Introduction of infrared countermeasures in closed-loop simulations

Marianne (M.A.C.) Degache[(1)], M.A.C.; Ric (H.M.A.) Schleijpen[(1)],

[(1)] TNO P.O. Box 96864, 2509JG The Hague (The Netherlands),
marianne.degache@tno.nl, ric.schleijpen@tno.nl

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ABSTRACT:

One of the TNO missions in support of the Dutch Ministry of Defence is to provide means for the assessment of operational electro-optical system performance in the various theaters.

To quantify the impact of both the environment and actors' intrinsic properties in a maritime scenario, TNO has defined a simulation framework using EOSTAR Pro (Electro-Optical Signal Transmission and Ranging) suite modules to model the incoming radiation on an EO sensor from a scene including targets and background through a propagation medium.

This simulation framework named ISISS (Integrated Scene Image Simulation Server) allows the sensor position and the targets to move in a dynamic way in a 3D scenario with six degree of freedom for the scene elements.

This paper will demonstrate the modular components of ISISS and shows the inclusion of new modules to simulate the launch of infrared countermeasures in a maritime scenario. ISISS generates high resolution images at run time and enables closed loop simulations of sensors (or seeker) approaching target objects.

1. INTRODUCTION

In order to insure the efficiency of navy military operations, one requires insight in the capabilities of the different assets in the operational theater.

To study the performance of onboard EO sensor systems but also the vulnerability of a platform in all weather, all region conditions of a maritime environment, the Dutch organization for applied scientific research TNO has developed the model suite EOSTAR an acronym for Electro-Optical System Transmission and Ranging. Since nowadays EO sensor systems can be severely hampered in their use by the environmental conditions in which they are operated, initial developments were focusing on the atmospheric and propagation modules [9]. However the philosophy of EOSTAR is to follow an end-to-end approach by considering the complete observation chain from target or threat up to the sensor and processor addressing a specific task. Complimentary modules have been included in an improved object oriented architecture to provide a high fidelity, cost effective software framework allowing to develop both batch console applications or user driven stand alone tool (using a dedicated GUI: graphical user interface).The second section of this paper provides a generic description of EOSTAR and relevant modules. More detailed descriptions of the model suite or the individual models have been given in previous publications (see reference [6] for the latest overview).

The new maturity of the EOSTAR software package allows it to be used for new tasks with minor upgrades, for example hit point analysis [1] or an exo-atmospheric interception [10]. Relying on agile software development, the different modules can be combined and integrated for the defined end goal. The key to an efficient use of the models in a simulation is to provide a low cost, alternative, user friendly but still enlightening solution.

In the context of the threat of infrared guided missiles, modern naval forces aim at ensuring a high level of protection for their own ships. To reduce the probability of being hit by an enemy weapon and thus improve the survivability of the platform, its susceptibility [1] must be assessed carefully for all the operational conditions. As a result countermeasures can be used to prevent a dramatic outcome. Since the infrared missile threat appeared, many countries had dedicated studies and developments on the topic. In the fifties, an Air Force study on infrared countermeasures already concluded that the two most promising methods to protect bombers were decoys and signature reduction. Meanwhile the maritime environment witnessed the deployment of naval infrared decoys. In 1968, a prognosis predicted the demise of decoy flares that were becoming obsolete and were going to be replaced by "active" IRCM [4]. However due to numerous advantages among which low unit cost, small unit volume and easy mounting, infrared flares are still widely used and being upgraded nowadays [2]. As a result such an important actor of the ship platform against IR threat must be considered for the assessment of military ship susceptibility.

