Digital Enhancement of Interferometric SONAR Imagery for Fringe Pattern Recognition

Dieter Kolouch and Manfred Ehlers
Institute for Photogrammetry and Engineering Surveys
University of Hannover
Federal Republic of Germany
Commission III

Abstract

Area covering sea floor mapping is operational only by active SONAR scanner, whose images, however, unfortunately cannot be processed stereoscopic for depth determination. This can be done by artificial produced interferometric SONAR images with fringe pattern. The image coordinates are used as input in a geometric model for depth computation. Interferometric SONAR images are unfortunately very noisy due to necessary high amplification of the signals. This prevents automatic determination of the fringe image coordinates and requires image preprocessing. Common filter techniques like 'moving average', 'median filtering' etc. are not sufficient. The authors use therefore Fourier transform techniques to involve filter functions in the frequency domain, where specific phenomena like direction components can be considered.

1. Introduction

Side-scan-sonar systems work on high frequency sound propagation for area covering imaging of the sea-bottom. A fan-shaped acoustic field - transmitted from a towed sensor - reaches a small strip of the sea-bottom. The back-scattered echoes are received by the same sensor and used for the recording of an image line. By repetition of this process an image is built up line by line (EG & G, 1974). Due to relative geometric distortion - caused by the towing dynamics - common stereoscopic evaluation techniques cannot be applied to overlapping sonar image strips (Clerici, 1977). More successful for depth determination is the application of interferometric methods based on the Lloyd-Mirror-effect (Heaton and Haslett, 1971). This mixing of coherent signals (interference) effects fringe pattern in the image, which are extremely sensitive for depth changes. At the Institute for Photogrammetry of Hannover University a special hardware system for artificial generation of interferometric sonar imagery (ISSS) has been developed as well as an accordant digital data processing system (Kolouch, 1983 b). Automated depth determination as basis for DTM and following map production can be performed on the base of computer controlled detection of interference maxima coordinates (Kolouch, 1983 a). Due to the system gain generated high noise level of the images picture pre-processing is presumed.

2. Geometry of Interferometric Sonar

The artificial generation of Lloyd-Mirror is done by means of two transducers working on the same side of the towed system. The geometric conditions are shown in fig. 1.

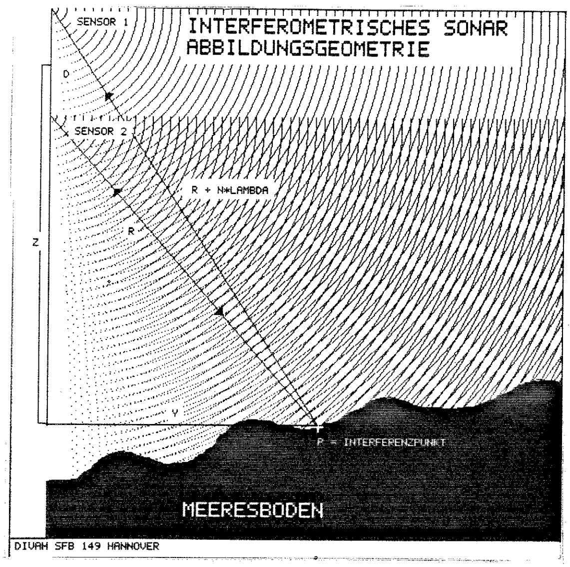


Fig. 1: Geometry of Pattern Generation

By mixing the received echo-signals of both transducers a fringe pattern image like fig. 2 is produced. If the path difference of the sound wave is an integer multiple of the signal wave length the resulting signal gets reinforced otherwise it is extinguished. This happens several times in an image line and leads at last to such an interferometric image.

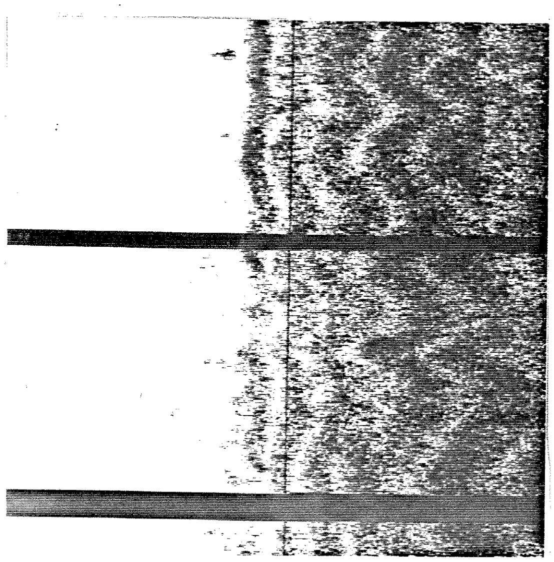


Fig. 2: Interferometric Sonar Image

For each maximum image coordinate y'_n in each single image line x'_n water depth Z_n and horizontal distance Y_n can be determined using the equations (1) and (2) with reference to the sensors origin:

