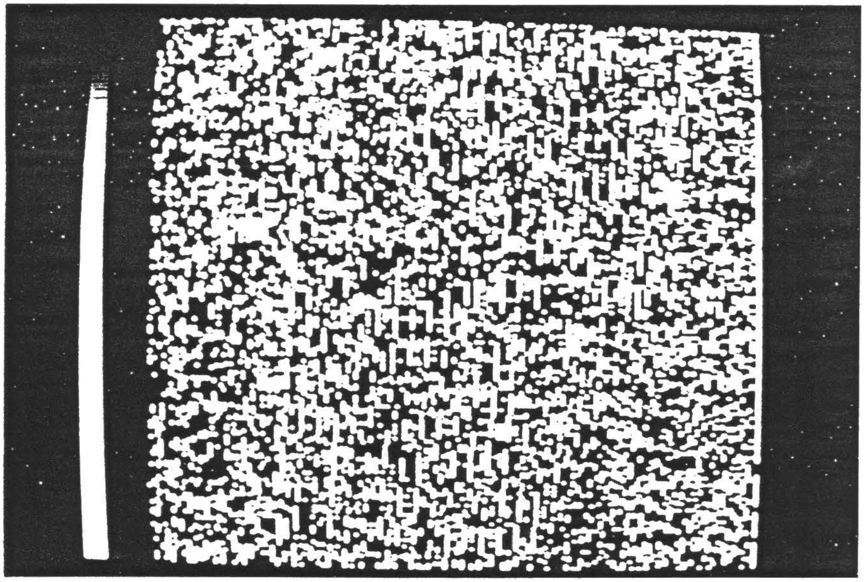

Photo 4 - Binary image (g_3) obtained by the elimination of non-vertical segments in the image of photo 3.

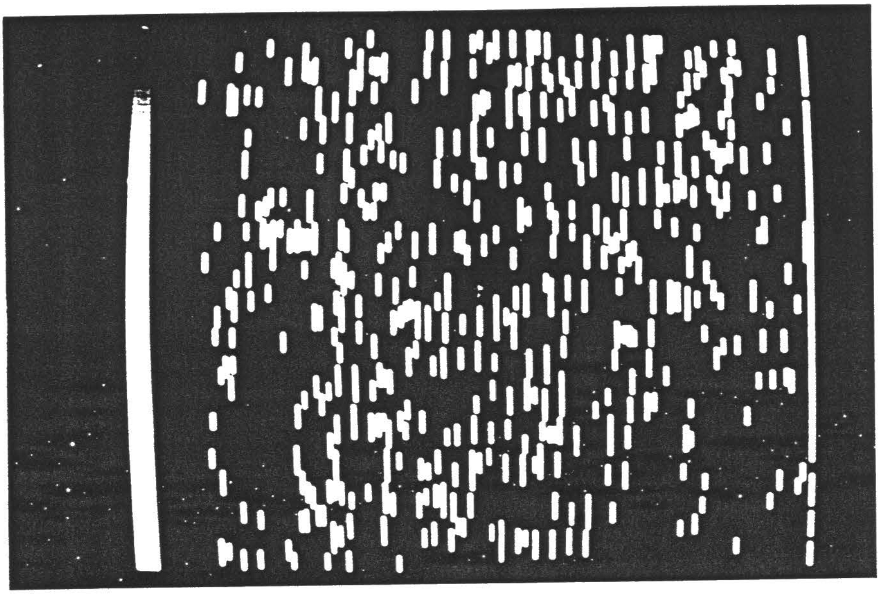

Photo 5 - Binary image (g_5) formed by the elimination of short segments in the image of photo 4.

