

An emulator of a border surveillance integrated system

A. Farina, R. Ferrante, A. Graziano, M. Ravanelli, G. Timmoneri, L. Timmoneri, T. Volpi
Selex Sistemi Integrati
Rome, Italy.

(a.farina)(r.ferrante)(a.graziano)(m.ravanelli)(g.timmoneri)(l.timmoneri)(t.volpi)@selex-si.com

Abstract - *This paper illustrates an emulator of an integrated system developed for predicting the system performance in a typical border control surveillance scenario. The sensor suite emulated is constituted by: one spaceborne surveillance radar, one airborne radar for long range surveillance, one radar devoted to Vessel Traffic Control (VTC) and one Infrared (IR) camera. The collected data are sent to the command & control centre which allocates the proper means for facing the “potential hostile” target intrusion. The reaction time and probability of correct reaction in presence of an un-identified moving object have been selected as representative of the integrated system operation. A key point to note is that the visualization is nowadays considered as an enabling technology; thus a great care has been dedicated to the presentation of results via movies realization.*

Keywords: Integrated system, border surveillance, system emulation, data fusion, homeland security.

1 Introduction

This paper describes a Notional Integrated System (NIS) emulator having the purpose of predicting the performance of a real border control surveillance system. In the frame of the Homeland Security (HLS), which has the purpose to guarantee the national security, the Border Surveillance (BS) faces the problem of controlling the national frontier against terrorism and illegal activities [1]. This goal is achieved via an accurate surveillance of the terrestrial, maritime and overland boundaries thus involving a large number of heterogeneous sensors and wide bandwidth communication links. The need of an emulator of the integrated system is to rapidly answer to the following main questions:

- (i) is the designed system compliant with the BS requirement in terms of adequate reaction and response time?
- (ii) Has the designed system reached the best trade-off between the selected technology and the BS requirements?
- (iii) Which are the best algorithms and procedures to be used to fuse the information collected by the different sensors thus producing the situation awareness?

- (iv) Are the communication links and bandwidth adequate for the BS purposes?

This paper is organized as follows: section 2 describes the environment (e.g. computers, consoles) where the emulator has been implemented. The emulator of a NIS is characterized by the number and type of the subsystems composing the NIS and the communication links connecting them; this matter is detailed in section 3. Section 4 describes the simulations results. Section 5 collects the conclusions and follow-on of the activity; the last section reports few selected references.

2 Emulator environment

The emulator has been implemented in one of the Command and Control System Facilities (CCSF) of Selex-SI. The CCSF has been developed starting from late 90's for the following main purposes:

1. Integration and testing of Selex-SI, COTS (Commercial Off-The-Shelf) or OTS C4I (Command & Control, Communications, Computers and Intelligence) products and applications in a comprehensive, flexible configuration.
2. Cross-projects investigation/evaluation of concepts, architectures, military processes, standards and emerging technologies.
3. Support of the evolutionary development of C4I systems/products (gap analysis).
4. Rapid set-up of prototypes in the initial phases of system acquisition and definition.
5. Demonstration facility.

The goal of emulating and evaluating the performance of an integrated system has been added as a consequence of the new challenging market of HLS. The CCSF technologies include:

- Workstations, based on Console SUN-Solaris, PC Windows and Unix;
- Directing Console with Touchscreen Monitor, Bluetooth and Wireless connection;
- Large Screen Display (LSD), equipped with a BARCO Projector BG1209s, with a resolution of 2500x2000, and a Management System EOS VISU OSIRIS.

The system is equipped with a powerful set of cartographic representations. The CCSF can manage the following map types:

- a. ADRG (Arc Digitized Raster Graphics);
- b. ASRP (Arc Standard Raster Product);
- c. CADRG (Compress Arc Digitized Raster Graphics);
- d. DAFIF (Digital Aeronautical Flight Information File);
- e. DTED (Digital Terrain Elevation Data);
- f. V-MAP (Vectorial Map) .

The CCSF architecture is represented in figure 1.