$$Z_n = \frac{R_n \cdot n \cdot \lambda}{D} + \frac{n^2 \cdot x^2}{2D} \qquad (1)$$

$$Y_n = (R_n{}^2 - (Z_n - \frac{D}{2})^2)^{1/2} \qquad (2)$$

where $R_n = m_{y'} \cdot y'_n$ = range in space

$m_y{}'$ = scale in transmitting direction

n = number of the fringe order

D = distance of the transducers

λ = wave-length

These coordinates are used as input for three-dimensional space coordinate determination. This works in a reference system with respect to the dynamic towing situation, where in sensor movement and positioning are taken into account. Basis for a successful processing is the automatic detection of the fringe pattern image coordinates in each single line.

3. Direction Dependent Filtering

As mentioned above the recorded images are seriously contaminated due to the high amplification of the echo signals. This prevents automatic determination of interference image coordinates in the original images.

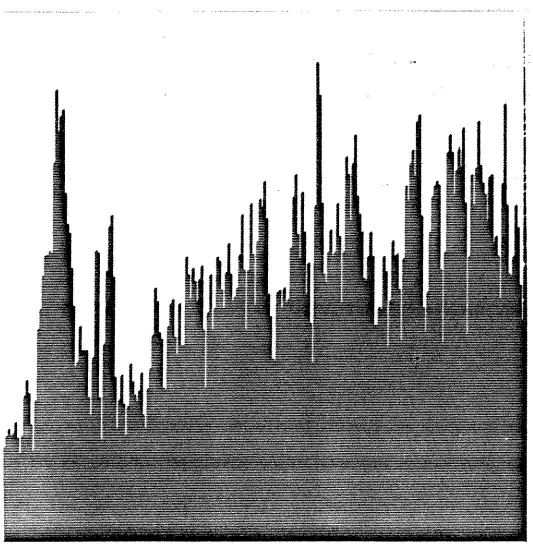


Fig. 3:

Densitometric Image Profile

Figure 3 shows an intensity profile of a typical image line, wherein five maximum values should be found. That is not possible and therefore such images require densitometric pre-processing.

For this common filter techniques like 'moving average', 'median filtering' etc. are not sufficient (Ehlers and Kolouch, 1982). Thus the development of sensor adapted filter procedures is necessary. The interferometric fringe pattern appears only in certain directions, so it seams meaningful to use procedures for direction dependent enhancement.

To find the main fringe pattern directions, it is convenient to transform the image into the frequency domain. This is performed by Fast Fourier techniques within the frame of the MOBI-DIVAH image processing system (Schaefer et al., 1982). Direction dependent image information (e.g. edges) is represented in the power spectrum perpendicularely. An example is given in figure 4 showing an artificial test pattern and its power spectrum.

