ELEMENTS OF A COMPLETE NAVAL TACTICAL ENVIRONMENT

David N. Siksik
CAE Inc.
St-Laurent, Quebec, Canada

ABSTRACT

In the creation of a naval tactical environment that will meet today's rigorous standards for helicopter Anti-Submarine Warfare and Anti-Surface Warfare training, there are several technical issues that must be considered. This paper describes the elements comprising a complete and fully integrated naval environment as built to support a full flight tactical simulator facility engaged in mission training. These are discussed with a view to their engineering aspects as well as their integrated functionality within the environment.

The consideration of a complete electronic environment implies elements of both entity modeling and tactics modeling. Entity modeling includes platform representations (eg: dynamics and scoring), weapons representations (torpedoes, torpedo search patterns, anti-ship sea skimming missiles) and sensor representations (sonars, radars, radar complexes, and radar warning receivers). Tactics modeling involves capabilities such as maneuvers (screening, zigzags, searches), communications (Link 11 networks), identification criteria and emission control strategy.

Additional elements include the realistic representation of weather (moving frontal systems, wind layers and wind shear) and underwater acoustic environments (sound velocity profiles and propagation loss models).

Components are discussed with respect to their engineering facets, their user interfaces and their collective roles as integral parts of the complete environment. An example includes several elements of tactical maneuvering that implied the creation of customized interfaces and provide for critical capability in training. Another example is the modeling of platform sonars, and both active and passive sonobuoys, along with an acoustic representation and interfaces to create an underwater sensor capability that is both consistent from the user perspective and fully integrated with the rest of the tactical environment.

Key technical concerns experienced in the development and integration of the naval environment are explored. These include such trade-offs as model fidelity versus complexity, development costs, and ultimately, training value.

ABOUT THE AUTHOR

David N. Siksik is a Systems Architect at CAE Inc. and is responsible for CGF and Flight Simulator architectures. He holds a Bachelor's degree in Electrical Engineering from McGill University and a Master's degree in the same discipline from Concordia University. He has been involved in flight simulation, including CGF systems, for the past 17 years.

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INTRODUCTION

In modern simulator training, the emphasis has shifted from procedural and task training to full mission oriented sorties. This advance takes pilots beyond the job of learning to fly, learning to use the aircraft systems and even interacting with one or several computer generated forces (CGF) and into the realm of performing mission specific functions within a live/simulated team in as close-as possible situation to the real thing.

The Royal Navy Merlin Training System Synthetic Crew Trainer (MTS SCT), a five-simulator facility built for the Lockheed Martin ASIC by CAE Inc is an example of the approach of mission emphasis towards training. The facility, as detailed below, includes both briefing and de-briefing facilities, five separate simulators, capable of network linking, and a fully integrated naval tactical environment.

This paper concentrates on a discussion of the tactical environment in order to present its components and the critical issues associated with its integration and use in the mission training application.

Following an introduction to the MTS SCT, the elements of the naval tactical environment are discussed in terms of elements of environment and command and control. Simulation issues are then presented with respect to the specific goals of: seamless operation, consistency and workload. Two specific examples are reviewed in detail. The final section discusses the key tradeoffs encountered including: control vs. automation, fidelity vs. cost and complexity vs. usability.

NAVAL TRAINING SYSTEM OVERVIEW

Previously built naval training systems have included simulator facilities for the P3C aircraft and the Lynx helicopter. These were primarily focused on flight and systems task training such as sensor and weapon deployment. Interactions with CGF systems were largely in support of these tasks. The training concept employed for the Lynx Mk-8 simulator progressively moved to that of mission exercises involving the own aircraft training in tandem with CGF entities that were capable of automatically supporting its mission. More emphasis was placed on own-team support for the trainee as he engaged in a full mission scenario.

This evolution continued with the naval training system described in this paper. The MTS SCT was conceived specifically for Anti Submarine Warfare (ASW) and Anti Surface Warfare (AsuW) training in a team-oriented environment (Siksik & Lemay, 2002). Throughout the design cycle of the system, emphasis was placed on the fidelity of the tactical environment and its role in supporting collaborative missions. Emphasis was also placed on the networking capability of the facility.