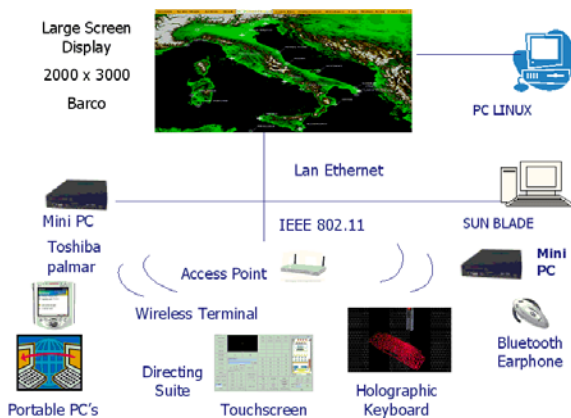


Figure 1 : CCSF architecture

The CCSF is based upon an open architecture design equipped with a Local Area Network (LAN), where several computers are connected to.

All the system is supervised by a dedicated processing node connected to the LAN, by which is possible to monitor all the on-going performances and capabilities of the system, directing the other nodes for the display sequences on the LSD and providing the operator with several software tools to control the system operational functions.

Dedicated processing nodes are supplied to host software applications, performing a flexible interface capable to fit the specific format and physical protocol, and to provide Support Services, as:

- Bluetooth phone capability;
- Portable Personal Computer;
- PocketPC Toshiba E750 Wi-Fi 400 MHz, display 3.8" color TFT (Thin Film Transistor);
- Server SUN E3500, double CPU, double Monitor;
- Holographic Laser Keyboard;
- Power supply unit: 1500 VA for workstation/server SUN.

3 System mission

The NIS emulator has been currently developed having in mind the following basic operational mission: presence of

one un-identified moving object approaching a coastline. The sensor suite emulated in the NIS is: one spaceborne surveillance radar, one airborne radar for long range surveillance, one radar devoted to VTC and one IR camera. The collected data are sent to the Command & Control Centre which allocates the proper means for facing the "potential hostile" target intrusion. Purpose of the study case is to determine the probability of correct reaction of the NIS for BS as a function of time. Figure 2 depicts the emulator mission.

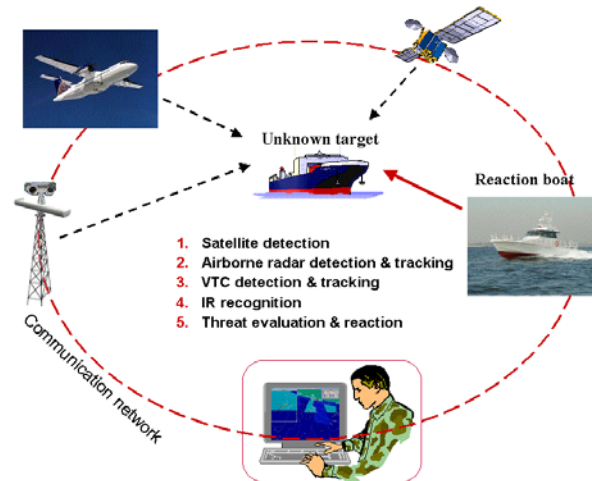


Figure 2 : emulated mission of the NIS

To react properly to a hostile target the NIS executes the following functions:

1. Target detection by means of the spaceborne radar and cueing to the airborne radar.
2. Target detection via airborne radar and cueing to the VTC.
3. Target detection via VTC.
4. Target tracking via VTC.
5. Target cueing to IR via VTC.
6. Classification/Identification via IR.
7. Decision and reaction.

4 Achieved results

The visualization is nowadays considered as an enabling technology; it is felt that this technology is important for performance analysis, support to the project development and presentation of achieved results to the Customer. To conveniently illustrate the capability of the emulator, the integrated system performance have to be presented in two forms: (i) numerical results, (ii) pictorial results.

4.1 Numerical results

For sake of brevity, it is assumed that the time period for computing the NIS response starts when the VTC is cued towards the un-identified target. Among others the following functions have been emulated.

1) Radar detection and track initiation

We assume that one VTC sensor is located in a proper site along the coast to be controlled. The VTC acts as a surveillance sensor cued by the upper layer sensors (spaceborne, airborne): it is in charge of detecting potential hostile targets, maintaining the target under tracking (i.e., computing its position, velocity and heading with high accuracy) and finally cueing the IR sensor towards the target position for target classification.