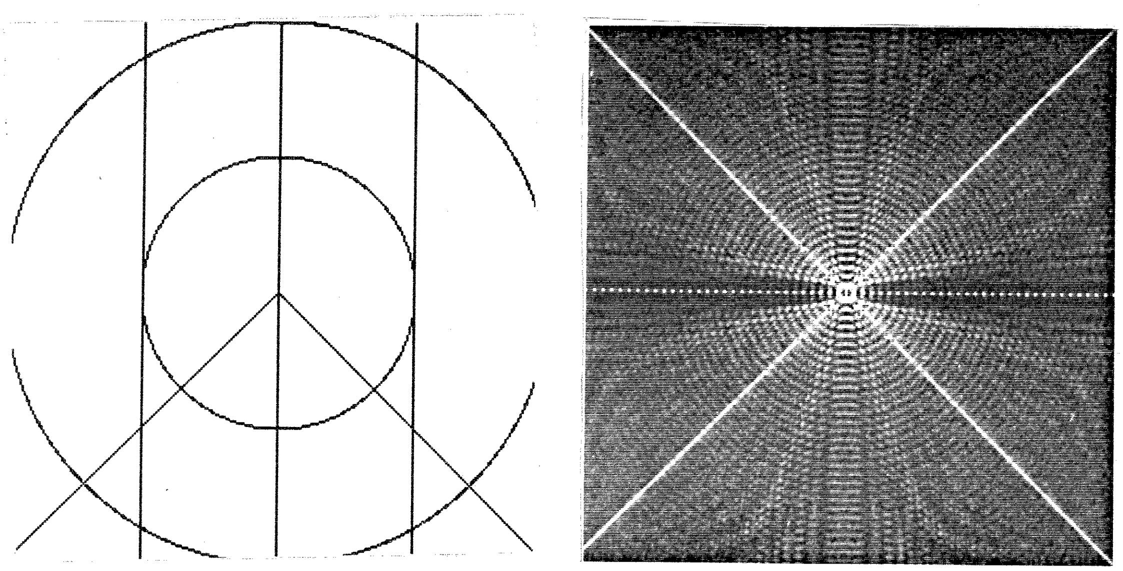


Fig. 4: Test Pattern and Power Spectrum

The effect of a direction dependent filter function designed in the frequency domain is shown in figure 5. Here only the spectral information between 30 ^{o} and 60 ^{o} is considered. Except a small area around the zero frequency all other information is neglected. The edges of the filter function can be smoothed by Gaussian or sinc masks to avoid the Gibb's phenomenon.

Additional isotropic low pass filtering can be superimposed, if desired (Koslowski, 1984).

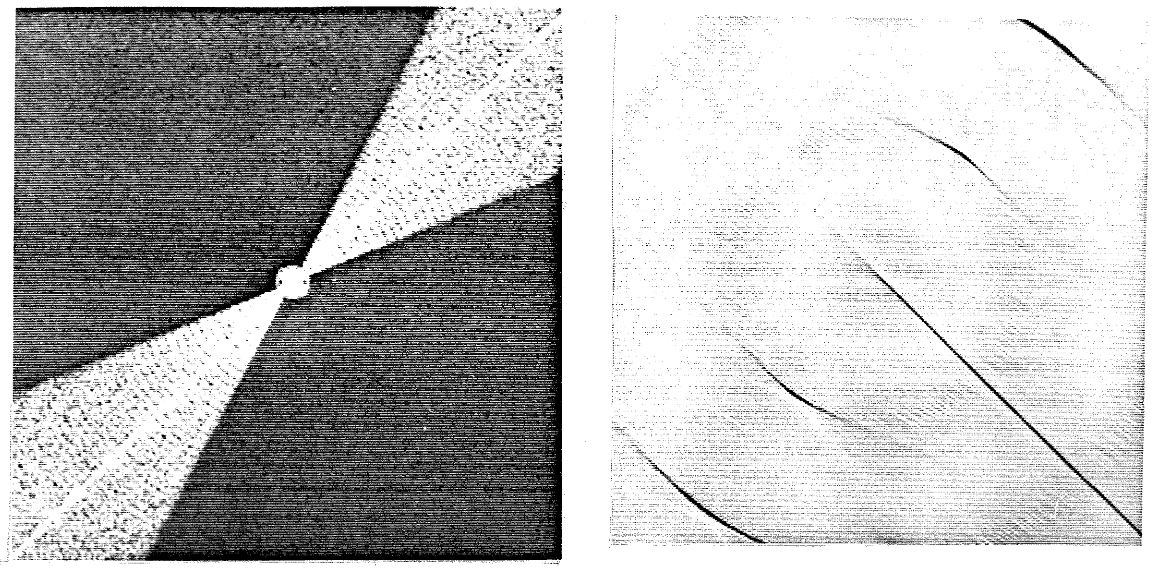


Fig. 5: Filter Design and Filtered Image

4. <u>Filter Results for Interferometric Sonar Images</u>

The construction of an optimized filter function for natural pictures is not so easy to do, if different main directions as in the interferometric image are to be detected. Figure 6 and 7 show two examples for narrow angle filtering with 45 ^{o} and 90 ^{o} emphasis. These results are not

