HIGH-SPEED SIMULATION OF AN UNDERWATER ACOUSTIC FIELD USING AN ARRAY PROCESSOR

by

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ABSTRACT

A computer model PAREQ for simulating the acoustic field of sound propagating in a complicated ocean environment has been installed on a real-time computer system (HP MX21) which includes an array processor (MAP 300). The use of the array processor has resulted in a reduction in running time of a factor of one hundred over previous usage on a general-purpose computer (UNIVAC 1106). Consequently, parametric studies, which prior to this installation were impractical to perform, can now be made. The model can be used for at-sea interpretation of experimental results and for the simulation of data which would be received by various acoustic arrays and analyzed by this same real-time computer system. Hence, array configurations and signal processing schemes can, to some extent, be tested before the actual sea trials.

INTRODUCTION

Computer modelling in underwater acoustics play an important role in understanding the physics of sound propagation in the ocean and therefore also has a significant impact in the area of sonar technology. In this paper we describe the goals of SACLANTCEN's modelling effort and how a real-time computer system with an array processor has been used to extend our modelling capabilities.

1 BACKGROUND

Computer simulation of underwater acoustic propagation is a component of the research, development, and usage associated with sonar system technology. Figure 1 illustrates the role of modelling (computer simulation) by showing a schematic of a part of the sonar technology area. The schematic is divided into two horizontal levels. The upper level may be roughly characterized as physics in which we are mainly concerned with understanding sound propagation in the ocean. This overall problem is approached both experimentally and theoretically (modelling). Experiments not only study sound propagation itself but also include simultaneous measurements of the ocean environment so that we may physically understand how sound propagates in the ocean. The modelling involves an attempt to describe propagation through this environment using the basic equations of physics. Hence the experiments are a check on the physical models, while at the same time models aid in the design of experiments.

For the second level of Fig. 1, there are three main aspects of development and usage:

1. Forecasting: predicting basic performance of specific sonars on a daily basis, based on the local ocean environmental conditions.

2. Analysis and performance prediction of existing systems: such studies can be used to optimize system performance by performing operations research type investigations.

3. Sonar system design: simulated data allows the systems designer to evaluate proposed systems under various environmental and operational conditions. Such studies require rather sophisticated modelling since future systems of, for example, extended aperture arrays require knowledge of the complex structure of the acoustic field.

Let us now briefly review the environmental acoustics of the ocean in order to make clear the complexity of the modelling problem. Figure 2 is a schematic of some possible propagation paths in the ocean. The ocean is bounded above by a rough wavy surface and below by an irregularly shaped bottom whose acoustic properties are generally quite complex. We show two possible locations of sources of sound on the left of the figure and we see that the sound is propagating to the right over a changing water depth, which adds increased complexity to the problem. The two dashed lines are sound-speed profiles (in electromagnetic theory they are the equivalent of indices of refraction) and we see that they vary with both depth and range. These profiles also have a statistical component caused by fluctuations in the ocean due to internal gravity waves.

Lines A, B, C, and D in Fig. 2 schematically represent four possible propagation paths. The shape of the paths are determined by the location of the source and the sound-speed structure over the extent of the propagation. Path A from the shallow source is a "surface-duct" propagation, because the sound-speed profile is such that the sound is trapped near the surface of the ocean. Complicating this path is the irregularity of both the ocean surface and the lower boundary of the surface duct, thereby allowing sound to escape and hence insonify other parts of the ocean. There is also the possibility that the ocean environment changes sufficiently that the duct disappears as illustrated in Fig. 2. Paths B, C, and D are from a deeper source. Ray B, leaving the source at a small angle from the horizontal, will tend to propagate in the "deep sound channel" without interacting with the boundaries (surface and bottom) of the ocean. This is usually a very stable path (propagation distances of thousands of kilometres are possible) but which can be interrupted by the water becoming shallower (as shown) or by a change in the ocean climate.

