A prototype software environment for bistatic acoustic detection analysis

E. Skarsoulis,[1] M. Kalogerakis,[2,1] J. Papadakis,[3,1] G. Piperakis[1]

[1]Institute for Applied and Computational Mathematics, Foundation for Research and Technology Hellas (FORTH/IACM), PO Box 1527, 711 10 Heraklion, Crete, Greece

[2]Technological Education Institute-Crete, PO Box 1939, 710 04 Heraklion, Crete, Greece

[3]University of Crete, Department of Mathematics, 714 09 Heraklion, Crete, Greece

A PC/Windows based prototype software called TRITON has been developed for the analysis of bistatic underwater acoustic detection systems operating in a particular geographical area under noise- and/or reverberation-limited conditions. The analysis is performed taking into account range-dependent environmental (hydroacoustic and geoacoustic) characteristics, as well as operational characteristics of the involved platforms, including orientation and directivity patterns. TRITON features electronic maps and user-friendly interfaces for the description of the analyzed systems and supports dynamically interchangeable environmental databases offering global geographic coverage, as well as integrated problem handling and saving capabilities. The produced results include transmission loss, bistatic reverberation, probabilities of detection and detection areas.

1 Introduction

Bistatic and multistatic underwater acoustic detection systems are increasingly used to detect silent underwater targets, especially in littoral waters [1]. Littoral environments are characterized by complicated bathymetry which challenges acoustic propagation modelling. Further, strong bathymetric features give rise to strong reverberation, which thus plays a key role for the performance of the detection systems.

TRITON is a PC/Windows-based software prototype developed at FORTH/IACM for the analysis of bistatic underwater acoustic detection systems in noise and reverberation environments. The system features an interactive geographic map which supports multiple interchangeable environmental databases offering global coverage, allowing the user to focus on any area of the world oceans and seas. Once the area of interest is selected, the geometry and the operational parameters of the detection problem can be easily defined through the interactive map and a series of user-friendly interfaces. For a fixed detection problem TRITON calculates the acoustic propagation and reverberation field and uses it to further calculate probabilities of detection and detection areas. All computations are performed on a three-dimensional grid enabling presentation of results as 2D graphs (adjustable horizontal and vertical sections) and 3D objects on a geographical background. The system also features integrated problem handling and saving capabilities and can be extended to address multistatic acoustic detection systems.

2 System Structure

TRITON features a modular architecture. It consists of several specialized modules integrated under a master kernel unit that interacts, manages and controls all system components. The main advantage of this design approach is the ability to attach and/or replace modules in the future, making TRITON an easily configurable flexible environment.

The principal system modules are:

- An interactive electronic map offering global coverage. The map is capable to display several layers of physical information such as coastline and bathymetry data, the location of CTD stations available etc. It also supports interactive definition and manipulation of the principal geometric parameters of a problem (source position, receiver position/bearing, maximum range of calculations, etc). Conceptually the interactive map is part of the problem definition module (see below).
- A problem definition module through which the user enters/modifies the problem parameters. Several parameters such as source and receiver location and properties can be defined either graphically by direct interaction with the map, or by manual editing.
- A problem solution module featuring a custom-developed acoustic propagation code based on ray theory for the calculation of the acoustic field in the water column and the scattered field at the water-bottom interface (the latter necessary for reverberation calculations).

- A results presentation module for the graphical representation of the produced results as 2D graphs (adjustable horizontal and vertical sections) on a geographical background. Results include transmission loss, bistatic reverberation, probabilities of detection and detection areas.

3 Solution Calculations

Propagation

A ray-theoretic code has been developed for the calculation of the acoustic field, in particular transmission loss versus range and depth, and intensity of the scattered field at the bottom versus range. 3D coverage is obtained by solving the propagation problem along 36 vertical range-dependent sections extending radially around the source location in angle steps of 10°, as well as 36 similar sections around the receiver location *(see Figure 1)*.

