Simulation of Operations in the Underwater Warfare Testbed (UWT)

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Surface vessels and submarines must be able to defend themselves against a torpedo attack. Several studies have shown the benefits of multi-platform and multi-static operations. To facilitate torpedo defence system studies and the development of future tactics, TNO Defence, Security and Safety started the development of the Underwater Warfare Testbed (UWT). This testbed integrates the simulation models TDSTB (Torpedo Defence System TestBed), MUST (MUltiSTatic facility tool) and ALMOST (Acoustic Loss Model for Operational Studies and Tasks).
The testbed models all relevant UWW assets, including vessels with sonars, helicopters with dipping sonars, and also enemy submarines (with their sonars and weapons). Each platform can use its own predefined tactics to operate alone or in task group formations. The UWT simulates the kinematics, communication and detailed acoustics signal levels (passive, active mono-static and bi-static, and intercept sonars) using the acoustic propagation and sonar performance model ALMOST. Within a simulation all systems will interact with each other. Simulated received signal levels are used to generate contacts and false targets for the tracker. The Detection, Classification and Localisation algorithms of the sonars can be modelled with high-fidelity and multi-resolution. This enables detailed runs and Monte-Carlo runs as well. The Underwater Warfare Testbed is used to evaluate operational tactics and future concepts for UWW. It is also applicable to develop submarine tactics operating in areas with multi-static sonar. The simulations in the UWT give the Royal Netherlands Navy valuable performance information for operational planning. In addition, it is also a useful tool for educational and training purposes. The authors will present the architecture and the applications of the Underwater Warfare Testbed.

1. Introduction

Surface vessels and submarines must be able to defend themselves against a torpedo attack. Consequently, the Netherlands Ministry of Defence (NL-MOD) has recognised the operational need for an effective torpedo defence system. The Royal Netherlands Navy (RNLN) uses torpedoes in its self-defence system. However, the currently deployed torpedoes need to be replaced in the near future. These considerations validate research regarding the procurement, operational introduction and evaluation of torpedoes and torpedo defence systems.
Beside torpedo defence modelling, several studies have shown the benefits of multi-platform and multi-static operations to perform anti submarine warfare (ASW). To facilitate our torpedo defence system studies and the development of ASW tactics in the near future, TNO Defence, Security and Safety started the development of the Underwater Warfare Testbed (UWT). In recent years, a multi-static facility tool (MUST) has been developed. This tool provides planning, analysis and evaluation of multi-static Underwater Warfare (UWW) operations. The Measures of Effectiveness can be evaluated, given the Measures of Performance of the systems. In addition to the evaluation of performance, it is also important to decide where the UWW assets should operate. Combined simulations with both torpedo defence and multi-static operations enable more research options. Therefore the Underwater Warfare Testbed (UWT) is being developed, which is an extension of our existing Torpedo Defence System TestBed (TDSTB) with multi-static assets as modelled in the multi-static facility tool MUST.

