

MARINE SIMULATION IN SE-WORKBENCH

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ABSTRACT

The SE-Workbench workshop, also called CHORALE (“simulated Optronic Acoustic Radar battlefield”) by the French MoD/DGA, is used to perform multi-sensors simulations on complex 3D synthetic environment. The SE-Workbench enables the user to create virtual and realistic multi spectral 3D scenes, and generate the physical signal received by a sensor, typically infrared (IR) and radar (EM) sensors. This article describes the recent enhancements of the SE-Workbench that aim at better representing the sea surface and the interaction with targets and shore. These enhancements enable the user to parameterize an open sea or coastal simulation.

The new model implemented is based on a third generation wave spectrum model. For coastal simulations, it takes into account the bathymetry data, wind characteristics, ... and creates wave spectrum for given positions in the 3D marine scene. Marine special effects such as rear wakes, bow wakes and Kelvin wakes created by moving objects are also simulated. At last, the paper insists on the validation process and the results of the comparison of simulated images with real images of the MIRAMER campaign.

1. INTRODUCTION

More and more defence and civil applications require simulation of marine synthetic environment. Currently, the «Future Anti-Surface-Guided-Weapon» (FASGW) or «Anti-Navire Léger» (ANL) missile needs this kind of modelling. This paper presents a set of technical enhancements of the SE-Workbench that aim at better representing the sea profile and the interaction with targets and shore. The operational scenario variability is a key

criterion: the generic geographical area (e.g. Persian Gulf, coast of Somalia, ...), the type of situation (e.g. peace keeping, peace enforcement, anti-piracy, drug interdiction, ...), the objectives (political, strategic, or military objectives), the description of the mission(s) (e.g. anti-piracy) and operation(s) (e.g. surveillance and reconnaissance, escort, convoying) to achieve the objectives, the type of environment (Weather, Time of day, Geography [coastlines, islands, hills/mountains]). The paper insists on the modelling of sea-surface based on hypertextures and shaders, the wakes modelling, the buoyancy models for targets, the interaction of coast and littoral, the dielectric infrared modelling of water material and the validation process.

2. SE-WORKBENCH-IR TOOL

2.1. Overall presentation of the SE-Workbench

The SE-WORKBENCH, also called CHORALE, is a multi-sensor battlefield modelling workbench mainly used by French DGA, German BWB, South Korea MoD, Singapore DSTA and Swedish FOI in order to achieve the synthesis of 3D scene observed by a sensor, this in three 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),
- at last the computation of the physical signal received by a sensor.

The SE-WORKBENCH is entirely based on software products developed by OKTAL-SE and realizes the multi-spectral unification of optronics,

electromagnetism and more recently 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 center, 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-WORBENCH 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]).

2.2. 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.

