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CURRENT STATUS OF METRIC REDUCTION OF ACTIVE SCANNER IMAGES

Invited paper

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ABSTRACT

Side looking radar (SLR) and side-scan-sonar are the essential active scanning systems for remote sensing of environment. They are both currently undergoing a technical change due to digital techniques and micro-electronics. SLR in addition has gained a role as satellite-borne radar (SEASAT-Synthetic-Aperature Radar). Generally it seems that metric analysis of radar has had a slower progress than during the early 1970's. Side scan sonar has only been subject of a very few photogrammetric research projects. Image rectification and stereo are, however, major topics of current and anticipated future research.

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ZUSAMMENFASSUNG

Seitwärts-Radar (Side-looking radar, SLR) und Seitwärts-Sonar sind die beiden wesentlichen aktiven Abtastsysteme in der Fernerkundung. Beide Systeme erfahren zur Zeit eine eingehende Wandlung als Folge digitaler Technologien und der Mikroelektronik. SLR hat zusätzlich eine Rolle als Satellitensensor erhalten (SEASAT-Synthetisches Apertur Radar). Allgemein scheint die Bearbeitung geometrischer Fragen bei Radar zur Zeit weniger schnell fortzuschreiten als zu Beginn der siebziger Jahre. Sonar war bisher nur sehr wenigen photogrammetrischen Untersuchungen unterworfen. Bildentzerrung und Stereo sind jedoch wesentliche Themen für gegenwärtige und zu erwartende Forschungsarbeiten.

RESUMÉ

Le radar latéral (SLR) et le sonar latéral sont les systèmes les plus importants pour le scanning actif de la télédétéction. Les deux systèmes se trouvent couramment dans un stage de transformation grace aux techniques numeriques et microéléctroniques. SLR aussi s'avait établi comme senseur de satéllites (SEASAT-SAR). En géneral les travaux photogrammétriques avec le radar sont moins intensif qu'il y a avant 1976. Sonar n'avais jamais encore le sujet de beaucoup de travaux photogrammétriques. Le redréssement et les méthodes stéréoscopiques sont les sujets principaux de travaux de recherche.

1. INTRODUCTION

Active scanner images are here understood to either be side-looking radar (SLR)* or underwater Side-Scan-Sonar (SSS) images. This limitation eliminates consideration of plan position indicator (PPI) or other types of radar, active laser imaging and SONAR profiling techniques. The limitation is applied to

*Satellite radar now seems to render the letter 'A' in the traditional acronym SLAR (for Side-looking Airborne Radar) irrelevant. Therefore SLAR is not used in this paper.

concentrate on those two imaging techniques of active scanning that currently have practical significance for remote sensing of the environment.

Mapping with Side-looking radar has in the past been extensively studied and elaborate publications are available on the results, also in the form of invited review papers at earlier symposia and congresses of the International Society of Photogrammetry (ISP) by Konecny (1972, 1975, 1976), Yoritómo (1972) and Leberl (1972, 1976) and at national conferences (e.g. Petrie 1979; Leberl 1977).

Side-Scan-Sonar has sofar found the attention of only a very limited number of photogrammetric research workers and no earlier papers exist on mapping aspects

We present in this paper a review of mapping with radar and side-looking sonar. As concerns radar we can now follow the reviews compiled for the 13th congress of ISP in that year (Leberl 1976). The most significant radar mapping development since 1976 was the satellite synthetic aperture radar of SEASAT that receives attention in the following chapters.

As concerns side-scan sonar, the past lack of reviews of mapping work requires that the topic is treated more exhaustively. We will thus address the basic methods for metric reduction of side-looking sonar images concerning rectification, stereo and interferometry.

2. AIRBORNE RADAR

During recent years photogrammetric work with radar images has had distinctly less emphasis than during the early 1970's. It may be caused by the attention given to satellite multi-spectral scanning and reflected in the number of publications on radargrammetry and the range of topics treated. However, this does not mean that geoscientfic work with radar images has slowed down in general. This may even have increased in the area of research.

2.1 Mapping Projects

A number of large SLR mapping projects was carried out, such as for example in Nigeria and Togo (Dellwig, in press), in Venezuela and Indonesia. These projects resulted in the wellknown products of semi-controlled image mosaics mostly at scale 1:200 000. The analysis of the images may currently be based more often on stereo than in the past. Mosaicing techniques have relied on dense nets of ground control (Dellwig, in press) or on block adjustments as described by Leberl et al. (1976).

Radar mapping services are currently performed by the two companies that were also available in 1976; in addition aerial SLR is being flown in numerous government and research organisations. No new trends have emerged in this respect in recent years.

2.2 Research Work

a) Motivation

SLR-research has been motivated significantly by satellite radar, in the U.S.A. through SEASAT, planned Space Shuttle sorties with radar* and the Venus Orbital Imaging Radar (VOIR) mission that is being prepared for the mid-1980's. In Europe a similar motivation derives from SLR-plans for Spacelab.

