

IMPROVEMENTS OF SE-WORKBENCH-EO FOR THE INFRARED REAL TIME RENDERING OF OUTDOOR SCENES

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ABSTRACT:

The SE-WORKBENCH workshop is used by the French DGA to perform multi-sensors simulations. It enables the user to create virtual and realistic multispectral 3D scenes that may contain several types of target, and then generate the physical signal received by a sensor, typically an IR sensor. In the SE-WORKBENCH-EO workshop, SE-FAST-IR is a set of physics-based software and libraries that allows preparing and visualizing 3D databases in real-time for the EO domain. SE-FAST-IR makes an intensive use of OpenGL Shader state-of-the-art technology. Most of the physics computations are processed on the graphic board, resulting in a minimal CPU load that thus remains available for other simulation tasks. This paper presents the recent evolutions that have been done in the SE-FAST-IR package to make the rendering of infrared images more accurate. The most important evolutions concerns:

- a) the realistic and physical rendering of reflections of the landscape on water surfaces. This evolution was made possible by recent improvements in the physical description of materials with new BRDF models as well as the new modelling of sea surface that have been presented in recent years.
- b) the use of procedural techniques for the managing and rendering of very large 3D databases. The principle is to use definitions and rules of terrain features to create, on the fly, refined terrain and contents from this description, at the required level of detail.
- c) the rendering of both radiative and thermal shadows. Radiative shadows are shadows cast by light sources and can be mainly seen in visible and near infrared bands. Thermal shadows are due to differences of temperature between the sunny parts and the shadowed parts of a scene and can mainly be seen in the long and medium infrared bands.

1. SE-WORKBENCH-EO

1.1. Overall presentation of the SE-WORKBENCH

The SE-WORKBENCH is a multi-sensor battlefield modelling workbench mainly used by - Defence agencies as French DGA, German BWB, South Korea MoD, Singapore DSO/DSTA and Swedish FOI, - research centres as ONERA, IOSB Fraunhofer Institute and - industrials in and out of France as MBDA, Dassault, LG, STC.

SE-WORKBENCH-EO is the infrared sensor dedicated part of the SE-WORKBENCH that achieves the synthesis of 3D scene observed by a sensor, in four steps:

- first, the physical characterization of the 3D scene behaviour,
- then, the scenario edition (definition of the objects of the scenario, of the 3D scene and objects, assignment of trajectories to moving objects, definition of atmospheric and thermal conditions, parameterization of the sensors),
- then, the computation of the physical radiance signal received by the sensor
- at last, the sensor effects modelling.

The SE-WORKBENCH is entirely based on software products developed by OKTAL-SE and realizes the multi-spectral unification of optronics, electromagnetism and GNSS (Global Navigation Satellite System), using a common kernel and physical extensions assignment both aimed at a unique 3D scene and a common technology. The SE-WORKBENCH is a winning initiative for sharing R&D efforts and federating a user group community that intends to exchange experience and knowledge.

The first development was in 1994 and has been strongly boosted by the French SCALP missile program and the qualification of the IR tracking system. At the beginning, the SE-WORKBENCH was focused on the IR domain. In 2001, an electromagnetic version of the workshop was initiated, with the help of ONERA French research centre, mainly focused on millimetre waves and wide scenes, typically for SAR applications. A new GNSS version for satellite application has started in 2009. The control of the SE-WORKBENCH-EO

validity domain is based on both a theoretical validation approach (development of physical models, general modelling and simulation knowledge, elementary tests and validity assessment) and a validation process based on comparisons with experiments (SCALP/EG missile [FR], AASM missile [FR])

1.2. The SE-WORKBENCH-EO architecture

The SE-WORKBENCH-EO is made of different components, as described hereafter, corresponding to the successive steps of a IR

sensor simulation that are the modelling of the synthetic environment, the scenario edition, the rendering without the sensor effects and finally the sensor transfer function simulation. Furthermore, the user can do software integration in order to control the generated scenario execution from a remote or custom application. This can be achieved with the help of the SE-TOOLKIT consisting of a set of dedicated libraries and application programming interfaces (API) to help the complex application design and integration.

