HIGH REALISTIC INFRARED TERRESTRIAL SCENE MODELING FOR INTELLIGENCE FUNCTION ASSESSMENT

OECD CONFERENCE CENTER, PARIS, FRANCE / 8–10 FEBRUARY 2012

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KEYWORDS: scene and target generation, physical model, model validation, simulation

ABSTRACT: In the field of optronics scene modeling, DGA Information superiority has recently extended its activities to compute space and airborne IR (InfraRed) imagery for intelligence function assessment. For scene preparation, the development of a terrain database, corresponding to a real site abroad, must be very accurate and relies on high resolution satellite products and on photos showing details above the ground. Textures on polygons are classified to add surface optical properties and to map multi layer thermal materials enabling to predict temperature distribution in the virtual world. A human activity is implemented in infrastructures and with ground-based vehicles having namely heat exchanges with environment. The level of realism requested for synthetic images is higher than ever. That’s why a special validation effort is done: the modeling process is applied to a French site and computed scenes are compared to real images acquired from helicopter with French ONERA Timbre Poste mean.

1. INTRODUCTION

1.1. Optronics scene modeling activities

In the field of optronics warfare, DGA Information superiority supplies DGA program managers with a technical assessment for risks control about different topics like survey and observation sensors, IR seekers and electronic counter counter measures, optical and laser stealthness, IR flares and self-protection systems. For that purpose it can resort to synthetic image generation to model the operational battlefield of an optronics system, to stimulate the sensors of this system and then to assess through simulation the function that is performed by the system.

The different simulated functions comprise mainly, on sensor side, intelligence, neutralization and observation and, on target side, stealthness and self-protection. Let’s give examples. Concerning intelligence, DGA Information superiority computes high spatial and radiometric resolution imagery in top of atmosphere condition in order to study new space imaging systems, to design advanced image processing algorithms and to supply operational photo interpreters with synthetic images that look real. About neutralization, DGA Information superiority and French ONERA spent two years and a half for SCALP air-to-ground missile program to establish the validity domain of the modeling process and to contribute to its agreement to qualify by simulation the missile terminal guidance. Concerning observation, DGA Information superiority generates synthetic naval scenes to evaluate through simulation the performances of the future multi mission frigate IRST (IR Search and Track). About stealthness, it prepares, among other things, the specification of nEUROn unmanned fighter IR reduced signature and, about self-protection, the specification of the A400M airplane IR self-protection system. In fact, DGA takes benefits of optronics scene modeling activities throughout an armament operation: feasibility study, specification, risk control, qualification, support to armies and help to exportation.

1.2. Modeling stakes for intelligence

To acquire a new space-based or airborne IR imaging system, expected to deliver a better image quality than ever, typical images of observable scenes are needed very early for feasibility study, then for specification, definition, development and risk control. The usual solution consists in reconditioning real images taken at lower altitude.

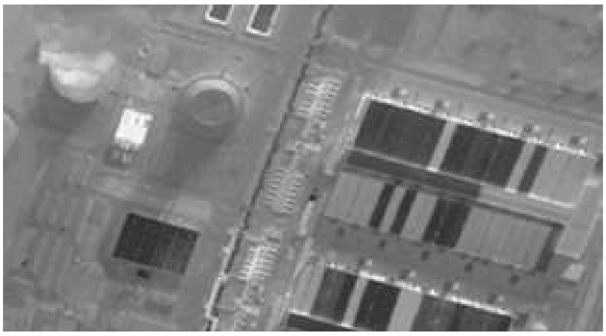


Figure 1. Example of real image from airborne IR sensor

The reconditioning process must deal with the necessity to compensate for image acquisition disturbances like carrier movement, scanning pattern or sensor effects: it’s for sure complex but achievable. Moreover this process has to transpose atmospheric propagation to the right altitude level, especially to a TOA (Top Of Atmosphere) condition for a space-based sensor.

The recourse to synthetic imagery can be an interesting additional solution if the time allowed to model the requested scenes is suitable and if the image quality and the radiometric realism can be comparable to real scenes. The key advantage of the synthetic approach is then the possibility to choose oneself the field truth about environment (climate, location, season, date, time, weather conditions), landscape (ground and/or sea surface, relief, vegetation, infrastructures, urban density) and human activity (military activity, industrial activity, urban activity). Nevertheless the validity of the modeling process must be demonstrated for such an intelligence application that is always more demanding. Lastly we must keep in mind that the resolution of the synthetic imagery content is obviously limited by the resolution of input data.

2. TERRAIN MODELING PROCESS

2.1. Choice of real sites to model

When the recourse to synthetic imagery is accepted for a new intelligence application, a crucial question is to choose which real sites have to be modeled. A way to answer the question is to select sites abroad that enable to explore extreme climatic situations in order to cover the best possible the variability of radiance distributions at sensor entrance. For that purpose, DGA Information superiority applies as far as possible the STANAG 2895 standard [1] and chooses as a minimum one site per extreme climate type: cold climate, hot and dry climate, hot and humid climate.