The target detection probability (P_d) defines the radar capability to detect a potential hostile target. The VTC features [2] and the target Radar Cross Section (RCS) are the inputs to the proprietary software tool Radar Work Station (RWS) [3, 4] used for computing the detection probability P_d vs. range R , as shown in figure 3.



Figure 3 : use of RWS

A suitable track initiation logic is to be defined for the case under analysis. Track initiation is required to start the VTC tracker (after target detection with a certain P_d) being confident that a “real” hostile target, and not a false alarm, is under tracking. The “2 out of 3” logic [5] has been selected for the emulated mission.

The results of detection and track initiation is that the unknown target is revealed by the VTC sensor, which then starts computing and updating its position, velocity and heading.

2) Radar tracking and cueing to IR sensor

The main objective of the VTC tracking is to get real time information on the “trajectory” and the corresponding velocity of the unknown target. The first rough classification performed with these basic information allows sending a quick alert to the CCSF.

The VTC tracker - in the frame of the BS demonstrator - is emulated with a Kalman filter [5] that is able to accurately compute the target kinematics and thus to cue the IR sensor. Once cued towards the target, the IR sensor captures a picture and/or a video of the target under tracking.

The diagram, describing the sequence of events (detection, initiation and tracking) and showing the inputs and outputs relative to each block, is depicted in figure 4.

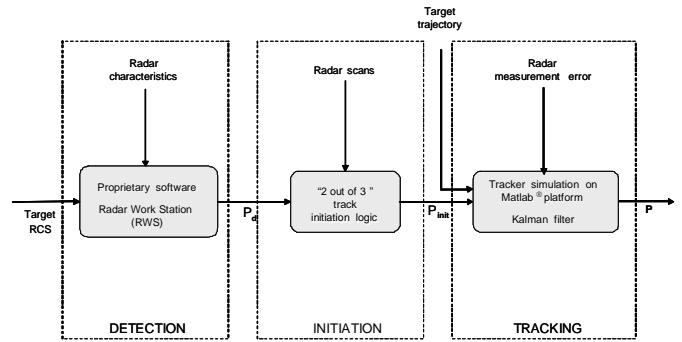


Figure 4 : sequence of events and input/output parameters assessing VTC radar performance

3) IR detection and recognition

There are three primary levels of target discrimination in static performance of professional infrared systems [6].

- Detection – the discrimination of an object on the display as being of potential interest. In the NIS emulator, it is assumed that the VTC firstly detects the target and then cues the IR towards the target itself. Once the IR device is properly pointed towards the target, it starts capturing images and/or videos. It is currently foreseen to produce videos for targets classified as “very hostile” and images for less aggressive targets. Since, in fact, a video transmission to the CCSF costs five times an image transmission, the number of videos has to be limited to avoid the communication channel saturation. In this phase, the output of the VTC tracker is essential, because the estimated target kinematics is the rough classification driving the selection of video or image transmission (i.e.: if the target path is aiming towards the coastline and does not correlate with scheduled vessel traffic it is considered potentially armful).

- Recognition – the discrimination of a detected target as being a member of one of several classes of targets. Once the IR output data are received in the CCSF, the presence of an Operator is assumed to perform the recognition function. The current version of the NIS for BS doesn't foresee any automatic means of threat identification. The Operator has the responsibility of assigning to the target under analysis the proper “label” and to start the proper reaction. The Operator capability of correct target classification is derived from [7] available in the open literature.

- Identification – the discrimination of a recognized target as a particular member of a class of targets.

4) Reaction

Reaction is the process opposing the possible outcomes of a critical event or of a threat and aiming at solving and/or reducing the relative consequences; it is also in charge of defeating the capacity of an hostile agent of carrying out and finalizing an attack. Reaction starts when a threat is detected, tracked and recognized. Its actuation is planned and coordinated by the CCSF. The guidance law under

consideration is of the cut-off type: the interceptor first changes tack into collision course, then it moves towards the estimated intercept point. An optimal guidance law [8] is also possible.

