XIV CONGRESS OF THE INTERNATIONAL SOCIETY FOR PHOTOGRAMMETRY

HAMBURG 1980

COMMISSION III WORKING GROUP 2

Presented Paper

FILTER TECHNIQUES AND THEIR APPLICATION IN DIGITAL CORRELATION

by

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Summary

Filter techniques for noise reduction and amplification of desired information are of great importance in digital image analysis. Two-dimensional filter theory is shortly presented. The effects of some designed filters are described. The results of digital correlation after image filtering are compared to those received without filtering. It is shown that especially a low pass filter increases exactness and efficiency of the objective function at the correlation process in a high degree.

1. Introduction

Remote sensing images of the earth's surface become a more and more indispensable data material for the research in various geoscience disciplines because of their great information contents. For a long while the photogrammetry has been using conventional aerial photographs taken by aircrafts for their purposes. New remote sensing systems (satellites) and sensors (multispectral line scanners, radar) enlarged tasks and chances of the photogrammetry in the recent years.
Lately it led to an extra branch of knowledge, the remote sensing.
This topic is studied by several projects of the Sonderforschungsbereich (SFB) 149 "Surveying and Remote Sensing Methods at Coasts and Oceans" at the University of Hannover. The test areas are the tidal zones of the North Sea near Wilhelmshaven. Because of the increasing "flood of data" and the partly even digital working remote sensing recorders the SFB 149 has installed an image processing system for analog/digital transformation and further digital image evaluation.(1)

For the purpose of rectification, change detection and classification in multitemporal pictures it is necessary to find out identical points in different images of the same object. One way leading to this is the application of similarity or correlation algorithms. A great number of them is described in (2). The preceding digital filtering is one effort to increase exactness and quality of the correlation process.

2. Fundamentals

2.1. Objective functions

Search and reference image for the correlation process are digitized in the range [0.255]. Two objective functions to detect identical points in both images are implemented in the correlation process:

a) the "normal" product moment correlation coefficient $r(\Delta x,\Delta y)$ with values between -1 and +1,

b) the correlation intensity coefficient $I(\Delta x,\Delta y)$ with the limits 0 and +1, which was derived from coherent optical considerations. The image signal is mapped on the complex plane and the intensity of the complex correlation function is computed.

The shift vector $(\Delta x,\Delta y)$ of the maximum of both fuctions gives the most probable position of a control point of the reference image in the search image.(2)(3)

2.2. Filter theory

In general filters are applied to separate desired from undesired information. The original ground signal g is distorted by several influences caused by atmospheric conditions, recording systems and analog/digital transformations. These distortions lead to a falsified image signal s:

$$s = A(g).$$

Thereby the operator A represents the sum of all distortion influences. An ideal filter F on the other side is an operator which restores the original signal g

$$g = F(s).$$

Because of the sampling theorem an entire signal restortion is not possible. Hence such an ideal filter F is not constructible. Therefore it is necessary to design various filters F_i for different aims (e.g. low pass filters for noise reduction)

$$s_i' = F_i(s)$$

A filter F is called linear if

$$F(c\cdot s_1+s_2) = c\,F(s_1) + F(s_2)$$

for an arbitrary constant c. Furthermore if

$$s'(x-x_0,\ y-y_0) = F(s(x-x_0,\ y-y_0))$$

for arbitrary x_0,y_0 the filter is called shift-invariant.
A linear filter could be described in the spatial domain by its unit pulse response.(4) If its unit impulse response is finite, we call the filter nonrecursiv.

Filters with the above mentioned restrictions are sufficient for our aims. They are easier to design and show no stability problems. A general view of filter techniques give Huang et al. in (5).

