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PROCESSING REQUIREMENTS FOR SYNTHETIC APERTURE SONAR SYSTEMS

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ABSTRACT- This paper develops expressions which relate the parameters of a sonar to the processing power and memory required for the system. These expressions can be used when designing a sonar to ensure that realistic demands are placed on the processing engine. Benchmark test results are also presented for simulation algorithms running on a variety of machines.

RÉSUMÉ - Ce document développe des expressions mettant en relation les paramètres d'un sonar avec la puissance et la mémoire traitements requises pour le système. Ces expressions peuvent être utilisées lors de l'étude du sonar de façon à s'assurer que les exigences réelles sont placées sur l'appareil traitant. Les résultats des tests de repérage sont également donnés pour les simulations algorithmiques d'une variété de machines.

INTRODUCTION

High resolution mapping of the sea-bed has traditionally been met by side-scan sonars. In radar, synthetic aperture processing is applied to side-scan systems to improve the resolution and this technique is now being investigated for side-scan sonar systems. The side-scan technique involves towing a transducer array along a straight path at a constant velocity. Sound is transmitted in a beam perpendicular to the motion of the transducer (fig 1). Range (across-track) resolution is obtained by either transmitting a short pulse, or by transmitting a longer modulated pulse which can later be compressed into a short pulse. Azimuth (along-track) resolution is obtained by using a narrow beam, which means that a traditional side-scan sonar needs to operate at a high frequency which in turn reduces the operating range or with a long antenna which makes the system more costly and more cumbersome.

FIG 1 Showing the Geometry of a Side-Scan sonar.

By coherently combining the returns at several sampling positions the synthetic aperture technique produces an effective beam-width much narrower than that of the real antenna. A comparison of the theoretical performances of synthetic aperture sonar against to the non-synthetic aperture sonar can be found in [1] and [2].

The use of synthetic aperture techniques in side-scan radar are now commonplace [3] but their use in sonar is, as yet, restricted to research projects with no commercial systems known to the authors. To make a useful synthetic aperture sonar, it will be necessary to implement the processing in real time. Previous investigations into synthetic aperture sonar have performed the synthetic aperture processing off-line [4], [5], [6]. Another investigator [7] determined the processing requirement for a narrow-band synthetic aperture sonar in terms of the map-azimuth resolution. This paper extends the result to cover wide-band systems, and presents the processing in terms of the fundamental parameters of the sonar. The result can then be used when choosing the parameters for the sonar system to calculate their impact on the processing requirement.

PROCESSING REQUIREMENT

We assume that the processing is performed on every sample in the line, and that the length of the synthetic aperture is given by the lowest frequency in the transmitted pulse. The length of the synthetic aperture L_{sa} for an object at a slant range R from the antenna is given by:

$$L_{sa} = \frac{\lambda_{max} R}{D} \quad (1)$$

where D is the length of the real antenna on the fish and λ_{max} is the maximum wavelength of the frequency band in the transmitted pulse.

Then:

$$N_{sa} = \frac{L_{sa}}{\delta_s} = \frac{\lambda_{max} R}{D \cdot \delta_s} \quad (2)$$

where N_{sa} is the number of samples that contribute to the focussing on one point. To calculate the number of operations that need to be performed on the whole line N_{tot} , we sum the above equation across the whole range:

$$N_{tot} = \sum_{R_{min}}^{R_{max}} \left[\frac{\lambda_{max} R}{D \cdot \delta_s} \right] = \frac{\lambda_{max} \cdot (R_{max} + R_{min})}{2D \cdot \delta_s} \cdot \frac{2 \cdot (R_{max} - R_{min}) \cdot f_s}{C} \quad (3)$$

now f_s is the sampling frequency, i.e $f_s = k_o \cdot f_c$, where f_c is the centre frequency and k_o is the over-sampling rate, $\delta_s = \nu / \text{prf}$ where ν is the boat velocity and prf is the pulse repetition frequency, and:-

$$\lambda_{max} = \frac{C}{f_{min}} = \frac{C}{f_c (1 - 1/2Q)} \quad (4)$$

Where Q is the quality factor of the transmitted pulse ($Q = \text{Bandwidth}/f_c$) Substitute these into (3):

$$N_{tot} = \frac{k_o \cdot \text{prf} \cdot (R_{max}^2 - R_{min}^2)}{D \nu \cdot (1 - 1/2Q)} \quad (5)$$

This equation gives the number of focussing operations required to process a complete line, to find the rate of processing M , we need to multiply the number of computations per line by the number of lines per second. i.e $M = N_{tot} \times \text{prf}$. We can also say that:

$$\text{prf} = \frac{C}{2 \cdot R_{max}} \quad (6)$$

Multiply (5) by prf and substitute (6) into (5) gives:

$$M = \frac{k_o \cdot C^2}{4 \cdot D \cdot \nu \cdot (1 - 1/2Q)} \times \frac{(R_{\max}^2 - R_{\min}^2)}{R_{\max}^2} \quad (7)$$

It can be shown that this result agrees with the result presented by Lee [7] for the narrow-band case. It should be noted that all of the ranges are slant ranges and thus the swath of sea-bed covered by the sonar is not given by $R_{\max} - R_{\min}$.