Prior development [1] have demonstrated how the use of EOSTAR combined with the TNO model EWM (Electronic Warfare Model [11]) provides a powerful toolset for hit point analysis and for countermeasure effectiveness. However decoys were not implemented in EOSTAR at the time (2010) so simulation including flares could not rely on the high resolution scene generation provided by EOSTAR but instead a very crude model had to be used. Although the decoy effectiveness is first a geometrical problem (i.e. have the flares at the right location in the field of view of the threat sensor), a need emerged for more realistic synthetic infrared images that can handle a variety of operational conditions (from clear sky high contrast scenes to a cluttered low contrast environment). This paper presents the first steps of the inclusion of an infrared flares module in the EOSTAR model suite to enable high resolution images generation in a closed loop scenario.

The following section 2 introduces the preexisting software framework. The next section 3 discusses the inclusion of a preliminary flare model. Section 4 investigates the use of the model in simulations. Section 5 discusses the step ahead before drawing a conclusion on this phase of the study.

2. PRE EXISTING MODELLING FRAMEWORK

2.1. EOSTAR framework

EOSTAR framework relies on a complete model suite of scientific modules covering a detection chain in electro-optical wavelengths for sensor systems in operational settings. The framework is Windows based and can run on a standard PC machine. At the exception of the well-known MODTRAN code [14], the various modules have been developed by TNO allowing a full control of the modularity and the optimization for case studies.

As a dedicated stand alone program used as a tactical decision aid (TDA), EOSTAR provides the user with coverage diagrams ("where can I see the target?") and synthetic sensor images ("how do I perceive the scene?"). An illustration of the typical GUI outputs of this dedicated tool is given in Fig.1 and Fig.2.

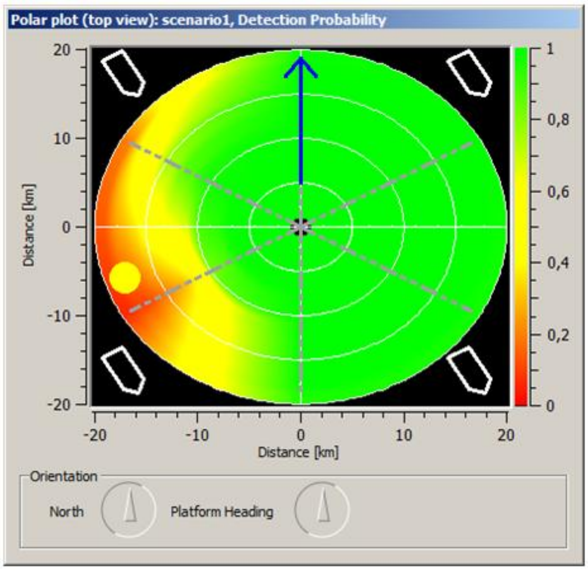

Figure 1 Detection probability of the "Quest" target by a mid wave infrared sensor on a 20 km range radius in the considered scenario.

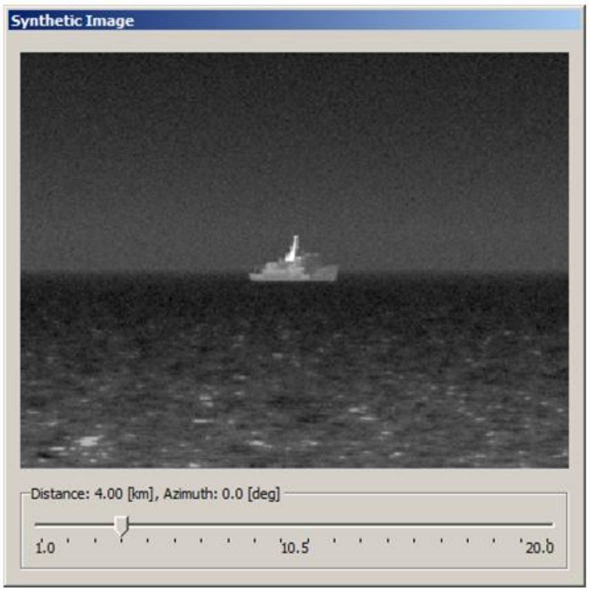

Figure 2 Synthetic sensor image on a given position (range = 4km, azimuth = 0 deg) for the considered scenario.