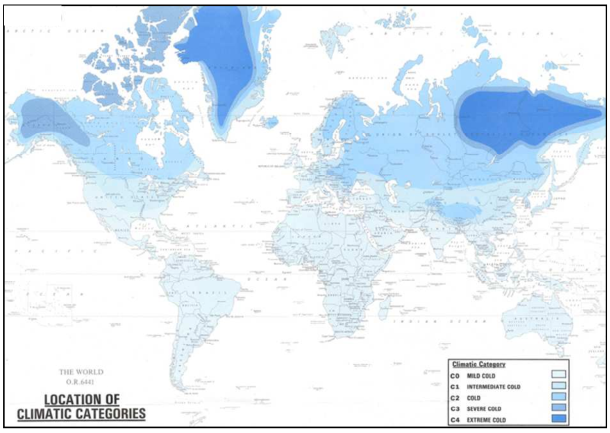


Figure 2. Cold climate categories

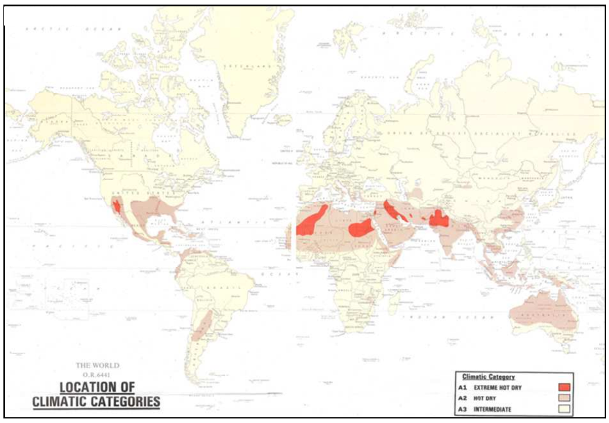


Figure 3. Hot and dry climate categories

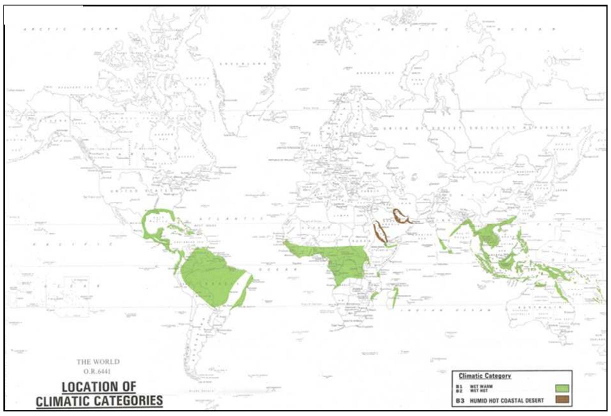


Figure 4. Hot and humid climate categories

Since the composition of ground surface evolves during seasons (e.g. snow cover, vegetation, cropland) as well as weather conditions (e.g. air temperature, snow or rain rate, sand dust), it’s a good idea to explore seasons too, at least winter and summer, and if possible spring and autumn too. Lastly, an IR channel in an optical sensor is essential for night condition observation, since the visible channel is blind, and is also very useful for daylight condition observation, knowing that collected imagery that can be different between night and day; so it seems necessary to model a site at several time instants during a 24hours cycle, at least one moment for night and one for day.

In addition to those foreign sites having extreme climates, the modeling of national sites for which real IR images and field truth data are available is fundamental to undertake a special validation effort and to have references that show the level of complexity of a real scene, in terms of radiance spatial distribution, that the modeling process must attempt to reach.

At last, when the first version of a given foreign or national virtual site is ready, it can be modified several times concerning weather conditions, landscape content and human activity to render numerous and various operational situations.

2.2. Generation of geographical terrain

The modeling of a real site is based on the processing of cartographic data made of altimetry, imagery and planimetry. The altimetry describes the terrain relief and the altitude of objects.

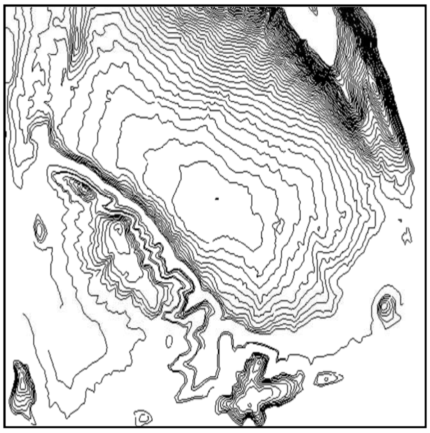


Figure 5. Altimetry data with height curves

The imagery, coming from satellite or airborne sensors, give pictures of the terrain from the sky.

Figure 6. Airborne imagery

Lastly the planimetry tells what is on the terrain thanks to areal, linear and punctual elements.

Figure 7. Planimetry data

For example, areal elements enable to describe the outlines of fields, lakes, forests or building areas, linear elements enable to describe the axis of roads, railways or rivers, punctual elements enable to describe the anchor points of objects like electric pylons or individual buildings.

All those cartographic data have geographical coordinates so that they can be associated to complete each other. It's even possible to modify planimetry data or to create new vectors using imagery as a background for planimetry edition. To produce a 3D terrain from those cartographic data, a basic concept is to generate a mesh of the terrain skin that consists in the projection of imagery on relief with a control of the meshing quality according to the target application.

Figure 8. Example of terrain skin mesh

The other basic concept is to associate planimetry elements to 3D templates that describe how to generate those elements on the terrain (for dropped elements like a 3level building) or in the terrain (for integrated elements like a highway or a forest area), and then to run the generation algorithms to get automatically a complete 3D terrain that inherits on 3D template instances.