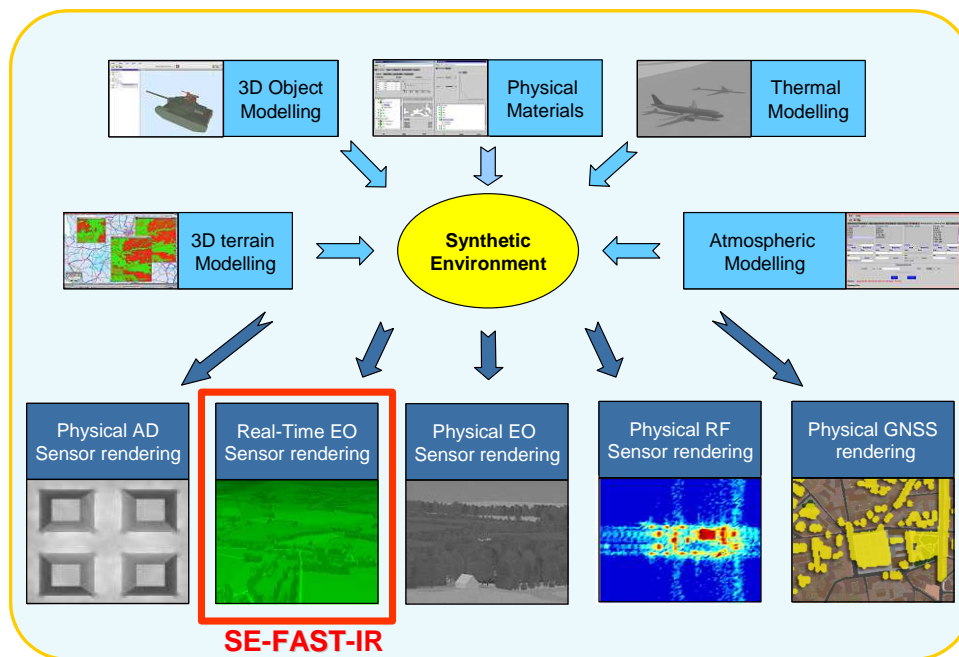


Figure 1. SE-FAST-IR inside SE-WORKBENCH-EO

1.3. Real-time rendering based on SE-FAST-IR package

The SE-FAST-IR package is made of a major product (SE-FAST-IR) and additional modules depending on the considered application. With the help of some pre-calculation steps, real-time images are computed with the SE-FAST-IR solution. It is dedicated to the rendering of images for near infrared sensors (light intensifying) and thermal infrared systems with short, medium or long waves (SWIR, MWIR, LWIR). The products make use of the results of the SE-CLASSIFICATION tool, the SE-PHYSICAL-MODELER modeller and the SE-ATMOSPHERE atmospheric files computation product. The

thermal pre-calculations are based on SE-THERMAL code.

SE-FAST-IR brings a technological rupture by using OpenGL pixel shaders enabling direct calculation on 3D graphic cards. A shader is a procedure written in a special purpose C like language that replaces a part of the graphic pipeline of a 3D graphic board. The new core of SE-FAST-IR is based on the open source "Open Scene Graph" layer upon Open GL.

When the ray tracing image is constructed pixel by pixel, the rasterized image is constructed by projection of the polygons. A given 3D polygon is projected in the screen 2D space, the varying data that characterize this polygon, being associated to this projection. Then the polygon is split into 2D sets of pixels, called fragments. Fragments are

stored and sorted (frame buffer) in function of their depth i.e. the distance to the screen.