EOSTAR software architecture as represented in Fig 3. allows multiple GUI to be developed and used with the same kernel (controller) and the same or different models.

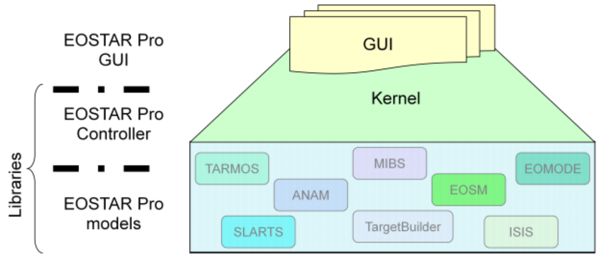

Figure 3 ISISS integrates all elements contributing to the generation of the scene.

For this work the following subsection gives an overview of the EOSTAR models used for the description of the environment, the target and sensor image generation.

2.1.1. Environmental modules

EOSTAR includes a propagation module handling transmission losses, refraction effects and turbulence. The focus on a maritime environment allows the inclusion of the Advanced Navy Aerosol Model (ANAM) [15] for the advanced modeling of maritime aerosol and the Marine Infrared Background Simulator (MIBS) [7] for the generation of realistic synthetic infrared backgrounds near the horizon.

The full characterization of a vertical environment fields is insured by meteorological models as well as interfacing with relevant meteorological sources. The propagation solver fully resolves the spatial and spectral information using outputs of the forenamed models as well as a ray tracer based on Snell's law. The output information of these modules includes transmission, path and background radiance, clutter information and image distortion.

2.1.2. Target models

EOSTAR addresses two types of targets in the maritime environment: sea-skimming missiles and ships. For the latter a full characterization of the 3D target is required. The geometry can be provided by computer aided design (CAD) programs or by a simplified model developed by TNO named TargetBuilder. TargetBuilder guides a user to generate a target from simple geometric elements or import an existing file and modify it (deletion, addition, scaling). Besides it provides the necessary tool to add material or coating properties as well as boundary conditions for the signature code EOSM [13]. EOSM standing for Electro-Optical Signature Model is an efficient solver of heat balance equations providing the infrared signature of ships in any type of environments. Despite its simplicity EOSM gives fair results and in an international comparison of infrared ship signature prediction models based on data from a NATO trial, EOSM performed very well and comparable to the SHIP-IR model [16].

2.1.3. Imaging modules

One of the key features of EOSTAR derives from its imaging capability in a semi-operational context. In infrared wavebands, EOSTAR can provide a statistical synthetic sensor image corresponding to the provided scenario parameters. The module responsible for this challenging task in EOSTAR is called Integrated Scene Image Simulator (ISIS). ISIS uses outputs from other modules in the suite (environment, target and sensor modules). As illustrated in Fig. 4, ISIS main task is the integration of the various inputs in a coherent manner. Handling various resolutions in spatial or spectral domains as well as the sharing of common data must be controlled by the module.

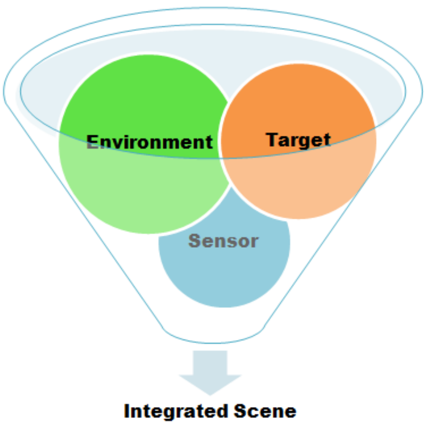

Figure 4 ISIS integrates all elements contributing to the generation of the scene.