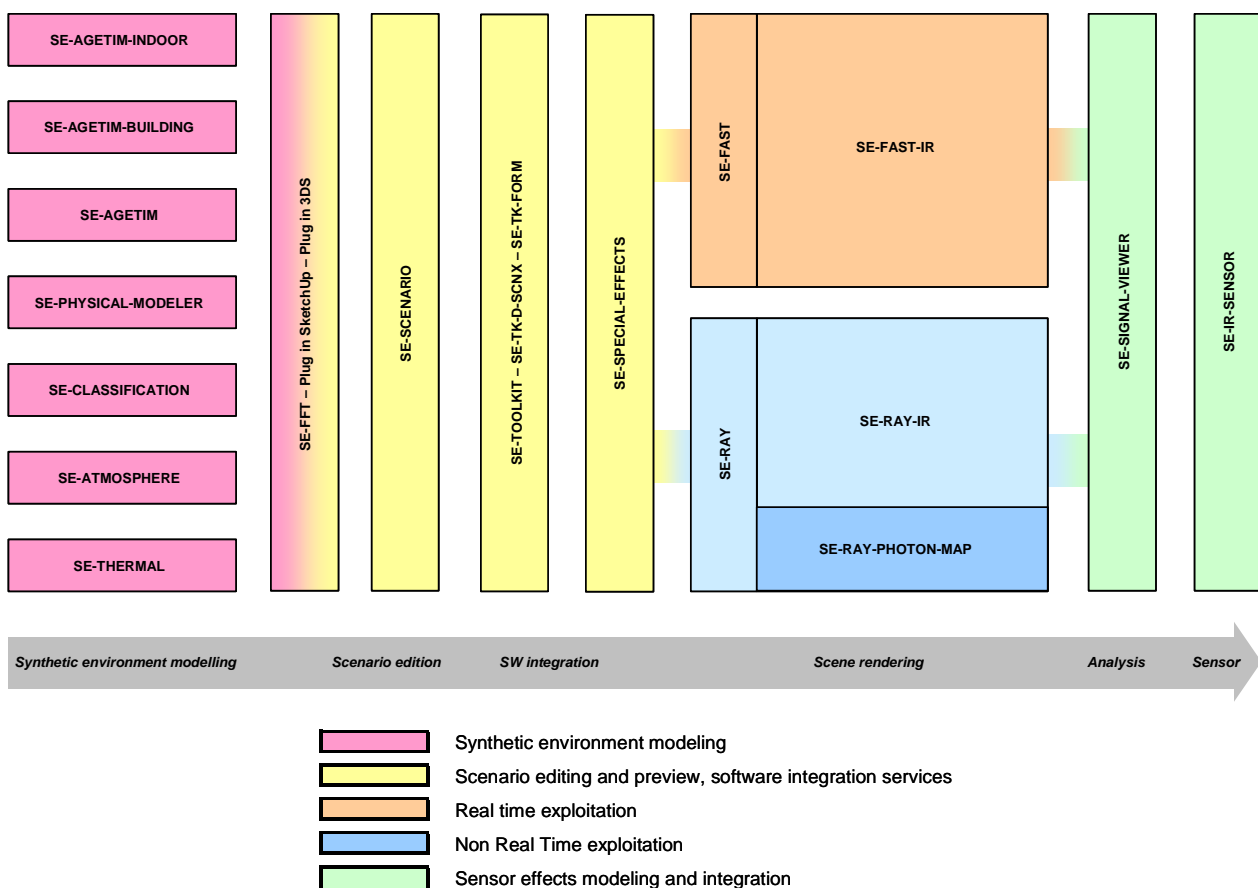


Figure 1: The SE-WORKBENCH-EO components.

2.3. Non real time rendering based on SE-RAY

SE-RAY is the ray tracing kernel developed by OKTAL-SE which enables to compute high realism images in several spectral domains. SE-RAY-IR is dedicated to the rendering of synthetic environments in the IR domain and is based on SE-RAY ray tracing kernel. The great originality of SE-RAY comes from its model based on physics. SE-RAY uses elementary pyramids, defined by four adjacent rays (one basic pixel), which allows one to compute elementary surfaces and solid angles.

Besides SE-RAY-IR takes into account the wavelength sampling. Actually SE-RAY-IR works wavelength by wavelength. Time consumption is very optimized using SE-RAY. Actually performances are nearly independent on scene complexity. To do this SE-RAY uses a spatial subdivision method that enables to get a perfect knowledge of the scene topology before computing the first image. The scene space is decomposed in a hierarchy of volume elements (voxels) and then turned into a recursive space of voxels that improves efficiently the intersection computations. The solution to improve image quality mainly consists in over sampling by tracing more rays. The method adopted for SE-RAY-IR is the adaptative one. The most important antialiasing criteria are the following: number of different polygons in the pixel, number of different materials, normal vector variation within the pixel. Based on generalization of texture definition to any physical data, SE-RAY-IR can simulate the variation of specular reflectivity with the observation angles.

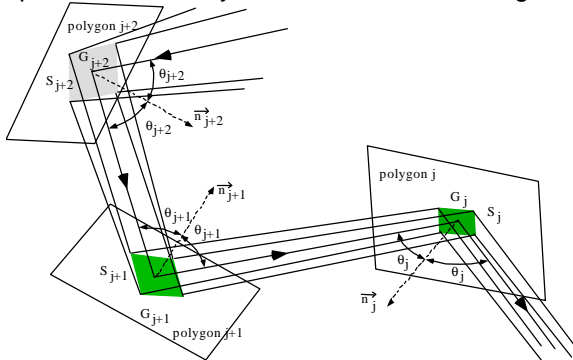


Figure 2: Management of ray tubes in SE-RAY-IR

Concerning the physical IR model, SE-RAY-IR can take the following contributions into account:

- the thermal emission,
- diffuse and specular reflections,
- direct sun lighting: direct sun or moon lighting takes into account the atmospheric attenuation and diffusion between the astral source and

any point in the 3D scene. An external data file (typically based on LOWTRAN or MODTRAN) contains irradiance values for discrete values of the wavelength and of the altitude,