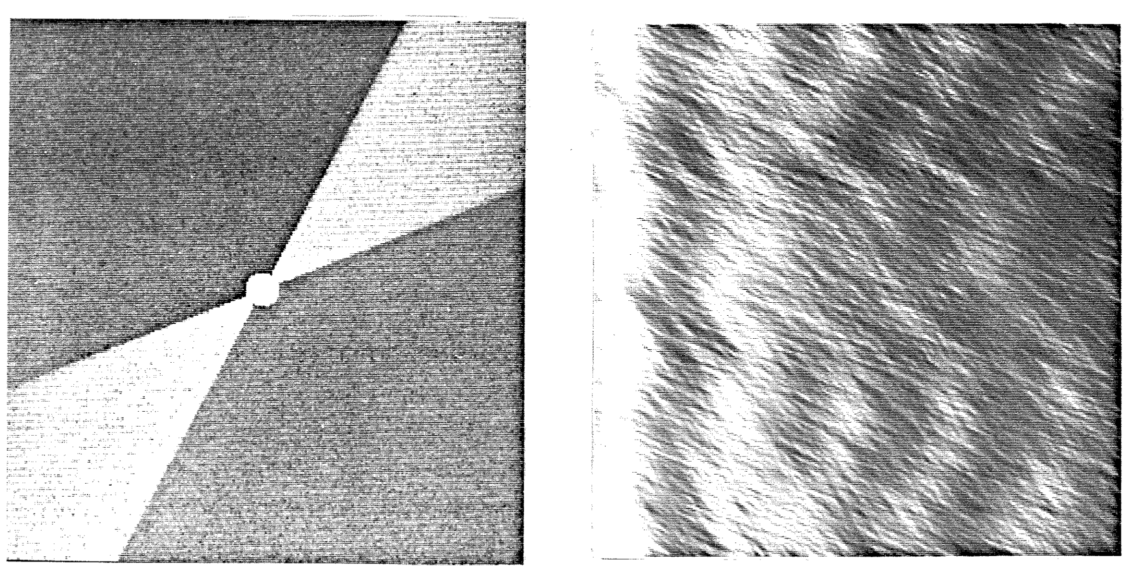


Fig. 6: Filter Design and Result (45 ^{o})

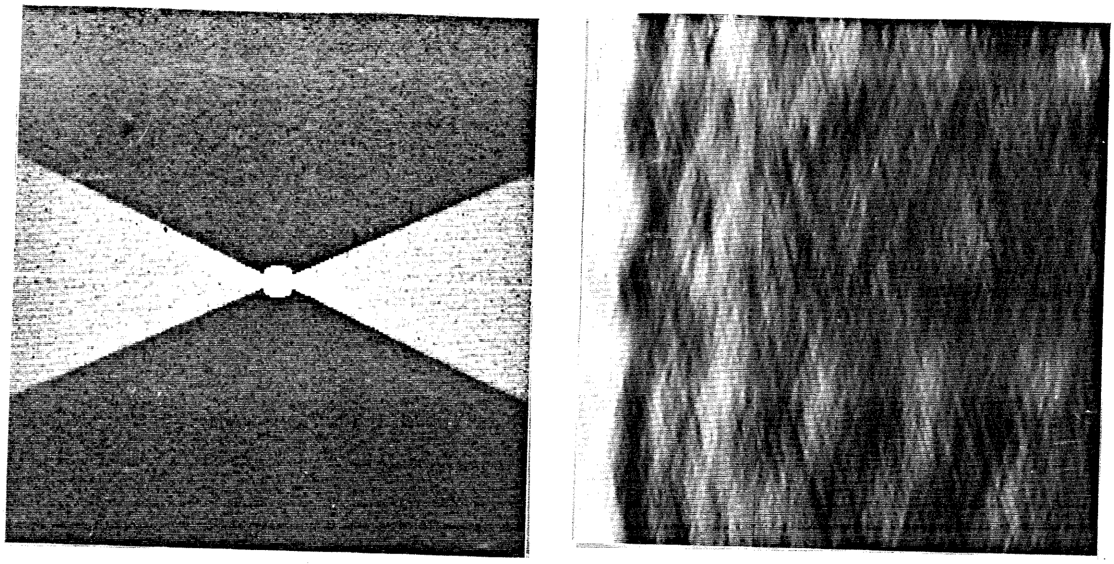


Fig. 7: Filter Design and Result (90 ^{o})

sufficient for following automatic interferometric image coordinate detection.