For the rendering, ISIS makes use of Opengl as well as internal graphics libraries. It has not been fully optimized or upgraded with new GPU techniques so that very limited hardware requirements are associated to the use of ISIS. However it can perform with a good execution time and has thus been selected to be included in various client-server applications. One example [10] of such architecture is given in Fig 5.

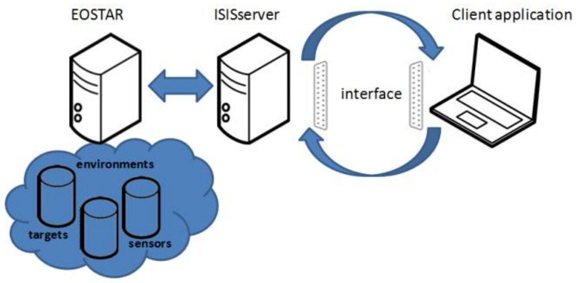

Figure 5 EOSTAR communication with a client using ISIS server

The main goal of such architecture is to use EOSTAR as a scene generator for a client. The server directly linked to EOSTAR is mainly providing an interface to ISIS input parameters and image outputs. The use in closed loop simulation is then possible due to the relative speed of the generation of an image in a 'standard' scenario.

2.2. EWM

The Electronic Warfare Model is a TNO model that has been developed for countermeasure evaluation studies. It can perform closed-loop simulations regarding the engagement of missiles against ships. It includes detailed seeker models both for infrared and radar guided missiles. The missile flight dynamics are modeled in a detailed manner so a complete missile fly-out including countermeasure deployment can be simulated.

Prior studies have shown the coupling of EWM and EOSTAR in open loop simulations. Issues concerning the definition of the sensor in EOSTAR compared to the seeker definition in EWM were fixed and the interface has been improved for closed loop simulations and to include the flare models as described in the following section.

3. INCLUSION OF IR FLARE MODELS IN CLOSED LOOP SIMULATIONS

3.1. Requirements for the IR flare model

From the concept, the prototype to the commercial production, a large variety of infrared decoys have been considered in the past 50 years including pyrotechnic agents, chemical smoke, radiant particles, ejected decoys including multiples and towed decoys. Actually the evolution of decoy flares did not follow a direct or pre-planned path. Instead, the development was influenced by many factors and requirements existing at the time.

In the 1968, Mr. Regelson of the Naval Ordnance Test Station, (China Lake, California) summarized the advantages and limitations of an infrared decoy flare [4]. These limitations are still a concern nowadays:

1) Requires a early warning
2) Increases visual detection,
3) Requires exact placement
4) Is susceptible to counter-countermeasure,
5) Does not match target radiative wavelength
6) Is often unreliable at altitude,
7) Requires special handling
8) Requires a special dispenser

To assess the effectiveness of flares, define a deployment strategy and avoid when possible the flares intrinsic limitations, it is important to be able to evaluate the relevant flare parameters. In that context it is highly beneficial to have a complete simulation framework of the system threat-flares-ship-environment.

Relying on EOSTAR-EWM framework, an initial stage of a phased study has been focusing on the initial development of an Infrared Flare Visual Model (IFVM) to be integrated in the model suite. The goal is to provide an addition to the ISIS model so that flares can be visualized in the integrated sensor image and provide an advantageous alternative to the preexisting crude models included in EWM.

The initial featured parameters for this flare model have been defined as:

- A geometrical shape
- A minimum and maximum radiant intensity level
- A burning time
- A trajectory

As a proof of concept, it was decided to focus on the effect rather than the cause and derive an empirical model from the sensor perspective. As a result the visual impact of the radiative properties of the flares and the consequences for the signal and image processors have been the driving factor rather than the physical description of the fluid and particles representation of the decoy. Once the simulation package can demonstrate the modeling capability as well as the need to further model (some aspects of) these flares, a new approach based on simplified computational fluid dynamics can be initiated.