- diffuse sun lighting and sky/ground illumination: sky and ground are considered as a global entity providing energy in any space direction,
- self emission of the atmosphere: an external data file (typically based on MODTRAN or MATISSE) contains atmospheric radiance data for discrete values of wavelength, altitude, elevation, azimuth and range. For each ray, both primary, secondary or lighting ray, the best value of atmospheric radiance is determined using linear interpolation,
- atmospheric attenuation: an external data file (typically based on MODTRAN or MATISSE) contains atmospheric attenuation for discrete values of wavelength, altitude, elevation and range. For each ray, both primary, secondary or lighting ray, the best value of atmospheric attenuation is determined using linear interpolation

2.4. 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 computation of image sequences 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.

The previous version of SE-FAST-IR was based on a pre computation of the whole 3D scene with specific radiance texture adapted to a given waveband for a given spectral response. The real time process only consisted in using Open GL laws, basically for non-static parts of the scene (for instance the specular parts, or the moving objects) and for the atmosphere propagation modelling depending on elevation, azimuth and range.

The new release of 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, that are stored and sorted (frame buffer) in function of their depth i.e. the distance to the screen.

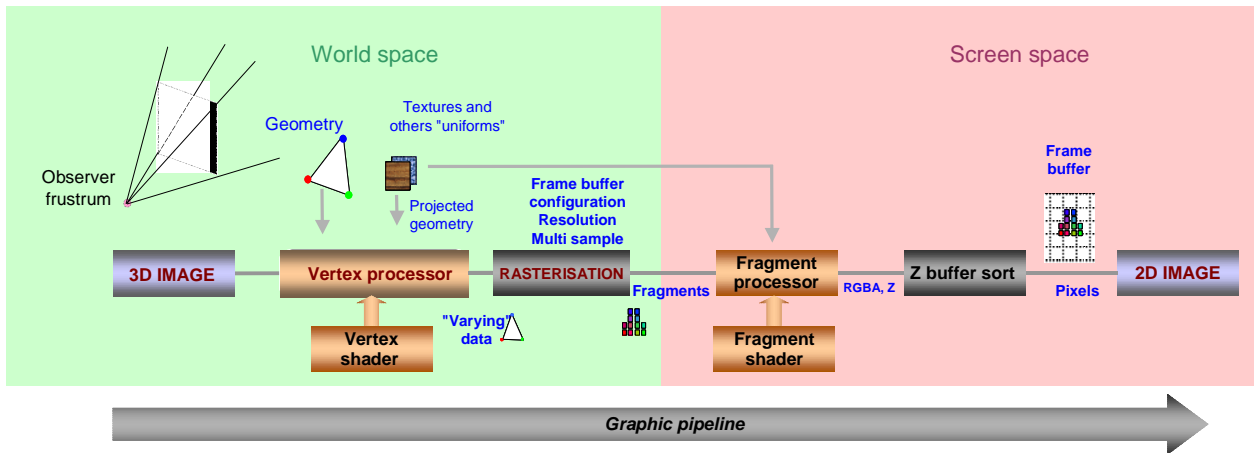


Figure 3: Rasterisation process

3. SEA MODEL

3.1. Introduction

The basis for deep-water wave spectrum models is the energy balance equation:

$$\frac{\partial E}{\partial t} + \bar{c}_g \cdot \bar{\nabla} E = \sum S_i \quad (1)$$

where t denotes time, E is the two-dimensional wave spectrum depending on frequency f and direction θ , c_g is the group velocity, and S_i represents the source and sink terms. A source term transfers energy into the system, whereas a sink term takes energy out of the system. In theory, the sum of all source and sink terms is zero.

First generation wave models (for example: Phillips or Pierson & Moskowitz models) did not consider nonlinear wave interactions.

Second generation models (for example: JONSWAP model), available by the early 1980s, parameterized these interactions. They included the “coupled hybrid” and “coupled discrete” formulations.

Third generation models (for example: WAM, WAVEWATCH III, SWAN models) explicitly represent all the physics relevant for the

development of the sea state in two dimensions.

3.2. Bathymetry

To compute the two-dimensional wave spectrum E , bathymetric data are required. A regular grid of bathymetric data needs to be processed to create adaptively a mesh with higher accuracy in the coast vicinity, as illustrated on figures 4 and 5.

