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Increase in Correlation Accuracy of Remote Sensing Imagery by Digital Filtering

The accuracy and efficiency of the objective function at the correlation process is essentially increased by a low pass filter.

Abstract: *For correlation of remote sensing photographs of Wetlands, a concept for rectification on a common reference image was developed at the University of Hanover. The results of two objective functions after previous filtering are compared to those obtained without filtering. It is shown that the accuracy and efficiency of the objective function at the correlation process is essentially increased by a low pass filter.*

Introduction

Owing to their high information content, remote sensing images of the Earth's surface are becoming more and more indispensable for research in various geoscientific branches. For a long time photogrammetry has been using conventional aerial photographs taken from aircraft. In recent years, new satellite-borne remote sensing systems and sensors (multi-spectral scanners, radar, sonar) have improved the work and enlarged the possibilities of photogrammetry.

For the purpose of rectification, detection of environmental changes, and classification in multitemporal pictures, it is necessary to locate identical points in different images of the same area. This can be achieved by applying similarity or correlation algorithms.

For the digital interactive image processing system of the Sonderforschungsbereich (SFB) 149 "Surveying and Remote Sensing Methods at Coasts and Oceans" at the University of Hanover, a correlation concept for rectification of remote sensing imagery was developed. The programs for image rectification by means of control points already developed by the SFB 149 were integrated into this concept, which is outlined in Figure 1 (Wrobel and Ehlers, 1980; Bähr, 1976.

Fundamentals

Test Area

The test area of the SFB 149 are the wetlands of the North Sea near Wilhelmshaven. Wetlands differ from almost all continental areas mainly in two characteristics:

- Because of the almost non-existent differences in height and the extremely flat slope of the terrain, one can consider tidal lands as an even plain. Therefore the correlation algorithm does not need to take into account changes in height and slope.
- On the other hand, the structureless nature of such terrain is a disadvantage. The small morphologic and vegetative differences complicate the finding of identical points in different images of the same area.

Figure 2 and 3 show the homogeneous structure of the tidal lands. Figure 2 shows a one-dimensional 2.5-cm section of an aerial photograph taken with a Zeiss RMK camera at a scale of 1:2000. It was digitized at a sampling rate of $\Delta x = 12.5\ \mu$m in 2000 discrete points. Figure 3 shows the power spectrum of this section. The frequency axis is normalized on the Nyquist frequency $f_N = ½\Delta x =$ 40 lp/mm. One can clearly see that the main information is in a small band of low frequencies.

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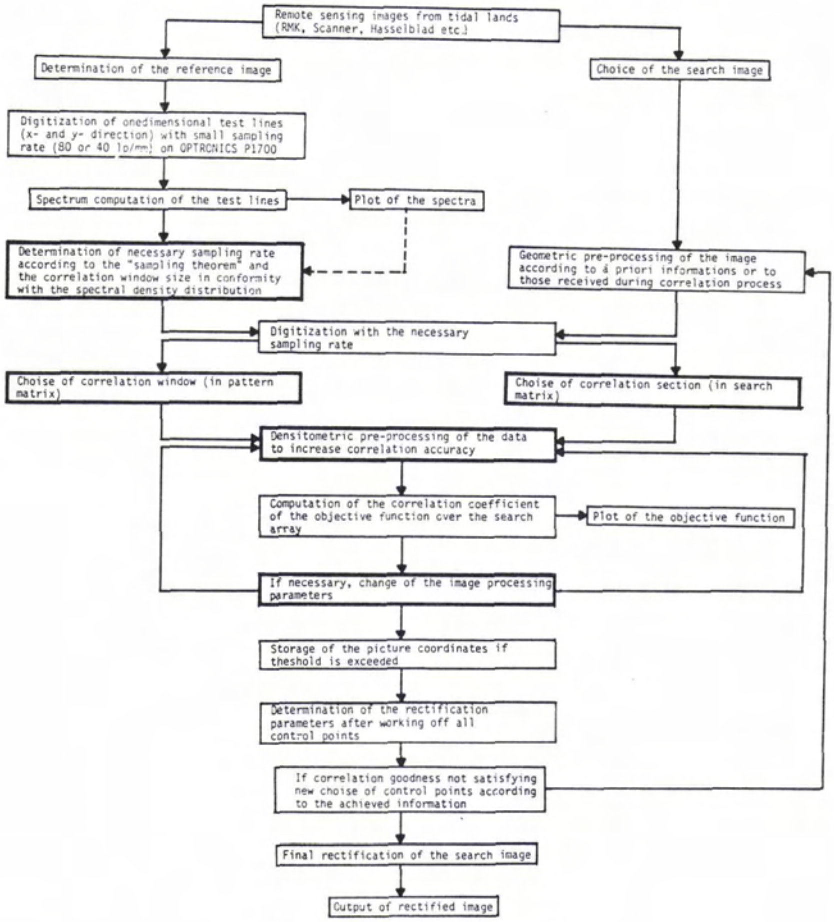


FIG. 1. Correlation concept.

