A Simulation Tool to Assess Recognized Maritime Picture Production in C2 Systems

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Abstract

This paper describes a simulation program used to assess the performance of the Recognized Maritime Picture (RMP) production function of maritime command and control (C2) systems in different scenarios, utilizing appropriate and quantifiable measures of performance (MOPs). The program is a tool for RMP production assessment, addressing the development of a future C2 concept and a future C2 system for maritime operations. The simulation program has been developed as part of a project at Norwegian Defence Research Establishment (FFI) sponsored by the Royal Norwegian Navy (RNoN). The objective of the project is to recommend a cost effective and future oriented C2 system for maritime operations.

The simulation program contains models of surface surveillance, including the picture compilation function, with particular emphasis on distributed picture production and object identification. The quality of an RMP depends on several factors, including the characteristics of the sensors, the sensor platforms, communication bandwidths and ranges, the information dissemination architectures and the protocols that are used. The simulation tool allows the user to vary these characteristics and by Monte Carlo simulation obtain statistical measures of the quality of the RMP in a given scenario.

1. Introduction

The main relationship between military operations and a C2 system is the sequence of decisions made by commanders based on the information, services and support provided by the C2 system. Given the difficulty of defining what constitute good decisions, this relationship could be analyzed indirectly by focusing on the preconditions for good decision-making. Situation awareness is a key factor in decision-making performance [Endsley, 1995]. Thus, a C2 system should enable and facilitate the ability of decision-makers to reach a high level of shared situation awareness. The situation pictures provided to the decision-makers are probably the most important contribution from the C2 system to achieve a high level of shared situation awareness. The quality of these pictures is dependent of a number of factors, i. e. the sensors, the communication systems, the information fusion process and the operational architecture of the situation picture production part of the C2 system. Hence, evaluation of the impact on situation picture quality with respect to changes in the parts and the behavior of this sub system stand out as an important analysis topic.

The scope of this paper is to present a simulation system, that is an attempt to establish a tool to be able to perform the above mentioned analysis. The simulation system has been developed and is being used in a study of future concepts and possible realizations of C2 systems for maritime operations. The study is performed by Norwegian Defence Research Establishment with the objective to make broad recommendations on the way ahead the coming years within this field to the Naval Staff of HQ Defence Command of Norway. The recommendations are to be based on cost-effectiveness analysis [Malerud *et al.*, 1998] and the simulation program is one of the tools that are being used in this analysis.

Performance of a situation picture sub system supporting two echelons is covered. That is, the picture provided at the operational level to plan and task maritime forces as part of joint operations - the operational Recognized Maritime Picture (RMP) - and the pictures provided at the tactical level for overall planning and direction within a maritime task group – the tactical RMP (also called WAP for Wide Area Picture). Evaluation of targeting data production and the different warfare area pictures is outside the scope of the simulation although closely linked. Moreover, the simulation is restricted to the surface part of the RMP. The command levels, the associated situation pictures and the scope of the study and the simulation program are depicted in Figure 1. As seen, both RMPs for commands ashore and afloat are covered as well as picture production at the single platform, task group and task force level and the associated communication and protocols between the entities and levels.



Figure 1. The hierarchy of maritime situation pictures

There are related work done by [Labbe *et al.*, 1998], which calculates measures of effectiveness (MoEs) of the tactical WAP for Over-The-Horizon Targeting, based on real data collected in

exercises. There is also basic theoretical work on the performance of multiple target tracking systems with respect to track combination strategies (sensor to sensor track fusion or sensor to system track fusion) [Chong *et al.*, 1999]. However, this paper describes a tool to assess the effects of changes in the operational architecture on the overall performance of the picture production sub system, simulating the whole chain from sensors detection to RMPs available at different nodes in a C2 system.

The paper is organized as follows. Section 2 gives a short introduction to measures of performance (MoPs) employed for studying the RMP production part of a C2 system. Section 3 outlines the basic characteristics of the models of the simulation program. The simulation program and the performance evaluation module are described in section 4. Finally, a simulation example is given before the paper closes with a conclusion.

2. Effectiveness Analysis and Measures of Performance

[Malerud *et al.*, 2000] presents a method for establishing measures of merit from high-level desirable properties a C2 system should posses and actual MoPs and MoEs employed in our study. With respect to one of these properties, the capability of the C2 system to enable and facilitate a high level of shared situation awareness, several MoPs have been defined. These MoPs are concerned with the tracks of the RMPs and their attributes.

One MoP is concerned with the completeness of an RMP. That is, whether all real world tracks are represented in the picture and no false tracks are present. The other MoPs are concerned with the attributes of the tracks of an RMP. The attributes include both kinematical and classification information and MoPs for both of these attribute types are covered. Finally, MoPs related to the differences between RMPs provided to different commanders concerning shared situation awareness are defined. These shared situation awareness MoPs includes both the tracks represented in the RMPs as well as their attributes. For more detailed information about the MoPs consult [Malerud *et al.*, 2000].