2.3. Filtering in the spatial and frequency domain

Linear nonrecursive filtering could be carried out in two ways: either in the spatial or in the frequency domain. In the first case the filtering of an image s(x,y) with a filter function f(u,v) leads to a two-dimensional convolution:

$$s'(x,y) = f*s = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(u,v)\, s(x-u,y-v)\,du\,dv \qquad (6)$$

With digital image data S(i,j) the filter function f changes to a filtermatrix F and integration to summation. Thus the equation becomes

$$S'(i,j) = F*S = \sum_{m}\sum_{n} F(m,n)S(i-m,j-n) \qquad (4)(6)$$

From a certain size of the filter matrix it is more time-saving to carry out the filtering in the frequency domain because convolution in the spatial domain corresponds to a multiplication in the frequency domain. For that purpose a Fourier transform (FT) transmits picture and filter in the frequency domain. Fig.1 shows the connexions between filtering in both regions.

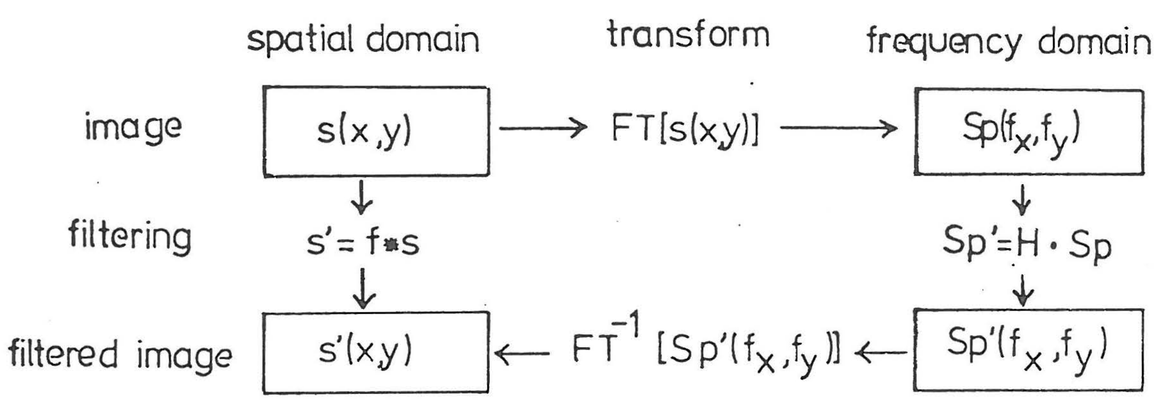


Fig.1: Filtering in the spatial and frequency domain

A filter process in the frequency domain needs three FTs: at first image and filter are transformed, then the image must be re-transformed. On the other hand in most cases filtering in the spatial regime also requires an image transform to design an optimal filter with respect to a spectral analysis of the picture. In the following the latter method has been used.

3. Picture pre-processing

3.1. Spectral analysis

Tidal lands differ from almost all continental areas because of their homogeneous structure (2). It therefore is not surprising that the spectrum of their photographs shows informations that are worth mentioning only in a small band of low frequencies. Fig.2 presents 8 corresponding sections of two overlapping aerial photographs (RMK) of wet zones and their power spectra. The size of one digitized section is 128x128 picture elements (pixel). The sampling rate was Δx = 100 µm and the Nyquistfrequency was computed to

$$f_N = \frac{1}{2\Delta x} = 5 \text{ lp/mm.}$$

The original scale of the photograph is 1:2000.