This spectral distribution has to be considered in the densitometric image processing.

OBJECTIVE FUNCTIONS

Given are the image signals digitized in the range 0 to 255, in which $S_1(x_i, y_j)$ $(i = 1, \ldots, N_1;$ $j = 1, \ldots, M_1)$ is the search matrix of the search image and $S_2(x_i, y_j)$ $(i = 1, \ldots, N_2; j = 1, \ldots, M_2)$ is the pattern matrix of the reference image. The centers of the pattern matrices give the coordinates of the control points in the reference image. By shifting the pattern matrix over the search matrix, one tries to find the position of greatest similarity of both matrices. As objective functions, a great

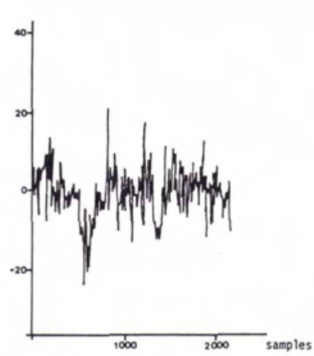


FIG. 2. Signal (mean subtrace).

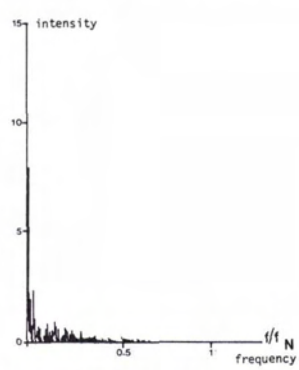


FIG. 3. Power spectrum.

number of mappings come into question (Wrobel and Ehlers, 1980; Gambino and Crombie, 1974; Pearson et al., 1977). Two of these have been integrated into the following concepts:

(a) *The "normal" product moment correlation coefficient.*

$$r(\Delta x,\Delta y) = \frac{\sum_{i=1}^{N_2}\sum_{j=1}^{M_2}\{S_1(x_i+\Delta x, y_j+\Delta y)-\bar{S}_1\}\cdot\{S_2(x_i,y_j)-\bar{S}_2\}}{\sum_{i=1}^{N_2}\sum_{j=1}^{M_2}\{S_1(x_i+\Delta x, y_j+\Delta y)-\bar{S}_1\}^2\sum_{i=1}^{N_2}\sum_{j=1}^{M_2}\{S_2(x_i,y_j)-\bar{S}_2\}^2}$$

in which

$$\bar{S}_1 = \frac{1}{M_2\cdot N_2}\sum_{i=1}^{N_2}\sum_{j=1}^{M_2} S_1(x_i+\Delta x, y_j+\Delta y) \text{ and}$$

$$\bar{S}_2 = \frac{1}{M_2\cdot N_2}\sum_{i=1}^{N_2}\sum_{j=1}^{M_2} S_2(x_i,y_j) \text{ the signal means.}$$

$(\Delta x, \Delta y)$ is the shift vector which specifies the relative position of the pattern in the search matrix.

(b) *The correlation intensity coefficient.*

$$\begin{aligned} I(\Delta x,\Delta y) &= \left\{\sum_{i=1}^{N_2}\sum_{j=1}^{M_2}\cos p(S_1(x_i+\Delta x, y_j+\Delta y)-S_2(x_i,y_j))\right\}^2 \\ &+ \left\{\sum_{i=1}^{N_2}\sum_{j=1}^{M_2}\sin p(S_1(x_i+\Delta x, y_j+\Delta y)-S_2(x_i,y_j))\right\}^2 \end{aligned}$$

normalized on (0,1) with the correlation parameter, p, which is derived from the signal variances; that is,

$$p = \frac{0.5\,\pi}{\sqrt{\dfrac{\sum\sum\{S_1(x_i+\Delta x, y_j+\Delta y)-\bar{S}_1\}^2+\sum\sum\{S_2(x_i,y_j)-\bar{S}_2\}^2}{M_2\cdot N_2}}}$$

The correlation intensity coefficient was developed out of coherent-optical considerations. The image signals are mapped on the complex plane and the intensity of the complex correlation function is computed. The intensity coefficient approximates a δ-function and, therefore, shows the respective maximum more sharply than the correlation coefficient (Wrobel and Ehlers, 1980; Göpfert, 1978). The shift vector of the maximum of both objective functions indicates the most probable position of the pattern matrix in the search image.