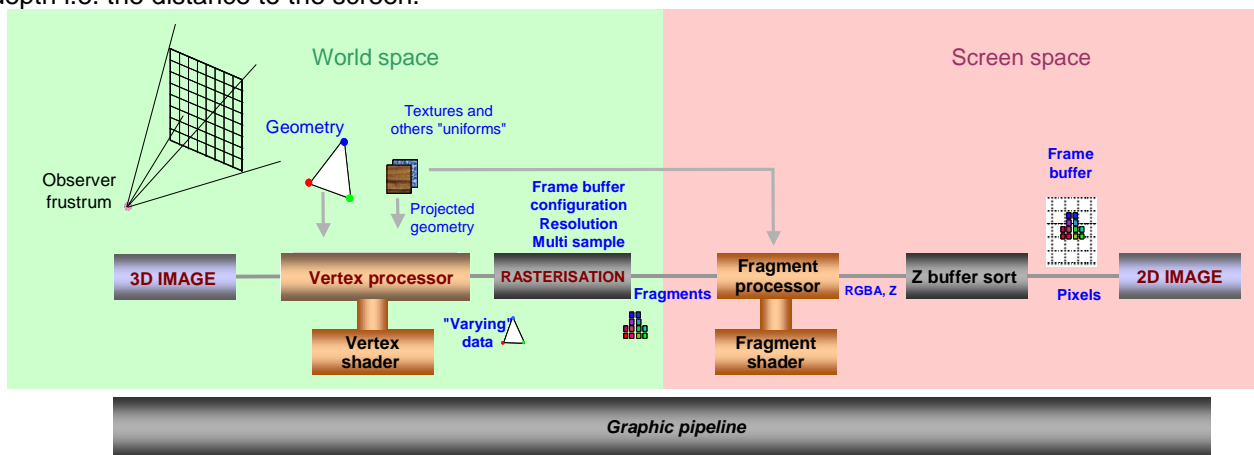


Figure 2. Rasterization process

2. SE-FAST-IR evolutions

2.1. Unlimited number of materials

The classification process, performed using SE-PHYSICAL-EDITOR, allows associating logical materials to a texture. This process is very important as it allows setting physical information to textures. Recent developments have been performed in SE-FAST-IR in order to extend the number of materials in a texture from 8 materials to an unlimited number of materials per texture. It is now possible to use, theoretically, an unlimited number of materials. This feature is very interesting for the classification of large ortho images with SE-PHYSICAL-EDITOR. But, even in the case of large ortho images, it is obvious that an unlimited number of materials is not necessary and typically a maximum value of 40 different materials is enough for the classification process.

However, this evolution presents some drawbacks. For example, the size of classified textures (IPC files) increases as it varies linearly with the number of materials used during the classification. Another drawback concerns the decrease of performances. Over 4 materials, SE-FAST-IR uses the multi pass mode. In this mode, geometry is rendered several times. The first pass displays the 4 first materials on opaque polygons, then a second pass displays the following 4 materials using Open GL blending, ... and so on.

The consequences are:

- for the CPU, an additional cost since the geometry must be rendered several times. In fact the compiler duplicates the polygons that have more than 4 materials. It therefore has a larger geometry.
- For the GPU, each rendering pass is

accumulated with the previous one using Open GL Blending. In order to get a convenient result, it is necessary to use a 16 or 32 bits buffer of floats for the rendering, that involves the use of a Frame Buffer Object, and a decrease of performances.

For most applications, these drawbacks are not important, but for HardWare In the Loop simulations, the decrease of performances may be prohibitive.

Figure 3 shows an example of a terrain with only one texture classified with 16 different materials.

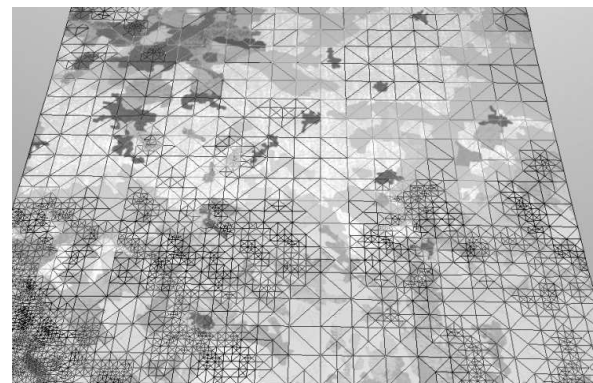


Figure 3. Example of classification with 16 materials

2.2. Multitexturing

Multi-texturing is a generic way of mapping polygons with several materials in order to create effects. In the SE-WORKBENCH, 3 techniques of multitexturing are available:

- a) Detail texture: The detail technique is used to

add detail at close range (for example, it allows to have more detailed road sides when seeing them from a close point of view, and a coarse representation when seeing them from a plane. It requires two materials: a detailed texture and a non-detailed texture. Given a pixel size threshold, a blending factor is computed in order to allow a smooth blending of the two textures.