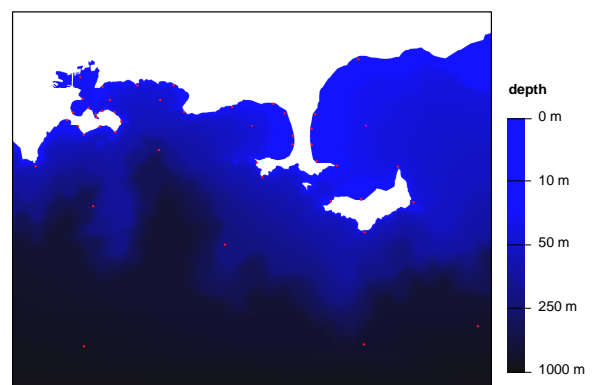


Figure 4: Example of bathymetry data

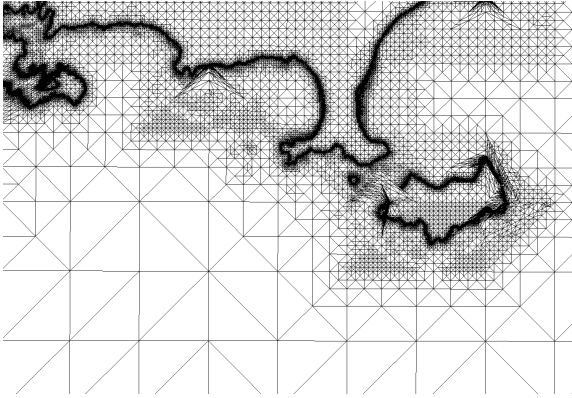


Figure 5: Mesh with higher accuracy in the coast vicinity

3.3. Hypertextures

For marine application, it is very important to represent the real and complex shape of the sea surface. The wave self shadowing effect is very important. The shadowing of floating objects is also important. We chose the solution of sampling this surface using a "height map" $Z(X, Y)$ i.e. a raster information rather than a polygonal vector information. Nevertheless, the polygon shaping remains important both for coast modelling and to take into account the sea surface rotundity. The hypertexture model answers these requirements. It is real substitute to a complex geometry within a volume.

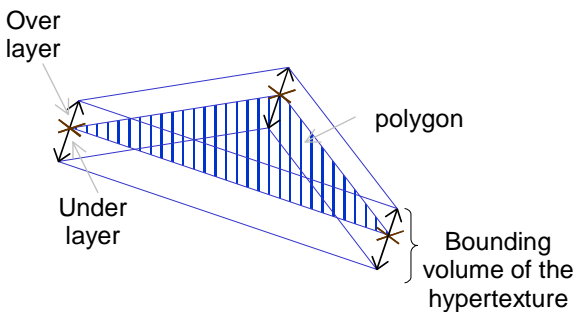


Figure 6: Hypertexture volume definition

Within this volume, the hypertexture contains the additional height modulation to the average altitude given by the polygons. The ray tracing process is applied directly on the hypertexture.

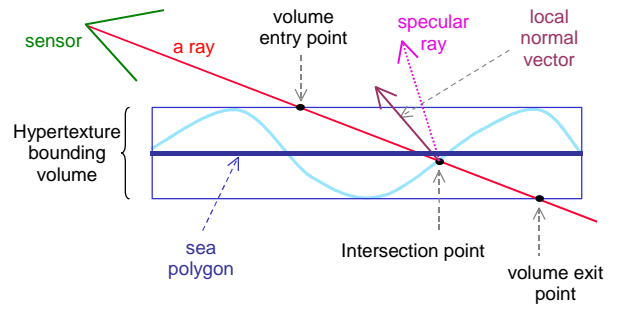


Figure 7: ray tracing process in the hypertexture

Besides, the coast is extended under the sea level, which also enables to take into account the bathymetry for the water representation. The advantage is that the waves naturally intersect the beach area.

3.4. Third generation model implementation

The third generation model computes two-dimensional wave spectrum $E_i(f, \theta)$ "Fig. 9" at given positions (X_i, Y_i) of the sea surface "Fig. 8". All these local informations are used to compute as many height maps $Z_i(X_i, Y_i)$ as (X_i, Y_i) positions. To perform these computations, we use cuFFT, the NVIDIA CUDA Fast Fourier Transform library for SE-FAST and SE-FAST-IR simulations and kiss FFT for SE-RAY-IR simulations. At each point (X, Y) of the sea surface, the sea surface elevation z is then computed by a bilinear interpolation between 3 maps $Z_i(X_i, Y_i)$, $Z_j(X_j, Y_j)$ and $Z_k(X_k, Y_k)$ "Fig. 10".