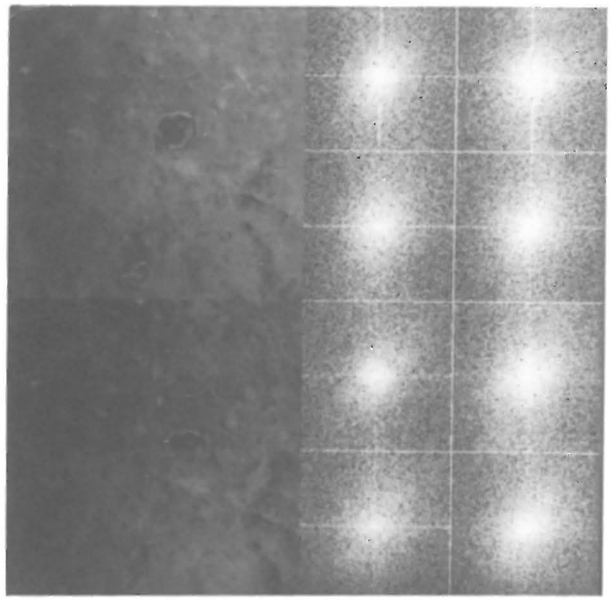


Fig.2: Aerial photographs of tidal lands and their power spectra

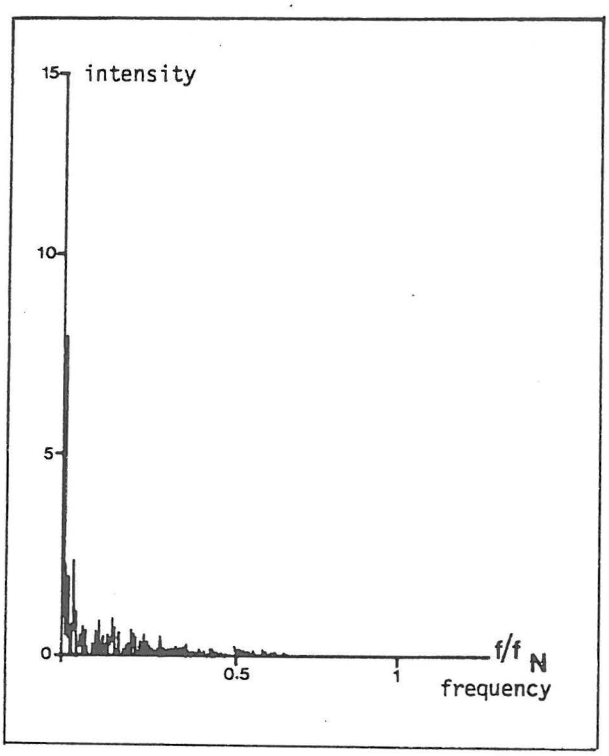


Fig.3: Onedimensional power spectrum

To make it clearer Fig.3 shows a onedimensional spectrum cut. The frequencies were normalized by the Nyquistfrequency and the signal mean was substracted before the FT was done. That means that the high amplitude of the zerofrequency was set to zero. In the high frequency range only little intensity exists. Information and noise hardly can be separated.

3.2. Filter design

Starting from the spectral analysis three different filters are designed: a low pass, a band pass (with emphasis on the middle down to the low frequencies) and a high pass filter. Thereby we worked with a method presented in (4). We chose the curve of onedimensional filter transfer function, made it twodimensional by rotation and transformed it into a filter matrix by an inverse FT. The computations for that have been done by the image processing system DIBIAS of the German Space Center DFVLR in Oberpfaffenhofen.
Fig.4-6 show the transfer functions of the selected filters.