Therefore filters should consider information in a wider angle area, and in addition a low pass filter should be applied to suppress high frequency noise too. In the next examples the filter angle is taken between + 60 ^{o} in the frequency domain and additional low pass filter with different degrees are superimposed (figure 8 - 10).
The effects of filtering for the special aim of maximum detection in ISSS-images can be seen more clearly in one-dimentional image profiles (figure 11) corresponding to figures 8 - 10.
The best result of all tests is obtained by filter 'C'. It is a good compromise between noise reduction by low pass filtering and fringe enhancement by direction filtering. The filtered image 'C' is now taken for further processing. It was found that now with an additional one-dimen ional 'moving median', which works row by row (result see figure 12), simple line-following procedures can be applied for the desired maximum detection. Figure 13 a shows a binary overlay of the automatic detected maximum coordinates from the filtered interferometric image with the original image. To optimize these results following image processing techniques (e.g. enveloping) can be obtained, which work directly on the artifical binary coordinate image. This is - again as overlay - presented in figure 13b.

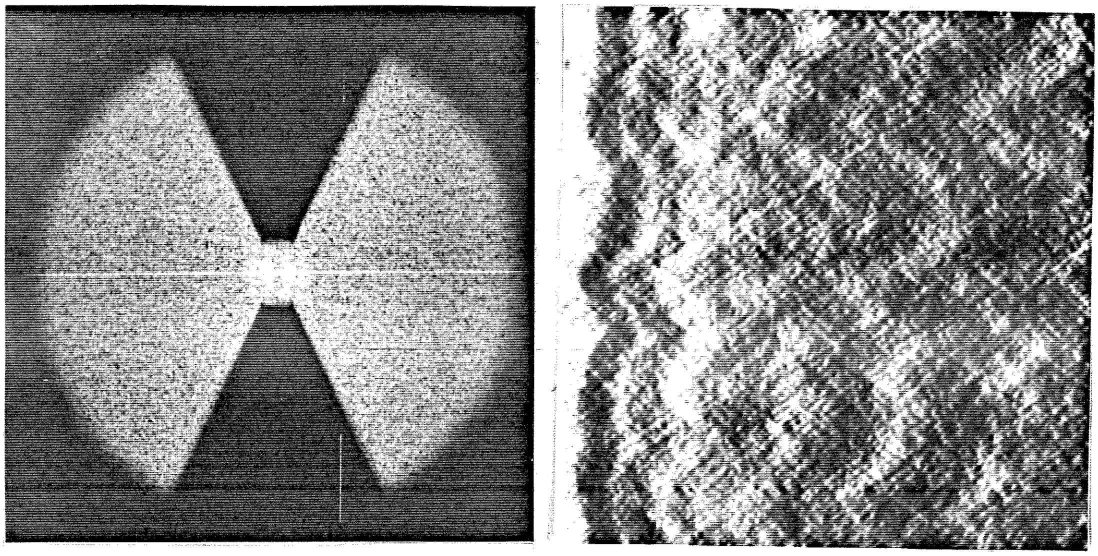


Fig. 8: Filter Design and Result (A)