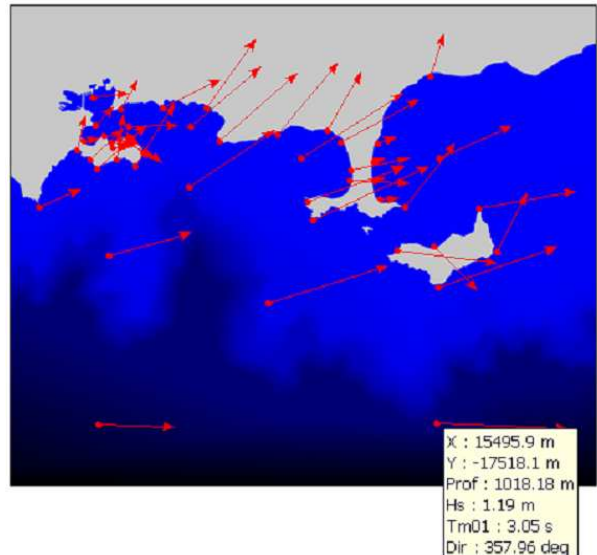


Figure 8: computation of Variance Density Spectrum $E_i(f, \theta)$ at different X_i, Y_i positions

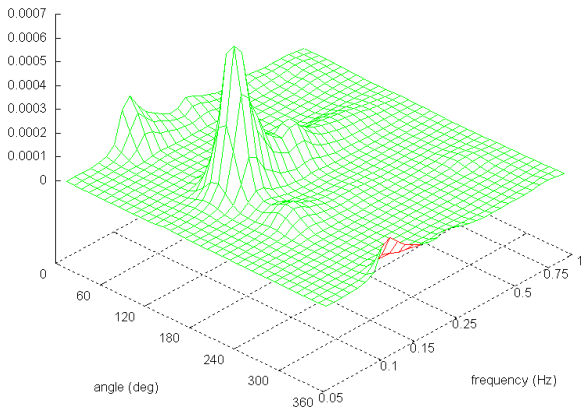


Figure 9: Wave spectrum function of f and θ

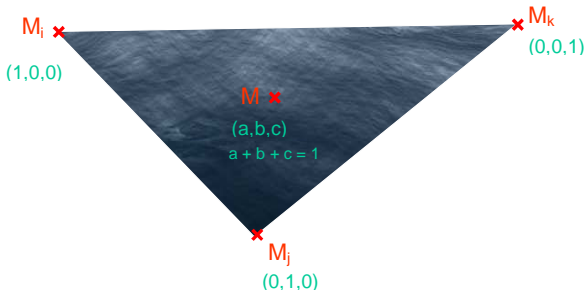


Figure 10: Bilinear interpolation of height maps

4. MARINE SPECIAL EFFECTS

Several basic mechanisms have been developed in order to render some very important effects, such as wakes that are very important for ship detection and identification

4.1. Foam wakes modelling

Beyond the 3D effect of a ship wake, the wake creates a local modification of the 2D sea surface due to foam. OKTAL-SE has developed special particle systems, that emits 2D surface particles that are first linked to the ship mobile frame and that are progressively linked to the sea static frame. Besides, these particles have to disappear after a time. This mechanism is currently used both for rear wake and for bow wake.

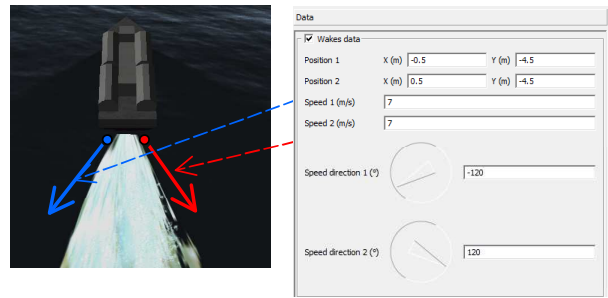


Figure 11: Parameterization of wakes using SE-SCENARIO



Figure 12: Example of wake simulation using SE-RAY

4.2. Kelvin wakes modelling

OKTAL-SE has also implemented a 3D local wake height map deformation which is consistent with hypertexture profile for the simulation of the Kelvin wakes. The Kelvin model gives the relation of the orientation θ of the wave and the ratio y/x .