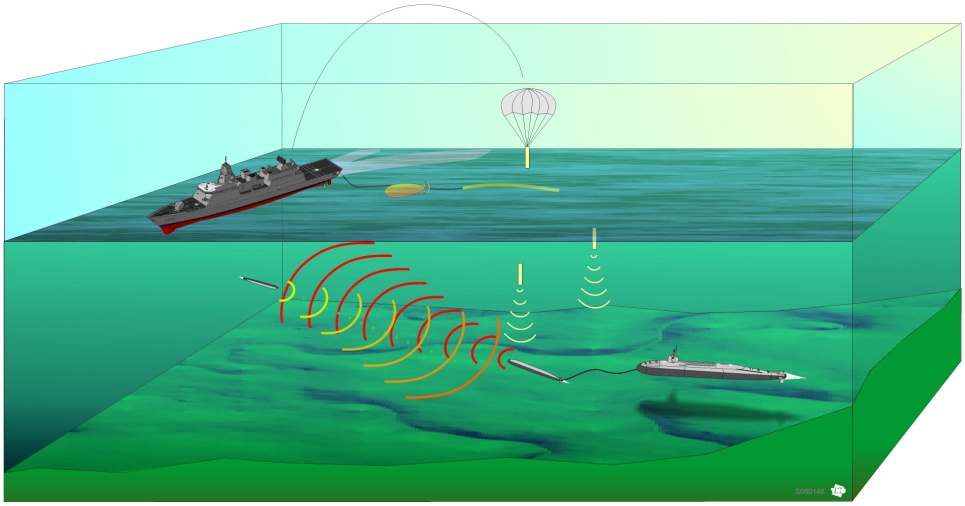

Figure 1 Underwater Warfare conceptual model

This paper focuses on the objectives, the architecture and the studies with the UWT. The multi-static facility tool, which will also be presented in this paper, has already proved its value by supporting several field trials. Finally, the future use and extensions of the UWT are discussed.

2. The Underwater Warfare Testbed (UWT) Architecture

2.1 Description of the UWT

TNO started the first development on underwater warfare simulation frameworks in 1995 [1]. This work has now evolved into the Underwater Warfare Testbed UWT, which is used in the whole area of underwater underwater warfare simulation: Mine Warfare, Anti Submarine Warfare, Torpedo Defence Systems and Multi-static operations.

The main models already available in the UWT are:

- TDSTB: simulating torpedo defence [2][3],
- HUNTOP: simulation of mine hunting operations [9],
- SWEEPOP: simulation of mine sweeping operations [6][7],
- MUST: simulation of multi-static operations of Low Frequency Active Sonar operations.

The latest development is the integration of the TDSTB and MUST. This integration enables the simulation of the underwater defence of a sea base and during transit operations.

Within the UWT a number of systems have been modelled:

- Torpedo: light and heavy weight torpedo, and more generic torpedoes;
- Frigate, helicopter, and submarine with the availability to define movements, reflection strength and radiated noise. All using systems to detect threats
- Countermeasure:
    - Jammer: acoustic noise jammer;
    - Decoy: pulsed signals and noise producing decoy;

The modelled targets (threats) in the UWT are submarines and frigates. The modelled detection systems of the UWT are the sonars, for example the torpedo, the hull mounted, towed low frequency active, and helicopter sonars.

The large building blocks (see Figure 2) of the UWT are: sonar, movements, platform characteristics, and the environment. A platform is described by a set of subsystems. These subsystems can interact with each other. Some functionalities of a platform are combined in one subsystem (e.g. the sonar consisting of a sensor, source (actuator), and DCL). When new platforms are defined, the existing subsystems can potentially be reused.

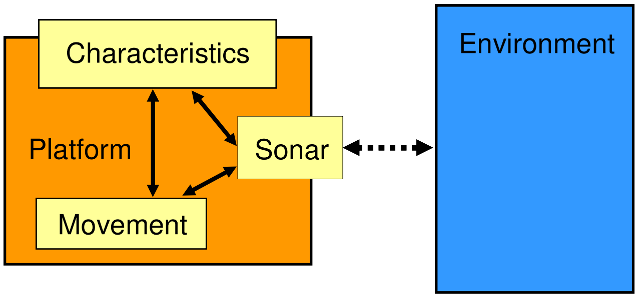

Figure 2. Building blocks within the UWT

Figure 3 shows the subsystems (which are part of the main building blocks) that can be reused across platforms, thus allowing new platforms to be built based on already modelled systems. Tactics and decision rules have been modelled to give behaviour to the platforms and their systems, and to define their interactions. Figure 3 shows the detailed model structure within the UWT.
The sonar systems in the UWT observe the environment by listening to transmitted acoustic signals (e.g. engine noise, sonar pulses). All signals propagate through the environment and are attenuated and scattered by the sea surface, bottom, and other reflecting objects (e.g. submarines).