Image Preprocessing

IMAGE MATERIAL

For testing the correlation concept, two overlapping RMK photographs (original scale 1:2000) of wetlands were digitized with a sufficiently high sampling rate $\Delta x = 100\ \mu m$ ($f_n = 5$ lp/mm). Figure 4 shows four corresponding sectors of each picture, at a size of 128 by 128 pixels, and their power spectra.

SPECTRAL ANALYSIS AND FILTER DESIGN

The chosen search and reference image sectors were transformed into the frequency domain by employing a fast Fourier transform (FFT). On the basis of the information content of their power spectra, we designed a low pass filter which considered 95 percent of the signal information, as well as a band pass filter which amplified the non-zero frequency of maximum amplitude. Thus, we worked with a method presented by Nowak (1979). We chose the curve of a one-dimensional filter transfer function, made it two-dimensional by rotation, and transformed it into a filter matrix by an inverse FFT (Huang, 1979; Ehlers, 1980; Nowak, 1979). Figures 5 and 6 show the transfer function of the selected filters.

The effects of the two filters, as well as the resulting image after a tested high pass filter, are shown in Figure 7. As expected, the high pass filtered image shows only a homogeneous grey area, i.e., it contains no information. The filtered high-frequency part of the signal consists of real

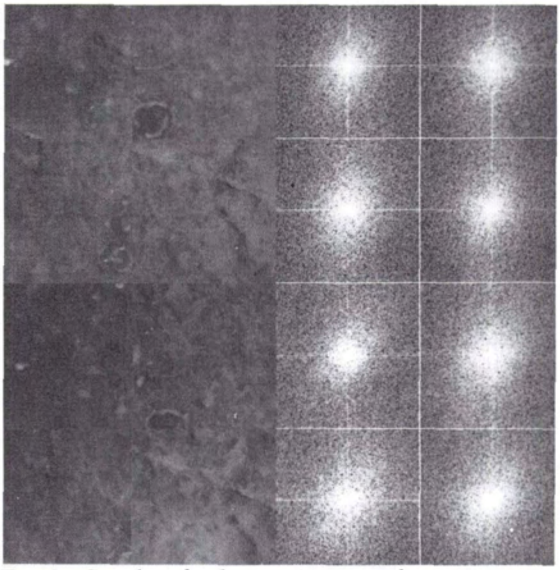


FIG. 4. Search and reference images with power spectra.

pure noise. A 3 by 3 median filter, as a more general and fast non-linear low pass filter, was also tested.

CORRELATION RESULTS

In the following we compare the results of the correlation process without filtering to those obtained after filtering. For this purpose, in all image pairs the same picture was chosen as the reference image and the other as the search image, respectively. In the reference image four 11 by 11 windows around the middle of the four image sections were chosen as pattern matrices (Figure 8). On the other hand, the search matrices consist of the whole 128 by 128 search images. The correlation results are listed in Table 1.

To explain these findings, Figure 8 shows the reference image (here the unfiltered one) with marked control ponits. Figures 9 to 12 illustrate the results of the correlation process without filtering and with the different filters.

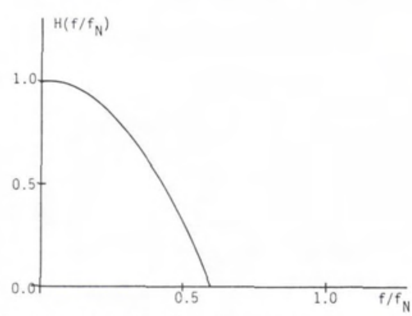


FIG. 5. Transfer function of low pass filter.