The facility is composed of five separate devices, two front-end cockpits and three back-end trainers representing the Merlin EH101 rotary wing aircraft. The front-ends consist of full-flight simulators (one of which includes motion and visual) while the back-ends consist of procedural trainers for sonar, radar, radar warning receiver, link 11and other aircraft tactical systems. High fidelity models are provided for these systems. The back-ends also include a flight model and basic controls to allow the device to train autonomously as a Merlin aircraft.

The facility networking capability permits the devices to connect to each other based upon several combinations. Each device may participate in its own separate scenario. A front-end may integrate to any back-end in order to create a device that flies as one aircraft. A back-end may link with any other back-end in order to play in the same exercise. All permutations of these combinations are possible with the most involved comprising all five devices participating in the same exercise. This situation consists of two front-end / back-end combinations with the third back-end representing three Merlin aircraft flying within the same scenario. In this configuration, a Merlin might leave the exercise, to engage in autonomous training, and return to the same exercise, as required.

In addition to these capabilities, the facility tactical environment augments the ability of the devices to train in a complete naval arena with large numbers of units. The tactical environment is provided by the Interactive Tactical Environment Management System (ITEMS™). Apart from furnishing specialized naval models for sonars, torpedoes, acoustic environment, etc., a large number of tactical maneuvers have been provided.

These are applied to CGF entities in the simulation in order to provide the trainees with a very realistic and representative environment. The following section describes the tactical environment in detail.

THE NAVAL TACTICAL ENVIRONMENT

The tactical environment provided on the trainer consists of elements that may be classified either as environmental or as command and control elements. These elements are listed and described in the following sections.

Environment Elements

Environment elements make up the simulated world in which the own aircraft interacts. This always must include the atmospheric, or weather, environment, the terrain / sea-surface representation, and, since the simulated helicopter engages in anti-submarine warfare, the underwater, or acoustic representation.

Weather:

The essentials of a weather model must provide the student with training in flight, mission execution and particularly ship–deck landings under adverse conditions such as low visibility, high winds and high sea states.

To accomplish this, the weather model includes several wind layers and wind corridors, a low-pressure system simulation and both global and frontal weather systems. The global system includes parameters such as wind, precipitation, temperature and pressure definable at multiple positions within the tactical environment geographic database. Similar information including course and speed may be defined for the frontal system.

Terrain / Sea-surface:

The terrain surface, including islands, is modeled based upon a polygonal structure derived from the same Open-Flight representation used to build the simulator visual system database. The approach ensures correlation between the visual and the tactical world as well as the lines-of-sight calculated between tactical environment entities including the own-aircraft. The underwater surface is also represented, including selections of known wrecks through importation from existing databases. Accurate depiction of the sea bottom is important for enhanced training in mission related dipping sonar deployment.

Acoustics:

The simulation of the underwater acoustic environment is essential to both the training of individual crews in the use sonar equipment and to team training within the mission context. Modeling of this regime includes salinity profiles, sound velocity profiles and temperature layers.

The acoustic representation of targets in the environment is based on several databases that are standard across the UK submarine community. These include the DGSM, Gridded, ASRAP and BLUG databases. Implicit to the databases are a comprehensive set of models such as cavitation, line modulation and transients. All features of the DGSM are supported in the trainer. In addition to this representation is an acoustic wake return model based on target dynamics and ocean conditions. Instructor control and monitoring of the target-emitted signals is also provided. Further details are discussed in the section 4 below.

Command and Control Elements

Entities:

Entities within the tactical environment are defined as platforms of tactical importance and include surface and subsurface vessels, including life rafts, rotary and fixed wing aircraft, oil rigs and sea biologics (for sonar stimulation).

The dynamics of fixed wing and helicopter (airborne) entities is simulated using linearized models. Entities are controlled by a speed vector that may be changed in both magnitude and direction. The dynamic response of the entity is provided by first order filters, and the wind speed and direction are also considered. This model does not consider any other external effects such as gravity or aerodynamic loading. Representative performance of different airborne players is obtained by specifying limits of velocity, acceleration and turn rate. The application of representative entity motion reflects on the training exercise when observing and interacting with entities performing their missions. Mission routing, formation management and demanded maneuvers are examples.