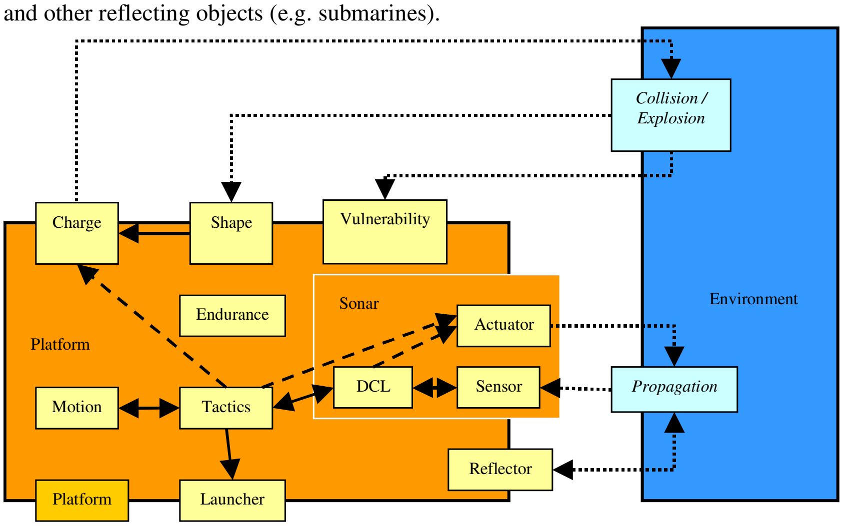

Figure 3 Detailed model structure within the UWT.

Interaction between the platforms is simulated in multi-static simulations. The platforms are able to receive the signals transmitted by other platforms and also the reflection of target platforms via the environment. The platforms also exchange information about the transmission location and time, and transmitted pulse information. The combination of the knowledge of each others transmissions makes multi-static operation possible. The exchange of target/track information that is available at each platform allows UWT to support NEC studies.
Communication with other simulations is supported through implementation of High Level Architecture (HLA) and Distributed Interactive Simulation (DIS) interoperability. The simulation kernel of the UWT is a time-based event-driven simulation kernel. For the UWT, dedicated tools are built to support the user in all phases of the development and use of models. A code generator is used in the design and implementation phase to generate consistent and structured source code including documentation. This code generator facilitates the rapid model development by generating most of the standard code needed with respect to the model and kernel interaction (e.g. loading/storing scenarios and checking parameter ranges). The main focus of the work of the developers are on the algorithm implementations.

2.2 The acoustics in the UWT

The acoustic propagation is modeled by ALMOST (Acoustic Loss Model for Operational Studies and Tasks) [4], of which the development started in 1980. This model computes acoustic propagation of signals through the water. It computes the received signal levels at specified locations and also determines time delays that are due to the sound speed in the water, and bending of the sound waves through the water. The functions of ALMOST are available in a library which is used in several stand-alone applications used within TNO.

To facilitate the programmers that incorporate the model, all functions are embedded in three C++ objects, see also Figure 4: 1) RepasObject (for passive and intercept sonar), 2) ReactObject (for mono-static active sonars), 3) ReabisObject (for bi-static active sonars). These objects provide a user-friendly interface to the acoustic model and they hide details that need to be known to use the Fortran code in the right order. The Repas object is used to compute the propagation loss for passive and intercept sonars. These sonars do not transmit signals but only observe the environment. The React object is used when one sonar is transmitting and receiving its own signals. The Reabis object is only used when the transmitted signals are received by another sonar in the environment, which is only the case in more complex simulations.

Within the UWT the propagation of the signals is modeled by the Environment object. This object is responsible for collecting and managing all signals that are produced in the environment. It also handles all reflections that are introduced by the reflecting objects in the environment. In the testbed sensors are introduced to observe the signals in the environment by creating observation collectors. Furthermore, the environment has the notion of the location time. This enables it to remove the signals when the levels drop below the background noise level. The environment uses the acoustic propagation model to build the bridge between the UWT and the ALMOST objects.