$$\frac{y}{x} = -\frac{\tan \theta}{1 + 2 \tan^2 \theta} \quad (2)$$

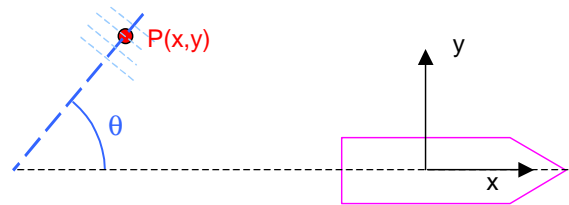


Figure 13: Example of wake simulation using SE-RAY

Temporal and spatial attenuation models have been developed to improve the realism. Finally, intersection of 3D wakes with geometry have been achieved, even the intersection between wakes are supported by the SE-Workbench.



Figure 14: Example of wake simulation using SE-FAST

4.3. Foam

Foam simulation is also taken into account. Foam is generated when local slope is greater than a given threshold. It then spreads and vanishes.



Figure 15: Example of foam simulation

4.4. Capillary waves

High frequency waves (capillary waves) are added to the height map using a texture of bump mapping.

5. WATER MATERIAL PHYSICAL MODELING

Water material is considered as a dielectric spectral material. It uses smooth dielectric materials (Fresnel approximation) of finite width. The model takes into account the variation of the water depth thanks to a material classification (texture) that combines several thicknesses.

For real time, Schlick's model is used by SE-FAST for the rendering: the specular reflection coefficient R is given by:

$$R(\theta) = R_0 + (1 - R_0)(1 - \cos\theta)^5 \quad (3)$$

where θ is the incident angle (which equals the reflected angle for specular reflection) and R_0 is the reflectance at normal incidence (i.e. the value of the Fresnel term when $\theta = 0$).

6. BUOYANCY MODEL

A buoyancy model is implemented in the SE-SCENARIO tool. We used a new feature of this tool: the possibility for the user to program a behaviour of an object using Python scripts.

Thanks to this functionality, the buoyancy model is open and can be easily improved or even replaced by a more sophisticated and specific customer in-house model.

For instance, an example is delivered with the last release of the SE-WORKBENCH: the floating object is considered as a "shoe box" with a mass M and transversal and longitudinal metacentric radius R_t and R_l . At each image rendering, the software automatically computes the volume of water that is under the mean sea surface, then it calculates the buoyancy force.

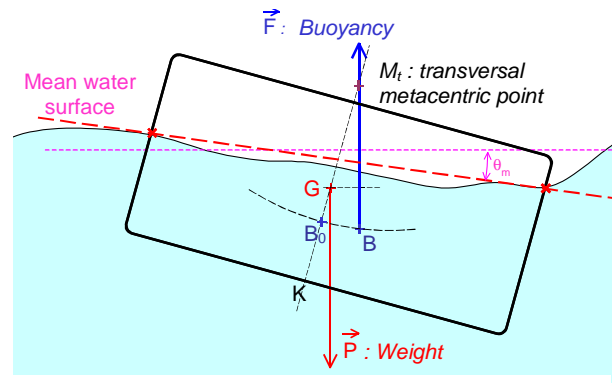


Figure 16: Buoyancy model

Buoyancy force \vec{F} and weight \vec{P} are then used to compute vertical acceleration \ddot{z} , and the moments of these forces are used to compute pitch and roll acceleration $\ddot{\theta}$ and $\ddot{\psi}$. The integration of these accelerations as a function of time allow to compute the new position and orientation of the floating object.

7. 3D Sea Database

A 3D mock-up, representing an area of 40 km x 40 km, has been created to perform scenarios of simulation with SE-RAY-IR or SE-FAST-IR, in the visible band or the infrared band. This 3D scene is composed of a large area of sea with beaches, cliffs, harbours (peninsula of Giens and Toulon harbour in the South East of France). Bathymetry data are set and allows the user to compute various sea state for different wind speed and orientation.