Entity sensors, including radar, sonar and electromagnetic sensors are all simulated using the physical model and considering the target signature and the environment (atmospheric effects, lines-of-sight, acoustic ocean model)

Each entity maintains its own complete view of the synthetic world. Once information is gathered by an entity's sensor suite, an arbitration mechanism is used in order to retain only the best-known data relating to a specific contact. If radar returns are considered more reliable than sonar, data originating from radar sensors will be favored. This latter could also include data received via communications including the Link 11.

Facilities to combine several sensors and weapons in one or several networks and to define the sensor and weapon reactions to specified threats provide for workload improvements.

Entity weapons are flown based on the initial launch conditions and flight characteristics defined for each weapon.

The guided weapon model used for missiles is a five-degree of freedom model that is roll stabilized. The algorithm considers the principal forces affecting performance: lift, drag, weight and the thrust developed by the propulsion system.

Guided weapons are launched from an entity and are steered towards their target using either a proportional navigation law, or a command to line-of-sight guidance law. The proportional navigation law is used for weapons that have an on-board homing head, and the command to line of sight is used for beam rider weapons.

The ballistic model (i.e. gun rounds and rockets) is a linearized drag, aeroballistic model which considers drag and gravity drop. The rocket model also considers the thrust developed by the propulsion system.

Entity behavior modeling is provided via a rule-based expert system. Parameterized, user-definable IF-THEN rules based on a forward chaining approach form the general architecture. Doctrinal molds are provided for both mission and opponent selection definition. The behavior representation provides the exercise with entities that can react and carry out their mission intelligently and is the basis for the support of the tactical maneuvers described below.

ID Criteria:
The concept of ID Criteria is an identification strategy based on situational criteria in addition to the standard methods of sensor-based recognition. Consideration is given to such aspects as the location, velocity and attitude of a threat as well as to specific observable attributes or behaviors. Based upon the situation of the threat, as detected, an appropriate identification label can be assigned.

Situational criteria are determined via entity rules as is the assignment of the selected identification. Tactical overlays, such as areas and lines, are important in determining a threat's positional information. Its other behavioral characteristics may be determined from direct observation.

Arbitration is required to select the pre-eminent identification determination of the threat. Sources include the actual sensor detection, ID criteria and communications (specifically Link 11).

Tactical Maneuvers:
Independent CGF maneuvers represent the first level of simulation and interaction with a manned cockpit. They include basic actions and generally include only one CGF entity. In terms of pilot training, basic one-on-one interactions with CGF entities enables the trainee to step past procedural flight training and begin to consider the tactical environment in which he will work.

A list of representative independent maneuvers follows:

- Search and Rescue
- Area Patrols and Searches
- Go to Points and Execute Actions at Destination
- Target Tracking and Approaches
- Shipboard Operations (Launch, Land, Refuel)
- Loiter and Patrol
- Sonobuoy Plant Patterns
- Intercept
- Dipping Sonar Deployment
- Countermeasures Deployments

Coordinated CGF maneuvers represent a level of complexity one higher than that for the individual maneuvers. As such, they are both more complex in structure and present a more representative and challenging scenario for trainee interaction.

The coordination of entities within a requested tasking implies several units working together towards a single goal. Helicopters may be directed in a plan to search out a reported submarine. Ship groups may be engaged in a datum search or in tactical transit. Several unit types (eg: helicopter and ship) may combine in a coordinated tactic of submarine prosecution. A representation of the maneuver categories built follows:

- *Helicopter group tactical searches*:
    - Bearing and pattern searches for specified contacts.
- *Helicopter and ship group tactical searches with target prosecution*:
    - Bearing and sector searches for specified contacts. Target prosecution may be role-played or automated via entity rules.