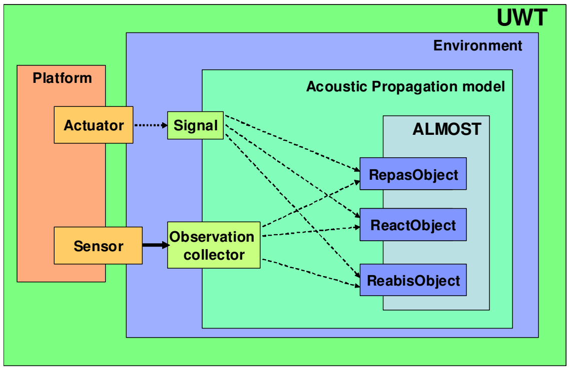

Figure 4 Model structure of the UWT

The computation of the received signal levels can be performed with different levels of fidelity. Especially in Monte-Carlo simulations, the fidelity of the acoustic modeling is chosen to be low, because otherwise the simulations last to long. In those cases the complexity of the calculations is reduced by parameter settings in the environment. This environment will then use derived classes of the Repas, React, and Reabis objects. These derived objects implement the propagation with a lower fidelity. Some of the functions in the ALMOST Fortran code are still used (e.g. calculations of time delays) but some are replaced by tables (e.g. propagation loss) or computed in a faster way.

Testing of the simulation and acoustic model is done after integration and also can be done separately. Each of the objects (i.e. RepasObject) is used to build a separate executable that can be executed using the same input as is used within the simulation environment. This enables detailed testing and maintenance by the domain experts and also by the simulation builders.

2.3 Scenario editor

There are two scenario editors available: the scientific editor and an editor at (operational) user level. In the scientific scenario editor it is possible to create scenarios and change many of the platform parameters (e.g. about 80 parameters for a torpedo). The user level editor has fewer options and it is therefore faster and easier to create a scenario. In this editor the user is for example able to modify only 15 of the most relevant torpedo parameters. The scenario editor enables the user to define manoeuvres for ships. There are 14 possible options to define parts for a ship manoeuvre. The output information includes: visualisation of the ships and torpedo in a top and side view and also provides detailed level analysis support, for example acoustic logging. A simulation in the UWT can for example be defined with a generic torpedo, an environment, a ship, and a decoy.

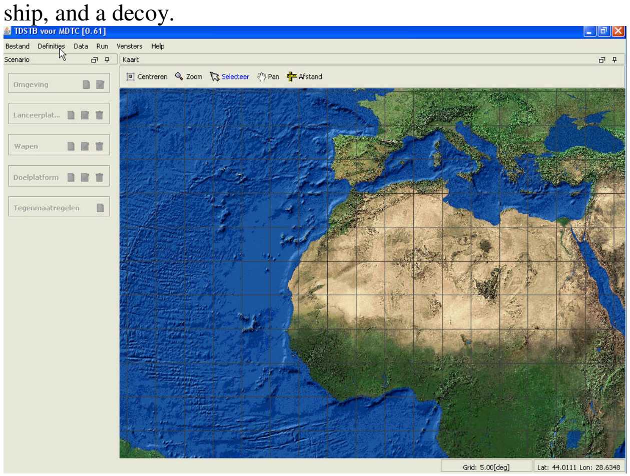

Figure 5 Scenario editor of the UWT at (operational) user level.

3. Objectives and studies of the UWT

3.1 Objectives of the UWT

In general, Naval forces are faced with questions regarding the procurement, operational introduction and performance evaluation of future underwater systems. Self-defence can be approached as a modular concept. The first module involves Detection, Classification and Localisation (DCL). DCL triggers the second module: Evaluator. These systems include sonars, torpedoes, decoys, jammers, and complete Torpedo Defence Systems (TDS). Detailed, open source, technical and validated performance information is hardly available, which makes comparison and identification of candidate underwater systems of different manufacturers, complex. This also limits early conceptual integration of future underwater systems with other existing systems and delays the development of tactical guidelines.