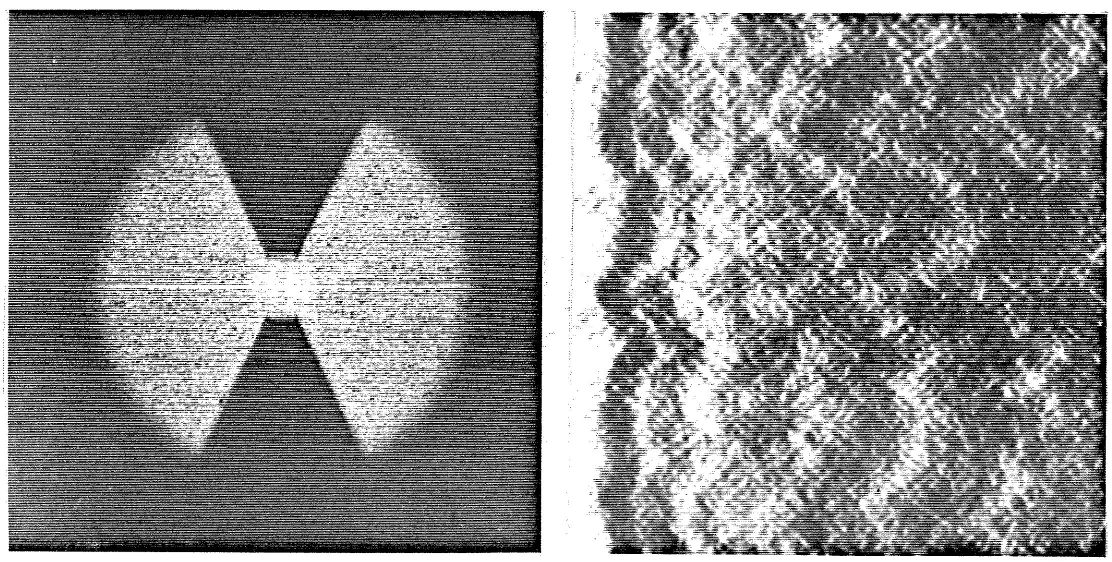


Fig. 9: Filter Design and Result (B)