Figure 4. Example of Detail texture (MWIR band) – Airport runway seen from far

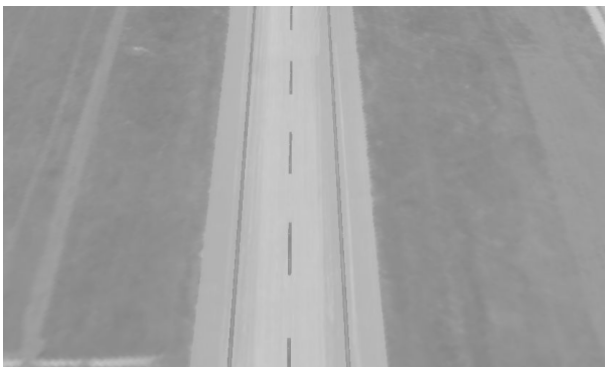


Figure 5. Example of Detail texture (MWIR band) – Airport runway seen from close

b) Mask: This technique is mostly used to add variety to a terrain material.

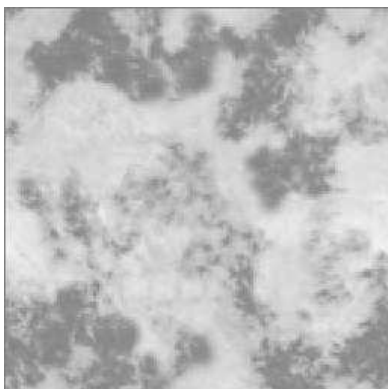


Figure 6. Example of mask texture

This technique requires three materials: a first and a second material that will be mixed by a mask texture. A mask texture is a grey scale

texture image with a transparency plane.

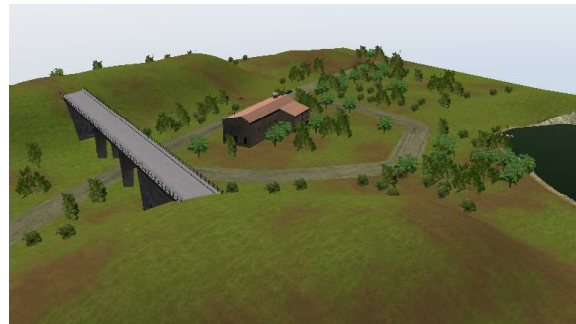


Figure 7. Example of multitexturing with the "mask" technique

c) Sea: Multitexturing is used for the sea surface rendering. The 1st texture is used for the rendering of seawater. The 2nd texture is used for the foam surface rendering. SE-FAST-IR computes sea surface slope, and, if the local slope on the sea surface is greater than a given threshold, foam is displayed.

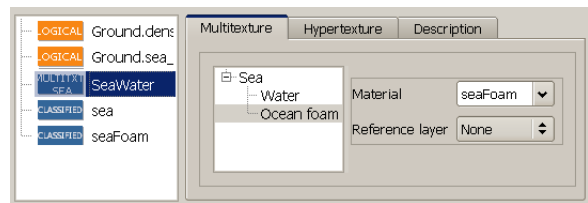


Figure 8. Edition of multitextures in SE-PHYSICAL-EDITOR



Figure 9. Sea surface with foam in the visible band

2.3. Thermal shadows

Accurate simulation of a 3D scene requires the reproduction of the scene thermal shadows onto the simulated landscape. Scene simulation in the MWIR and LWIR wavebands with thermal shadows is very complex and needs a big amount of computation time. Thermal shadows are already taken into account accurately in the non real time software (SE-RAY-IR) of SE-WORKBENCH. The non real time software computes, for each surface

of the 3D scene that is seen by a sensor, a history of sun illumination. According to this history of illumination, the non real time software computes an interpolation coefficient that is applied to 2 values of temperature: a temperature of the material (always illuminated by the Sun) and a temperature of the material (always in the shade). This method allows computing a "smooth" transition of temperatures between areas illuminated by the Sun and areas in the shade.