- *Helicopter and ship screening maneuvers*:
  - Sector patrols with respect to a high value unit. Helicopter dip maneuvers.
- *Missile attack reaction strategy*:
  - Missile attack reactions for helicopters and ships

Emission Control:
Emission Control consists of a strategy for the control of any sort of electromagnetic emission. The approach is matrix based, allowing emission sources to be separated and specifying particular conditions upon which emission may or may not take place.

Since player emissions are simulated by many different systems, an arbitration system is required in order to which emissions must be filtered out. Additionally, it must be possible for players to break emission control and emit signals in spite of the rules in place.

SIMULATION ISSUES

Simulation and Training Goals

Seamless Operation (between several simulation devices and between simulation devices and CGF's) (Siksik & Lemay, 2002):
The consideration of multi-simulator training at a single facility implies that the simulator devices are necessarily connected via a local area network. In a single running exercise, the devices may then participate as a group in the scenario.

In order to ensure that the trainee reacts as expected and does not receive any negative training, it is important that the distinction between real (other simulator devices in the exercise) and CGF entities be as small as possible. This requirement, in turn, suggests that the operation of CGF entities with real entities be seamless

Shipboard activity is an important point to consider. On board ship, CGF entities must behave realistically because of their proximity to simulator devices. More importantly, since simulators may link into and out of a running exercise, it is critical to ensure that this action does not affect what the trainee sees (his tactical picture).

The concept created to solve this problem provides a vehicle for the definition and management of the transition process of a simulator. In order to mask the fact that a simulator is entering an exercise, the joining device would take over the role of an existing (pre-determined) CGF entity. This entity would be removed from the simulation. Similarly, upon leaving the exercise, the device would release control of the CGF entity, allowing it to return to the exercise.

Consistency (between simulated elements and controls across the breadth of the simulation):
Since the naval environment simulation is very broad and covers very many aspects, all of which are related to each other, it becomes very important to ensure that there is a conscious level of consistency throughout. This relates to the consistent treatment of a specific element over several interfaces and systems, as well as to common approaches to the functionality of disparate elements.

Some examples of the first include such aspects as sonobuoys control and Control Measures handling. Examples of the second include common selection, positioning and monitoring methods for entities within the tactical environment.

Workload:
This is an obvious goal since a reduction in workload for the instructor allows him to maximize the quality and level of training offered to the student.

Two methods used to achieve workload reduction include the automation of various tasks and interface re-use, which presents identical interfaces across applications.

Link 11 automation was introduced in order to reduce the effort required to release entity Link 11 messages to the network. Because the number of parameters and options associated with each message of the protocol is prohibitive, it was necessary to devise an approach that would permit the instructor to release entity messages with minimal effort. The construction of messages has been automated, based on the information already available within the tactical environment, such that several levels of intervention are possible, from no intervention to complete override.

Interfaces such as those used to define positions were standardized and made identical across the entire simulation. This permitted the instructor to position entities, sonobuoys, control measures, and weather fronts using the keystrokes and thought process.

Specific Cases

Acoustics Modeling:
The acoustic ocean environment was identified by the customer as one of the critical elements of the simulator. A comprehensive review of the possible avenues for modeling was performed in conjunction

with the customer and led to a solution that took into account the main criteria from a trainer perspective, as follows:

Realism: Proven models were used as the main propagation loss engine, including INSTANT, and an active propagation and reverberation model. In addition to these, specific models are used to represent training critical propagation effects such as ocean floor backscattering and occultation, and ocean fronts and eddies. Realism also implies correct representation of the operating area. To achieve this, mainstream databases were incorporated in the simulator, including ocean floor, sound speed profiles, shipping noise and wrecks.

Correlation with other elements of the virtual environment: Ocean floor information is centralised, so the same common data can be used by all elements of the virtual environment (Acoustics, radar, sonar winch/SU handling, entity maneuvering, visual)

Ease of Use: In order to define, monitor and control the acoustic environment, tools are provided to the scenario editor and to the instructor, among which are:

- A path analysis tool which gives the propagation characteristics between the acoustical entities;
- A sensor specific raw data analysis tool giving full access and control over the acoustic data of a sensor. For a passive sensor, a graphical representation of the frequencies and noise is presented to the instructor;
- A sound velocity profile/propagation loss tool to modify the propagation characteristics on-line and immediately assess the effect prior to inserting it in the simulation;
- An ambient noise spectral analysis/control tool, allowing monitoring and modification of the spectral content of the ambient noise
- Graphical aids to the main geographical situation display, such as ocean front identification, sensors in contact, convergence zones annuli, etc.