At slightly steeper angles (C) we have "convergence zone" propagation, which is a spatially periodic phenomenon of zones of high intensity near the surface. Here the path interacts with the ocean surface but not with the bottom. Typically, the periodicity of the zones is of the order of 30 to 50 km and two or three successive zones are the most one can utilize with a sonar because of the combination of decaying intensity with range and the "blurring" of the zones of high intensity by irregularities in the ocean.

The third path (D) is the "bottom-bounce path"; its cycle period is shorter than that of the convergence zone and only distances of one, or at most two, bounces can be utilized because of the reflection loss at the bottom. The right-hand side of Fig. 2 depicts propagation on the continental shelf (shallow coastal waters) where a complicated bottom structure combined with variable sound-speed profiles result in rather complicated propagation conditions not always suited for a simplistic ray picture representation. Finally, all of the above discussion is complicated by the fact that the propagation is also highly dependent on the acoustic frequency.

The above is only a brief description of sound propagation in the ocean, intended to convey an impression of the complexity of the problem. It should now be easy to see that computer models to describe sound propagation in the ocean based on physical principles are likely to be large and complicated. In fact, at SACLANTCEN, we are to a large extent interested in the region of Fig. 2, where the ocean bottom has a significant slope. In this region the propagation is sufficiently complex that we have not attempted to make a schematic diagram of how sound would couple from the deep water to the shallow water. However, an example of propagation over a sloping bottom as simulated by an acoustic model will be shown later.

2 THE ACOUSTIC MODEL AND THE ARRAY PROCESSOR

There exist many acoustic models of propagation in the ocean. Some are special to certain types of environments, while others are more general, these latter constituting very sophisticated computer programs. We shall not discuss the various models here but confine ourselves to a specific one, the PAREQ model [1] which is a large, general-purpose model that is able to simulate all the phenomena discussed in Ch. 1.

Figure 3 is a schematic of the algorithm used in the PAREQ model. Essentially, this model produces the acoustic field as a function of range and depth by "marching" out in range step by step away from the source. The computational cycle shown to the right of Fig. 3 is for a single range step. Each range step requires two complex FFT's and two complex vector multiplications. The elements of the vector multipliers change as a function of range because of the varying ocean environment, but the range steps required are generally so small that many cycles are passed before the vectors need to be changed.

The cycle shown in Fig. 3 is particularly suited for an array processor, which can do both vector multiplications and FFT's very fast. Hence, we have dedicated the MAP 300 array processor [2] to do the simple computational cycle of Fig. 3, while the HP MX21 host computer changes the vectors occasionally when the sound-speed profile or bottom properties change.

Before implementing the model on this system it was resident on the SACLANTCEN's UNIVAC 1106 system. Not only was the reduction in running time an important motivation for using the array processor, but also, from the algorithm represented in Fig. 3, it is obvious that only very little change in the software structure of the model was required. For other models, even less sophisticated ones, the numerics are such that installation of these models would essentially require rewriting the software in order to benefit from the speed of the array processor.

In this particular case, a speed factor of the order of 100 is gained by going from a UNIVAC 1106 without an array processor to a HP MX21 computer with an array processor. This means that computer runs that took several hours on the UNIVAC system can now be reduced to minutes. Furthermore, because running times for this type of model go up as the square of the frequency, studies can be made that were not possible at all on the previous system.

3 SOME RESULTS

Here we will briefly present some output results from the PAREQ model. Figure 4 shows a deep-water convergence zone result (Fig. 2, Ray C). Plotted is propagation loss versus range for the specific source and receiver depths. Here we see the zones of high intensity appearing periodically with range. This run took around three hours on the UNIVAC 1106 and has now been reduced to only about two minutes. The second example, Fig. 5, shows a shallow-water example. The important thing to realize about this run is that in shallow water, as depicted in Fig. 2, there is a continuous interaction with the bottom, which leads to the necessity of a very precise environmental prescription and to very long running times. Again, running times have been reduced from hours to minutes. As a final example, we study propagation of sound up a sloping bottom into a shallower water region. Figure 6 shows a range/depth plot of propagation-loss contours for sound propagating up a bottom slope (indicated by the dark line). Here we see that at certain ranges part of the sound is radiated into the bottom and hence lost from the water column. Such a phenomenon has been verified experimentally. Again, we emphasize, this is an extremely complicated environment that cannot be treated by simpler models.