The UWT accepts existing platforms and generic or parametric underwater systems as input and provides insight in the performance of these systems against, or in combination with, other underwater systems in a specific environment. This allows evaluation and formulation of staff requirements and comparison of e.g. torpedo and TDS candidates. Studies with the UWT can be carried out into how to deploy own torpedoes and to deploy countermeasures or a complete TDS for defending own ship(s). Collaboration between units can be evaluated and positioning and manoeuvring of units for optimisation of (multi-static) sonar coverage against various threats can be analysed. Furthermore, sea trials for validation of developed tactics can be prepared by using the UWT.

3.2 Studies with the UWT

Studies with the UWT are concentrated on system evaluation, planning and evaluation of operations, and deployment of underwater systems. The following studies will be or have been carried out with the UWT:

1. System evaluation:
   - *Support of evaluation and procurement of LWT (Light Weight Torpedo), HWT (Heavy Weight Torpedo), countermeasures, and TDS candidates.*
     With the help of the UWT, potential successors of the light and heavy weight torpedoes can be evaluated. Research has been carried out into new torpedoes that meet the requirements of the RNLN. Information on torpedo candidates has been collected and evaluated. Based on expertise and simulations with e.g. the parametric or generic torpedo in the UWT, staff requirements and staff targets can be evaluated and formulated. Depending on the level of detail of the available input, the performance of several underwater systems can be mutually compared. Further, in addition to the planned LFAS systems on board the Multipurpose Frigates (M-FF) of the Royal Netherlands Navy.
   - *Evaluation of a cost-effective underwater defence.*
     Different torpedoes, decoys, jammers and other underwater systems can be evaluated for other navies in the same way as for the Royal Netherlands Navy. The extension of the present underwater systems in the UWT makes the UWT very suitable for consultancy studies for potential customers of underwater systems.
     Also Smart underwater defence options can be evaluated. E.g. by analysing how disposable decoys can be launched from the AWW chaff tubes as a possible concept for torpedo defence.
   - *Validation of the heavy weight torpedo modelling with the help of TFX- and WAF-runs.*
     The objective of this study was to perform a technical evaluation of the modelling of the heavy weight torpedo in the UWT. Real torpedo runs at sea have been simulated with the UWT. It concerns some TFX-runs (Torpedo Firing eXercise) carried out by RNLN and one torpedo run that has been simulated on the Weapon Analysis Facility (WAF) of Naval Underwater Warfare Centre (NUWC) in Newport (Rhode Island). The real sonar head of a torpedo is linked with the WAF. In this way the acoustic performance, the DCL, and the tactical decisions of a real torpedo can be studied.
     The data stored by an exercise torpedo and the data that can be used for evaluation of the modelling in the UWT have been studied in detail. The data stored by the exercise torpedo have been compared with the similar data calculated with the UWT for the relevant runs. This study resulted in a list of proposed model extensions and improvements for the TDSTB.
   - *Demonstration of the operational value of classified underwater systems.*
     The operational value of existing torpedoes with sensitive data can be demonstrated by implementing the concerning torpedo as a black box in the UWT with the help of the manufacturer.