3.2.Closing the loop between EOSTAR-EWM

EOSTAR and EWM provide both an access to different models and allow simulation based on user defined scenario. If EOSTAR can generate high resolution synthetic imagery of a third generation infrared electro-optical imaging system as well as the spectrally resolved radiance of a scene covered by its field of view, EWM can use multiple scene objects with the full control of their dynamics and simulate an engagement scenario.

Closing the loop between EOSTAR and EWM require a translation of the scenario description to encompass the common elements as well as their own unique parameters. For a full coupling of the models the definition of the scenario geometry in EOSTAR had to be reviewed and improved in order to adapt to the reference frame selected by EWM. The time factor has also been introduced to allow for the generation of time coherent image sequences.

The generic client-server architecture given in Fig. 5 has been reused for this work and a new interface has been designed with a new distribution of responsabilities for the two models as well as a new shared set of parameters. Although backward compatibility is maintained, the new design makes use of the sensor model of EOSTAR in coherence with the infrared seeker of EWM. As for the flares models, EWM controls the activation and deployment of the countermeasures being released in the scenario. EOSTAR is in turn responsible for the visual rendering of the flares following the client's events and the defined object trajectory in the 3D scene.

4. SIMULATIONS

This section provides first simulation results of the infrared flares visual model (IFVM). Simple upgrades are then introduced to avoid simulation artifacts as well as to improve the interaction between the different elements of the modeled scene. The impact of this new development for hybrid simulations and the use as an analytical tool is then discussed.

4.1.Initial model

Following the initial requirements of the flare model, IFVM was developed to handle several optional new objects in the infrared imaging scene of EOSTAR. Each model and version of IFVM provides a complete parameterization of the flare type.

The first model of IFVM uses a simple disk for the reference geometrical shape of the flare radiant blob that could be extracted from the sensor image. The shape has been selected for the best crude approximation but also because of its symmetry and capability to give the best match for various scales. Fig 6 shows the resulting image of different types of individual flares generated by IFVM model 1. The first type corresponds to a disk of a radiant intensity with a hot core and a linear decreasing intensity outside. Type 1 aims at representing the flare as a single element in the sensor image. Type 1 can be used as a generic approach when an image processing algorithm is rejecting clutter and rely on region detection. The second type is meant to represent particles effects in a disk region. In Type 2, the "particles" are generated using configurable statistical distributions to provide a parameterization of the density distribution. Type 3 is a combination of the two types.

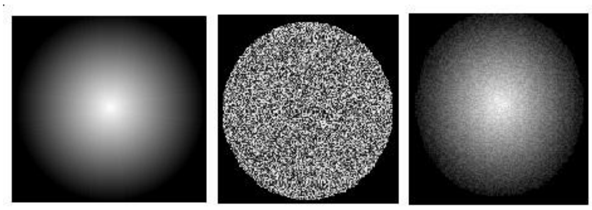

Figure 6 IFVM – model 1, type 1-4

4.2.Upgrades toward more realism

The initial model of IFVM is very easy to parameterize and can handle various scenario for hot spot seeker and simple generic imaging seeker. However its simplicity introduces simulation artifacts due to the edges of the defined region and its perfect symmetry. A new model has been proposed that can combine new reference of geometrical shapes as well as a more complex representation of the flare no as a unitary element but as a group. Examples of IFVM model 2 are given in Fig. 7.

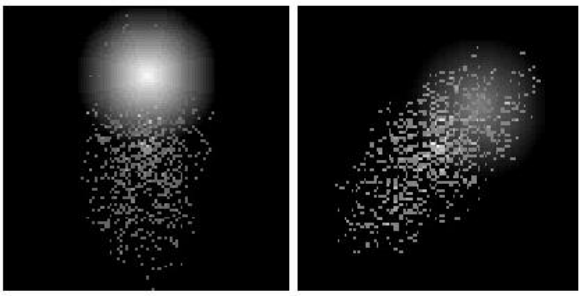

Figure 7 IFVM – model 2

The main addition in model 2 for the examples of Fig. 7 is a tail part with the energy spread into finite elements. In the left image, the core of the energy is still concentrated in the disk region. On the right image, the particles effect dominates.