*the first will be SIR-A during the second Shuttle flight.

b) Digital Processing of Images

Typically, radargrammetric aspects are peripheral to this research. However, activities have taken place and addressed the computer processing of digitized SLR-images for rectification of geometric and radargrammetric errors, by Bryan et al. (1976) and by Shakine and LeThoan (1978). This type of digital processing has also been used to merge radar images taken at two polarisations, wavelengths or from two positions, or to merge radar with Landsat (e.g. Dailey et al., 1978).

c) Sea-Ice Mapping

A major radargrammetric element exists in efforts to map polar sea-ice from SLR-images. This task is currently a subject of initial experimentation with the hope to ultimately find an operational solution from a satellite radar. Ling et al. (1978) discussed a method to map coastal sea-ice using ground control along the coast line, Leberl et al. (1979) presented results obtained from active airborne SLR-images -- ice drift was measured with accuracies of ± 100 m (relative) to ± 3.5 km (absolute). The large absolute errors are caused by limitations of aircraft navigation. This type of work is also being done in the USSR; publications have come to our attention from Loshilov and Voyevodin (1972), Zhurkin and Korneyev (1974).

d) Radar Stereo

Interest presently exists in radar stereo capabilities. This interest is also caused by plans for satellite radar and publications have recently appeared on this topic by Leberl (1979 a,b) and Graham (in press). The error propagation has been understood for a long time since there are mathematical models available for radar stereo computation (Rosenfield 1968). However, limits to radar stereo fusion by a human observer of the stereo model are not well understood: as the stereo model has better error propagation properties, its stereo viewability reduces. Experimental work is currently going on to more fully establish data on radar stereo viewing. Of particular interest is opposite-side stereo due to its promise of better stereo accuracies and vertical exaggeration. Indications exist that successful opposite side stereo may be possible with medium elavation angles (Graham, 1979).

e) Radar Ortho-Images

Radar images can be converted to ortho-images An early approach with a dedicated machine was described by Yoritomo (1972). A fast and still comparatively inexpensive method of producing a radar orthophoto is by a standard photogrammetric differential rectifier. Examples for such orthophotos were produced on a Wild Avioplan OR-1 (Leberl, Fuchs, 1978; Leberl, Fuchs and Ford, in press). The same technique could be, but has not yet been applied also in a digital image processing system. Inputs are: The navigation data, a digital height model, control points and the raw radarimage. An example of a radar orthophoto map is shown in Figure 1.

f) Radar Block Adjustment

No developments have come to our attention in the area of radar block adjustments. Dowideit's work (1977 a,b) has been concluded, but its main results have been presented in earlier review papers (Leberl, 1976).