2. Planning and evaluation of operations:
   - *Area Torpedo Defence.*
     Defence operations do not always take place at individual level but can also be carried out collectively. In a formation of ships and in expeditionary operations, defence in depth and mutual interference are important aspects with great influence on self defence capability. This collective defence concept (Area Torpedo Defence, ATD) can substantially contribute to the defence capability. However, the extent of the contribution of STDS (Ship Torpedo Defence System) and ATD to the total protection of ships is not sufficiently clear.
     With the help of the UWT insight can be gained into the added value of Area Torpedo Defence [5]. The value of a formation for torpedo defence will emerge. The formation of surface ships with the highest probability to detect hostile torpedoes will be determined. In response, the formation can deploy countermeasures: e.g. jammers, decoys, evasive manoeuvres and/or hard kill.
   - *Underwater defence of a sea base with the help of ASW, multi-static operations and torpedo defence.*
     The missions of the Royal Netherlands Navy are more often than before aimed at supporting and influencing land operations. After arrival in the coastal environment the task group operates in a stationary mode, for example if the task group acts as a sea base at a fixed position. In this static situation the operations including defence are relatively new and result in new problems. More insight has been gained in the way hostile units operate in a littoral environment. The underwater threats in scenarios for stationary operations have been analyzed, for example after arrival of the expeditionary task group in a littoral environment. The UWT is being extended to be able to investigate different options to defend a sea base against underwater threat consisting of submarines, Unmanned Underwater Vehicles, Diver Delivery Vehicles, and torpedoes. Protecting units can operate multi-statically with the help of LFAS sonars to improve detection capability against underwater threat**.**

   - *Planning and evaluation of multi-static trials.*
     The UWT has been used in the planning and evaluation of several multi-static trials, such as:
     - Cerberus trial.
       This trial was carried out by NURC (NATO), FWG (Germany) and DSTL (UK) near the southwest approaches (SWAPPS) to the UK in August 2001. The Cerberus trial was evaluated with the help of the MUlti-STatic facility tool (MUST). Conversely, the data of the Cerberus trial were also used to validate MUST. The outcome of the tool was compared with real data and the tool showed quite similar results.
     - ADvanced mULTi-static Sonar (ADULTS) trial.
       This trial was carried out by NURC (NATO) and TNO (Netherlands) in the neighbourhood of Sardinia in September 2003. MUST was used in both pre-planning and evaluation of the ADULTS trial.

3. Deployment of underwater systems:
   - *Simulation studies into tactical deployment of underwater systems.*
     Studies can be carried out into how to deploy own torpedoes and to deploy countermeasures or a complete TDS for defending own ship(s).
     Further, the UWT can be used to provide insight into the operational consequences of LFAS deployment (taking into account limiting factors such as speed, curves).
     With the help of the multi-static facility tool MUST, the operational value of LFAS systems in net centric operations can be compared to other underwater systems. The same holds for the operational value of LFAS systems in multi-static operations. MUST can also be used to lend support to the tactical deployment of platforms and systems in multi-static net centric operations, and to advise the Royal Netherlands Navy on the tactical deployment of multi-static ASW means.
     Finally, the UWT can be used in support of:
     - formulating tactical guidelines for LFAS deployment by the Royal Netherlands Navy;
     - formulating tactical guidelines for HELRAS deployment by the Netherlands Armed Forces.
   - *Anti Submarine Warfare.*
     The effectiveness of different ASW units operating stand alone or with other units can be determined in different areas, e.g. detection, classification, and prosecution.
   - *Network Enabled Capabilities.*
     Network Enabled Capabilities (NEC) aims at the improvement of the operation and coherence of military systems: better sharing and combination of information in the network will result in more effective operations of military units, which will increase the operational effectiveness as a whole [10].

In this specific study, the added value of a new concept for detecting and tracking an enemy submarine was considered with the help of the multi-static facility tool MUST. In this concept the positions of one or more ships are adapted dynamically in order to increase the tracking quality of the task group. The position of the ships can be adapted after the position, speed and heading of the submarine are known. New positions (or speeds and headings) of one or more of the ships can be determined to increase or maximise the tracking quality of the task group. The benefit, an increased tracking quality of the task group, will especially occur in the presence of shadow zones. Due to shadow zones, it is possible that the detection probabilities of all ships during some periods of time will be very low. By moving a ship (in particular, the ship with the active sonar), it is possible to prevent that the detection probabilities by all ships will be low during the same period of time.
These different aspects of NEC can be modelled in more detail in the UWT to determine the added value. With the help of the UWT, the operational value of net centric operations can be compared to platform centric operations. The same holds for the operational value of LFAS systems in net centric operations compared to other underwater systems.