4.3. Flare imaging in the EOSTAR scene

The integration of the flares model in EOSTAR scene is done by a close link to ISIS imaging library. All elements of the scene (Fig.4) are combined with the new model:

- IFVM outputs are integrated in the background. The impact of the background radiance level and the transparency are taken into account.
- Flares can be deployed in various geometric configurations with regards to the target. The positioning of the flares is defined from a reference point of 3D geometry of the target. A special care is find what is foreground and what is background. Partial overlap may exist.
- Several flares can coexist in the same scenario within the scene image. As a result the overlap but also the merging of two unitary elements is considered.
- Finally the effect of the transmission and path radiance between the flares and the other elements of the scene are included.

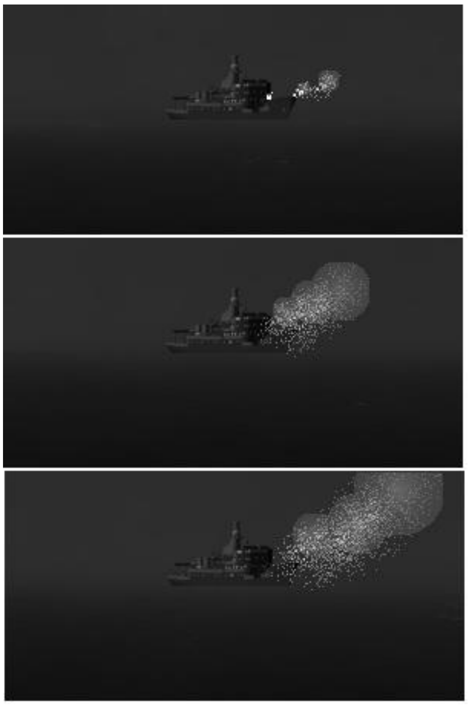

Figure 8 IR flares simulation (IFVM model 2) in an EOSTAR scene

4.4. Hybrid simulations and analytical tool

The work of described previously have shown that the integration of various radiation sources in a propagation medium must be controlled step by step. Analytical tools have been developed for this control process as shown in Fig. 9. Images produced or used by ISIS can be displayed and analyzed by a user using GUI widget tools. In Fig 9, the left image is an output of MIBS model in a midwave infrared band. The user used the analytical tool to read the actual radiance value corresponding to the selected image pixel. The right image shows a false color image of 3 flares of IFVM model1 merged in a single blob. The analytical tool gives the code value associated to the current pixel.

Figure 9 Analytical tool

In addition to the visual aid for the reading of the inputs/intermediate and final results of ISIS, the analytical tool is useful to support hybrid simulations. Indeed interfaces have been provided to import external images or camera recordings. Since there is often a need for a manual control of the raw data, the analytical tool provides the necessary insight for the user to control the simulation.

5. DISCUSSION AND FUTURE WORK

A flare can be characterized by its visual aspect in a sensor field of view by a number of key features: apparent size and shape, intensity distribution and statistics.

The postulate that a generic parametric model can be derived from these features can be discussed. Switching to a different band of interest or very different sensor characteristics may render this well tuned model useless. However an agile software development has been chosen for the inclusion of countermeasures in EOSTAR software framework. A test environment and a first order approach have been defined as the initial phase for the simulation of a ship protection against an IR guided missile scenario.

Closed loop simulations using a mature software framework will allow the proper testing of a large variety of seeker models. The continuous development of EOSTAR and EWM models at TNO provide there a good opportunity to create or upgrade models and invest in a robust architecture. Both EOSTAR and EWM make use of a plug-in/plug out approach to allow external models to be used (using for example DLLs or Matlab/Simulink code).