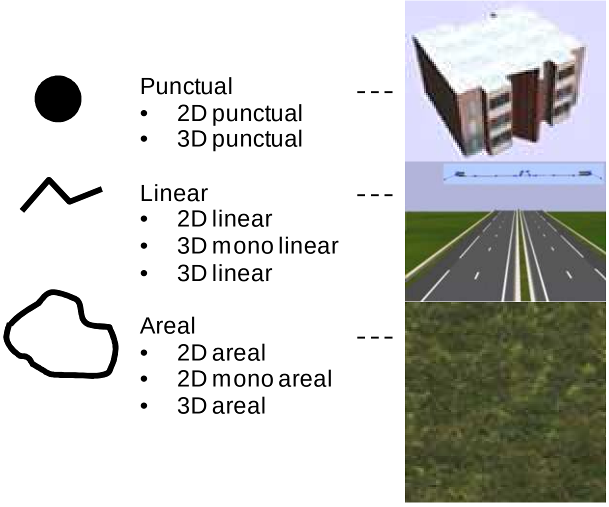


Figure 9. Association of planimetry to 3D templates

Figure 10. Automatically generated terrain

To produce 3D geographical terrain, DGA Information superiority benefits from two terrain generators: SE-Agetim [2] from SE-Workbench suite that runs with GeoConcept geographical information system and Terra Vista from Presagis suite. It uses also Global Mapper tool for special operations on cartographic data. For preparation of 3D templates, it employs products from SE-Workbench suite, especially SE-FFT for file format transfer, SE-Physical-Modeler for 3D modeling and SE-Agetim-Building for automatic generation of buildings; it uses another product from Presagis suite, Multigen Creator for 3D modeling, and other tools to work with textures (Photoshop and Gimp) and geometry (3D Studio Max, SkechUp, Blender or Polytrans).

About input cartographic data, DGA Information superiority receives data from French military staff that are satellite imagery products. Those products include stereo images enabling 3D reconstruction of relief or objects above the terrain like infrastructures. Since these data are sensitive, it's convenient to use also open source data. Concerning imagery, free data can be obtained for example on Global Land Cover Facility website [3] like Landsat ETM+ imagery (panchromatic band#8 delivers 15m resolution images) or Google Maps website for higher resolution images that can be then rectified thanks to military staff data.

Figure 11. Examples of Google Maps imagery

About planimetry, open source data can be obtained from Digital Chart of the World server [4] or from National Geospatial-intelligence Agency raster roam website [5] delivering Vector MAP Digest VFR data. Concerning altimetry, the previous website enables to download free DTED (Digital Terrain Elevation Data) level 0 with 1km resolution at equator while GDEM (Global Digital Elevation Map) ASTER server [6] enables to download elevation tiles with a DTED level 2 equivalent resolution (30m at equator).

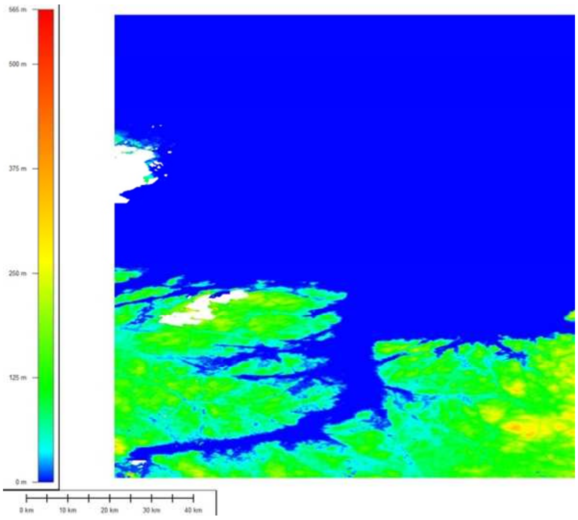


Figure 12. GDEM ASTER elevation tile

To raise 3D buildings on the terrain skin, the automatic generation used by DGA Information superiority consists in creating several styles of buildings, in describing each style with a few construction solutions for groundwork, frontage and roof, and in associating areal elements from planimetry to building styles so that the software can use the footprint and the height of a building to choose automatically construction algorithms between available solutions and can produce numerous buildings offering a satisfying variability in terms of shape and visual aspect.

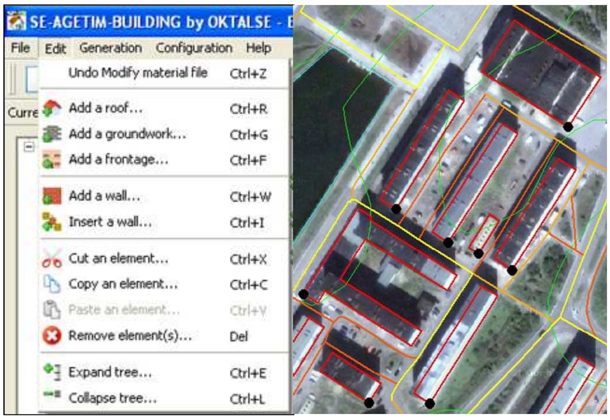


Figure 13. Principle of building automatic generation

If necessary, the operator can enrich construction algorithms with special keywords and assign such keywords to individual planimetry vectors in order to drive the automatic generation.

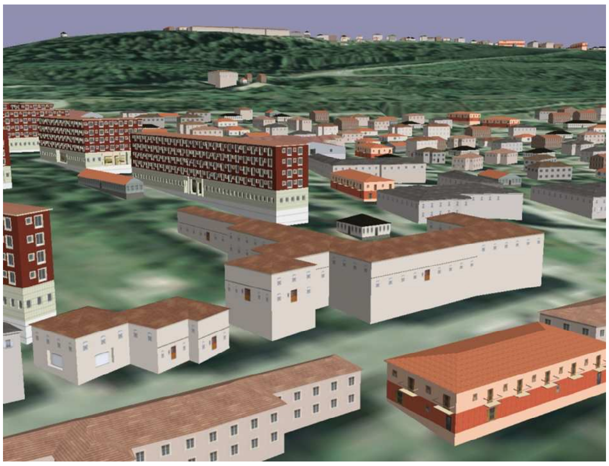


Figure 14. Automatically generated buildings

In order to produce a 3D geographical terrain that is as close as possible to the corresponding real site, at least inside a selected target zone, DGA Information superiority performs a specific modeling of buildings so that they look like the real ones. For that purpose, it employs a 3D reconstruction realized by French military staff from stereo satellite images. Since those data are sensitive and include namely top view textures extracted from satellite images, it's convenient to use the knowledge of footprint, height and 3D shape of each building in order to create new models with top view textures extracted from open source imagery and to add generic textures for vertical walls. It's then possible to exploit photos taken from ground level in order to select generic textures in accordance to the appearance of the real buildings. For a foreign site those photos are often obtained on the Internet, for example on websites like Wikimapia [7] or Panoramio [8].