A few of the MoPs outlined in [Malerud *et al.*, 2000] are presented in section 5 as examples. These are the completeness of an RMP, the level of classification of the tracks, and the age of the tracks. Also, an additional MoP is introduced, namely sensor coverage of individual objects.

A separate performance evaluation module based on data generated by the simulation system performs the MoP calculation and visualization. This module and the simulation system are described in section 4.

3. Models

The basic purpose of the models is to capture the quality of the situation pictures that resides on different nodes in a C2 system. From a picture production point of view the system can be described by sensors (data collectors), fusion nodes and end users. The fusion nodes collect, process and disseminate data from own (organic) sensors and other fusion nodes in order to produce an unambiguous picture, while an end user receives data from a fusion node. Sensors,

fusion nodes and end users are further associated with platforms, which may be stationary or mobile. Mobile platform models include surface vessels, submarines, airplanes and satellites.

Sensors, collecting data about their environment, produce the input to the picture production system. The sensors perform detection, localization, tracking and classification of surface vessels, and send reports to the fusion node to which they are attached. The fusion node processes the collected information and disseminates data to other fusion nodes and/or end users. The simulation covers hierarchical picture compilation, with some platforms responsible of fusing a set of sources and reporting the result to a higher echelon ensuring that the pictures are consistent. This relationship between the different platforms/nodes is described by the operational architecture i. e. the role, responsibility, activities and information flow of the different nodes. The concepts explained above are illustrated in Figure 2, and the models are further described throughout this section: Sensors and sensor platforms in section 3.2, communications in section 3.3 and the model of the fusion nodes in section 3.4.



Figure 2. The relationship between sensors, fusion nodes and end users

3.1 Sensors and sensor platforms

A sensor is connected to one (sensor) platform that may be stationary or mobile, e. g. coastal radar site, surface vessel, airplane or satellite. A sensor platform may be equipped with several sensors of various types: Surveillance radar, Synthetic Aperture Radar (SAR), Inverse SAR, Identify Friend or Foe System (IFF), electro-optical sensor and Electronic Support Measures (ESM). For satellites only SAR is modeled.

The detection capability of a sensor is modeled as a range interval (minimum and maximum range) and is, dependent of operating frequency, line of sight restricted. A terrain elevation database is used to calculate terrain masking. If the detection requirements are satisfied a track is established. The track is assumed to be stable until it is lost (out of sensor coverage).

The classification model intends to capture the potential classification ability of the various sensor types. A sensor reports to the fusion node to which it is attached indicating at which level of precision it is able to classify a certain vessel. Five different levels of classification have been defined: Platform (air, subsurface, surface), role (e. g. combatant, non combatant), type (e. g. frigate, patrol, merchant), vessel class (e. g. Fridtjof Nansen) and the unique identification of a vessel. The ability of a sensor to perform classification is range and target dependent. Further certain imaging sensors (e. g. electro-optical) are able to classify at different levels depending on the range to a target.

3.2 Communications

Presently the long haul communications between maritime forces, or between an afloat tactical commander and an ashore headquarter is often restricted by low bandwidth. The model implemented covers satellite communications, HF/VHF/UHF radio communication and ground based WANs and LANs.

A fusion node may send and receive data on a set of channels. The characteristics of a channel are throughput, whether the channel is broadcast or bi-directional, the maximum communication range and line of sight limitations.

3.3 Fusion nodes

The task of a fusion node is to produce an unambiguous picture based on data from own (local) sensors and reports from other fusion nodes, and disseminate the result to other fusion nodes or end users. The tasks of a fusion node may be divided into the following steps (see Figure 2):

- 1. Information collection
- 2. Track processing and track management
- 3. Information dissemination

A protocol which models current systems but yet facilitates for some flexibility in order to examine properties of future alternative protocols, e. g. event based data transmission, has been defined.

Data exchange between fusion nodes is network based. A network consists of a set of nodes communicating on one or more channels using a certain protocol. The protocols used by the different nodes in a network may not be identically, e. g. a Force Track Coordinator (FTC) typically have a slightly different protocol than other nodes participating in a certain network. A fusion node may participate on several networks, e. g. a tactical data link (TDL) network, a

network used for the tactical RMP exchange in the Task Group, and a third network exchanging data with an ashore headquarter.

A fusion node performs fusion of data residing on the node. Only classification reports made by sensors (non-fused reports) are used in the classification fusion in order to avoid data looping. The classification fusion is rule based and leads to a classification decision with an associated confidence level (certain, probable, possible or unknown).

The types of tracks that are to be transmitted by a particular fusion node are defined for each network. The model differentiates between the origin of a track and possible sources are own position, organic or local data, data from specific fusion nodes or data received on other networks. This is necessary in order to control the information exchange and to avoid data looping within the C2 system.