TYPICAL VALUES

$D = 2\text{m}$, $\nu = 1\text{m/s}$, $k_o = 5$, $Q = 1.5$ (i.e 1 Octave), $R_{\max} = 750\text{m}$, $R_{\min} = 100\text{m}$

Substituting these values into equation (7) above gives 2.1 Million operations per second! This result in itself is fairly meaningless without knowing the complexity of an operation. In fact an operation involves finding a point that corresponds to the current focussing point, extracting it from memory and adding it to an accumulator. Thus, focusing on a point can take many computer instructions.

MEMORY REQUIREMENT

In addition to the processing requirement, an important consideration for the processing system is the total memory capacity needed to store the data. This section derives an equation which can be used at the sonar design stage to predict the impact that the relevant sonar parameters have on the memory requirement. The number of samples which must be stored per line is given by:

$$\text{samples/picture} = \text{samples/line} \times \text{lines/picture}$$

thus:

$$\text{samples/picture} = \frac{f_s}{\text{prf}} \cdot \frac{\lambda_{\max} \cdot R_{\max}}{D \cdot \delta_s}$$

Where $\delta_s = \nu/\text{prf}$, also

$$R_{\max} = \frac{C}{2 \cdot \text{prf}} = \frac{C \cdot D}{4 \cdot \nu}$$

and :

$$f_s \lambda_{\max} = \frac{k_o \cdot C}{1 - 1/2Q}$$

Thus:

$$\text{samples/picture} = \frac{k_o \cdot C^2}{4 \cdot \nu^2 (1 - 1/2Q)}$$

TYPICAL VALUES

Using the same parameters as above: $D = 2\text{m}$, $\nu = 1\text{m/s}$, $k_o = 5$, $Q = 1.5$ (i.e 1 Octave), $R_{\max} = 750\text{m}$, $R_{\min} = 100\text{m}$; then the amount of memory required is approximately 4 Mbytes assuming 8 bits per sample.

BENCHMARK TESTING

To evaluate accurately the processing requirement it is necessary to know the execution time for one operation. In theory this could be done by counting the number of instructions for one operation and then calculating the time taken to perform these instructions. Unfortunately, with modern processor architectures, which have complicated pipelining systems for instruction execution, it is very difficult to calculate the time taken to perform a complicated algorithm, thus the best way is to run the algorithm which would be used for synthetic aperture processing on a real machine and time it.

A simulation program was written in C consisting of two parts, the first, generating received sonar data from a simulated sea-bottom, the second, implementing the synthetic aperture processing algorithm to reproduce an image of the sea-bottom from the simulated sonar data. The algorithm was timed on several processors. Where possible hardware timers were

used to obtain the timing of the second part of the simulation program. When hardware timers were not available, the whole program was timed, and then the program was timed again without the second part of the simulation, when these two timings are subtracted the time taken for the second part of the simulation is obtained. The results of these tests are shown in table 1. The tests were based on the following processing parameters:

Max Range : 100m; Min Range : 0m; Boat speed : 2 m/s (4 knots); Array Length : 1m; Centre Frequency : 50 kHz; Over-Sample : 1; Number of platform positions stored : 60; Number of platform positions processed : 30

These parameters are much easier to process than the typical parameters shown in the previous, based on further simulation results and on the formula derived above, we would expect the processing to be five times greater than the simulation and to perform the processing for the typical parameters above in real time, a processor would need to be capable of performing the simulation program in 400ms. Using this, we can calculate the number of processors required for real-time execution. These figures are shown in table 1.

Table 1. Time taken by various processors to implement the synthetic aperture algorithm.

Name	Timing with process (s)	Timing without process (s)	Difference (s)	No. of processors required
Mototorola 68030 with 68882 co-processor	73.2	41.3	31.9	80
Sparc1	22.4	12.8	9.6	24
Intel i860	5.08	3.25	1.83	5
Inmos T801 (20MHz)	-	-	12.3	31
Motorola 88000 (16k cache)	-	-	8.0	20

CONCLUSIONS

We have shown that synthetic aperture processing of side-scan sonar data is possible in real-time with a favourable choice of sonar parameters. We have also derived expressions which allow the designer of synthetic aperture systems to predict the impact of his choice of sonar parameters on the processing system.

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REFERENCES

- [1] Lois. J. Cutrona "Comparison of sonar system performance using synthetic-aperture techniques with the performance achievable by more conventional means" J. Acoust. Soc. Am., Vol. 58, no. 2 pgs 336-348.
- [2] Lois. J. Cutrona "Additional characteristics of synthetic-aperture sonar systems and a further comparison with nonsynthetic-aperture sonar systems" J. Acoust. Soc. Am., Vol. 61, no. 5, pgs 1213-1217.
- [3] Kiyo Tomiyasu "Tutorial Review of Synthetic-Aperture Radar (SAR) with Applications to Imaging of the Ocean Surface". Proc. IEEE, Vol. 66, no. 5, pgs 563-584.
- [4] Nai-Chyuan Yen, William Carey "Application of synthetic-aperture processing to towed-array data." J. Acoust. Soc. Am. vol 86, no. 2, pgs 754-765.
- [5] Ross. E. Williams, "Creating an acoustic synthetic aperture in the ocean." J. Acoust. Soc. Am. vol 60, no. 1, pgs 60-73.
- [6] Peter.T. Gough and Michael.P. Hayes "Test results using a prototype synthetic aperture sonar.", J. Acoust. Soc. Am. vol 86, no. 6, pgs 2328-2333.
- [7] Henry. E. Lee. "Extension of Synthetic Aperture Radar (SAR) Technique to Undersea Applications", IEEE-OE, vol. 4, no. 2, pgs 60-63.