The following issues were encountered during development and integration of the acoustic environment.

As mentioned above, in order to refine the requirements for ocean modeling, a specific process was adopted during the design phase, where detailed discussions took place with the end user and with detailed support from subject matter experts. The resulting "ocean model matrix" was an approach that allowed all the elements of the ocean model to be compared and scoped in terms of complexity, database sources, and resolution. These elements include propagation loss models, sound velocity profiles, bottom topography, bottom type, environmental area definition, eddy/ocean front modeling, ambient noise, reverberation, buoy drift and wrecks.

The fact that more than one crew can be trained in the same virtual environment induces the additional complexity of ensuring complete correlation between cues perceived by all trainees (seamless operations). For example, if one crew is using its active dipping sonar, the other crew must perceive it at the proper position and with the appropriate propagation effects. Also, random effects such as frequency drifting of a particular tonal must be correlated between platforms, i.e.: both operators must observe the same random drift behavior on a particular frequency line. To accomplish this, the random noise seeds used within the model must be transferred between the simulation devices at synchronized intervals.

The tactical environment scenario accounts for acoustic emissions and detections between entities using a representative subset of the full acoustic emissions. Specific manipulation of the acoustic signature data must be performed, to translate the detailed acoustic environment information into a subset appropriate for scenario usage. For each entity, a set of frequency bands is defined, and for each of these, the level of energy emitted by the target is specified at 0 knots and a one dB increase per knot is specified. This information is inferred from the full acoustic spectral definition at various speeds.

Some instructor interfaces for acoustic environment control were complex in nature, involving graphical tools and information relevant to instructor role-play functions. During integration and initial testing of the trainer, modifications to these pages were implemented to ensure that their intended role was fulfilled. The sonobuoy monitor page (see Figure 1) and strongest line display page are essential tools that allow the instructor to role-play another Merlin. They present in a synthetic manner, spectral information and detection / localization information for various sonobuoys in the scenario. To allow the instructor to easily select the relevant line to track, controls are given to de-clutter the display, uniquely identify each line, and automatically select a line.

These controls were refined with the participation of experienced operators.

