Scientific Report

First name / Family name	Lei Dong
Nationality	China
Name of the *Host Organisation*	NTNU
First Name / family name of the *Scientific Coordinator*	Hefeng Dong
Period of the fellowship	02/05/2013 to 01/05/2014

I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

My ERCIM fellowship from 02.05.2013 to 01.05.2014 was hosted at Acoustic Group of Department of Electronics and Telecommunication, Norwegian University of Science and Technology. My scientific supervisor is Prof. Hefeng Dong.

During the one year research, I opened mind to underwater acoustics. The research in underwater acoustics for acoustic remote sensing for characterization of the seabed and sea surface (sea ice in the Arctic region) involves development of propagating models based on wave propagation. Modelling of propagation conditions is an important issue in underwater acoustics and there exist a variety of mathematical/numerical methods based on different approaches. Approaches such as ray tracing theory, wave number integration techniques and the parabolic equation are relevant, as well as numerical methods such as finite difference, finite elements and boundary element methods. The mentioned methods require a wide knowledge, such as mathematics, physics and signal processing.

My research originally was planned to focus on the Acoustic Characterization of Ice using ray tracing model. The arctic region is covered by ice during winter and characterization of ice is of importance for offshore operations, transportation, oil exploration and production. During my fellowship, I explored the ray tracing software – BELLHOP for acoustic characterization. Furthermore, I explored the parabolic equation software – RAM and wave number integration software – OASES (SAFARI), and compared the BELLHOP and RAM at low and high frequency for various sound speed profiles.

BELLHOP is a ray (beam) tracing model to model the propagation of underwater sound. It can predict acoustic pressure fields in ocean environments. Beam tracing starts from the integration of the usual ray equations to obtain the central ray of the beam. Beams are then constructed about the rays by integrating a pair of auxiliary equations, which govern the evolution of the beam in terms of the beamwidth and curvature as a function of arc length. The resulting pressure field describes a beam, in that the filed falls off in a Gaussian fashion as a function of normal distance from the central ray of the beam. The central ray of the beam obeys the standard ray equations. The beam tracing structure leads to a particularly simple algorithm. Several types of beams are implemented including Gaussian and hat-shaped beams, with both geometric and physics-based spreading laws. BELLHOP can produce a variety of useful outputs including transmission loss, eigenrays, arrivals, and received time-series. It allows for range-dependence in the top and bottom boundaries, as well as in the sound speed profile. Additional input files allow the specification of directional sources as well as geoacoustic properties for the bounding media.

In parabolic equation (PE) approach, the Helmholtz equation is factored to yield an outgoing wave equation which can be solved efficiently as an initial value problem in range and a boundary conditions problem in depth. The equation is solved through a range-marching technique and, at each range step, the solution is computed along a grid in depth using finite difference or finite element techniques. The factorization is exact in range-independent environments. However, range-dependent environments are approximated as sequences of range-independent regions and the PE is used to propagate the filed through each region by neglecting the back-scattered energy at the vertical interfaces between each region. PE-based models are therefore valid for weakly range-dependent environments. The RAM software used herein is an implementation of the PE approach. It handles range-varying bathymetries and can handle multiple fluid layers as well as depth-varying sound speed profiles. Solutions by RAM have been used as reference solutions for benchmarking in range-dependent environments.

In the wave number integration approach, the dimension of the Helmholtz equation is reduced by a Hankel transform to obtain the depth-separated wave equation. The reduced Helmholtz equation can be solved by providing the depth-dependent Green's function and the complex acoustic pressure field is obtained through the inverse Hankel transform. The OASES model used herein (and its predecessor, the SAFARI model) is based on this approach. It is valid for range-dependent bathymetries and can handle multiple fluid and/or elastic layers, as well as depth-varying sound speed profiles. Solutions by OASES have been widely used as reference solutions, among others, in benchmarking.

Especially, I explored the BELLHOP for the case in which the bottom has several elastic layers. For layered elastic bottom, BELLHOP can use BOUNCE to generate the efficient reflection coefficient, which fits perfectly with the analytical solution. For the cases studied, BELLHOP fits very well with RAM which is used as a reference solution.

II – PUBLICATION(S) DURING YOUR FELLOWSHIP

L. Dong, H. Dong and J. Hovem, 'Bellhop – a modelling approach to sound propagation in the ocean'. Submitted to Proceedings for the 37th Scandinavian Symposium on Physical Acoustics.

III – ATTENDED SEMINARS, WORKHOPS, CONFERENCES

1) ABCED Seminar, Athens, Greek, 31.10-01.11.2013
2) 37th Scandinavian Symposium on Physical Acoustics, Geilo, Norway, 02.02-05.02.2014

IV – RESEARCH EXCHANGE PROGRAMME (REP)

1) Location: VTT, Finland
Duration: 23.09.2013-27.09.2013
Contact: Prof. Ilkka Norros

It was a nice experience to visit the group led by Prof. Ilkka Norros. I got to know the probability theory in may flavours and application contexts, such as reliability theory, stochastic geometry and random graphs. Mathematical methods are very important in computational simulation.

2) Location: ULB, Belgium

Duration: 24.03.2014-28.03.2014
Contact: Prof. Jean-Pierre Hermand

Prof. Hermand and his group gave me a very warmly welcome and introduced their on-going projects. The discussion with this group was very helpful for my project at NTNU and expanded my knowledge about the acoustics.