In SE-FAST-IR, a first order computation of thermal shadows has been implemented. SE-FAST-IR computes areas that are illuminated by the sun and areas in the shade and associates an interpolation coefficient equal to 0 or 1. If the area is illuminated by the sun, then the temperature is computed as if the material had been always illuminated by the Sun. If the area is in the shade, then the temperature is computed as if the material had been always in the shade. The drawback of this method is that transition of temperatures between areas illuminated by the Sun and areas in the shade is very quick (cf. *Figure 10*).

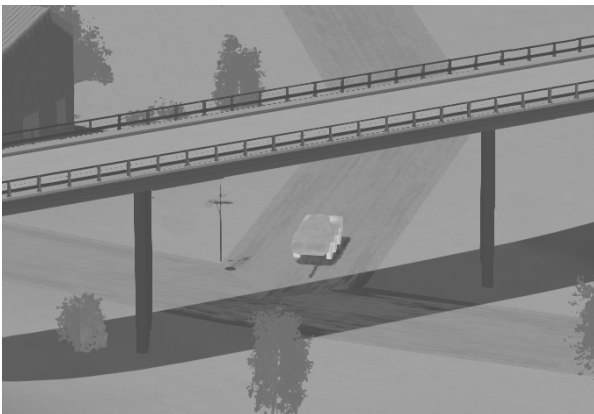


Figure 10. Computation of thermal shadows with SE-FAST-IR

2.4. Specular reflections

SE-FAST-IR computes the specular reflections of the 3D scene on dielectric materials or materials with a specular BRDF component. This new functionality can be activated or deactivated on SE-SCENARIO.

The user has to set a water plane altitude. For a sea surface, the water plane altitude is equal to 0 m, but for the rendering of specular reflections on the surface of a lake, the altitude of the surface of the lake has to be set to the correct value.

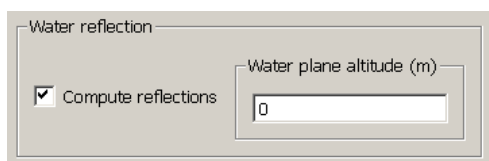


Figure 11. Edition of reflections in SE-SCENARIO

The simplified Schlick model is used to compute the specular coefficient of reflection of the water. In the Schlick's model, the specular reflection coefficient $R(\theta)$ can be approximated by:

$$R(\theta) = R_0 + (1 - R_0) \cdot (1 - \cos \theta)^5 \quad (1)$$

with:

$$R_0 = \left(\frac{n-1}{n+1} \right)^2 \quad (2)$$

n is the average refraction index of water over the spectral band of the sensor. θ is the angle of incidence. The use of the Schlick's model allows computing an angular dependant coefficient of reflection.



Figure 12. Specular reflections on the sea surface



Figure 13. Specular reflections on the sea surface with glint effect

2.5. Procedural enhancement

For the visualization of 3D scenes, one classic method is to use a static approach. In this case, all the polygons of the 3D scene are already prepared and stored in files. During the rendering, the polygons are simply displayed. For very large 3D scenes, this technique quickly reaches the limit of

what is possible to visualize in real time.

In contrast to the static approach, the procedural technique allows rapid creation and visualization of vast real-time 3D databases with high level of detail. With the procedural approach, only contours and seeds are already prepared and stored. During the rendering, the polygons are generated and displayed in real time. Procedural approach uses only definitions and rules of terrain features instead of storing and streaming the extensive position of all items (cf. *Figure 14* and *Figure 15*).