Reverberation

The bistatic reverberation is calculated by combining the transmission loss and scattered field intensity results provided by the propagation code. The contributions of the scattered field at the bottom are integrated along ellipses having the source and receiver locations as focal points, taking into account the directional characteristics (directivity pattern, steering angle) of the receiver.

Directivity

In the current version of the system the acoustic source is assumed to be omnidirectional while the reception is considered to be directional, and subject to beam steering. The directivity pattern and the resulting directivity index is calculated at any steering angle of the array by applying spatial filtering – beamforming [2].

Probability of Detection

Using the results of the above calculations and the operational characteristics of the involved platforms (source, target, receiver) the signal-to-noise and signal-to-reverberation ratios at the beamformer output are calculated for each target location. Then the probability of detection is calculated using receiver operating characteristics (ROC curves) for energy or matched-filter detection [3].

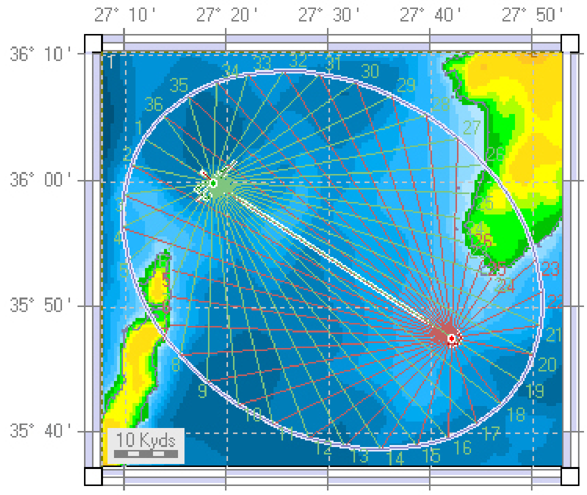

Figure 1. The 36+36 sections along which propagation calculations are performed

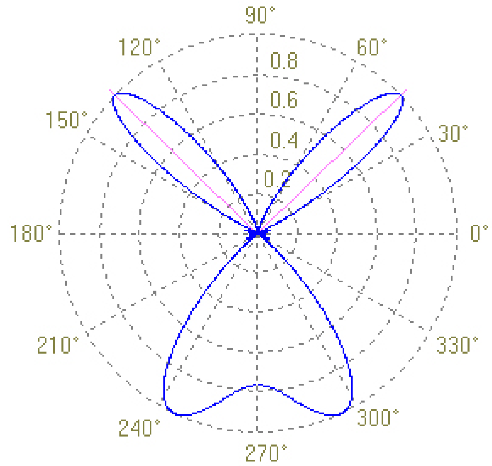

Figure 2. Directivity pattern graph of a typical linear receiving array for a steering angle of 44° and for a frequency beyond the Nyquist limit

4 Produced Results

There are two types of results produced by TRITON: Primary and synthesized 3D results.

Primary results are calculated for a number of vertical range-dependent sections defined radially around the source (also around the receiver) sweeping a full circle in steps of 10°. The maximum range of calculations for each section equals at most to the maximum distance that has been set for the problem, however a section can be shorter if constrained by the bathymetry/coastline *(see Figure 1)*.

Primary results include:

- Transmission loss from source (or receiver)
- Scattered field intensity at the bottom

- Transmission loss from source (or receiver) to the bottom

Synthesized 3D results are produced by interpolating primary results inside the elliptical area of the problem. While intermediate calculations are carried out in problem-adapted coordinate systems (e.g. elliptical coordinates for reverberation calculations) synthesized results are computed on a 3-D Cartesian grid permitting their presentation in a variety of ways.

- Transmission loss around the source
- Transmission loss around the receiver
- Transmission loss field (a synthesis of the two above)
- Scattered field intensity at the bottom
- Transmission loss from receiver to the bottom
- Bistatic reverberation
- Signal - to - noise / reverberation ratio
- Probability of detection

Primary results are visualized in graphs and 2D plots of range vs. depth. Synthesized results are superimposed on the geographical map with a variable level of transparency (Fig. 3). A separate three-dimensional viewer is also available for synthesized results (Fig 7).