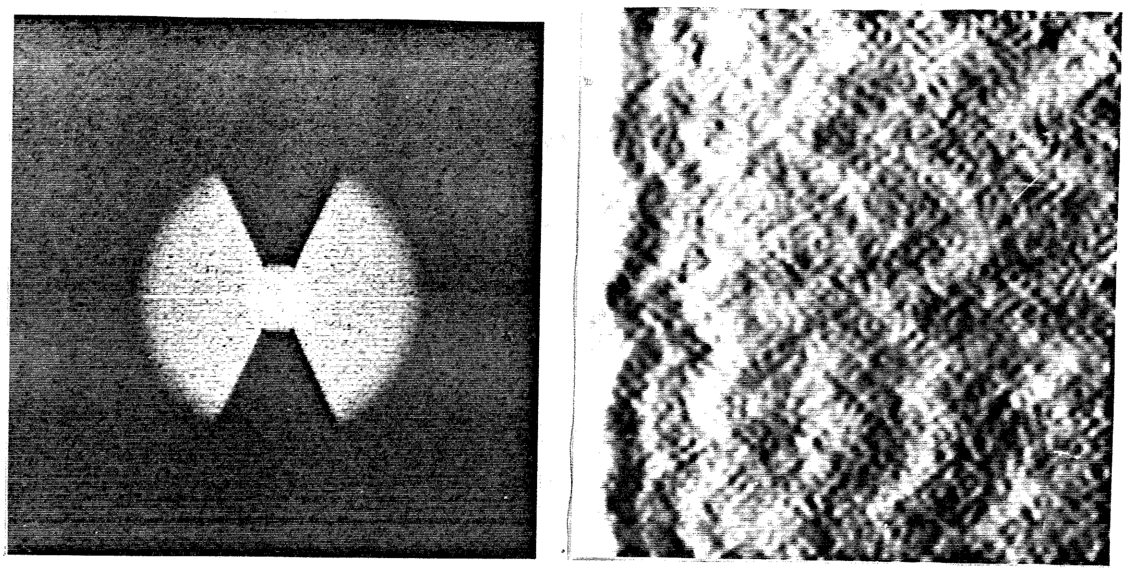
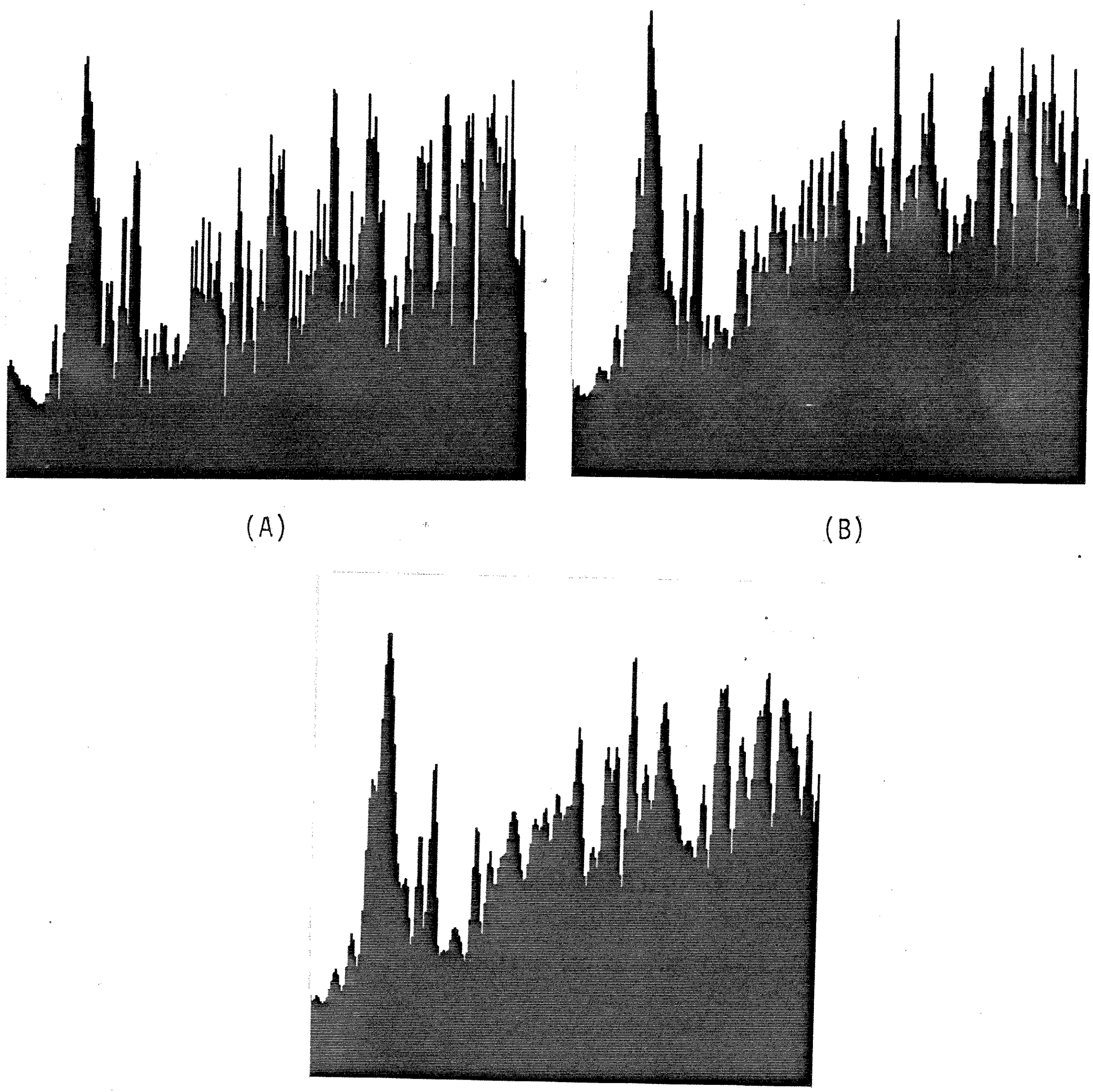