Figure 14. Example of landscape



Figure 15. Example of landscape

The terrain and its contents are generated on the fly, from their description at the required level of detail. Levels of detail are intensively used, adaptatively, according to the machine load. The procedural technique offers a lot of advantages:

- possibility to create richly populated terrains at a planetary scale
- real time performances insured by automatic conforming to machine load
- a simple top level description of content need is only necessary

Procedural approach is well adapted for the rendering of "geotypical" 3D scenes, and, as a consequence, this technique is less appropriate when "geospecific" constraints are needed. OKTAL-SE has recently implemented procedural

technique in the SE-WORKBENCH. The adopted solution consists in hybridizing static approach (for "geospecific" areas such as airports for example), and procedural approach (for "geotypical" areas: the landscape for example). Developments are on the road and have recently been integrated to SE-FAST-IR (cf. *Figure 16* and *Figure 17*).

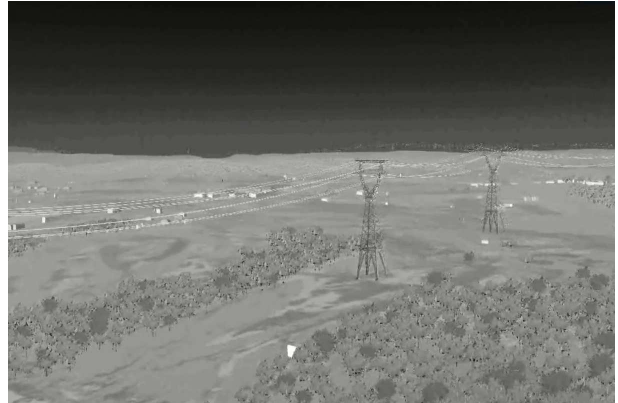


Figure 16. Procedural terrain in the MWIR band rendered with SE-FAST-IR

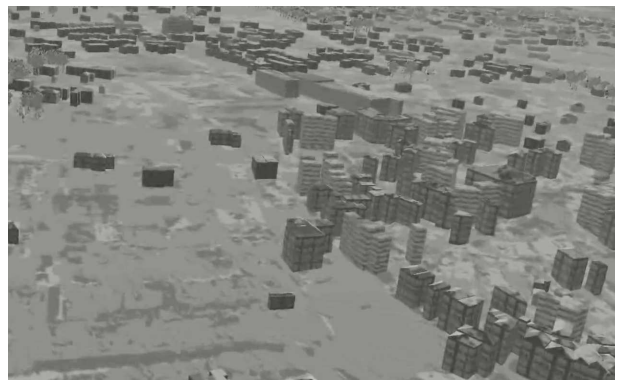


Figure 17. Urban area rendered with SE-FAST-IR

2.6. Directional environment effects

The purpose of this evolution is to take into account polygon orientation for the computation of the irradiance of the environment. Sky and ground radiance data are stored in atmospheric files. For a given polygon with an associated normal vector, we compute the part of the sky and ground that are seen from the polygon, and subsequently, the irradiance. For example, a horizontal polygon sees only the sky, and a vertical polygon sees part of the sky and part of the ground. In SE-FAST-IR, for each material, directional environment irradiance are calculated and applied, during the rendering pass, on polygons according to their orientation.

Figure 18 and *Figure 19* show the difference of rendering between the use or not of environment effects for the polygons of the roof.

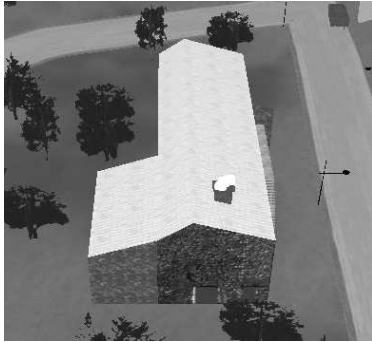


Figure 18. without directional effect

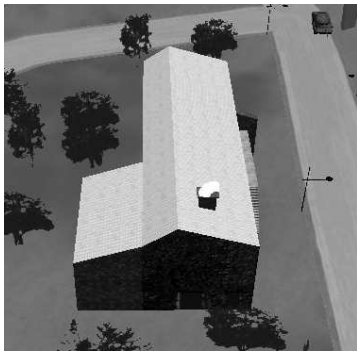


Figure 19. with directional effect

3. SE-FAST-IR new interfaces to external modules

3.1. Interface to BB3D™

BlueBerry3D™ is the procedural kernel that has been selected by OKTAL-SE to be integrated within SE-FAST-IR. SE-FAST-IR is already included in the OKTAL-SE SE-FAST-IG special packaging for Man In the Loop real time simulation. A new version called SE-FAST-IG-P is now available that includes a combination of SE-FAST-IR and BB3D™, as illustrated hereinbefore.