Figure 6 Example of submarines to be considered in the UWT

- *Submarine modelling.*
  The modelling of the Walrus class submarine in a previous simulation model MORSE can be used to model the sonars, data processing, command and control, and tactics in the UWT. The MK48 torpedo has already been modelled in the UWT. Probably, the successor of the MK48 will also be modelled in the UWT.

4. Other:
   - *Simulation Based Performance Analysis (SBPA).*
     SBPA facilitates analyses and evaluations of not-yet-existing materiel with the help of simulations. This is applied in materiel acquisition projects (e.g. for the Royal Netherlands Navy)

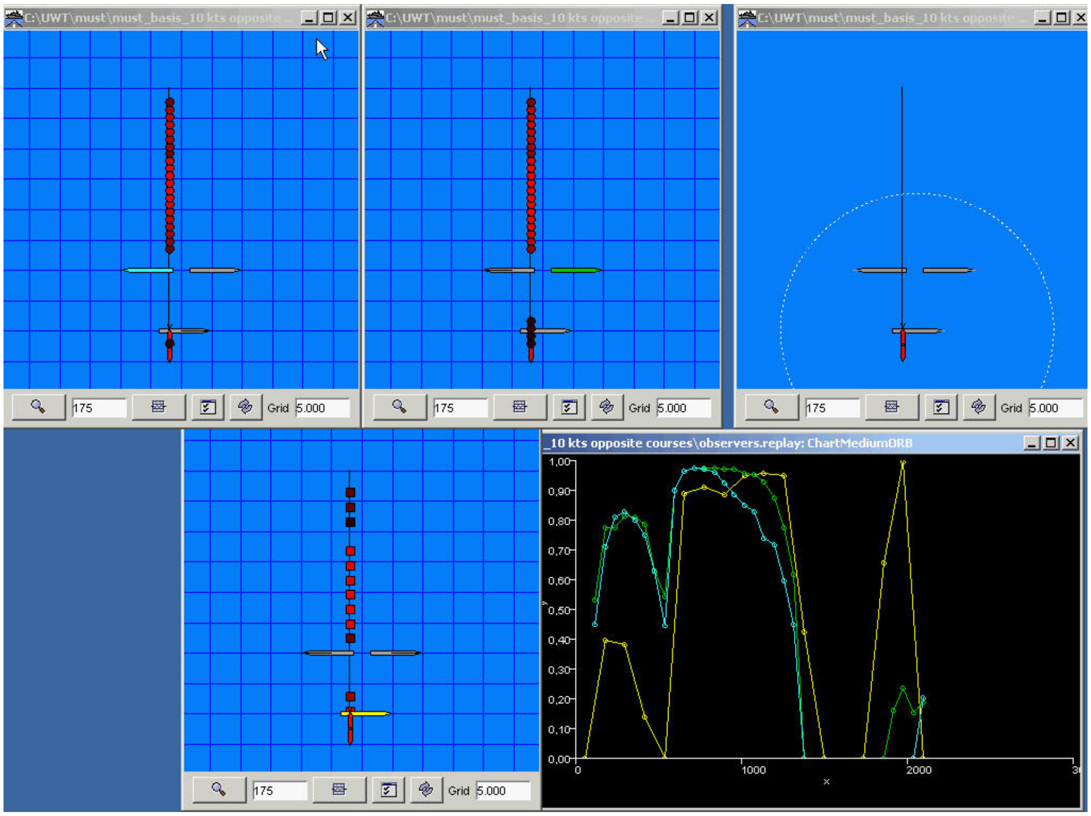

Figure 7 Example of a multi-static NEC simulation

4 Future

The UWT is structured and developed such that it can be easily extended with new models and linked to other application/testbeds. In the future TNO will use the UWT to evaluate torpedo defence systems and other underwater systems that will be purchased by the RNLN.