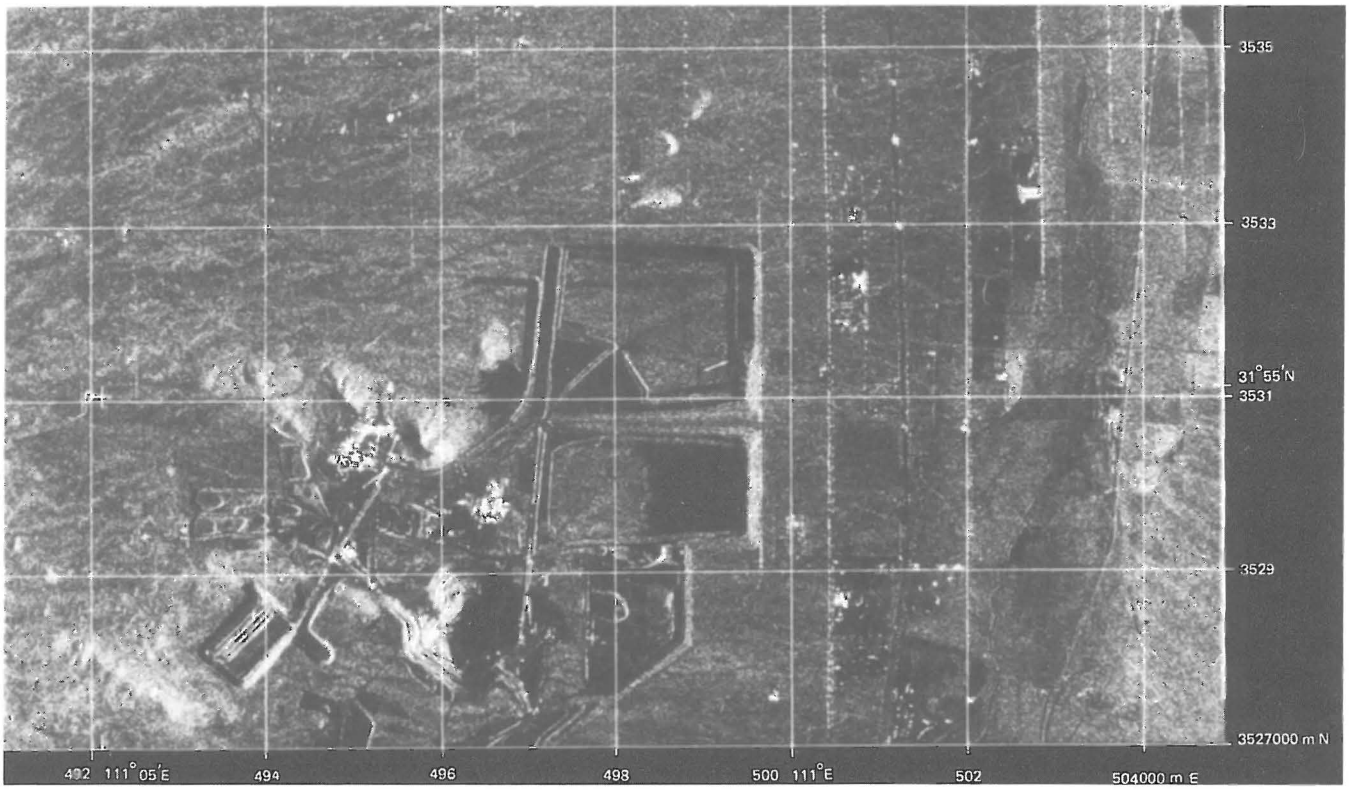

Figure 1: Example of a radar orthophoto of Sierrita, Arizona, USA (Section). Produced on Wild Avioplan OR-1 from X-band Goodyear GEMS images (Leberl et al., 1980).

3. SATELLITE RADAR

Satellite radargrammetry was to have had its breakthrough with the U.S. N.A.S.A. SEASAT-A synthetic aperture radar (SEASAT-SAR). This project generated radar imagery with parameters as listed in Table 1; after 1502 orbits the

Mission duration	4 July - 11 October 1978
Orbit height	790 - 820 km
Orbit inclination	108 retrograde
Orbit period	100 min
Radar wavelength	25 cm, L-band
Radar look angle offnadir	17^{o} to 23^{o}
Swath width	100 km
Resolution	25 m nominal

Table 1: Seasat-SAR Mission parameters

satellite failed. A large mass of images was generated, covering a variety of countries in the Western hemisphere, e.g. Austria in the East and the U.S. in the West. However, the short duration of the mission caused a failure to stimulate worldwide interest in any similar form as this occurred with LANDSAT.

SEASAT images have been produced in optical correlators and in specifically designed digital processors. In fact, digital correlation of synthetic aperture radar image data may owe its breakthrough to SEASAT. Figure 2 shows an example of an optically as well as digitally correlated image .

A theoretical analysis of image errors due to orbit perturbation has been published by Kratky (1979). Radargrammetric experimental work has not been reported to date with SEASAT data in the open literature. Spotty coverage did also not permit an attempt at systematic coverage of extended areas.

However, the basic radargrammetric mapping accuracy potential of SEASAT has been evaluated in an early internal report (Leberl, 1978). This and some work since leads one to conclude that SEASAT radar images have errors in the order od $\pm$ 100 m when ground control points of a high density of 1.2 points per 100 km^2 are used (compare Table 2). The greatest problem is the identification of

	Optical Correlation		Digital Correlation	
	m_x (meter)	m_y	m_y (meter)	m_y
4 Parameters (linear Conformal	300	273	502	574
5 Parameters	294	243	535	222
6 Parameters (affine)	284	241	119	198
8 Parameters	220	349	155	188
Identification errors	57	48	47	72

Table 2: Seasat-SAR geometric coordinate errors in meters on the ground, as found after overdetermined transformations. Identification errors were found from 15 well defined points distributed in small area.

control points. Figure 2 presents the example of a SEASAT-SAR image detail to highlight the difficulty to clearly identify such points. The stadium (baseball) can be identified, as well as some major freeways. However, identifiability is not consistent. Freeway Nr. II (Pasadena Freeway) disappears in the vicinity of the stadium.

