A 'REAL TIME' EXPERIMENTAL SYNTHETIC APERTURE SONAR AND A STUDY ON AUTOFOCUS IN SONAR ENVIRONMENT

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1. INTRODUCTION

Synthetic Aperture and Autofocus Techniques have been used in radar for many years and have given excellent results (Ref. 1,2,3,4), but unfortunately the adverse environment of Sonar i.e., the variability of the medium, the slow speed of propagation and difficulty of maintaining a smooth path for the sensor, has restricted the application of the techniques in Sonar (Ref.5,6,7).

This paper will describe a study of implementations of a time domain synthetic aperture algorithm and the performance of an autofocus algorithm in a Sonar environment.

2. THE IMPLEMENTATION OF A SYNTHETIC APERTURE ALGORITHM

A time domain algorithm has been implemented on an experimental synthetic aperture sonar system in a large tank available in the Department (Ref. 8). The basic principle is that for each image point the signals received at each element point are summed with appropriate delays depending on the position of the image point being reconstructed.

An obvious implementation is to capture and store the echos from all the points of transmission first, and then for each pixel of the image to be reconstructed, sum corresponding date collected from every column when the end of aperture is reached. In this way, the result will be presented in the time taken to process all the data captured. Clearly, for a fixed range, the wider the area to be observed the longer it will take to reconstruct the image.

An alternative way to process the data column by column as it is collected. The system works in real time in that data is processed continuously column by column as the sensor moves across the aperture no matter how wide the area to be observed. The quality of the reconstructed image thus improves as more data is collected.

The present processing system comprises a Motorola DSP56001 digital signal processor hosted on a 20MHz 386 PC. The aperture is about 2 metres and the range up to 5 metres. The operating frequency is 40kHz and the range resolution is determined by the bandwidth of the transducer. Using a Gaussian pulse of about 5us gives a range resolution of a few cms which compares with the minimum cross range resolution available of half a wavelength i.e., about 2 cms. Samples are taken along the aperture at intervals of 2cms i.e., 100 transmissions in a 2 metre aperture.

With these parameters and with the present relatively slow processing system it takes approximately 75ms to process the output from one column i.e., one transmission. Thus the processing is able to keep pace with the relative slow movement of the sensor across the aperture.

An experimental result is shown in Fig.1. The target comprises a number of table tennis balls spaced about 10cm and arranged in the form of the letters LUT. Each table tennis ball has a target strength of about -40db. The aperture is 2m and a section of range from 1.5-4.5m is shown. The resolution capabilities of the system can readily be observed. The cluster of target around the LUT target are due to reflection from the floor of the tank and the defocus effect due to error motion of the sensor.

3. AUTOFOCUSSING

Autofocussing means that, in the absence of complete knowledge of the motion path of the sensor and the scatterer geometry, the matched filter i.e., the proper delay in the time domain for processing, is estimated from the raw data itself (Ref.1).

The distorted geometry due to sensor motion can be divided into two categories: along-track and across-track. In the case of radar, the image is most seriously defocused by along-track velocity error and across-track acceleration. The latter can be expressed as a range-dependent effective along-track velocity error (Ref. 1,2,3). In the case of sonar, a perturbation in the across-track direction i.e., sway, is the most critical motion in causing defocussing (Ref. 5,6,7).

An autofocus technique, contrast optimisation, has proved very successful in radar applications and some excellent results have been obtained from real data (Ref. 1,2,3,4,5).

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Unfortunately, in the case of underwater applications, the development of autofocussing techniques has not been so dramatic due to a number of problems peculiar to the environment. The low propagation speed of acoustic waves in water means the that the time to collect the data is such that the unknown movements of the towed body can be finer than the sampling time across the aperture. No autofocus method has been developed which will be capable of resolving unknown motions with a structure much finer than the length of the raw data (Ref. 1). However, when the error motion is relatively simple and slow, e.g., a sinusoidal wave in the direction of across-track with a period approximately the same as the aperture length, it can considerably improve the quality of image to apply contrast optimisation. Also when the length of the raw data is long enough, a whole aperture may be divided into several pieces to deal with error motion.

A set of computer simulated results with across track sinusoidal error of 1cm amplitude and a period of 0.5 cycle/aperture is shown in Fig.2. Three curves are shown namely the ideal result, the raw processed data and the autofocus data. Fig.3 shows similar results but for 1cm amplitude, a period of 1 cycle/aperture and processed in two blocks each half the full aperture. It can be seen the improvement from autofocussing if not as good when the motion structure becomes finer.