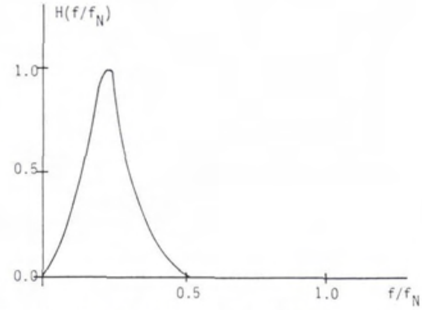
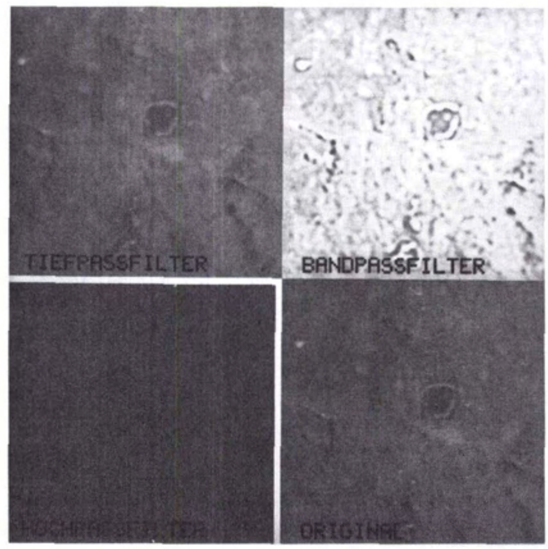


FIG. 6. Transfer function of band pass filter.



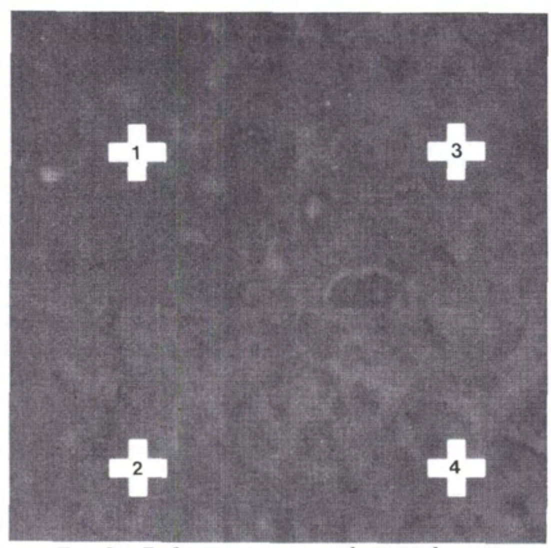


FIG. 8. Reference image with control points.

TABLE 1. CORRELATION RESULTS

Point number	r_{max} $-1 \leq r \leq +1$	I_{max} $0 \leq I \leq +1$	Filter*	position parameter of r_{max} line	position parameter of r_{max} column	position parameter of I_{max} line	position parameter of I_{max} column
1	0.664	0.626	*u*			66	22
	0.903	0.787	*l*	50	52	50	52
	0.922	0.990	*b*			66	22
	0.851	0.690	*m*	51	53	51	53
2	0.726	0.514	*u*				
	0.912	0.767	*l*	180	55	180	55
	0.925	0.786	*b*				
	0.853	0.688	*m*	189	90	189	90
3	0.800	0.514	*u*	101	141		
	0.934	0.775	*l*				
	0.932	0.761	*b*	46	180	46	180
	0.909	0.717	*m*				
4	0.906	0.781	*u*				
	0.954	0.876	*l*				
	0.959	0.869	*b*	176	182	176	182
	0.939	0.843	*m*				

* *u* = unfiltered, *l* = low pass filter, *b* = band pass filter, *m* = medianfilter.

One can easily see with the human eye that both objective functions give the right results only in the low pass filtered image. Also the values of the correlation maximum are decidedly higher than those of the unfiltered image. The reason for the failure of the 0.99 intensity coefficient after band pass filtering at point 1 is not quite clear. It is possible that a high distortion in the amplified frequency band of the search image leads to the wrong position because the unfiltered and band pass filtered pictures show the same effects. Also the 3 by 3 median filter does not increase correlation accuracy. The same is also valid for tested 5 by 5, 7 by 7, and 9 by 9 median filters. The results differ slightly from those obtained with the 3 by 3 median filter. Only the special low pass filter, designed after a spectral analysis, leads to acceptable results. The values of the correlation coefficient are between 0.90 and 0.95 and, thus, near autocorrelation. We also achieved high cor-