SUMMARY AND CONCLUSIONS

A model to simuate an underwater acoustic field has been installed in an array processor connected to an HP MX21 computer with a resulting increase in speed of a factor of a hundred over its previous running time on a UNIVAC 1106. This will allow us to perform multi-frequency studies of complicated ocean environments, studies that could not have been done in a reasonable time on the UNIVAC system. In addition, since this model is now working on SACLANTCEN's real-time sea-going computer, the model can be used for at-sea analysis and interpretation of experimental data. For example, an existing, towed device to measure sound speed can be used to feed data into the model so that an in-situ acoustic prediction can be made and compared with the actual experimental data in real time. This procedure will allow the investigation at sea of anomalous experimental features that could not usually be studied until the experiment is over and the ship is far from the area of interest. Finally, the real-time computer system is being used for processing and beamforming of data from large moving arrays. The existence on this same system of a model for simulating data could aid in the design of the optimum configuration of these arrays and in selection of optimal signal-processing schemes.

REFERENCES

1. JENSEN, F.B. and KUPERMAN, W.A. Environmental acoustic modelling at SACLANTCEN, SACLANTCEN SR-34. SACLANT ASW Research Centre, La Spezia, Italy, 1979.

2. SEYNAEVE, R. et al. SACLANTCEN real-time signal processing system (WARP 1), Paper 3 of these Proceedings.

DISCUSSION

J.M. Griffin Did you run into any memory restrictions in implementing this model?

W. Kuperman No. The looping algorithm storage is done in the MAP and the resulting field at each range step is stored in the host computer.

S.G. Lemon Could the propagation model be used for optimum mode selection for a sonar system? (Mode such as towing depth optimization.)

W. Kuperman Yes, in the sense that it simulates the acoustic field and therefore allows the user to vary array geometry and see the results.