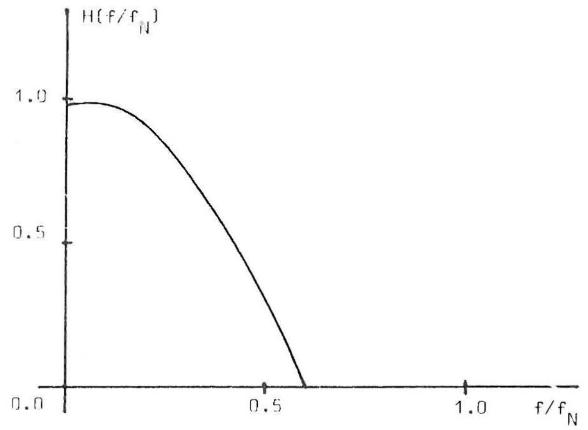


Fig.4: Transfer function/low pass filter

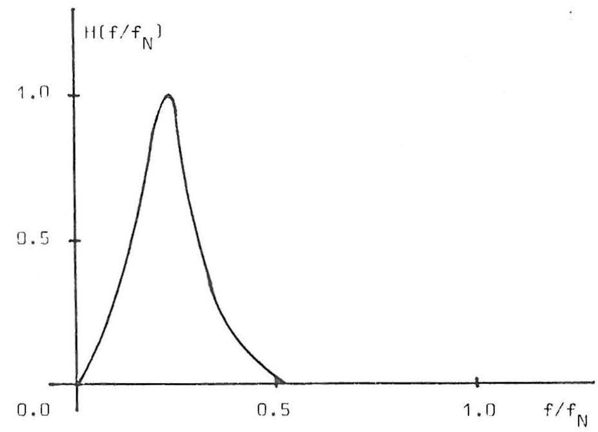


Fig.5: Transfer function/band pass filter

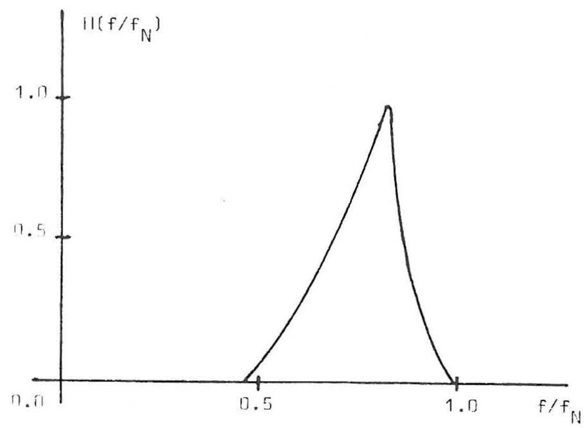
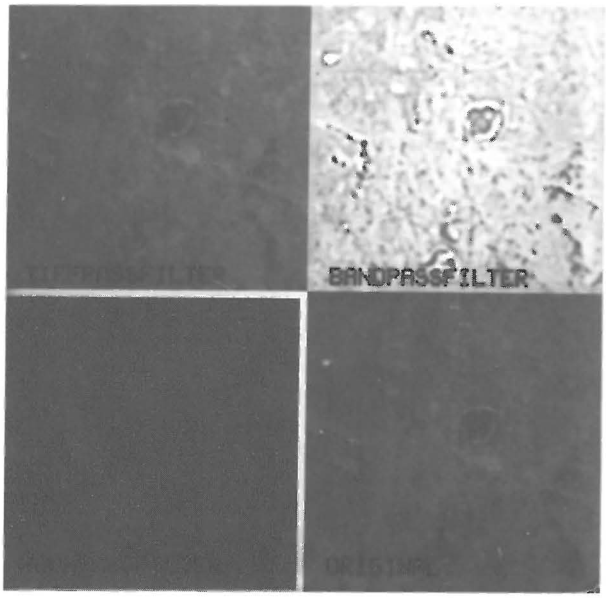


Fig.6: Transfer function/ high pass filter

The effects of the filters are shown in Fig.7:



As expected the high pass filtered image shows only a homogeneous grey area, thus it contains no informations. The filtered high-frequency part of the signal contains real pure noise.

Fig.7: Original and filtered scene

4. Correlation results

In the following we compare the results of the correlation process without filtering to those received after a pre-filtering with a low and a band pass filter. For this purpose in all three image pairs the same picture was chosen as reference image and the other as search image respectively. In the reference images four windows of 11x11 size around the middle of the four image sections were chosen as pattern matrices.
On the other hand the search matrices consist of the whole 128x128 pixel search image.(2)
The correlation results are listed in table 1.

*) U = unfiltered, B = band pass filter, L = low pass filter

Point number	r_{max} $-1 \le r \le +1$	I_{max} $0 \le I \le +1$	Filter*)	position parameter of r_{max}		I_{max}	
				line	column	line	column
1	0.664 0.903 0.922	0.626 0.787 0.990	U L B	50	52	66 50 66	22 52 22
2	0.726 0.912 0.925	0.514 0.767 0.786	U L B	180	55	180	55
3	0.800 0.934 0.932	0.574 0.775 0.761	U L B	101 46	141 180	46	180
4	0.906 0.954 0.959	0.781 0.876 0.869	U L B	176	182	176	182

To explain these findings Fig.8 shows the reference image (here the unfiltered one) with the marked control points. Fig.9-11 illustrate the results of the correlation process without filtering and with precedent low and band pass filtering.