Figure 15. Specific buildings with coarse 3D shapes

In fact photos are used above all to produce high resolution building models, that means to refine 3D shapes, to add geometrical details, especially for elements that are visible from the sky like chimneys, and to create specific textures.

Figure 16. Photo from Internet for building modeling

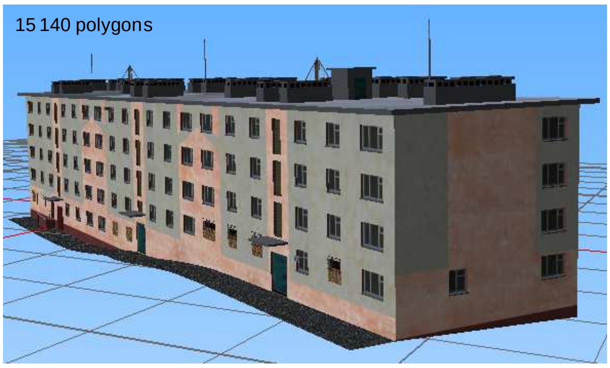


Figure 17. Specific building with fine details

DGA Information superiority has recently experienced the production of several hundred high resolution buildings for the generation of an accurate terrain database.

At last, since 3D elements are generated with the terrain, those elements must disappear from the textures mapped on the terrain skin, including their shadows. In other words, a cleaning of the terrain textures must be done on the whole extent of the terrain where 3D objects are raised.

Figure 18. Terrain texture before and after cleaning

2.3. Physical characterization of terrain

To compute IR images of the geographical terrain, it’s obviously necessary to add physical data into the terrain model, more particularly surface optical properties and temperatures. For that purpose, since all polygons of the model have textures and since these textures are 2D arrays of colors (than can be grey levels) that show spatial distributions of matters, the physical characterization is based on the classification of textures, that means the transformation of each color texture into a material texture. In this texture classification, each texel (i.e. texture element) is no more a composite color or a set of primary color ratios (a RGB color is a mixture of red, green and blue primary colors) but a composite material or a set of primary material ratios. The link with physics is done insofar as primary materials have physical properties.

For this classification, DGA Information superiority uses SE-Classification tool from SE-Workbench suite. This tool takes as input data a texture in PSD format having one or several layers and refers to a physical primary material database. It enables for each layer to define up to 4 primary colors, to associate each primary color to a primary material from the reference database, to compute each texel as a combination of primary colors and then as a combination of associated primary materials with the same ratios, and to store the result as a classified texture.

So before using SE-Classification, a texture is prepared with Photoshop or Gimp software to split the texture content into layers, with the goal to use afterwards a maximum of 4 primary materials per layer, and to save the file in PSD format. DGA Information superiority has experienced the preparation and the classification of terrain textures larger than 10.000x10.000 texels.

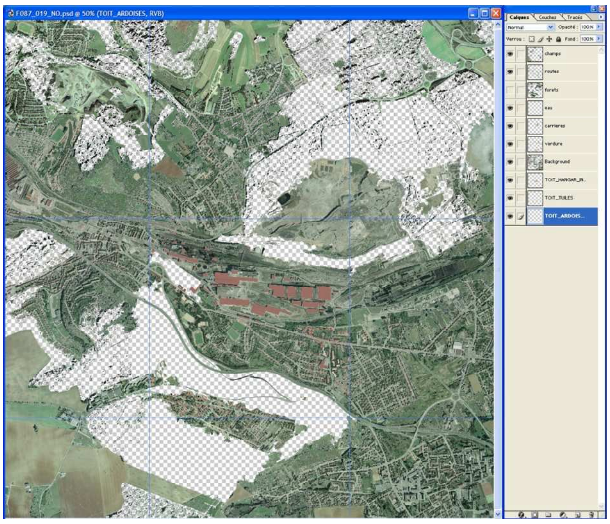
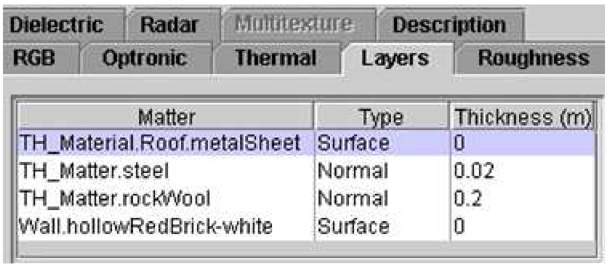


Figure 19. PSD texture with 10 layers

The physical primary material database contains materials that are physically characterized with surface optical properties but also multi layer thermal properties. Optical properties can be described with SE-Workbench BRDF (Bidirectional Reflectance Distribution Function) classical model with spectral emissivity, BRDF (diffuse and specular components), transmittance and potentially angular textures to modulate radiometric factors. They can also be described with new BRDF models [9] for both smooth dielectric materials (Fresnel model) and rough dielectric materials (He-Torrance-Sillion-Greenberg and Li-Torrance-Schlick models). Thermal properties are described with one or several layers characterized with quantities like thickness, density, specific heat, conductivity, convection coefficient, back temperature curve or back flux curve.