Each network has a set of filter criteria, both for reception and transmission. Examples are:

- 1. Maximum age of track data
- 2. Threat designator (hostile, neutral, friend or unknown)
- 3. Geographical area
- 4. Reports that are produced by a specific fusion node
- 5. Tracks previously received on a network





The protocol used by a network may be configured to simulate e. g. tactical data links to a certain degree of fidelity. An example could be:

- Use a three minutes fixed reporting interval
- Always send own position
- Do not report tracks that are already reported by another node in the network
- The message size is N bit

Examples of protocols are shown in Figure 3

In order to implement a simple yet flexible protocol some assumptions and simplifications have been made. No false tracks are present in the system, and perfect data association is assumed. This means that classification reports and track reports that belong to the same vessel always are processed collectively. A sensor reports to which level of detail it is able to classify a certain vessel, and does not produce an estimate of the classification (e. g. output the name of the vessel, or an actual vessel class). Thus, the simulation program outputs the potential quality (best possible) of the pictures in different fusion nodes. The factors mentioned above eliminate potential conflicts in data received by the fusion nodes, and hence no conflict resolution protocol between the fusion nodes is necessary.

4. Simulation Program

The simulation program is non-interactive and may only be paused or stopped during execution. During execution the movement of platforms may be visualized on a map together with the range of the sensors. It is also possible to show the track histories of the fusion nodes using a different color for each node. This has been implemented in order to verify the scenario and the behavior of the simulation. The user may also specify how fast the simulation shall run with respect to real time.



Figure 4. Main components and data flow

The simulation program is written in ANSI C++ and runs on major UNIX platforms (HP-UX, Solaris and Linux). The configuration of a simulation (platforms, sensors and networks) is described in flat text files that are parsed by the simulation during the setup phase. The text format is man readable (Motif resource style) which gives the ability to define the simulation using a simple text editor. The performance evaluation module that calculates and visualizes the MoPs has been implemented in MATLAB. The different tools and the information flow between them are illustrated in Figure 4.

4.1 Configuring a simulation

The configuration of a simulation includes the following steps:

- 1. Define the trajectories of the platforms participating in the simulation (vessels, subs, airplanes, satellites, etc). The trajectories may be deterministic or defined using a fairway with a user defined width.
- 2. Allocate sensors and fusion nodes to the relevant mobile platforms and ashore sites. Sensor parameters as range and classification performance are defined.
- 3. Define which networks the fusion nodes participate in, the protocols used and the properties of the channels used for the communication.
- 4. Define networks in order to exchange data for picture production or picture dissemination. The protocol that is to be used on a certain network is also defined.

5. Example

An example scenario is illustrated in Figure 5. Two frigates supported by a maritime patrol aircraft (MPA) are patrolling an area outside the Norwegian coast. There are two opponent vessels, which will be the target for surveillance, present in the area. One of the opponent vessels is patrolling an area outside the territorial border, while the other is sailing into Norwegian territorial waters. Additionally, there are three merchant vessels and one ferry in the area.

The picture production is organized as follows. The frigates and the MPA exchange data on a HF Link 11 network with 3 minutes net cycle time. Two coastal radar sites in the area report data to an ashore fusion node that produces an operational RMP. One frigate is serving as Force Track Coordinator between the ashore command and the Task Group. The FTC feeds the RMP data onto the Link 11 network and the tracks present on the Link 11 network to the ashore fusion node. Thus keeping the two pictures consistent. The RMP exchange is made on a HF net with periodic transmission every 10 minutes.



Figure 5. Illustration of scenario

Figure 6 shows examples of output from a Monte Carlo simulation. The left picture in figure 6 shows the vessel coverage in the picture that resides at the FTC in run number one. The yellow lines indicate when the vessels are active in the scenario (e. g. have left port), and the black lines when they are being tracked by some of the sensors reporting to the FTC directly or indirectly through other fusion nodes.



Figure 6. Sensor coverage and level of classification of tracks

The right part in Figure 6 shows the level of classification of the tracks present at the FTC. The bar graph indicates the level of classification related to the amount of time the vessels are being tracked.



Figure 7. Completeness as time series and the age of the picture

Figure 7 shows the completeness and the age of the RMP at the FTC. The completeness (left part) is the relative amount of vessels being tracked as time series. One sigma deviation is shown as dotted lines. The picture at the right is showing the distribution of the age of the RMP. The peak at zero minutes of age is due to data received from own sensors (mainly own position). The calculation of precision and completeness does not include own frigates participating on the Link 11 network.

6. Conclusion

A simulation program for the estimation of MoP of RMP production has been presented. The basic purpose is to capture the quality of the situation pictures that resides on different nodes in a C2 system. Thus, the simulation explicitly models the operational architecture including the protocols used for information exchange between the C2 nodes in the system. Models of sensors, data fusion and information exchange are implemented. For MoP calculation and presentation a separate tool has been implemented that allows the user off line to select which set of fusion nodes or sensors that is input to the MoP calculation. The set of MoPs implemented include level of classification of tracks, the completeness of the picture with respect to coverage and the age of the data in a C2 node.

7. References

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