Future work is expected to deliver simulation results of the (upgraded) infrared seeker models that have been developed in prior studies [1]. The generic flare model will be parameterized in order to provide models for the flares of interest. Validation of the models and hybrid simulations can be achieved with the use of new recordings from national, NATO or other international cooperations.

6. CONCLUSIONS

New developments in EOSTAR have provided new tools and a new preliminary model of infrared flares. Despite the modest modeling of this first version, the visual impact of the inclusion of flares in a calculated infrared scene has been emphasized. It is also now possible to generate and display parametric infrared flares in an EOSTAR environment.

Additional developments of the preexisting tools EOSTAR and EWM are giving now extra insight on open and close loop simulations for the deployment and effectiveness of the infrared countermeasures in an operation setting. Analytical tools and batch fly-in simulations are bringing a new means to better understand and evaluate defence strategies for the Navy.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

1. Robin Schoemaker and Ric Schleijpen, "*Evaluation tools for the effectiveness of infrared countermeasures and signature reduction for ships*", Proc. SPIE 7662, 76620Q (2010)
2. Brian Butters, Edgar Nicholls, Roy Walmsley and Richard Ayling, "*Infrared decoy and obscurant modelling and simulation for ship protection*", Proc. SPIE 8187, 81870Q (2011)
3. Wim de Jong, Frans A. Dam, Gerard J. Kunz and Ric Schleijpen, "*IR seeker simulator and IR scene generation to evaluate IR decoy effectiveness*", Proc. SPIE 5615, 100 (2004)
4. Douda Bernard E., “*Genesis of infrared decoy flares*” Naval Surface Warfare Center ,Crane,IN. (2009)
5. Marianne A. Degache, "*Software toolkit for evaluating infrared imaging seeker*", Proc. SPIE 8014, 80140E (2011)
6. Alexander M. J. van Eijk, Marianne A. C. Degache, Dirk-Jan J. de Lange, Steve M. Hammel and Dimitris S. Tsintikidis, "*EOSTAR Pro: a flexible extensive library to assess EO sensor performance*", Proc. SPIE 7828, 782804 (2010)
7. P. B. W. Schwering, D. F. Bezuidenhout, W. H. Gunter, et al. *“IRST infrared background analysis of bay environments”.* SPIE, 6940:1-12 (2008)
8. RTO-TR-SCI-139 - Platform Survivability Against Advanced IR Threats
9. Gerard J. Kunz, Marcel M. Moerman, Alexander M. J. van Eijk, Stephen M. Doss-Hammel and Dimitri Tsintikidis, "*EOSTAR: an electro-optical sensor performance model for predicting atmospheric refraction, turbulence, and transmission in the marine surface layer*", Proc. SPIE 5237 (2003)

10. Wouter Halswijk, "*Application of the high-fidelity electro-optical model suite EOSTAR to an exo-atmospheric interceptor scenario*" 7th International Conference on Missile Defence "Challenges in Europe" (2011)

11. Frans A.M. Dam, Wim de Jong, Harry R. Mühren, "*Naval ECM, a quantitative analysis*", TNO Report TNO-DV 2008 A514, Stg Confidentieel.(2009)

12. Piet B.W. Schwering, "*IRST evaluation methodologies: Maritime infrared background simulator*". SPIE Proc. 6206-71, 620621 (2006).

13. Neele, F.P.,"*Infrared ship signature prediction, model validation and sky radiance*". SPIE Proc. 5811, 180-187 (2005).

14. http://www.ontar.com

15. Alexander M. J. van Eijk, Leo H. Cohen, Laurent .J. Navarro, and Gerrit De Leeuw, "*Near-surface aerosol transmission in the marine environment*". SPIE Proc. 4884, 160-169 (2002).

16. Arjan.L. Mieremet, Wim. de Jong, "*EOSM validation using SAPPHIRE data*", TNO report TNO-DV 2008 A253, NATO restricted.(2008)