(a) (b) (c)

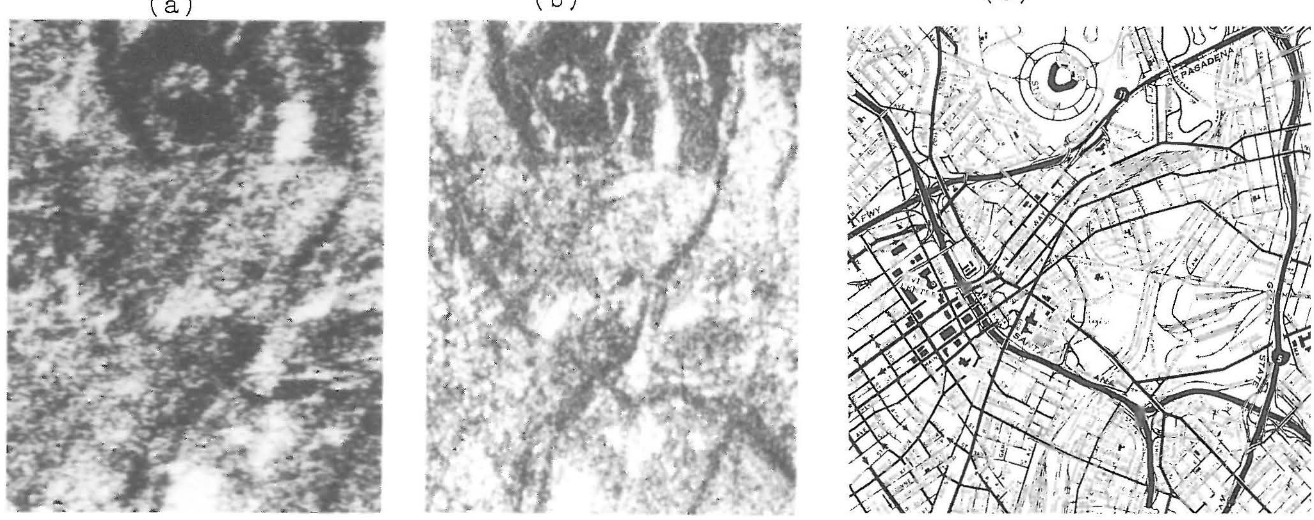

Figure 2: Seasat image of Los Angeles down town area with intersection of Harbor and Santa Ana Freeways. (a) optical correlation; (b) digital correlation; (c) map at scale 1:50 000.

SEASAT-SAR images permit us to evaluate the applicability of satellite radar for sea-ice mapping. There is early but clear evidence that this application is possible (Leberl, in press). However, accuracies will be those listed in Table 2: therefore expectations that SEASAT-SAR would be more accurate than data from an inertially guided aircraft have not been fulfilled.

4. SIDE-SCAN-SONAR

4.1 General

Side scan sonar is a sensor which is not likely to be widely known outside marine science disciplines hence a brief description of at least its geometric principles of operation follows;for a more comprehensive description reference is made to the literature (e.g. Cholet et al., 1968).

Side scan sonar is a dynamic imaging system in which high frequency acoustic signals (ultrasounds) are radiated by two transducers (antennae) at right angles to the heading of the hydrodynamic tow body housing them. These pulses propagate through water as two acoustic beams (Figure 3).

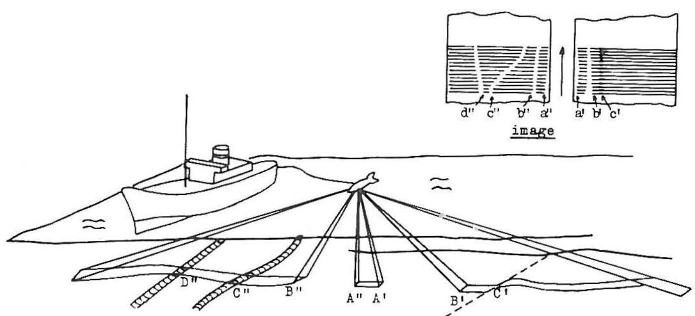

Figure 3: Principle of operation of dual channel Side Scan Sonar

The acoustic beams intersect the sea bottom over two more or less trapezoidal areas from which acoustic energy is partially reflected back to the sensor. The echoes, whose amplitude changes are functions of distance, incident angles of the sound wave front and of bottom reflecting properties, modulate the intensity (or brightness) of an imaging element which is synchronized to sweep across the width of the recording medium (electrosensitive paper or film) with the same frequency of the transmitted pulses. The recording medium is synchronized to move forward with a speed proportional to the velocity of the survey vessel. In this way,as the vessel proceeds,adjacent image lines are built up as variable grey density of the sea bottom topography.

From the preceeding discussion it is evident that, from the point of view of geometry and of image formation, Side Scan Sonar works essentially in the same way as SLR. However, system image errors in Side Scan Sonar can be much more serious than in SLR, because

- the influence of the so-called slant range representation is accentuated since ratios of range to depth (and the elevation angles of the line of sight) are usually smaller than the corresponding ratios in SLR;
- significant variations in velocity of propagation of sound may occur over relatively short distances causing a "bend" of sound rays (refraction);
- due to instrumental limitations synchronisation of forward motion in the graphical recording medium and of vessel velocity is hard to achieve resulting in significant image scale differences in x an in y;
- attitude variations in the sensor's carrier (tow body) are not controllable.