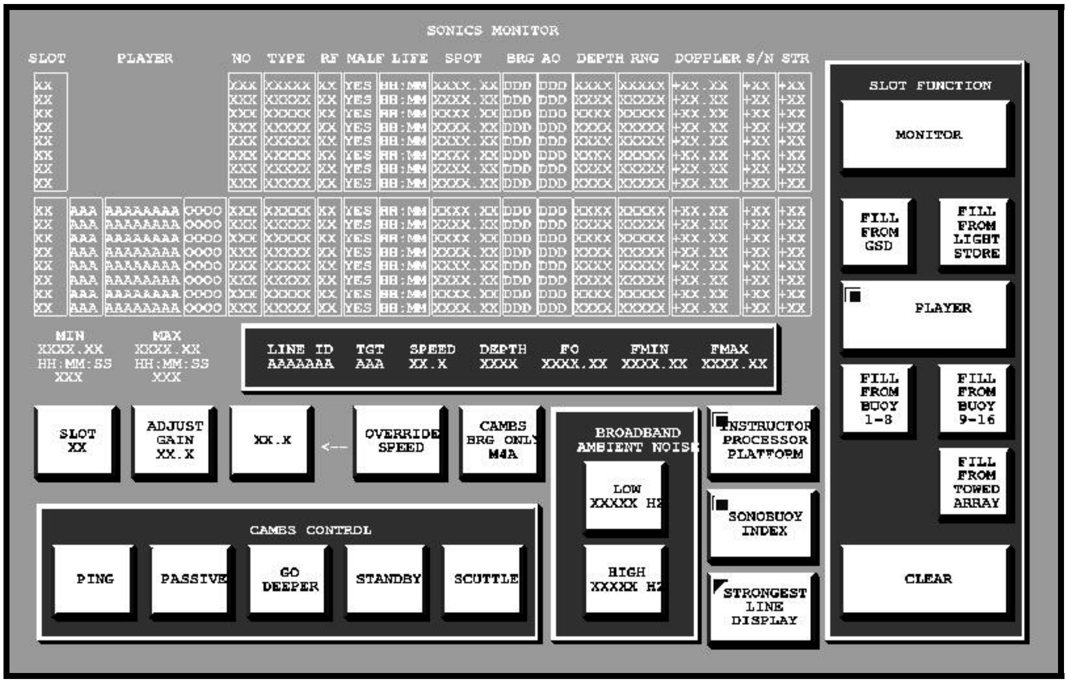

Figure 1 Sonics Monitor Page

Voice Contact Reporting Facility:
The purpose of this facility is to provide the instructor with a facility to gather, organize and analyze entity contacts so that he is able to issue voice contact reports during role-play. Specifically, the contact data released must match the contact indications gathered by the trainees.

The interface was designed to allow the indication of a contact to easily and quickly be expanded to a full contact list by entity and, ultimately, to detailed information on a specific contact based upon the primary detecting sonar. The interfaces also permitted data reduction via filtering by entity sensor type and entity team.

As described above, the own-aircraft sonar model consists of a complex acoustic model. Necessarily, because of computational limitations, CGF entities use a less complex representation. This provides the opportunity for a conflict of data when an instructor is role-playing. In order to provide him with the same sonar data as the trainee, a specific sonics interface was created to enable, via the selection of either a set of CGF sonobuoys or towed-array sonars, the entity standard model to be switched to the full own-aircraft acoustic model.

Detection of contacts via sonobuoys introduces the question of "which CGF entity should the instructor report from", since there could be several monitoring the same sonobuoys at any one time. If a contact is released to the Link 11, it is not straightforward to determine which entity was responsible. To reduce the workload associated with this and similar tasks, cross-references were created that allowed specific information such as "contact" to be matched to other data, such as "originating entity".

For reporting purposes, radar and ESM information is generally organized according to very specific report styles. The voice report facility interface was designed expressly to provide the instructor with all the appropriate information for these reports in a method that allows for the quick combination of data into different groupings. While the interface itself presented the data in a generic form, it was organized such that it could easily and quickly be re-combined and read-off as any one of the required report types.