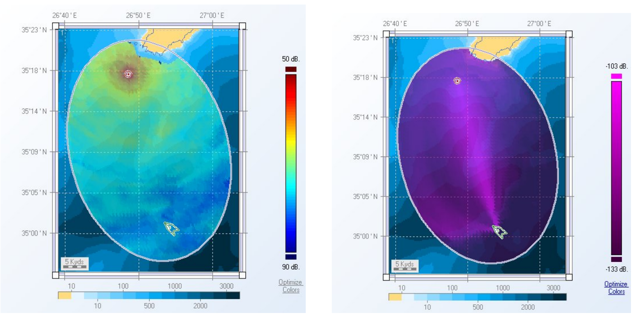

Figure 3. Synthesized results are superimposed on the geographical map

5 Graphical User Interface

To facilitate user interaction, TRITON's GUI features three *modes of operation* that correspond to the natural steps taken towards the solution of an acoustic detection problem. The user can freely navigate among these three modes of operation at any time

- Problem definition/editing mode. In this mode the user defines the geographical area, the position of the source and receiver on the map as well as the maximum range for target seeking. The local bathymetry, geoacoustic and oceanographic data (seasonally selected) are automatically extracted in the greater area of the problem (Fig 4). In the existing version of TRITON the user manually enters the operational characteristics of the source and receiver as well as the target strength. In later versions this information will be retrieved from operational databases attached to the system. Currently the environmental noise spectrum is modeled from the sea state and shipping density in the area of the problem (Knudsen curves) [4]; in a later version it will be also possible to import external noise data.

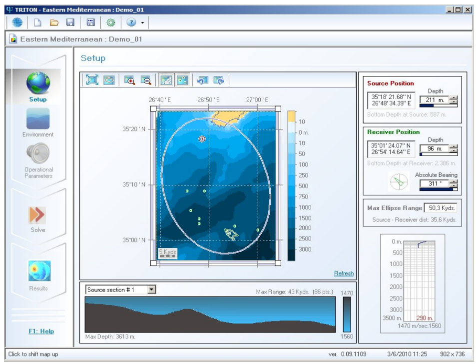

Figure 4a. Problem definition mode - Setup. The positions of the source and receiver are shown on the map. The bounding ellipse denotes the maximum distance of calculations

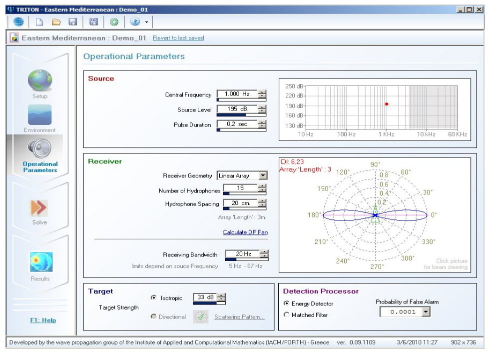

Figure 4b. Problem definition mode – Operational parameters. The directivity pattern is calculated by the system for simple receiving array geometries.

- Problem solution mode. When this mode is initiated, the system starts a sequence of actions to produce the primary results of the problem. (Fig 5). Thus the acoustic propagation code is running at first for 36 vertical sections around the source sweeping a full circle in steps of 10° and then for 36 additional sections around the receiver. After the completion of all 72 propagation runs, the produced results are used for the calculation of the reverberation integral on a family of ellipses covering the bottom of the problem area. The time required to complete all propagation runs for a typical problem running on a standard PC is about 1 minute.
- Results presentation mode: In this mode, primary results are visualized in graphs and 2D plots of range vs. depth. Moreover these results are combined and interpolated on a 3D rectangular grid covering the geographical area of the problem from surface to bottom and visualized as horizontal sections at any

specific user-selected depth (Fig 6). Synthesized results are presented as transparent plots superimposed on the map (the user controls the level of transparency).