Due to these sources of image errors mosaicing of Side Scan Sonar images is hardly possible without some previous form of image rectification. Therefore a number of rectification systems have been developed in the past.

4.2 Rectification of Side Scan Sonar Images

4.2.1 Past Development

First attempts to restitute bottom features using Side Scan Sonar were made by the traditional users of the system, namely the marine geologists. The necessity was felt to assemble mosaics from different images to facilitate identification of geological structures. These restitution techniques aimed at minimizing the largest systematic distortions with some form of piece or patchwise rectification procedure. The rectified patches, or units, were then combined into photomosaics. This is similar to the procedure used in photogrammetry prior to the introduction of the orthophoto production.

a) Institut Français du Pétrole

First results were reported by Cholet, Fontanel and Grau (1968) of the Institut Français du Pétrole. Their system employs an optical anamorphic rectification for correction of image scale differences in x and y. The original record is photographed patchwise through an optical system which included two cylindrical lenses.*

To minimize distortions due to slant range representation only the far range portion of the images was used (where far ranges are at angles of incidence larger than 60°). One was considering to incorporate gyros in the tow fish to provide dynamic attitude control; however, no actual development has been reported along this line.

b) University of Bath

The next published work on a restitution system for Side Scan Sonar was by Hopkins (1970) and Chesterman and Hopkins (1971) of the University of Bath. The system is based on magnetic tape recording of the Side Scan Sonar signal and subsequent play back and processing by a specially developed analogue electronic processor. The output ot the processor is a frame of the Side Scan Sonar image on the face of a Cathode Ray Tube (CRT). The CRT was photographed, frame by frame, with a 35 mm camera. The frames are then assembled into a mosaic.

The corrections applied to the individual frames during play back onto the CRT are:

- uniformity of scale in x and y direction
- constant drift angles.

The value of the image scale in the direction of tow is obtained from the mean of a number of position fixes (Kelland and Hopkins, 1972). The drift angle is also derived from the navigation data, under the assumption that its value is constant from fix to fix.

No attempt has been made to correct for slant range representation although the implementation of such feature should not represent serious technical difficulties (Hopkins, 1972).

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* Anamorphic optics was also used for radar images in the early days.

The main advantage of the Bath system is that the image is produced directly on stable film material avoiding the possible deformation of wet paper recorders.

c) University of Wisconsin

Berkson and Clay (1973) published a restitution method developed at the Geophysical and Polar Research Centre at the University of Wisconsin. Like the Institut Francais du Pétrole and Bath's methods, the output is a rectified image unit to be assembled into a mosaic. The only correction implemented is for slant range representation. The system is basically a modified facsimile copying machine which has two drums mounted on a common shaft (Figure 4). The original image is scanned on one of the drums and simultaniously recorded on the other using non-linear ratios of scanning/recording.

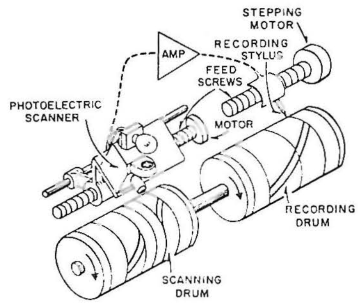


Figure 4: Image rectifier of the G.P.R.C. University of Wisconsin (Berkson and Clay, 1973).

d) Using a Photogrammetric Rectifier

Pollio (1971) reports on restitution of Side Scan Sonar images by using a photogrammetric rectifier to obtain uniform x,y image scales. The degree of freedom of such a rectifier, however, allow only for a very approximate anamorphic rectification.

4.2.2 Current Status

a) Fiber Optics Recorder

The Fiber Optics recorder originally developed by Edo Western and Westinghouse Corporation for the U.S. Navy (O'Farrell and Winston, 1971) is by far the best of the Side Scan Sonar analogue rectifiers (Figure 5).

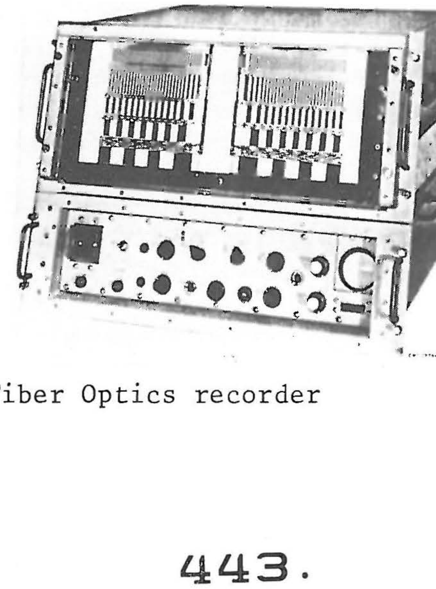


Figure 5: Edo Western Fiber Optics recorder

A civilian version of this equipment is marketed by Edo Western Corporation (Edo Western, 1972). The main characteristics of this advanced image recorder-rectifier are summarized as follows:

- very high resolution from 50 to 75 µm depending on the film used;
- continuous double channel recording using dry processing method with high image tone density range (20 dB) and good dimensional stability;
- correction for slant range representation;
- possibility of continuous correction for yaw, up to $\pm 5^{o}$ (providing that the input from such parameter is available);
- possibility of continuous correction for homogeneous x and y image scales;
- continuous alpha-numeric annotation on the edge of the image by a nine digits (letters) character generator.