Figure 17: view of Saint Mandrier harbour



Figure 18: view of a cliff

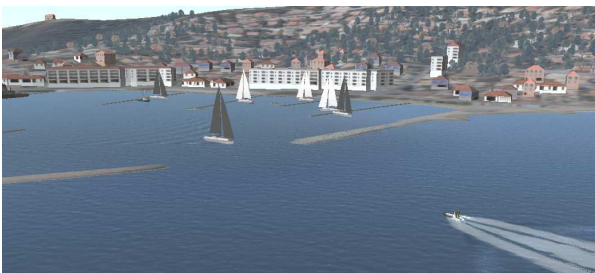


Figure 19: view of Saint Mandrier harbour with moving object, buoyancy model, sea special effects

8. Validation

A big effort has been done for validating all these developments. We used the results of the MIRAMER campaign. The purpose of this campaign was to collect MWIR / LWIR calibrated images with ground truth (weather and oceanic context data) in order to evaluate quality & realism of sea background signature modelling. The campaign took place in the South East of France (Toulon) from 13 to 28 May, 2008. We have used the measurements of 23 May, 2008 for the validation. For this date, data from 20 trials were available.

We modelled the spectral response $\phi(\lambda)$ of the LWIR and MWIR cameras and we calibrated the simulated images with black body objects in the simulation.

For each trial, we modelled the following set of data:

- altimetric profiles of air pressure, air temperature, relative humidity, wind speed and wind direction,
- sea surface temperature,
- sequences of calibrated images in the MWIR and LWIR band.

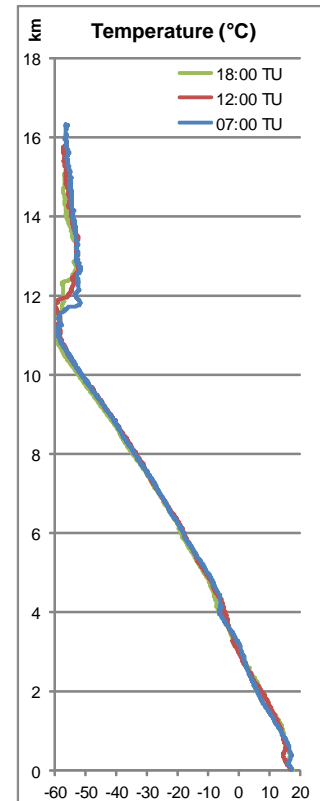


Figure 20: example of air temperature profile

A specific 3D database was created.

For the sensors, we modelled the spectral response $\phi(\lambda)$ for the LWIR and MWIR cameras and we calibrated the simulated images with black body objects in the simulation.

For each trial, we created :

- the atmospheric data file and the thermal data for the sea surface,
- the configuration file for the hypertexture model.
- the scenarios of simulation for non real time tool SE-RAY-IR.

In most cases, we found a good agreement between simulated images using SE-WORKBENCH and MIRAMER images.

Examples

Trial 1093

wind speed : 2 m/s and glint on the images



Figure 21 : MIRAMER image (MWIR band)



Figure 22 : simulated image (MWIR band)

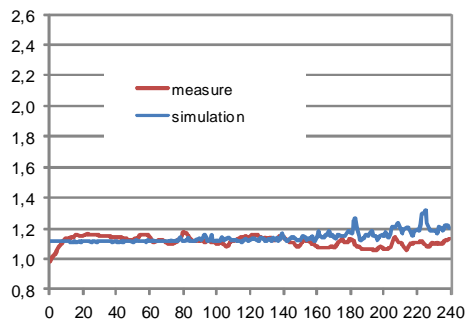


Figure 23 : vertical variation of radiance

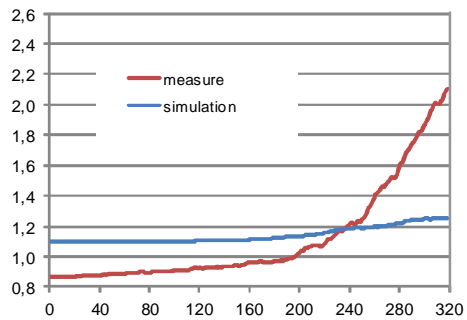


Figure 24 : horizontal variation of radiance

Trial 1187

wind speed : 1.5 m/s



Figure 25 : MIRAMER image (MWIR band)

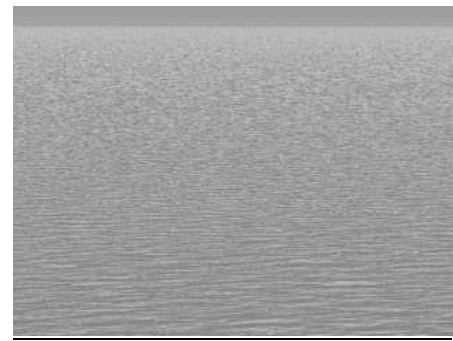


Figure 26 : simulated image (MWIR band)