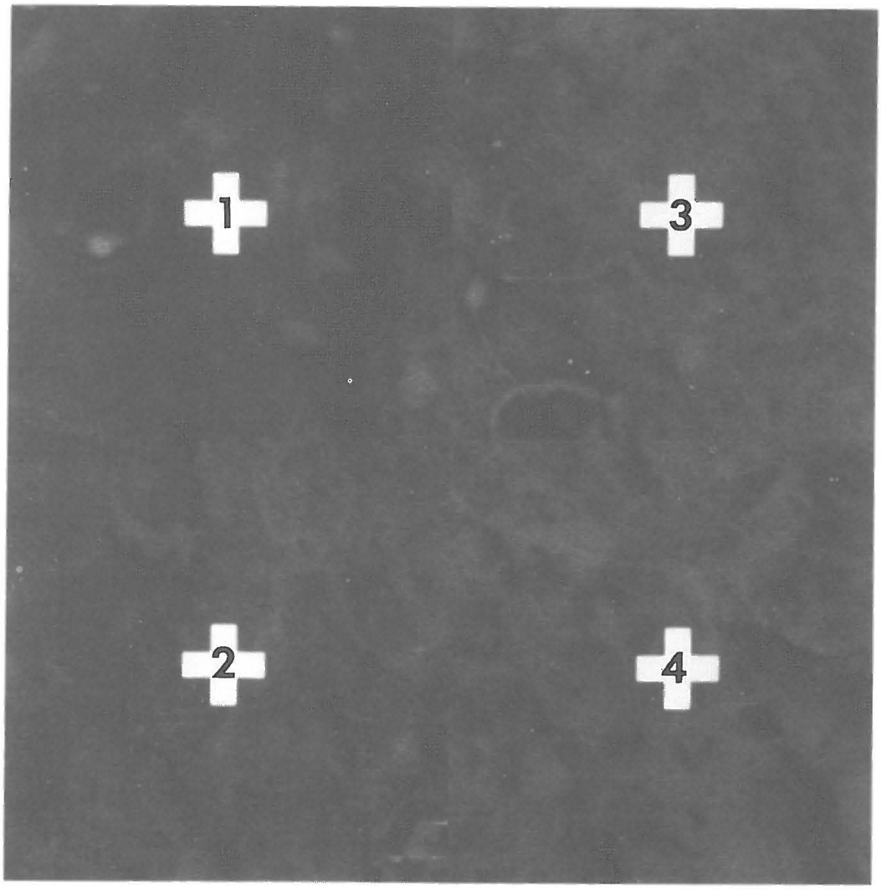


Fig.8:

Reference image with control points

One can easily estimate by the human eye that both objective functions give the right results only in the low pass filtered image. Also the values of the correlation max. are decidedly higher than those of the unfiltered image. The reason for the failure of the 0.99 intensity coefficient after the band pass filtering at point 1 is not quite clear. It may be that a high distortion in the emphasized frequency band of the search image leads to the wrong position as the unfiltered and band pass filtered pictures show the same effects.
In any case low pass filtering removes the distortion and achieves the right results. The values of the correlation coefficient are between 0.90 and 0.95 and by that near to autocorrelation.