The rectifier can be used on-line or off-line. In the latter case the input would be from analogue recorded Side Scan Sonar signals.

b) The System of the Netherland's Rijkswaterstaat

The Data Processing Division of Rijkswaterstaat, in co-operation with Netherland's Interdepartmental Working Community for the Application and Development of Remote Sensing Techniques, developed a digital image rectifier processor for airborne remote sensing data (Clerici, Eckhart and Kubik, 1974), which was modified to accept and process input from Side Scan Sonar. Figure 6 schematically illustrates the principal components of the system.

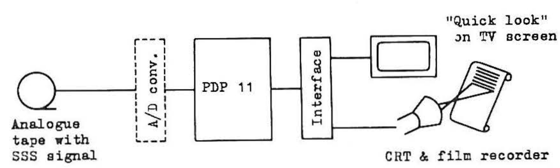


Figure 6 : Rijkwaterstaat -NIWARS equipment adapted to Side Scan Sonar processing.

The modifications to the original equipment consist of an A/D interface to input analogue recorded Side Scan Sonar signals into the digital processing unit.

c) Digital Image Processing

Undoubtedly spurred by user requirements for improved image quality and for some form of image rectification which would allow meaningful mosaicing, one of the leading Side Scan Sonar instrument manufacturers is marketing a new generation image recorder (E.G. & G., 1978). In this system the sonar signal is digitized on line and can either be recorded on tape for later processing or used directly to generate an image via a micro-processor controlled graphic printer. A minimum amount of geometric processing, such as approximate slant range correction and equalizing of x-y scales, is carried out on line prior to imaging. The latter type of processing is the most significant improvement of the two. The graphic printer has high geometric resolution (0.125 mm) and adequate dynamic range (16 grey tones).

The marketing of such a recording system is a welcome development which will lead to significant improvement of image interpretability and geometry. Improvement of interpretability can be achieved by applying off-line well established digital image processing algorithms to the recorded sonar data (Clerici 1977, Paluzzi, 1979). Improvement of image geometry can only be achieved if attitude and station parameters are adequately sensed and recorded during the survey mission. An overview of a possible digital image processing and rectification system is given in Figure 7.

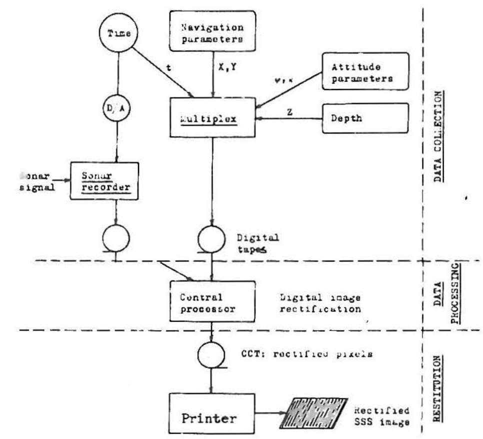


Figure 7: A digital image processing and rectification system.

4.3 Depth Determination from Side Scan Sonar

There are basically two possibilities of determining depth information from Side Scan Sonar data, namely by interferometric or by stereoscopic methods, these will now be discussed in some detail.

4.3.1 Interferometric Methods

Some of the earlier works on image interference in under water acoustics and of its relation to water depth have been reported by Young (1947) and by Sanders and Stewart (1954).

Chesterman et al. (1967) were the first to obtain sea bottom contours by means of fringe interference patterns, appearing on Side Scan Sonar images. These interference patterns were caused by reception of signals travelling along direct and along surface reflected paths. Further experimental work was published by Heaton et al. (1971). A practical shortcoming of the method used by these authors was the necessity of specular surface reflection to obtain image interference; this problem could be overcome by using two transducers working at the same wavelengths and placed vertically above each other (Stubbs et al., 1974; SFB 149 Jahresbericht 1978). When the incoming signals are added the value of the amplitude of the summed signals is zero, whenever the difference of the two ray paths is an integer factor of one half the wavelength used (Figure 8).