In typical integrated system dedicated to BS, the inputs to the reaction process are:

- track data provided by the radar sensor (target position and velocity);
- classification data provided by the IR device (target size and images);
- presence or absence of target response to an automatic identification system;
- correlation level to scheduled vessel traffic plans.

The reaction is carried out according to the following steps:

1. threat identification, that provides one of the possible threat levels (High, Medium, Low) defining the potential danger resulting from the target behaviour;
2. mission selection, which evaluates, on the basis of position, velocity data and threat level the type of action to be performed against the target;
3. resource allocation;
4. resource control law.

The outputs of the reaction process are:

- commands to intervention vehicles (e.g.: coastguard, navy vessels);
- notification messages regarding on going operations to the superior CCSF.

The reaction itself is a function of a number of variables mainly depending on:

1. the Operator classification of the unknown target,
2. the correlation of the target classification with the “key areas” defined in the region under control.

These two information, among others, determine the “threat evaluation” which, coupled with the continuous update of the target kinematics and the a priori knowledge of the “reaction resources” available in the controlled area, establish the selection of the proper reaction.

The block diagram of the threat evaluation process is depicted in figure 5.

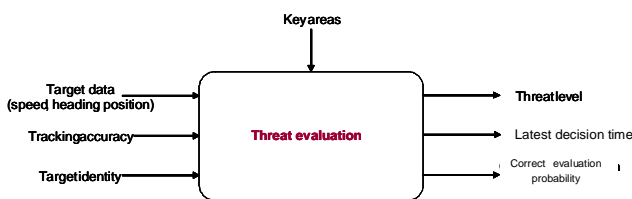


Figure 5 : threat evaluation block diagram

This process is implemented in the NIS with some simplifications and permits the numerical computation of the reaction time (T_{reaction} , see equation 1) and the probability of correct reaction (P_{cr}) as a function of time (see equation 2) which is one of the main goals of the NIS. The reaction time is equal to:

$$T_{\text{reaction}} = T_{\text{VTC}} + T_{\text{IR}} + T_{\text{class}} + T_{\text{response}} \quad (1)$$

where

T_{VTC} : time required by the VTC to initialize the target track with probability higher than 0.9,

T_{IR} : time needed by the IR sensor to correctly classify the target,

T_{class} : Operator-based threat level assessment,

T_{response} : time required by the friendly vehicle to intercept the target.

It has been noted the two quantities T_{VTC} and T_{class} are negligible with respect to the others and for simplification purposes they are omitted.

The radar is located at the origin of the reference Cartesian system and the target trajectory starts at $x_0=7$ km, $y_0=20$ km with a constant speed with absolute value $|v|=23$ m/s and heading $h=240^\circ$. Let's consider as starting time ($T=0$ s) the time required by the VTC to initiate the track with probability equal to or higher than 0.8. It has been found that T_{IR} is equal to 653 s having set to 0.8 the required value of the correct classification probability achievable with the IR sensor, while the interceptor vehicle reaches the unknown target after 231 s. Note that in this study case no communication delay is explicitly considered; however the NS2 (Network Simulator 2) is a tool available to model the performance of an heterogeneous communication network.

The estimated T_{reaction} is equal to $653+231=884$ s which complies with reasonable expectations for the study case under analysis.

Another interesting parameter is the probability of correct reaction (P_{cr}). Following a procedure similar to the one taken for equation 1, it is found that:

$$P_{\text{cr}} = P_{\text{VTC}} + P_{\text{IR}} + P_{\text{class}} \quad (2)$$

where:

P_{VTC} : VTC probability of continuously tracking the target (practically equal to 1),

P_{IR} : IR probability to correctly classify the target,

P_{class} : Operator-based probability of correct reaction.

In correspondence of $T=653$ s, i.e. when the IR is cued by the VTC along the target direction of arrival ($P_{\text{IR}}=0.8$), it results:

$$P_{\text{cr}} = 1 \cdot 0.8 \cdot 0.86 = 0.69.$$

This value rapidly increases, as time runs, as the IR and the Operator confidence increase and it reaches in few seconds values higher than 0.9.

4.2 The visualization technology in the NIS

A modern way of presenting the results achieved in the emulation of a NIS for BS is via the realization of a movie as discussed in this section. The movie summarizes what an operator or a team of operators observe on the LSD of the CCSF in figure 1. The movie realization is possible only in an environment like the CCSF because it requires the use of the technologies described in section 2.

