ERCIM "Alain Bensoussan" Fellowship Scientific Report

Fellow: Assaf Mar - Or
Visited Location : NTNU
Duration of Visit: 12 months (1/04/2008 – 31/03/2009)

I - Scientific activity

The research work I had conducted with Prof. Dong during my stay at NTNU was part of an ongoing research into detection methods of subsurface inhomogeneities in marine / atmospheric environments using acoustic/elastic waves. Within this broad field, I became concerned with the numerical simulation of acoustic and elastic wave propagation with the aim of exploring some of these methods.

One of the methods considered was the use of time reversal methods. Time reversal methods, which had been developed by, amongst others, Fink and his collaborators (see the survey and references in [1]). Put in simple terms, a time reversal set-up includes a receiver array which records incoming waves, and a "back-end" which reverses them in time and re-transmits them into the medium via the array. Such a system is sometimes called a Time-Reversal Mirror (TRM). In practice, additional stages such as time-gating the received signal or repeated re-transmissions take place.

Working in an elastic medium (such as the seabed) allows two main types of waves to be considered for time-reversal – pressure waves and shear waves. These two wave types differ in several aspects, and in particular the pressure waves' propagation speed is considerably greater than that of the shear waves. It therefore follows that if shear waves are to be considered for the purposes of time reversal, the TRM should receive signals over a longer period of time than in the case of pressure-wave time-reversal.

The numerical simulation of the method presents us with two main difficulties. Firstly, numerical dispersion considerations dictate the use of a fine spatial mesh (which, in turn, results in small time steps for the calculation). Secondly, because the aim is to record the slower shear waves, steps must be taken to ensure that pressure waves reflected from the (finite) computational domain's boundary would not pollute the recorded data.

In order to reduce the pollution we have decided to use the perfectly matched layer (PML) method. This method, originally developed by Berenger [2] for computational electro-magnetics, and later extended to acoustics [3], fluid-dynamics [4] and elasticity [5]. The PML method extends the computational domain by attaching a layer which allows waves to propagate in without reflection (perfectly matched) while attenuating them (thus making reflections negligible). This is achieved by modifying the problem's equations inside the PML domain – either by artificially splitting the field variables into a parallel and normal components w.r.t. layer (split PML) or by introducing auxiliary fields (unsplit PML). Split formulations are easier to implement, however they may give rise to numerical instabilities in the resulting scheme.

For this reason, I have decided to construct an unsplit PML formulation for the elasticity equations, based on Hu's formulation for Euler 's equation [6]. This formulation, which had been implemented for the P-SV form of the elasticity equations [7] has the advantage of requiring less auxiliary fields than other unsplit formulations such as [8].

References

[1] B. E. Anderson, M. Griffa, C. Larmat, T. J. Ulrich, and P. A. Johnson. Time reversal. *Acoustics Today*, pages 5–15, January 2008.
[2] J.-P. Berenger. A perfectly matched layer for the absorption of electromagnetic waves. *J. Comput. Phys.*, 114(2):185–200, October 1994.
[3] Q. Qi and T. L. Geers. Evaluation of the perfectly matched layer for computational acoustics. *J. Comput. Phys.*, 139:166–183, 1998.
[4] C. K. W. Tam, L. Auriault, and F. Cambuli. Perfectly matched layer as an absorbing boundary condition for the linearized euler equations in open and ducted domains. *J. Comput. Phys.*, 144:213–234, 1998.
[5] F. Collino and C. Tsogka. Application of the perfectly matched absorbing layer model to the linear elastodynamic problem in anisotropic heterogeneous media. *Geophysics*, 66(1):294–307, January 2001.
[6] F. Q. Hu. A perfectly matched layer absorbing boundary condition for linearized euler equations with non-uniform mean flow. *J. Comput. Phys.*, 208:469–492, 2005.
[7] J. Virieux. P-SV wave propagation in heterogeneous media: Velocity-stress finite-difference method. *Geophysics*, 51(4):889–901, April 1986.
[8] F. H. Drossaert and A. Giannopoulos. Complex frequency shifted convolution PML for FDTD modelling of elastic waves. *Wave Motion*, 44(7–8):593–604, August 2007.

II- Publication(s) during your fellowship

None.

III -Attended Seminars, Workshops, and Conferences

None.

IV – Research Exchange Programme (12 month scheme)

FORTH/IACM – Wave Propagation Group (5.10.2008 – 13.10.2008)
(http://www.iacm.forth.gr/wave/)
Host: Prof. G. N. Makarkis

During my visit to the Wave Propagation group, I have met with Prof. G. N. Makrakis and Prof. C. Tsogka, with whom I have discussed certain underlying aspects of time - reversal acoustics, drawing on previous work. In particular, the possibilities of implementing a time - reversal approach for obstacle detection building on previous work on the Hagstrom-Warburton/Carpenter high-order open boundary condition.

INRIA/Rocquencourt – Team POems (22.02.2009 – 28.02.2009)
(http://uma.ensta.fr/poems/)
Host: Prof. P. Joly

My stay at the POems research group was focused on the PML method and its implementation, which I had discussed with Prof. P. Joly and Prof. E. Becache. In particular, some aspects of the construction of a Hu-like unsplit PML formulation (*J. Comput. Phys.*, 208:469–492, 2005) for the P-SV form of the elasticity equations and its properties had been discussed.