Matter	Type	Thickness (m)
TH_Material.Roof.metalSheet	Surface	0
TH_Matter.steel	Normal	0.02
TH_Matter.rockWool	Normal	0.2
Wall.hollowRedBrick-white	Surface	0

Figure 20. Example of multi-layer material

The physical primary material database can be edited with SE-Physical-Modeler tool that enables as well to map materials and temperatures on a 3D object. It includes data from different sources: the thermo-optical database developed by DGA Information superiority in the 90s, the ASTER database from California Institute of Technology [10], the MEMOIRES database from French ONERA [11], some lab measurements including micro scale roughness measurements [12] and lastly several theoretical models.

In fact thermal properties of materials are used to compute automatically with SE-Thermal tool from SE-Workbench suite heat exchanges during a 24hours cycle and to establish, thanks to a 1D solver, equilibrium temperature distribution in the virtual world, for natural landscape and infrastructures, at the IR rendering time instant. During this thermal computation, sun temperatures and shadow temperatures are evaluated to enable the rendering of thermal shadows.

$$\frac{d^2T(x,t)}{d^2x} = \frac{\rho.C}{\chi}.\frac{dT(x,t)}{dt}$$

$$\text{with}\quad \begin{cases} \rho : \text{density}\,(kg.m^{-3}) \\ C : \text{specific heat}\,(J.kg^{-1}.K^{-1}) \\ \chi : \text{thermal conductivity}\,(W.m^{-1}.K^{-1}) \end{cases}$$

Figure 21. Temperature equation to resolve

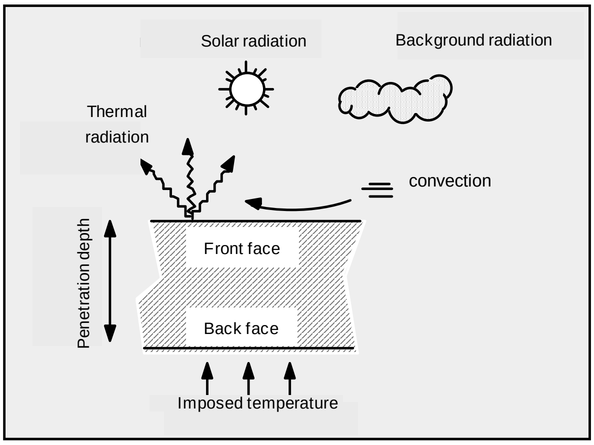


Figure 22. Heat exchange phenomena

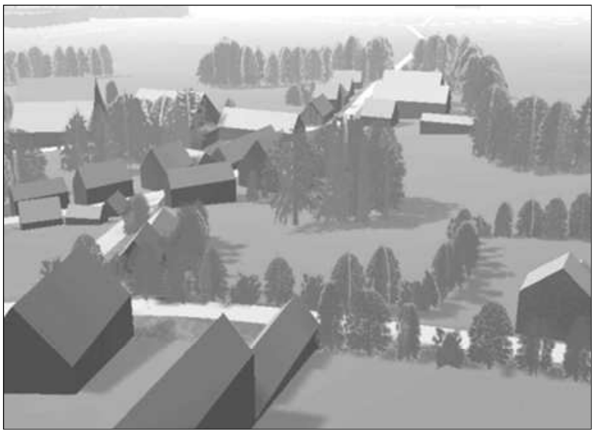


Figure 23. Thermal shadows in long wave IR

To feed the thermal computation, it's necessary to calculate the incident natural fluxes that may be absorbed during the 24hours cycle. Those fluxes are evaluated with SE-Atmosphere tool from SE-Workbench suite that enables to parameterize weather conditions with a 30minutes time step, to define the sampling of output data (in wavelength, altitude, elevation and azimuth), to run an atmospheric code that can be either MODTRAN from US Air Force Research Lab [13] or MATISSE from French ONERA [14], and to get sun/moon irradiance, sky radiance and ground radiance.

3. MODELING OF OTHER SCENE ELEMENTS

In addition to the geographical terrain, the scene elements to be modeled for IR rendering comprise atmosphere, vehicles and eventually sea surface.

3.1. Atmosphere modeling for rendering

The same SE-Atmosphere tool is used to compute atmospheric quantities that are needed for the rendering phase, that are established in the sensor spectral band and that comprise in addition to the previous ones atmospheric transmittance and atmospheric path radiance.

To illustrate the use of atmospheric computation results, the next figure shows the IR rendering of a mirror ball (i.e. with specular coating) observed by a sensor above the ball (the sensor is virtual and produces no shadow effect on the ball) and the projection of the illumination sphere on the object.

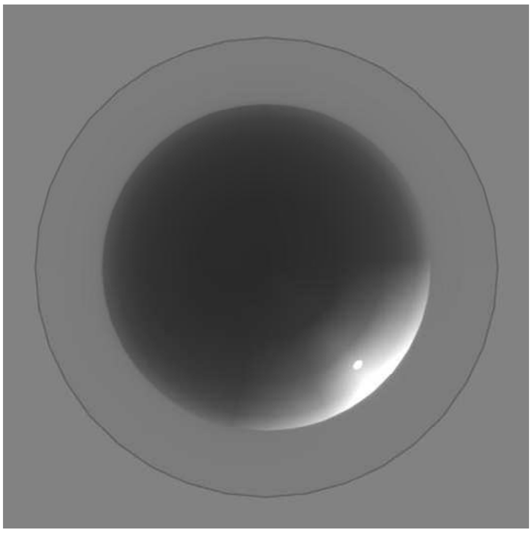


Figure 24. Top view of mirror ball

3.2. IR modeling of vehicles

In order to model the IR signature of a vehicle, DGA Information superiority uses three different methods [15]: the experimental modelling [16] consists in measuring the real signature and inverting the radiative transfer in order to map temperatures and optical materials on a 3D model; the use of an industrial delivery enables to benefit from an accurate physical model coming from the manufacturer; lastly the predictive approach consists in pre-computing physical phenomena that lead to the optical and thermal instantaneous state of the vehicle.