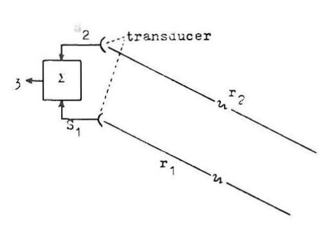
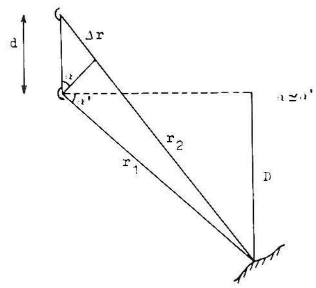


Figure 8: Principle of image interference using double transducers.

A similar system has been developed for Side Looking Airborne Radar (Manual of Photogrammetry, 1966; Graham, 1974), but is currently not anymore in use.

The geometry relating the resulting interference fringe to water depth is indicated in Figure 9 .



$$\sin \alpha = \frac{\Delta r}{d}$$

or

$$\sin \alpha = \left(\frac{2m + 1}{2}\right)\frac{\lambda}{2}$$

D = r sin α

m = interference fringe number

Figure 9: Geometry of depth determination by interferometric methods

The model described in Figure 9 is based on two simplifications: one geometric, implying that the locus of points generating interference patterns are far enough to the transducers that the two rays r_1 and r_2 can be considered parallel, and one physical implying constant propagation velocity of sound. Contrary to electromagnetic propagation in air, velocity of sound in water may vary quite considerably even over short distances.

An analysis of errors in depths due to these simplifications and to roll angles of the tow housing the double transducer assembly has been made by Clerici (1977). Ignoring variations in depth of the tow body an upper limit for the error in depth $_z$ resulting from errors due to roll ($I\varepsilon_z$) due to errors in range ($II\varepsilon_z$) and from simplified geometry ($III\varepsilon_z$) is given by

$$|\varepsilon_z| = |I\varepsilon_z| + |II\varepsilon_z| + |III\varepsilon_z|$$

or

$$|\varepsilon_z| = |\sin \alpha \varepsilon\rho| + |\omega \cos\alpha\ (\rho + \varepsilon\rho)| + |d \cos^2\alpha|$$

where
- α : as given in Figure 9
- d : vertical separation of the two transducers
- ω : roll angle
- ρ : range
- ερ : error in range

A graphical behaviour of the individual error components is given in Figure 10.

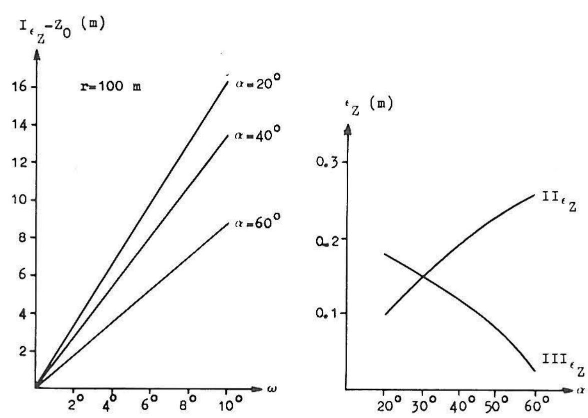


Figure 10: Contribution of individual error components to total depth error

As indicated in Figure 10 roll angle ω has by far the largest influence and has to be sensed, recorded and accounted for to obtain meaningful depth information; work in this field is in progress at the University of Hannover (SGB 149 Jahresbericht, 1978).

Experimental results indicated variations in depth of a (standard) Side Scan Sonar tow body of 0.5 to 1.3 m (m.s.e) with respect to a mean value Z_o (Clerici 1977).

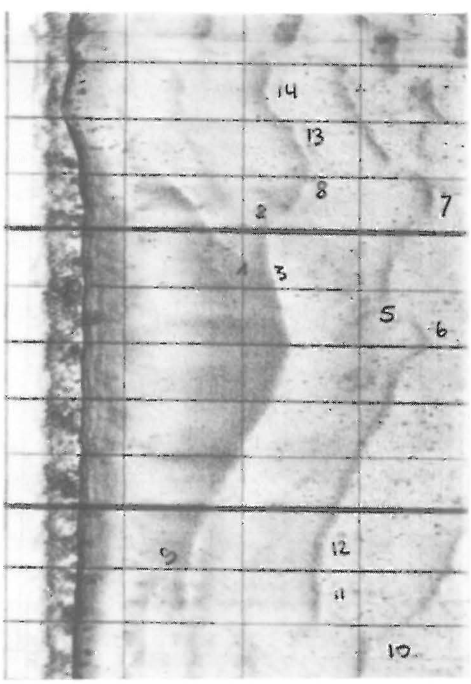
These figures indicate the necessity of sensing, recording and accounting for variations in vertical position of the transducer, this could be done using pressure cells.