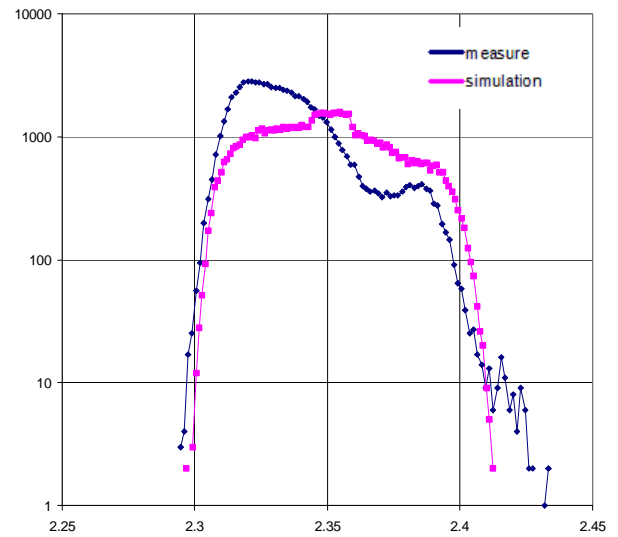


Figure 27 : histogram of the images

9. CONCLUSION AND PERSPECTIVES

Thanks to these recent developments fully supported by French DGA / Information Superiority and MBDA France, the SE-Workbench is now fully operational for marine research simulation.

A large community uses SE-Workbench: army, research and industry.

SE-Workbench presents a unique solution in the world that merges three technical complementary approaches that are: CPU, GP-GPU and GPU shaders and that combines the advantages of these three approaches.

A lot of work is still to be done. It mainly concerns the GP GPU implementation for SE-RAY-IR, the GPU shader improvement in terms of functionalities and performances. Plans are elaborated also to improve the atmospheric definition close to water thanks to MATISSE ONERA software.

A coupling with ShipIR software product could also be very interesting for our customers in the future.

We also plan to perform new tests of validation using other MIRAMER data (different weather conditions, sea state, ...).

gaussian sea surfaces, (2007), *Proceedings of the 18th IASTED International Conference: modelling and simulation*, 30 Mai - 1 Juin 2007

5. W. J. Pierson and L. Moskowitz, (1964), A Proposed Spectral Form for Fully Developed Wind Seas Based on the Similarity Theory of S. A. Kitaigorodskii, *J. Geophysical Research*
6. K. Hasselmann, T. P. Barnett, E. Bouws, H. Carlson, D. E. Cartwright, K. Enke, J. A. Ewing, H. Gienapp, D. E. Hasselmann, P. Kruseman, A. Meerburg, P. Müller, D. J. Olbers, K. Richter, W. Sell, and W. H. Walden, (1973), "Measurements of Wind-Wave Growth and Swell Decay During the Joint North Sea Wave Project (JONSWAP)", *Deutsche Hydrographische Zeitschrift*
7. P. Simoneau, K. Caillault, S. Fauqueux, T. Huet, L. Labarre, C. Malherbe, (2009), MATISSE-v2.0 and comparison with MIRAMER measurements, ITBM&S

REFERENCES

1. A. Le Goff, J. Latger, (1999). Realistic multi spectral simulation including IR simulation. *SPIE Proceedings.*, Vol. 3694, April 1999.
2. Thierry Cathala, Nicolas Douchin, Jean Latger, Karine Caillault, Sandrine Fauqueux, Thierry Huet, Luc Labarre, Claire Malherbe, Bernard Rosier and Pierre Simoneau, (2009) The coupling of MATISSE and the SE-WORKBENCH: a new solution for simulating efficiently the atmospheric radiative transfer and the sea surface radiation, *SPIE Proceedings.*, April 2009.
3. 1. K. Caillault, S. Fauqueux, C. Bourlier, P. Simoneau, and L. Labarre, (2008), Multi resolution infrared optical properties for gaussian sea surfaces, *SPIE European Symposium on Remote Sensing*, September 2008.
4. K. Caillault, S. Fauqueux, C. Bourlier, P. Simoneau, and L. Labarre, (2007), Multi resolution infrared optical properties for