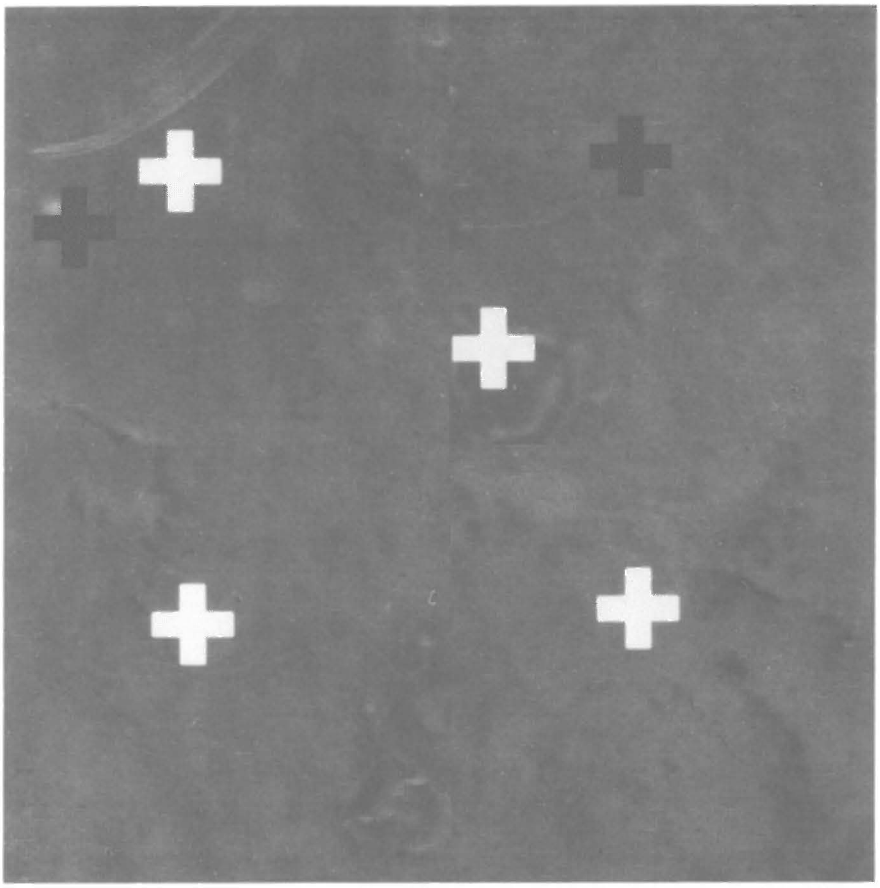


Fig.9:

Unfiltered search image with the measuring positions of the correlation coefficient (white) and the intensity coefficient (black if different)

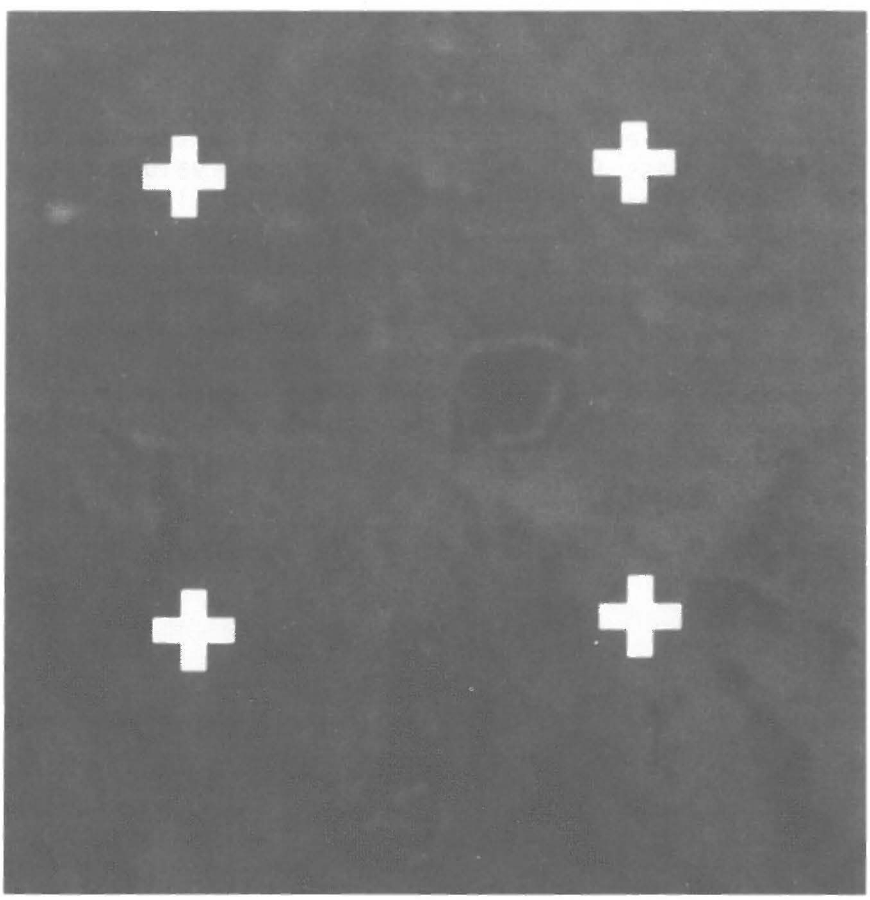


Fig.10:

Low pass filtered search image

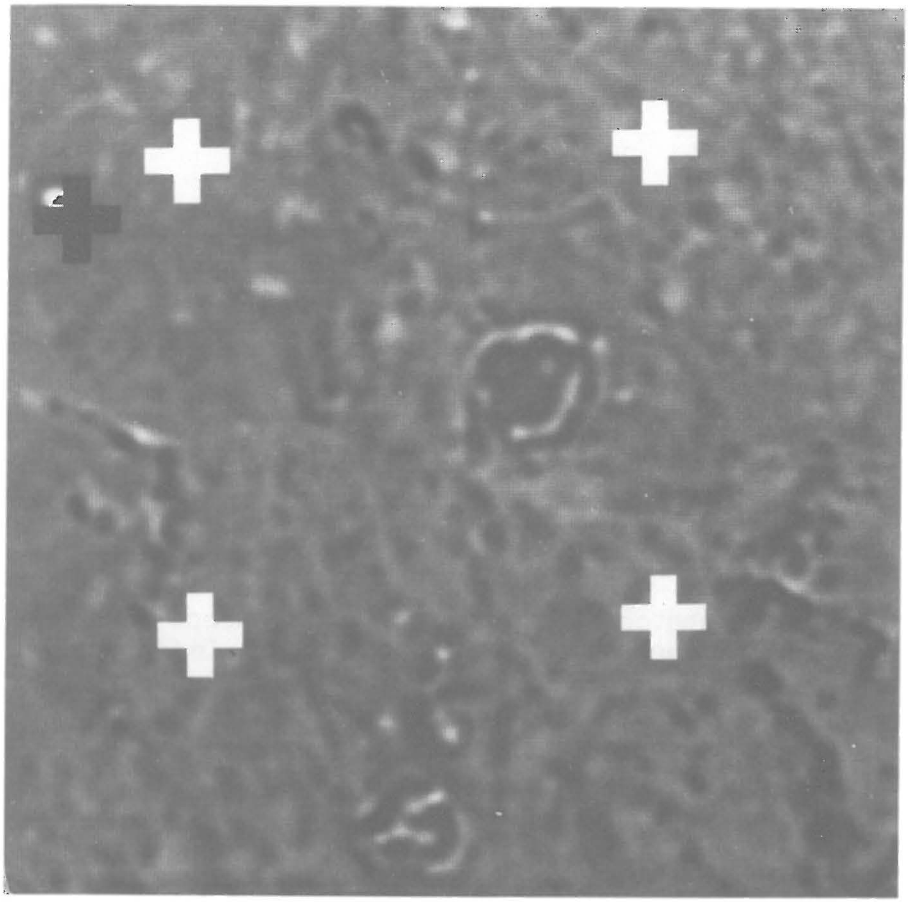


Fig.11:

Band pass filtered search image

5. Conclusions

The convincing findings from the section above let us come to the conclusion that digital correlation of remote sensing imagery from unstructured lands can only be successfully automated by precedent image filtering.
A low pass filter shows good results and less susceptance to failure than a band pass filter. Due to these experiences filter techniques shall be tested with multitemporal correlation likewise. Also additional filters shall be put to test with other films and sensors to extract their relationship from these parameters. The most effective ones can be integrated in the correlation concept. Moreover we hope that the filter matrices can become smaller to save computation time. The filters represented here had a size of 9x9 and 13x13. But after all digital correlation with previous low pass filtering turned out to be an effective method to detect homologeous points in different images even of unstructured objects.

References:

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(5) T.S.HUANG (Ed.): Picture Processing and Digital Filtering, Springer Verl. 1979

(6) K.R.CASTLEMAN: Digital Image Processing, Prentice Hall, 1979