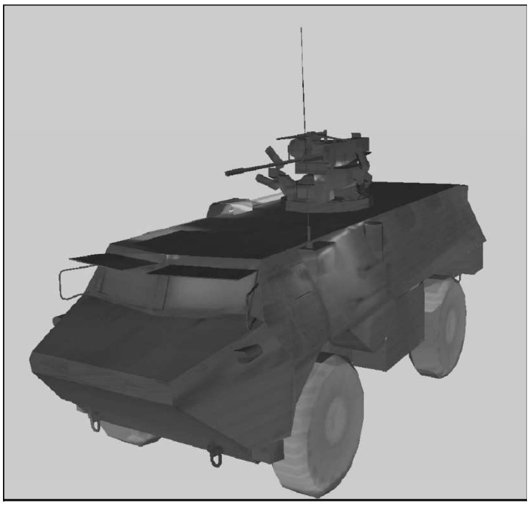


Figure 25. Experimental modeling of terrestrial vehicle (from DGA Land systems)

For the predictive approach, DGA Information superiority benefits from high-performance solutions that complement each other: these are PRESAGE [17] for all types of civilian and military aircraft, NTCS/ShipIR [18] for ships and RadThermIR [19][20] for ground-based vehicles.

Figure 26. Predicted IR signature of helicopter

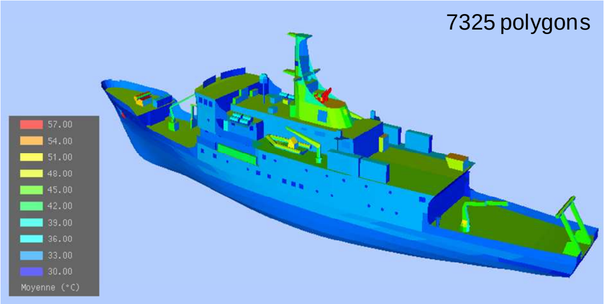


Figure 27. Thermal state of Quest ship

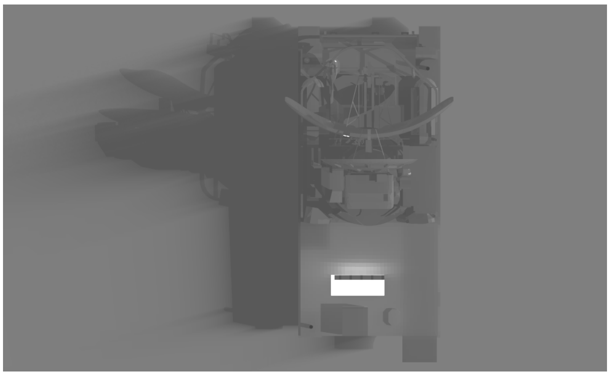


Figure 28. Predicted IR signature of SA-6 radar vehicle

3.3. Sea surface modeling

DGA Information superiority has recently sponsored enhancements of SE-Workbench suite that aim at better representing the sea surface and its interaction with ships and shore [21]. So if the real site to be modeled comprises a shore and a sea extent, it's now possible to model a realistic sea surface, with namely transition from open sea to coast, sea effects at cliff and beach interface, and wave height spectrum modification inside a harbor. It's also possible to model some moving ships with their Kelvin wakes and foam wakes that are significant for detection purpose. Such capabilities are shown in the next figure.

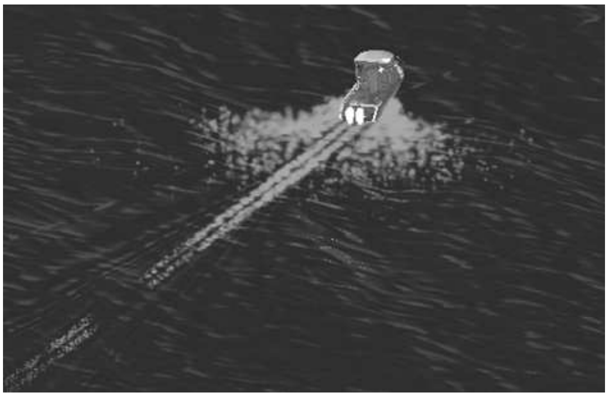
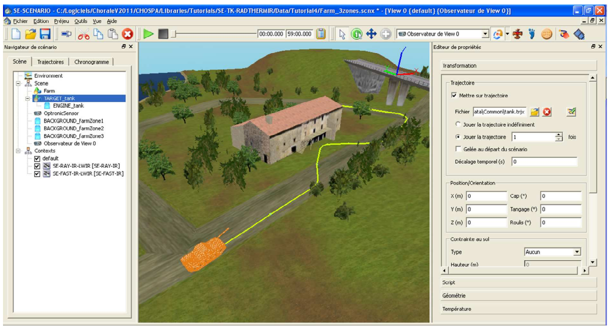


Figure 29. Ship with sea surface interaction

4. SCENARIO EDITION AND RENDERING

The scenario edition is performed with SE-Scenario tool from SE-Workbench suite and consists in gathering the scene elements (geographical terrain, atmosphere, vehicles and eventually sea surface), in positioning and orientating those elements, in creating trajectories for moving objects and in defining the observation conditions comprising position and orientation of sensor, field of view, pixel resolution, waveband and spectral sensitivity.