E. Hug What graphics package did you use for the contouring slide showing continental slope modes?

W. Kuperman That graphic package was on the UNIVAC.

R. Seynaeve We are completing the graphics package for the HP.

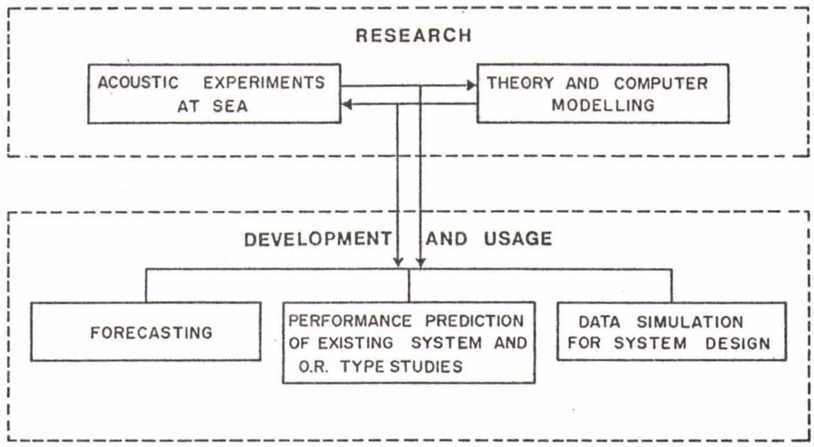

FIG. 1 ACOUSTIC MODELLING IN THE CONTEXT OF SONAR TECHNOLOGY

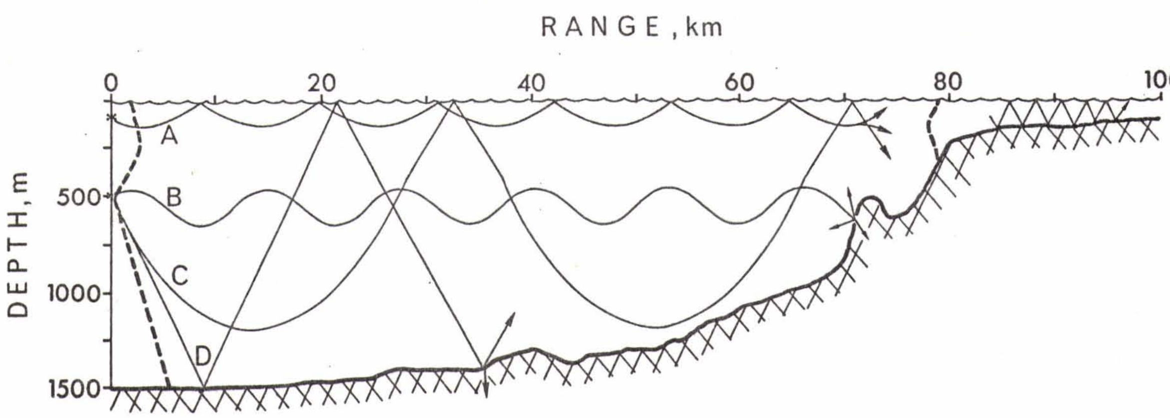

FIG. 2 SCHEMATIC REPRESENTATION OF SOUND PROPAGATION IN THE OCEAN