4. EXPERIMENTAL RESULTS

Fig.4 shows a set of results processed from real data captured in the tank with varying along-track velocity. The best result is processed with 1.25 times the nominal platform speed.

Fig.5 shows the image formed from the same data from which result in Fig.1 was processed but with 1.05 times the nominal tow speed.

5. CONCLUSIONS

The continuing rapid developments in the speed and cost of digital signal processing makes it possible to implement synthetic aperture algorithms in real time. Because of the speed available it is possible in some sonar applications to use direct sampling of the received signal rather than using the I-Q technique to reduce the signal frequency to base band.

Even though the synthetic-aperture and autofocus techniques have been proved dramatically successful in radar, applications in the sonar environment are still likely to be restricted. Further studies are being made of the problems.

6. REFERENCES

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Fig.1 Reconstructed image of LUT

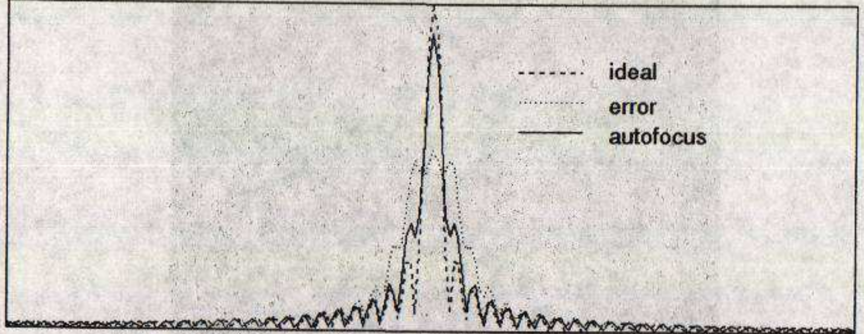

Fig.2 Simulated beam pattern

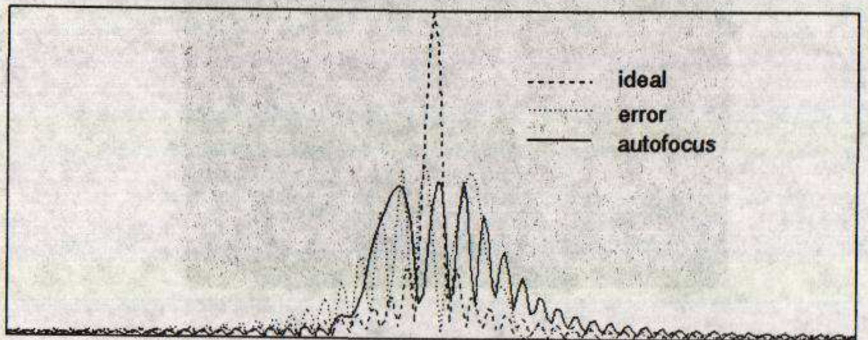

Fig.3 Simulated beam pattern

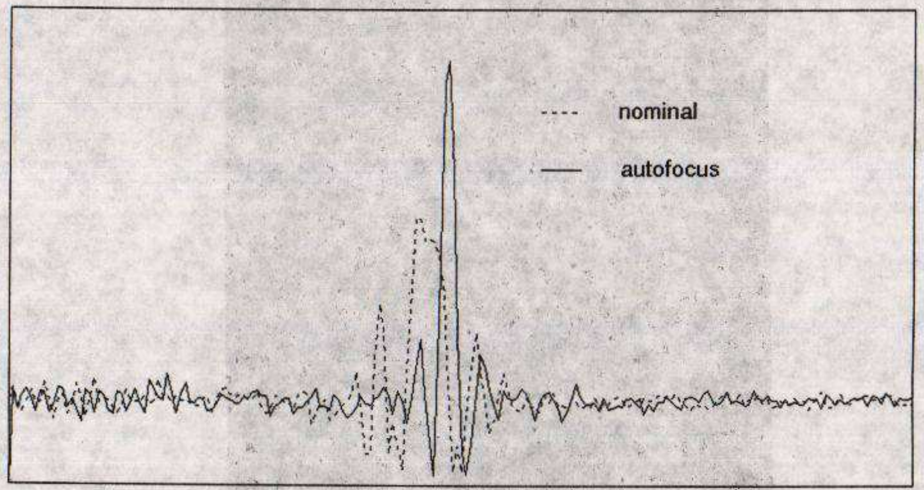

Fig 4 An experimental result of a single ball target

Fig.5 Reconstructed image of LUT