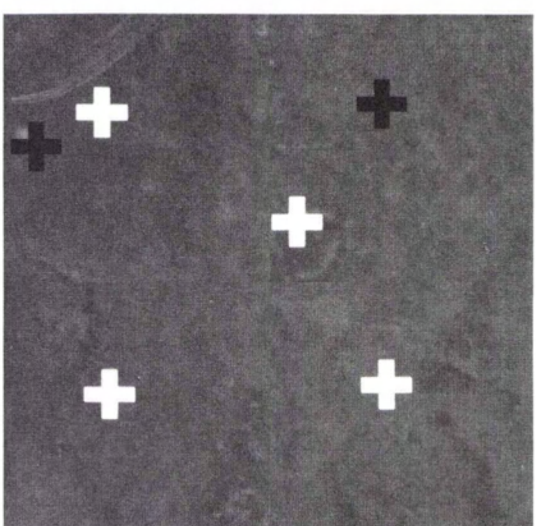


FIG. 9. Unfiltered search image with the measuring positions of the correlation coefficient (white) and the intensity coefficient (black if different).

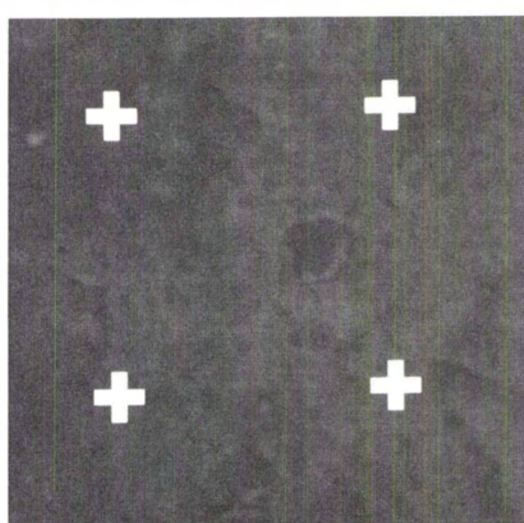


FIG. 10. Low pass filtered search image.

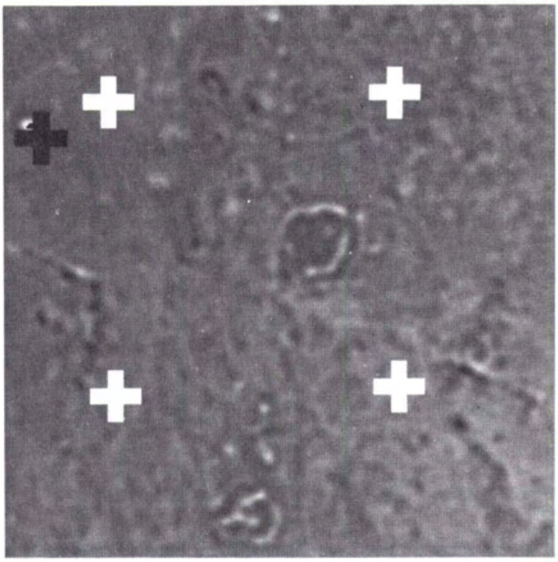


FIG. 11. Band pass filtered search image.

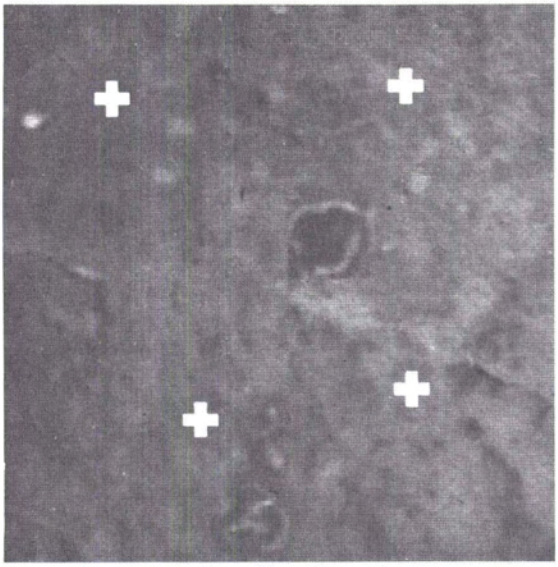


FIG. 12. Median filtered search image.

relation values after band pass filtering, but the low pass filter is less susceptible to distortions. Therefore, it satisfies the requirements of the unstructured object surface.

CONCLUSIONS

The presented results allow us to come to the conclusion that digital correlation of remote sensing imagery from such homogeneous areas as wetlands can only be successfully automated by precedent image filtering. The crucial point seems to be the right choice of the filter and not of the objective function. A low pass filter which considered 95 percent of the signal information increases accuracy and value of both tested objective functions. Therefore, this filter will be implemented into the correlation concept of images with a low signal-to-noise ratio.

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