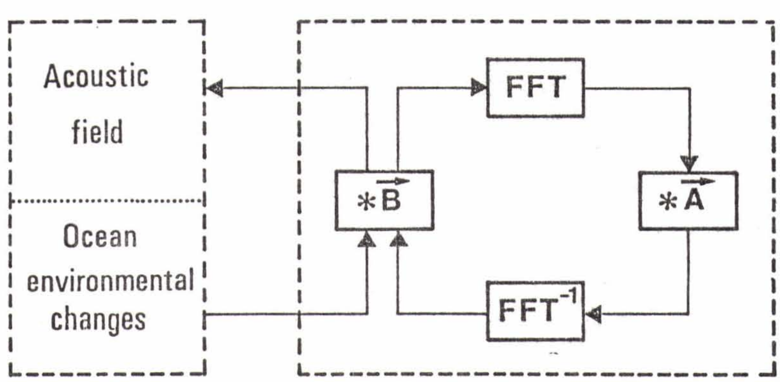

FIG. 3 MAIN COMPUTATIONAL CYCLE OF PAREQ MODEL

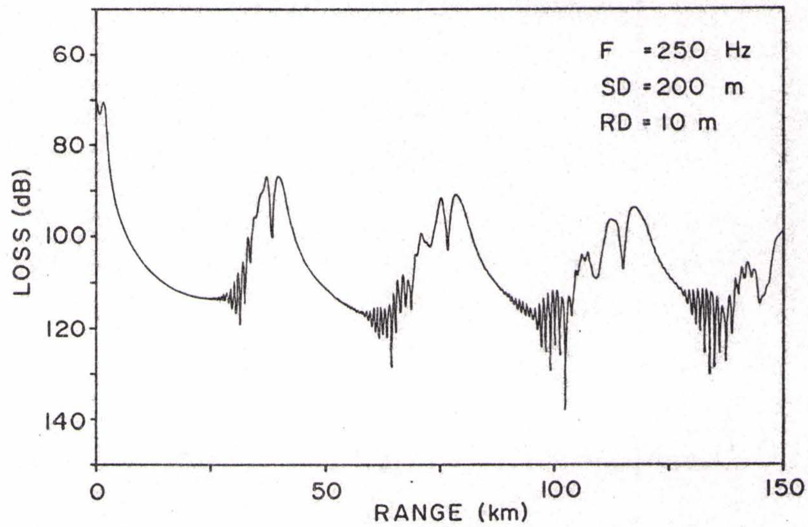

FIG. 4 PAREQ SOUND PROPAGATION PREDICTION FOR DEEP-WATER ENVIRONMENT

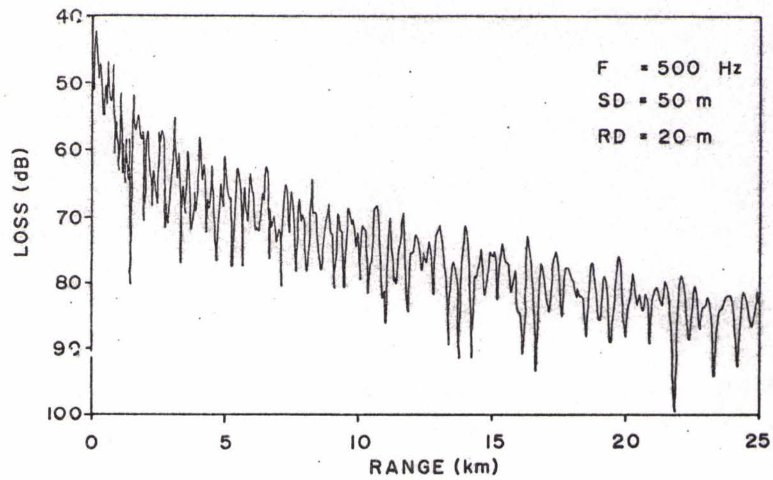

FIG. 5 PAREQ SOUND PROPAGATION PREDICTION FOR SHALLOW-WATER ENVIRONMENT

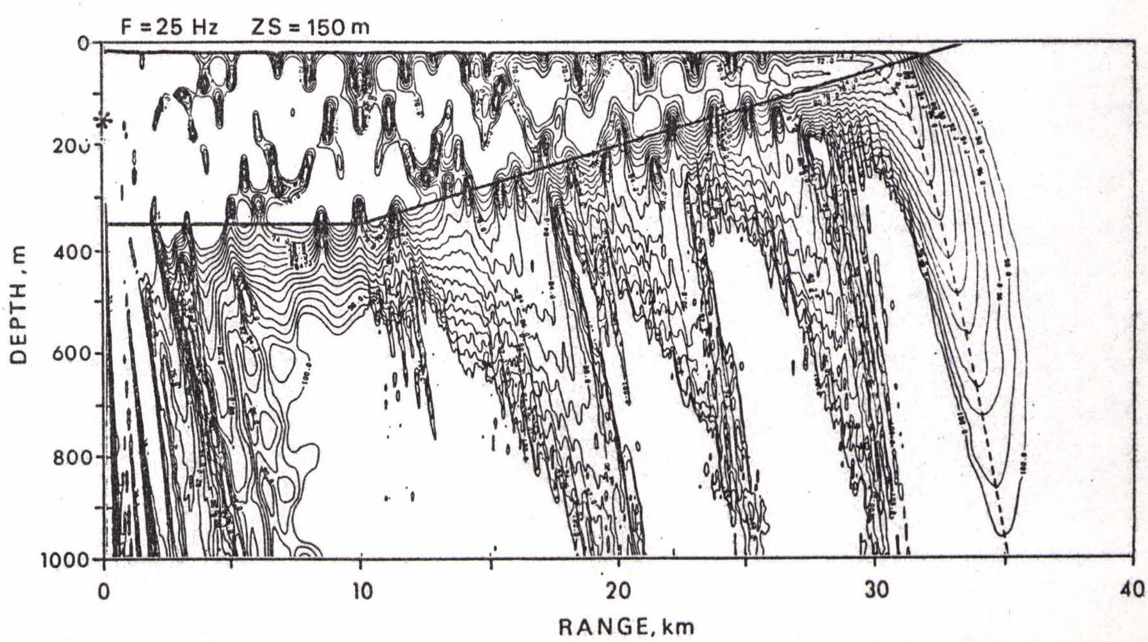

FIG. 6 CONTOURED SOUND FIELD FOR PROPAGATION OVER A SLOPING BOTTOM