4.3.2 Stereoscopic Methods

The geometric conditions for depth determination by stereoscopic methods in Side Scan Sonar are practically identical to those in Side Looking Airborne Radar. A suitable mathematical model has been published by Clerici et.al., (1978). A study of error behaviour led to the conclusion that the same side geometry proved to be unfavourable for depth determination in Side Scan Sonar (Clerici, 1977). From this analysis and considering present day navigation technology, it is concluded that determination of the relative position (b_o) for the sensors generating conjugate images is the critical factor and that opposite side stereo must be used.

Figure 11 shows example of "stereo" Side Scan Sonar images. Actual stereoscopic observation proved to be either very difficult or altogether impossible due to relative image scale changes and to lack of sea bottom detail in the images.

Controlled tests off Hoek von Holland resulted in the mean square error from check points of ± 1 and 3 m in image pairs such as shown in Figure 11.



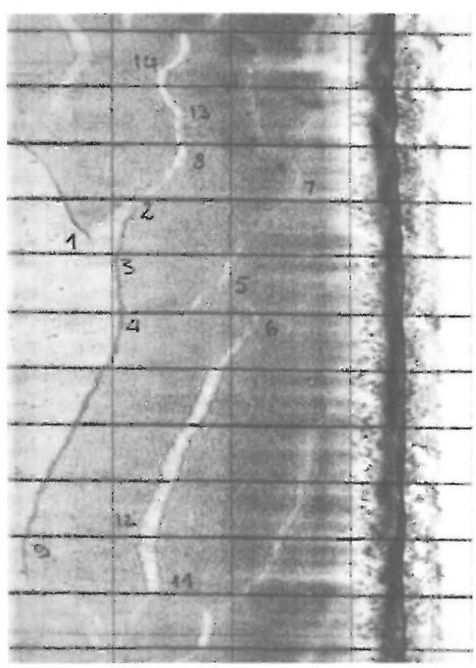


Figure 11 : Example of "stereo" Side Scan Sonar images.

4.4 Application of Side Scan Sonar

The following list of applications of Side Scan Sonar is far from being complete but is considered to be representative of the main purposes for which the sensor has been applied in operational environment:

- marine geology: study of geological structures, detection of sediment distribution;
- costal engineering: monitoring of sand transport, site inspection for gravity structures, pipe lines inspection, detection of man made objects;
- hydrographic surveying: detection of wrecks and of other obstructions to navigation, qualitative topographic information as guidance to completeness of soundings coverage and to depth contouring from sounding lines.

Geometric image processing is a common denominator to many of these fields of application. Image rectification is of great significance where mosaicing is required and where determination of relative position of imaged features is desirable.

Application of Side Scan Sonar as a quantitative sensor for determination of depths is still in an experimental phase.

5. OUTLOOK AND CONCLUSIONS

Both Side Looking Radar (SLR) and Side Scan Sonar will be affected greatly by digital technology and micro-electronics. The synthetic aperture radar signals from SEASAT have been processed digitally to form high resolution images initially at great costs and with large time lags after data acquisition. Currently, however, real-time digital formation of SAR-images is being done routinely, e.g. with the SAR-systhem of the Canada Centre of Remote Sensing -CCRS in Ottawa (Sloan, 1980). The advantages of digital processing, together with those of micro-electronics, combine to make possible very small and inexpensive SAR-systems that can be mounted in common survey aircraft. Given the fact that SAR-antennae are small, much smaller than those needed for real aperture radar, one may foresee a future situation where SAR ceases to be a privilege of large organisations. Replacement of bulky electronics and optical-mechanical hardware by small, dedicated digital computers may simply bring SAR in the realm of national surveying agencies.

This development for radar is also being seen with Side Scan Sonar: the recent introduction on the civilian market of an improved graphical image recorder and of on-line digitalization of the signal (E.G. & G., 1978) is probably the most significant development since the beginning of Side-Scan Sonar. This will allow the realisation of the sensor's full potential in operational environments and bring to bear the advantages of digital image processing.

The main metric reduction for both radar and sonar images will be rectification, to merge images with other data or combine them into mosaics. Height or depth determination has unclear prospects for both radar and sonar: while stereo radar has become a rather widely accepted means for improved thematic interpretation and is of particular interest for planetary exploration, the hydrographic surveying profession has been less than enthusiastic about the sonar imaging techniques available sofar for depth determination. Should it be possible in the future to develop sonar techniques where depth measurements are nearly automatic, e.g. by digital data processing and direct contour plotting, then Sonar images may be a viable means of depth measurements. However, one should not fail to see the role that airborne profiling can have in this area: this tool has recently made the step from research to development (Goodman, 1978) and may well prove to be an active alternative altogether.

As concerns radar it seems that technological development will enhance its usefulness and reduce costs dramatically. Therefore a requirement will continue to exist to explore radargrammetric aspects of mapping with single images, stereo-models, image blocks and to present radar data in conjunction with other data.

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