Fig. 10: Filter Design and Result (C)



(A) (B) (C)

Fig. 11: Densitometric Profiles after Filtering

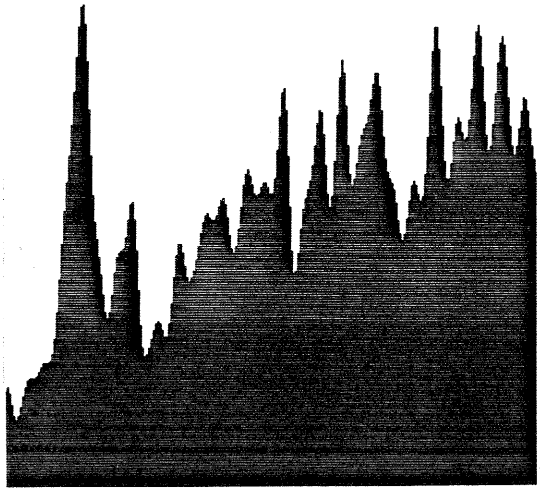


Fig. 12: Profile of Image "C" after "moving median"

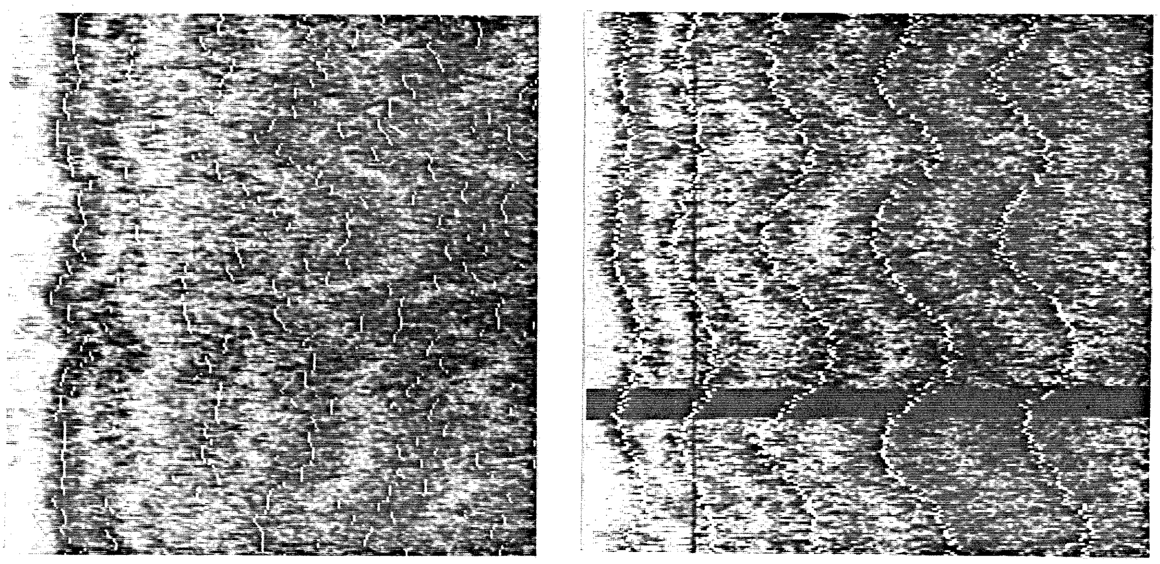


Fig. 13: Maximum Detection without and with Enveloping

5. Conclusions

The enhancement of interferometric side-scan-sonar images with direction dependent and superimposed low pass filtering shows already acceptable results. They are the basis for the following automatic process of image coordinate detection in the interference pattern. This is an important step within the extensive software system, which determines three-dimentional space coordinates from two dimentional image values.
Nevertheless more tests with the direction dependent filter functions must be performed to optimize the results, so that no longer following 'moving median' and enveloping procedures are necessary. Because of the different directions in the interference image pattern it is obvious to combine several single filter functions working in these specific directions and having a more narrow angular effect. In the resulting image line following procedures should be applied without additional pre-processing.

References

Clerici, E.: Über die Anwendbarkeit von Side Scan Sonar zur Erstellung von topographischen Karten des Meeresbodens. Wissenschaftliche Arbeiten der Fachrichtung Vermessungswesen der Universität Hannover Nr. 71, Dissertation 1977

Environmental Equipment Division (EG & G): Instruction Manual, Side-Scan-Sonar, Mark 1 B, 1974

Ehlers, M., Kolouch, D.: Interferometrisches Sonar, Datengewinnung und digitale Filterung. Bildmessung und Luftbildwesen, Nr. 50, 1982

Heaton, M.J.P., Haslett, R.W.G.: Interpretation of Lloyd Mirror in Side-Scan-Sonar. Seminar on Side-Scan-Sonar Application, University of Bath, 1971

Kolouch, D.: Geometrische Auswertung von Sonarbilddaten und Interferometeraufnahmen mit Hilfe digitaler Bildverarbeitung. Wissenschaftliche Arbeiten der Fachrichtung Vermessungswesen der Universität Hannover, Nr. 124, Dissertation 1983 a.

Kolouch, D.: Interferometrisches seitwärts schauendes Sonar. Ein System zur flächenhaften topographischen Seevermessung. Zeitschrift für Vermessungswesen, Nr. 108, Heft 11, 1983 b

Koslowski, H.-D.: Zur Erzeugung und Realisierung eines Programmsystems zur richtungsabhängigen Filterung im Frequenzraum, Institut für Photogrammetrie und Ingenieurvermessungen, Universität Hannover, Diplomarbeit 1984 (unpublished)

Schaefer, H., Dennert-Möller, E., Ehlers, M., Kolouch, D. und Lohmann, P.: MOBI-Handbuch zum Modularen Off-Line-BIldverarbeitungspaket des Sonderforschungsbereiches 149 an der Universität Hannover, 1982