3.2. Interface to RadTherm™

RadTherm™ can perform an accurate prediction of the thermal state (steady or transient) of a ground vehicle, while SE-Workbench enables to prepare a sophisticated virtual IR environment, including a thermal state prediction for both geographical terrain and infrastructures.

Beyond the conversion of 3D and physical data between software, an interactive coupling is available and allows to run both products simultaneously so that dynamic heat exchanges between targets and surrounding objects can be computed and rendered during an animated scenario. Fugitive phenomena like thermal shadows or warm-up effects due to a vehicle that can be rendered as shown hereafter:

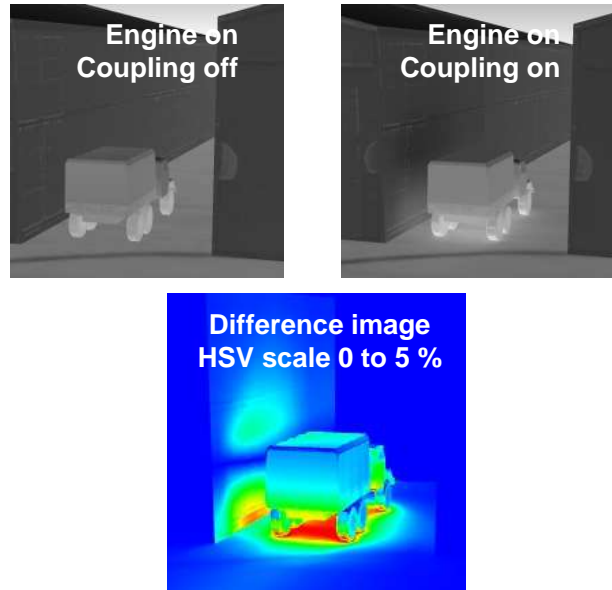


Figure 20. thermal coupling enhancement

3.3. Interface to TESS™

TESS™ is a Canadian physics-based tool that enable users to analyse, evaluate, understand and optimise countermeasure effectiveness. Tactical Technologies Inc. (TTI) and OKTAL-SE have integrated TESS™ and SE-WORKBENCH-EO (SE-FAST-IR). The joint solution allows TESS to leverage the power of SE-WORKBENCH-EO in order to generate complex and realistic electro-optical (EO) and IR synthetic environments (land, air, sea) in support of IR countermeasure systems development, tactics and effectiveness assessment against the latest generation of imaging IR guided threat systems.

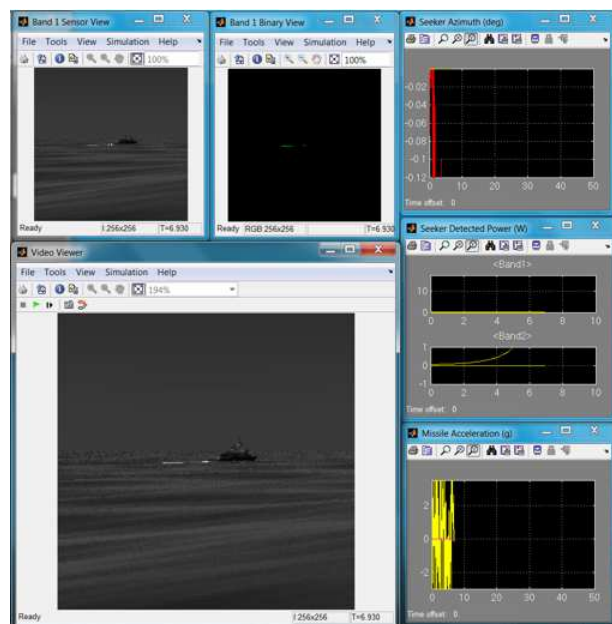


Figure 21. SE-FAST-IR integrated to TESS™

The next phase of development, which is currently underway, focuses on TESS anti-ship ASM(IR)