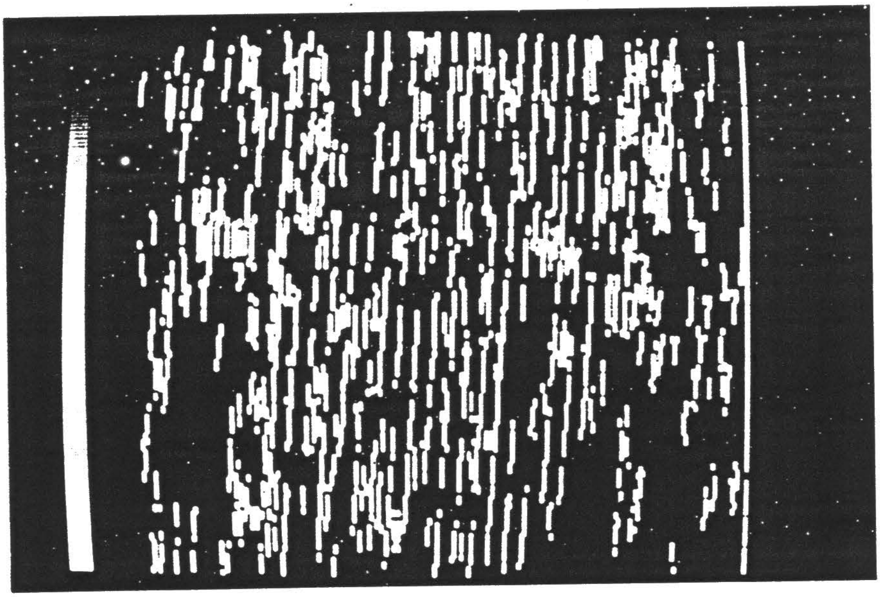

Photo 6 - Binary image (g_7) that identifies the pixels of the original image that must be corrected.

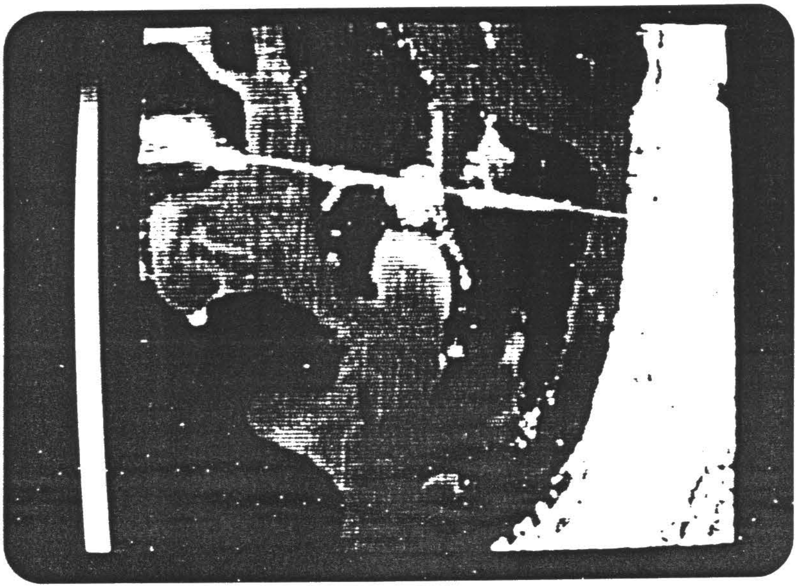

Photo 7 - Restored image (f') by the proposed morphological procedure.

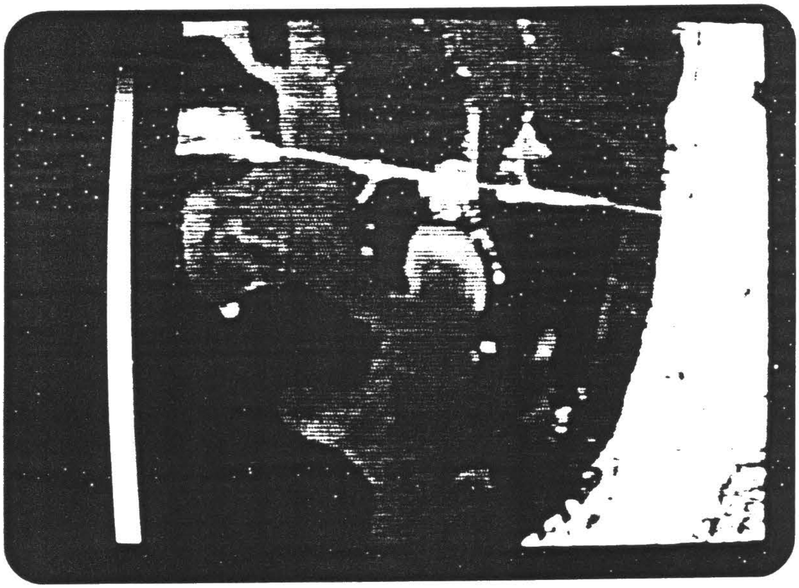

Photo 8 - Restored image (f") by a neighbourhood filter (horizontal opening).