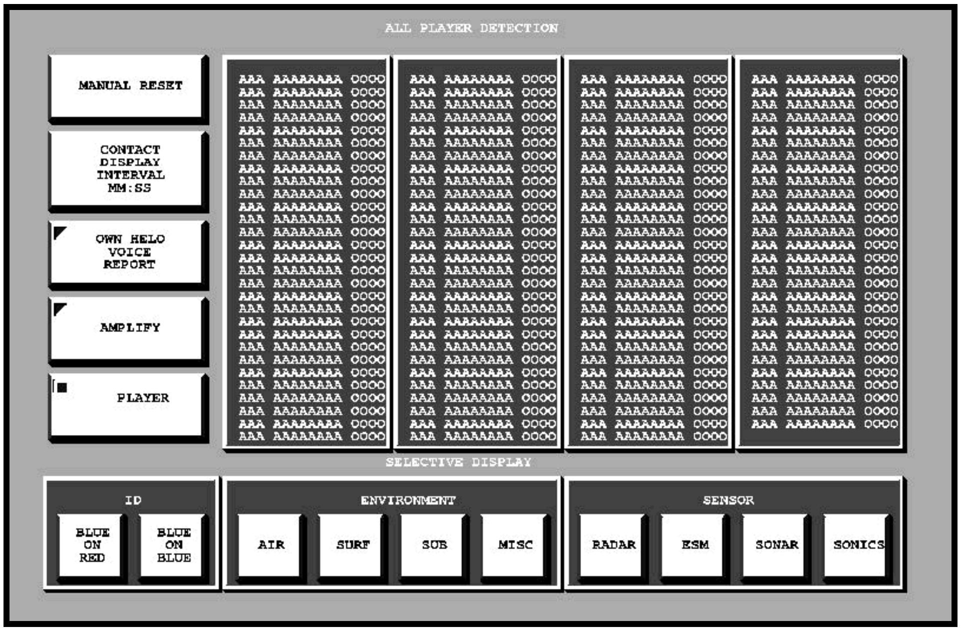

Figure 2 All Player Detection Page

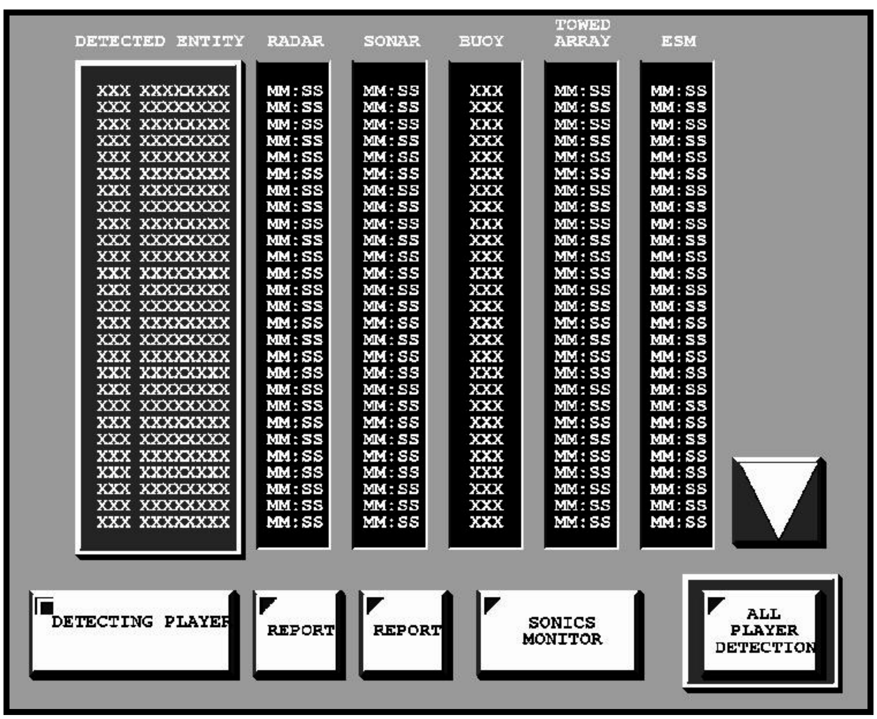

Figure 3 Player All Contact Page

The Voice Contact Report Facility interface is shown in Figure 2 and Figure 3. At the highest level, an alert page provides the instructor with indications of entity contacts. All entities are listed and a new contact is color coded red. The alert list may be filtered based on criteria such as team, platform type and sensor type.

Based on the selection of a particular entity, an amplification page may then be accessed. At this level, the user is presented with the complete contact view of that entity. Contacts are ordered chronologically and the sensors associated with each contact are identified and time-stamped. Color is again used for clear visual identification of the latest data.

From this level, the user may access pages providing specific contact detail such as location, speed, heading, etc. Each of these pages provides a particular sensor picture such as radar or sonar. The sonics page shown in Figure 1 is an example.

It is worthwhile to note that while the above issues were listed and treated separately, they are, in fact, often inter-related. A design approach that incorporates consistency will imply a reduction in the instructor workload, since he has less re-learning and exceptions to deal with. Similarly, seamless operation provides for a more realistic training environment thus reducing the amount of role-play required by the instructor.

KEY TRADEOFFS

Control vs. Automation

The discussion on workload, above, has already highlighted the existing tradeoff issues for the Link 11 system. While automation of the message release mechanism from entities to the network is desirable, the capability to control the content of the message and thereby better guide the resulting training is essential. The balance between these was achieved through extensive reviews with the end-user and with subject matter experts (SME).