SE-SCENARIO - C:/Logiciels/ChoraleV2011/CHOSPA/Libraries/Tutorials/SE-TK-RADTHERMIR/Data/Tutorial4/Farm_3zones.scnx * - [View 0 {default} {Observateur de View 0}]

00:00.000 59:00.000

Observateur de View 0

Navigateur de scénario

- Environment
- Scene
  - Farm
  - TARGET_tank
    - ENGINE_tank
  - OptronicSensor
  - BACKGROUND_farmZone1
  - BACKGROUND_farmZone2
  - BACKGROUND_farmZone3
  - Observateur de View 0
- Contexts
  - ☑ default
  - ☑ SE-RAY-IR-LWIR [SE-RAY-IR]
  - ☑ SE-FAST-IR-LWIR [SE-FAST-IR]

Editeur de propriétés

Transformation

Trajectoire

☑ Mettre sur trajectoire

Fichier ata\Common\tank.trjx

○ Jouer la trajectoire indéfiniment

● Jouer la trajectoire 1 fois

☐ Gelée au départ du scénario

Décalage temporel (s) 0

Position/Orientation

X (m)	0	Cap (°)	0
Y (m)	0	Tangage (°)	0
Z (m)	0	Roulis (°)	0

Contrainte au sol

Type Aucun

Hauteur (m) 0

Figure 30. Scenario edition with SE-Scenario tool

The IR rendering is done with SE-Ray-IR tool from SE-Workbench suite that applies a spectral ray tracing method and if needed an additional photon mapping method.

Figure 31. Photon mapping rendering

We can find hereafter a few synthetic images showing terrestrial scene IR renderings in MWIR (Medium Wave IR) or LWIR (Long Wave IR).

Figure 32. Rural scene in MWIR

Figure 33. Same rural scene in LWIR

Figure 34. CELM field test centre in MWIR

Figure 35. Salon de Provence airport in MWIR

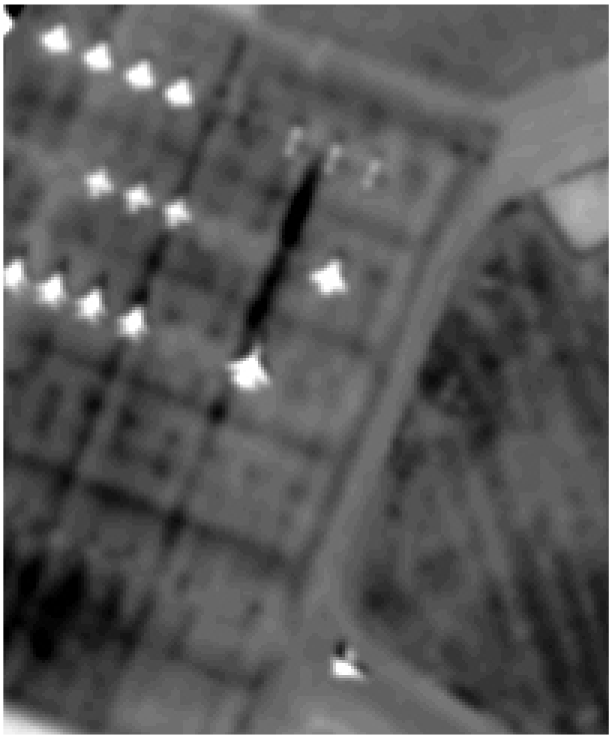


Figure 36. Zoom on Salon de Provence airport in MWIR

In the previous image, several aircraft models of different types have been added on the virtual airport and a sensor effect is simulated with a modulation transfer function.

5. VALIDATION OF MODELING PROCESS

Current and next space-based and airborne IR imaging systems are more and more accurate, and lead to demand from synthetic imagery, when this solution can be retained, an image quality and a physical realism that were never requested before. That's why a special validation effort is necessary to check that synthetic IR images are enough realistic to complete or partially replace reconditioned real images.

In fact, since the creation of a pole of activities for optronics scene modeling in 1998, DGA Information superiority (previously called CELAR) has been taking care about the validity of computed images and has been developing a general VV&A (Verification, Validation and Accreditation) process that is not limited to the modeling tools but starts with the input data for geometry and physics, and goes up to the effect on the threat behavior [22]. So a new modeling project benefits from capitalized validation results and can focus on more demanding new test cases.

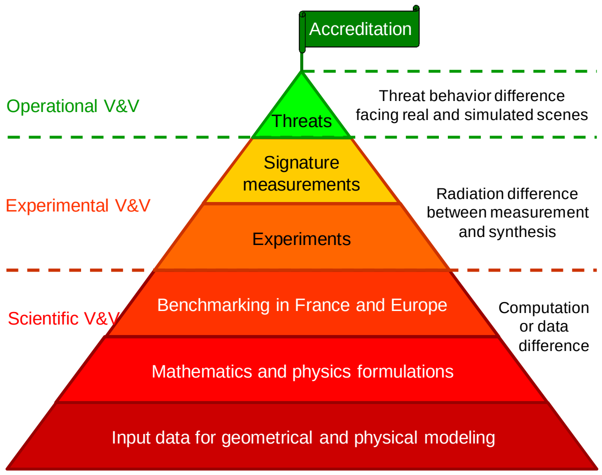


Figure 37. VV&A pyramid

So the special validation effort is based on the restitution of VIROISE 2009 campaign with the same modeling process as for a foreign site. This campaign was organized in September 2009 is Oise department (East of Paris) in order to acquire visible and IR real images with Pelican and Timbre Poste airborne sensors, and to store simultaneously a very detailed field truth dataset.

This dataset includes complete weather condition measurements that were used as input data for the thermal computation and the rendering instead of statistically probable weather conditions in order to enable a narrow comparison between synthetic scenes and real images. These measurements at ground level, stored with a 1minute time step, are pressure, temperature, relative humidity, wind speed, wind direction, visibility and rain rate.