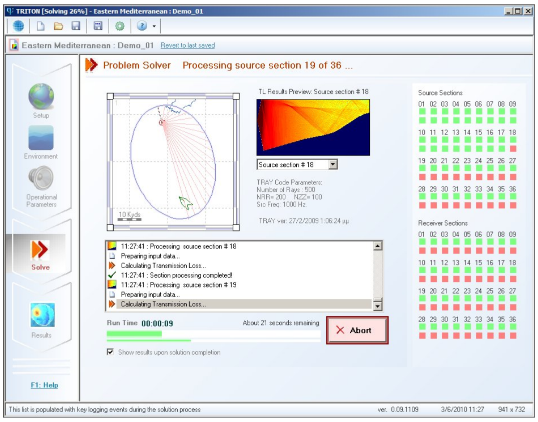

Figure 5. Problem solution mode. The section lines on the map as well as the horizontal green bars at the bottom indicate the solution progress. The propagation results for each vertical section are displayed as soon they are calculated

- The system also features an interactive three-dimensional results viewing module where synthesized result layers are superimposed on a 3D geographical background (latitude / longitude / depth) that can be freely manipulated in the three-dimensional space. In particular the user can adjust in real-time the roll, pitch, yaw and viewing distance of the 3D model as well as the cut depth of the horizontal section for the displayed synthesized results.

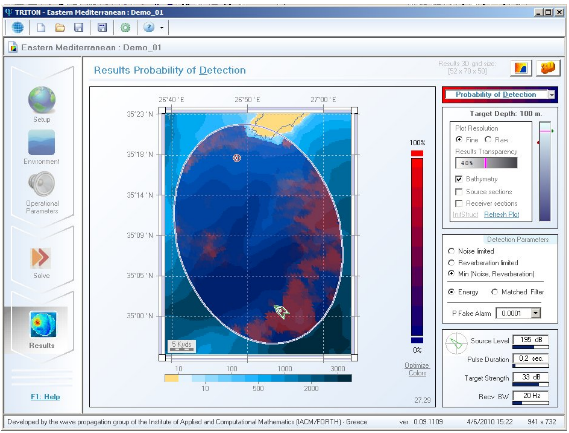

Figure 6. Results presentation mode. The semi-transparent plot of probability of detection for a specific target depth is superimposed on the map. Options include selection between energy/matched filter detection plus more detection parameters, as well as several input parameters such as source level and target depth and strength.

TRITON supports multiple environmental databases offering global geographic coverage, allowing the user to focus on any area of the world oceans and seas. Each database is focused on a specific world area containing public domain environmental and/or geological data. In its current configuration the system contains three databases covering the areas of the Eastern and Western Mediterranean Sea and the North Sea. The databases can be interchanged dynamically even while the system is running.

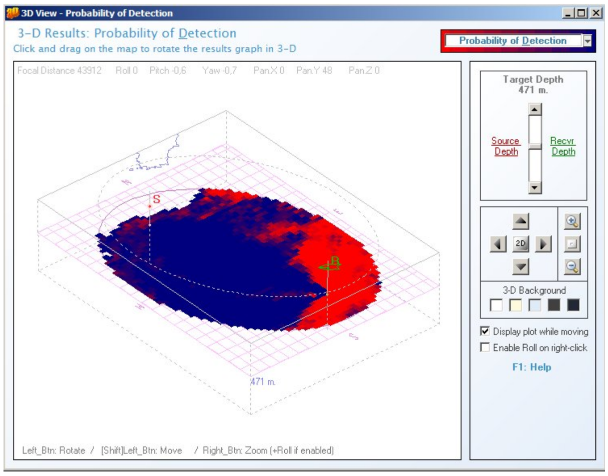

Figure7. 3D results viewing mode. The user can adjust in real-time the roll, pitch, yaw and viewing distance of the 3D model as well as the cut depth of the horizontal section for the displayed results

Another interesting feature of the system is integrated problem and results handling. This means that when a problem is solved all produced results are bundled to it and saved jointly, so that they become directly available when the problem is opened again.

More information about TRITON can be found at triton.iacm.forth.gr

References

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