The tradeoff of control vs. automation may also be observed in the development of the entity tactical maneuvers. In this domain, the automatic control of entity maneuvers is critical in order to reduce the instructor's workload. Automation, however, becomes more of a hindrance than help when training calls for the instructor to intervene and drive the exercise in a very specific direction. At this point, a very manual approach is preferred.

To accommodate for this, it is necessary to build in to each maneuver, the parametric settings required to allow it to perform automatically while matching the specific training requirements at the moment. Additionally, the facility to take complete manual control over one or several of the entity's behavior categories provides a method to mitigate this tradeoff.

A behavioral functionality matrix was used to evaluate the control source per behavior category per maneuver. The control source varied from full manual to semi-automatic, to fully automatic. The population of these series of matrices was accomplished through end-user and SME consultation.

Fidelity vs. Cost

This age-old tradeoff is common to most applications. In this trainer, fidelity issues applied generally to the physics based models and the behavioral models used to represent the real world within the tactical environment. In both cases, it was a question of the level at which the model ceased to contribute significantly to training.

The weapons models simulated for entities and for the own aircraft must have sufficient fidelity to ensure that they behave in a manner similar and consistent with those in the real world. Considering the torpedo model as an example, this model was applied to both entities and the own aircraft. It incorporated representation for the following effects: torpedo pre-sets, torpedo orientation at splash point, seeker head modeling (active and passive) and search pattern definition. The model did not include detailed lost contact procedures since it was determined that the training value received by this behavior could not mitigate the development cost.

Behavioral models as complex as tactical airplans and search maneuvers are necessary in order to place the student in an environment where he can participate in team training. He must be able to interact with and react to entities as he would in real life. At the same time, the maneuver model is limited in scope to direct user controls. Command and control to the level of a higher entity releasing orders to a lower entity is not modeled. While the latter might be a higher fidelity representation of the naval world, in the application of the trainer, this functionality provides little benefit to training and could possibly detract from it. With the instructor molding the training session to the greatest benefit of the student, the instructor is the linchpin in role-playing higher echelon C^2.

Complexity vs. Usability

While similar in many respect to fidelity vs. cost, with many issues shared between them, the tradeoff of complexity vs. usability presents several examples.

This tradeoff is best applied to the areas of control methods and user interfaces, both of which may be made, inadvertently, overly complex in the name of added functionality with the result of reduced utility.

Two appropriate examples are the tactical maneuvers and the voice contact reporting facilities discussed above. In each case, several iterations of SME and engineering reviews were necessary in order to direct and preserve the usability of the interfaces or controls.

With respect to tactical maneuver controls, the problem was to ensure that for every possible behavior category, the method of control was obvious to the user and easily modified. Since there were several possible control paths, such as fully automatic, fully manual or combination of both, it was through a methodology of imposing control states that were very clearly and logically delineated that usability was addressed.

In the case of voice reporting, the challenge was to maintain the usability and clarity of the information received in the face of mounting complexity from its possible sources and context. The solution, in this case, was to use a cascading level-of-detail strategy with a top-level interface detailing contact alerts and lower-level interfaces addressing more specific information at each stage. This interface is described in the previous section: “Simulation Issues”. This approach allowed the data to be broken down logically and efficiently in order to make the system, ultimately, more usable.

SUMMARY AND CONCLUSIONS

While the issues discussed in this paper represent some of those encountered in the representation of a naval tactical environment, others exist. Common themes that run through the issues and tradeoffs include a clear understanding of the training requirement and the importance of the man-machine interface. Both imply and underline the necessity for iterations of subject matter expert and end-user reviews in order to establish the best training solution.

Future efforts in the simulation of tactical environments will work towards mitigating some of the specific examples raised here, by providing better models and by taking advantage of more computing power.

However, these same advances in technology, modeling and scientific methods, will inevitably be used in the actual aircraft tactical systems. Currently, weapons, sensors, command and control as well as tactical decision making tools are all benefiting from the latest capabilities.

The implication is that any progress made in simulation techniques will eventually be overtaken by the actual systems. In this respect, issues such as seamless interaction, consistency and workload are likely to remain and possibly become more important than they are today.

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