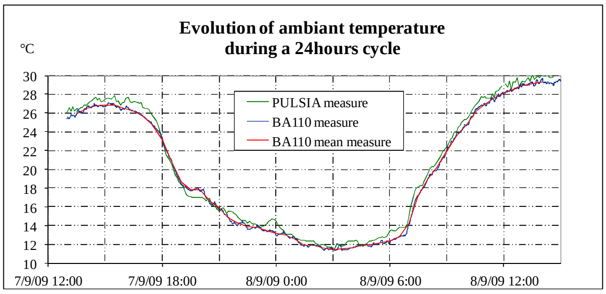


Figure 38. Air temperature measurements

These measurements include as well a few atmospheric profiles giving evolution of pressure, temperature and relative humidity as a function of altitude.

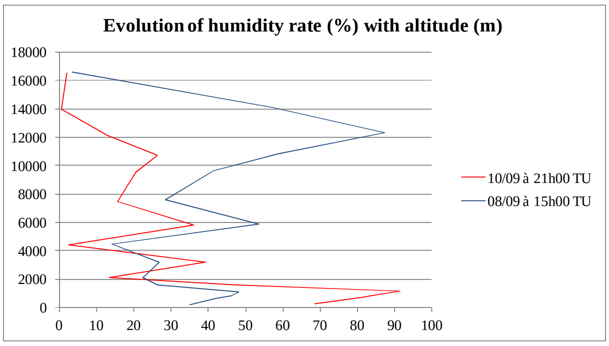


Figure 39. Atmospheric profile measurements

The field truth dataset comprise as well the storage of IR sensor trajectory (3D position and 3D orientation of line of sight) at 200Hz frequency and lab measurements about sensor characteristics like field of view, geometry of detector array, spectral sensitivity and point spread function. Those data are used as input data for the rendering scenario edition.

The computed images are then sent to French military staff so that photo-interpreters evaluate image quality, give an opinion about modeling validity upon an operational point of view, identity potential defaults and suggest corrective actions.

In a second step, typical zones in the images are selected, metrics are defined to compare signatures between measurement and simulation, and selected zones are compared through those metrics to give an opinion about modeling validity upon a radiometric point of view.

Figure 40. Selection of typical zones
(real image was converted to low resolution)

In a third step, intermediate computation results are compared to available experimental results: global irradiance, surface temperatures, vehicle IR signatures thanks to ground-based cameras, human activity for vehicles and infrastructures. Metrics are defined and applied to compare those experimental and simulated results, and to give an opinion about modeling validity upon an experimental point of view.

In a fourth step, field truth data that could have been used as input data for the modeling process are compared to the input data effectively used. They comprise measurements of hemispherical directional reflectance for a few material samples, GPS statements, numerous photos and Pelican visible images that enable to appreciate the nature of present materials or objects. This comparison leads to give an opinion about modeling validity upon a “scientific” point of view.

Finally, the validation approach is a top-down method in reference to the VV&A pyramid. This approach is devoted to supply military photo-interpreters with synthetic images produced with the same modeling process as for a foreign site and this way to validate the modeling process for a foreign site. It enables to identify gradually defaults that may be introduced among input data in the modeling process and to evaluate the impact of those defaults on the differences between real and synthetic images upon operational, radiometric, experimental and scientific points of view.

The validation approach is then followed by a bottom-up method in order to correct progressively met defaults, to evaluate how differences between reality and simulation can decrease, and lastly to quantify the validity of the modeling process for a national site according to available field truth data.

This validation approach is first applied to the airport area acquired during VIROISE 2009 campaign and uses both MWIR and LWIR real images in both day and night conditions that represent about 400.000.000pixels. It will be then applied to the three other areas that were acquired during the campaign and that are dense urban areas with dense industrial extents.

6. CONCLUSION

The modeling process of a foreign site for intelligence function assessment is complex, it requires detailed and sensitive input data from French military staff and can benefit from open source data to get more information, it needs powerful and efficient software as well as motivated and experienced operators. It can generate synthetic images that are comparable to reconditioned images in terms of image quality and physical realism.

7. REFERENCES

1. STANAG 2895, *Climatic extremes and derived conditions to use in design and trial criteria definition for equipment intended for NATO forces*, edition 1 promulgated on 15th February 1990
2. J. Latger, A. Le Goff, T. Cathala, M. Larive, *Automatic 3D virtual scenes modeling for multi sensors simulation*, SPIE 2006
3. http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp
4. http://www.maproom.psu.edu/dcw/
5. http://geoengine.nga.mil/geospatial/SW_TOOLS/NIMAMUSE/webinter/rast_roam.html
6. http://www.gdem.aster.ersdac.or.jp/index.jsp
7. http://wikimapia.org
8. http://www.panoramio.com
9. A. Le Goff, *Advanced modeling and rendering of target optical reflectivity*, ITBM&S 2010
10. http://speclib.jpl.nasa.gov/
11. http://www.onera.fr/dota/memoires/index.php
12. A. Le Goff, *Helicopter coatings modeling from optical properties measurements*, ITBM&S 2007
13. http://modtran.org/
14. http://matisse.onera.fr/
15. A. Le Goff, *Advanced modeling and rendering of stealth aircraft optical signature*, OPTRO 2010
16. A. Le Goff, *Experimental modeling of flying aircraft IR signature*, ITBM&S 2008
17. A. Le Goff (2010), *Predictive modeling of aircraft IR signature*, ITBM&S 2010
18. http://www.wrdavis.com/NTCS_intro.html
19. http://www.thermoanalytics.com/products/radthermir/index.html
20. A. Le Goff, *Thermal modeling coupling between RadThermIR targets and SE-Workbench environment*, OPTRO 2012
21. T. Cathala, A. Le Goff, J. Latger, *Marine simulation in SE-Workbench*, OPTRO 2012
22. A. Le Goff, *IR scene modeling VV&A*, ITBM&S 2008