Currently, operational research studies for above water and underwater warfare are done with separate testbeds. Since sensor and data fusion becomes more important to obtain a complete picture of the operational situation, combined studies within one simulation framework become important. Therefore a link between the above water models and the UWT will be developed to enable combined scenario modelling. The linked testbeds will exchange information and events to enable controlling platforms with above and underwater sensors. With these linked testbeds, the total system/platform performance can be studied including repositioning of platforms. Also signature balancing and NEC studies can be performed in more detail.

In the future the use of the own submarine in ASW scenarios can be studied to evaluate new tactics of operations. The UWT can also be used to study how the submarine could operate such that it will not be detected by hostile ‘multi-static’ operating sonars.

In the current implementation of the UWT, the models developed on the TDSTB architecture have an easier to use structure than the previously available mine warfare models (HUNTOP and SWEEPOP). The possibility of the reuse of subsystems in the new UWT architecture creates reuse opportunities for these models. When combined scenarios or complete modelling of large exercises including mine warfare [7] are required, the mine warfare models might be restructured to enable easier integration and linking. When Autonomous Underwater Vehicles (AUV) become operational, these systems will also be modelled and evaluated in the UWT. Then communication and collaboration between mine hunting systems can be studied too.

Beside systems also the environmental impact of naval operations can be modelled by the UWT. For instance by modelling marine mammals and their behaviour, the impact and disturbance of underwater transmissions can be studied. This will lead to a responsible used of underwater sounds (e.g. active sonars) by the navies during exercises.

The UWT is initially being built for research purposes, but can be used in tailor made standalone applications that study specific operational system aspect for the navy. Dedicated tools will be developed for use on board frigates and submarines to support the sonar operators in using their systems more effectively. Also quick-look analysis tools will be derived from the existing UWT models to analyse the system performance.

References

[1] **Lentze, S.**, MOSES, development of an Underwater Warfare Testbed, *UDT Europe,* 2001.

[2] **Grootendorst, H.J., Benders, F.P.A., Driessen, F.P.G., & Witberg, R.**, Torpedo Modelling in TORSIM and Torpedo Defence System Testbed, *UDT Europe,* 2001.

[3] **Benders, F.P.A., Witberg, R.**, **Grootendorst, H.J.**, Torpedo and countermeasures modelling in the Torpedo Defence System Testbed, *UDT Europe,* 2004.

[4] **Schippers, P.**, REACT, a model for Active Sonar Range Predictions, *UDT Europe,* 1991.

[5] **Grootendorst, H.J., Benders, F.P.A., Fitski, H.J., & Veldhoven, E.R. van**, Operational Analysis on Torpedo Defence, *UDT Europe*, 2007.

[6] **Keus, D., Beckers, A.L.D., Cleophas**, **P.L.H.,** SWEEPOP, a simulation model for Target Simulation Mode minesweeping, UDT Europe, 2005.

[7] **Veldhoven, J. van , Riet, M.W.G. van, Dol, H.S., Mohamoud, A.A., Keus, D. Beckers, A.L.D.** A generic mine model, *UDT Europe*, 2009.

[8] **Keus, D., Benders, F.P.A., Kraker K.J. de, Meer, R. van der, Langeslag, P., Huiskamp, W.**, Guidelines for reuse of multiresolution physical models, 09-SIW-32, *2009 spring SIW*

[9] **Kleijen, J.P.C.**, Statistical validation of simulation models, European Journal of Operational Research, vol 87, issue 1, November 1995, p 21-34.

[10] On Analysis of Network Enabled Operations, Final report of ANNCP WG IX Collaborative Project 20