The threatening target is shown on the wall screen at the beginning of the movie.

After showing the spaceborne and airborne sensor suite, the rotating coastal radar (VTS stands for Vessel Traffic Service) comes into the play; the movie presents the console where the first plot relative to the target appears. Simultaneously with the plots a window appears to visualize the results of the analysis: the detection probability of the coastal radar and the accuracy of the tracker. The angular sector of the estimated heading and the uncertainty ellipses (obtained multiplying by 5, a guard factor, the values of σ_x and σ_y , standard deviations of position estimation) are shown (figure 6).

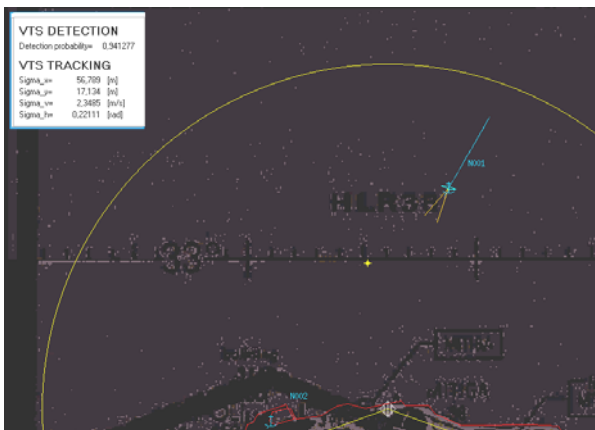


Figure 6 : the threatening target track on the console

When the target is approximately 10 km away from the coast, a IR video is shown (figure 7).



Figure 7 : the IR video

From now on, the window associated to the target starts to contain also the IR recognition probability. When the value of that probability becomes greater than 0.8 it is highlighted in yellow: it is time to take a reaction decision. The CCSF room, where the data relative to the reaction are indicated, is shown (figure 8).



Figure 8 : the CCSF room

The reaction starts and a patrol boat leaving a suitable friendly harbour is visualized on the console. The video ends up when the reaction boat reaches the threatening target (figure 9).

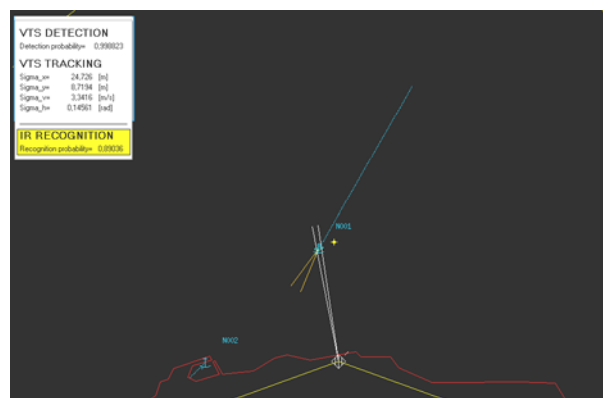


Figure 9 : the reaction boat towards the threatening target

5 Conclusions

The paper has presented the results achieved in the activity dedicated to predict the performance of an integrated surveillance system in a HLS study case.

The conclusions of this study is that the sensor suite involved in the current design of the NIS for BS (spaceborne and airborne radar, VTC, IR, interceptor vehicles) permit to achieve reasonable reaction time and probability of correct classification in presence of threatening targets. It has been shown that, in presence of the target defined in the study case, the friendly vehicle reaches the potential hostile target in less than 15 minutes; this is an achievement in line with the expectations of the surveillance system.

The NIS emulator is being improved towards the development of an emulator of an integrated system capable of predicting the performance achievable by a number of heterogeneous sensors in presence of different types of targets where sensors and target positions that can be selected "on-line" before the running of the study case. It is a challenging problem requiring the integration, inside the frame already designed for the video realizations, of a number of software packages dedicated to: (i) prediction of performance of airborne and spaceborne radars, (ii) prediction of performance of ground-based surveillance radar, (iii) predictor of IR performance, (iv) prediction of reaction time and probability of correct classification and (v) evaluation of the effects of communication devices emulated via NS2.

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