simulator and the development of naval IR decoys in SE-WORKBENCH-EO. In subsequent phases, the integrated IR scene generator and target discrimination framework will be made available to other TESS™ IR countermeasure effectiveness simulators such as Surface-to-Air and Air-to-Air SAAM(IIR) and Active Protection System ILAPS.

This coupling will enhance TTI's core IR countermeasure product capabilities and establish the groundwork for future modelling and simulation, training and hardware-in-the-loop (HWiL) requirements.

3.4. Interface to STK™

STK™ performs complex spatial relationship analysis of land, sea, air and space assets, and models results in one integrated solution. A comprehensive STK™ plug-in for visualization application, based on SE-FAST-IR, is now available. It is a significant enhancement of STK tool for users who want to take advantage of a realistic infrared sensor simulation, for instance for UAV application.

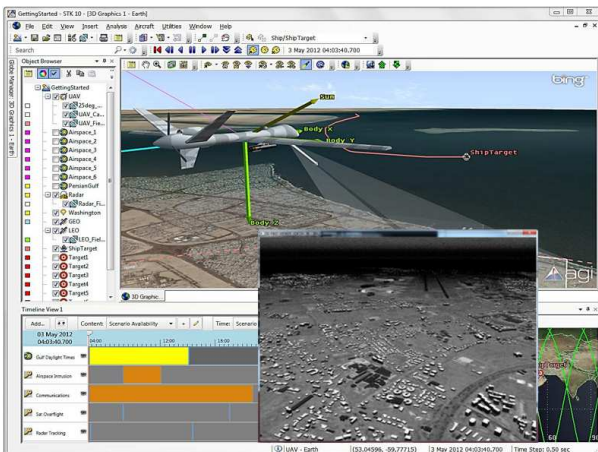


Figure 22. SE-FAST-IR integrated to STK™

3.5. Interface to SCANer™

SCANer™ studio is a modular driving simulation workbench dedicated to car and ground vehicle simulation. SCANer™ requires more and more sophisticated sensor simulation. Recently, SCANer™ has been coupled to SE-FAST-IR and SE-FAST-IG for both visible and EO rendering. The interface relies on a CIGI standard network communication.

4. CONCLUSION

One key feature of SE-WORKBENCH-EO is the Non-real-time and Real-time duality. The technique associated to Non-real-time solution is called “ray tracing”. It runs on the CPU (Central Processor Unit) of the computer.

The advantage of the Non-real-time approach is that the computation is made very accurately,

wavelength by wavelength. The interaction with surfaces can take into account very sophisticated models. Typically, radiative coupling between surfaces or thermal shadows (in addition to normal shadows) can be accurately simulated.

The technique associated to Real-time solution is called “rasterization”. It runs on the GPU using pixel “shaders”. A shader is a piece of code that enables to control the way of drawing pixels. Rasterization consists in projecting triangles of the 3D scene onto the 2D screen and then to draw pixels to fill the triangles. It has no correlation at all with any physical process. The advantage of real-time is the performance. For simple images, frequency of some hundreds Hz can be reached.

In all cases, this Non-real-time and Real-time duality is very important in order to assess the simplification made in the field of Real-time rendering with regards to Non-real-time rendering.

As a consequence, functionalities available in the Non-real-time software are more mature than their implementation in the Real-time software.

A first step in the process for reducing the gap between the Non-real-time and Real-time approaches has been described in this paper.

Two main evolutions pave the way of SE-FAST-IR evolution. Firstly the procedural enhancement of the rendering process which will be soon generalized to Radio Frequency domain, and secondly, an wide aperture to external software which allows SE-FAST-IR to target new scopes.

5. REFERENCES

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