

TUNING OF PHYSICAL INFRARED SCENE SIMULATION USING REAL IMAGES OPTRONICS IN DEFENCE AND SECURITY

Jean LATGER ⁽¹⁾, Dominique MALTESE ⁽²⁾, Thierry CATHALA ⁽¹⁾, Diane MORCHAIN ⁽²⁾, Emmanuel CARNIS ⁽²⁾, Hong-Lien PHAM ⁽²⁾

(1) OKTAL Synthetic Environment, 11 avenue du Lac, 31320 Vigoulet-Auzil, France

(2) SAFRAN Electronics & Défense, 100 Avenue de Paris, 91300 Massy, France

KEYWORDS: Simulation, Validation, Accreditation, NIR, SWIR, LWIR, Infrared, Sensor, Airport, SE-WORKBENCH-EO, ATLAS, SKYNAUTE

ABSTRACT:

SE-Workbench-EO, also called CHORALE in France, is a comprehensive set of tools that aims at modelling the 3D environment with a virtual and synthetic approach and at rendering the 3D scene for a given IR/VISIBLE sensor. Main application focuses on assessing infrared/visible sensors efficiency, using parametric approach specially to test several environments (3D scene, time of day, season, weather condition etc.). Safran Electronics and Defense (SED) has been using SE-Workbench-EO from years in the defense domain. Here we present a common project in the field of aeronautics, with the support of French DGAC ('Direction Générale de l'Aviation Civile'). Its name is COCOTIER ('COnccept de COckpit et Technologies Intégrées En Rupture' - 'Breakthroughs in Cockpits concepts and attached Built-in Technologies'). The point we want to emphasize is the way to tune the synthetic environment and the infrared sensor model in order to stick to reality. SED has made flying campaigns on a French airport including landing and taxiing ground truth records. SED handled its own sensor platform in LWIR (Long Wave Infra-Red), SWIR (Short Wave IR), NIR (Near IR) and visible wavelengths ('Voie Jour' (VJ) for 'Day Light Channel'). On its side, OKTAL-SE has created an accurate geospecific 3D model of this airport. SED and OKTAL-SE have together made a precise model of each embedded sensors. They have also tested and shared several methods to tune both the synthetic environment and the sensor suite. SED and OKTAL-SE prove that it is possible to achieve the ultimate challenge, which consists in competing with reality, using simulation.

The introduction shortly presents SE-Workbench-EO/CHORALE main features and objectives. SED will insist on their requirements for simulation and will explain its dedicated use-cases.

In the second part, we will present the R&D project shared by OKTAL-SE and SED, the operational targeted application based on Image Processing

and the global methodology of tuning synthetic sensor images using real images.

In the third part, we will focus on the 3D synthetic scene and put forward examples of high-resolution objects such as approach lights and ILS (Instrument Landing System) device near the runway. Concerning radiometry, we will insist on the amount of physical material, and the resolution of the distribution of material. We will also detail our method to control the light point's spectral intensity and directivity to fit to the real images. We will provide examples of SE-PHYSICAL-EDITOR tool usage to control the material behaviour with regard to wavelength.

Then we will explain the way to compute the atmospheric and thermal files, taking into account on-ground measurements of air temperature and hygrometry in particular, and the characterization of an advanced physical model of fog needed to model the attenuation and self-emission of atmosphere at low altitude. We describe also sensors models from SED.

Finally, and before the conclusion, we explain the gait that OKTAL and SED achieved to perform the full VV&A process of the Simulation Environment (Verification, Validation and Accreditation).

The next steps in the future are a conclusion, both on SED side as users and experts of physical simulation, and on OKTAL-SE side as simulation toolmaker in compliance with customers' needs.

1. SE-WORKBENCH-EO

1.1. Overall presentation of SE-WORKBENCH

The SE-WORKBENCH is a multi-sensor modelling WORKBENCH mainly used by:

- Defense agencies e.g. French DGA, German BwB, South Korea MoD, Singapore DSO/DSTA, Finnish Defence Forces and Swedish FOI
- Research centres e.g. ONERA, IOSB & FHR Fraunhofer Institute, CNRS/LAA
- Industrials in and out of France e.g. MBDA FR & UK, SAFRAN, Airbus, Dassault, LG, Hanwha-

Samsung

SE-WORKBENCH-EO is the infrared sensor dedicated part of the SE-WORKBENCH that achieves the synthesis of 3D scenes observed by Electro Optical (EO) sensors, 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, assignment of trajectories to moving objects, definition of animations, definition of atmospheric and thermal conditions, parameterization of the sensors)
- Then, the computation of the physical radiance signal received by the EO 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, laser/LiDAR 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 millimetric waves and wide scenes, typically for SAR applications. A 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. Architecture of SE-WORKBENCH-EO

The SE-WORKBENCH-EO is made of different components, as described hereafter, corresponding to the successive steps of an IR sensor simulation that are the modelling of the synthetic environment, the scenario edition, the intrinsic 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 complex applications design and integration.

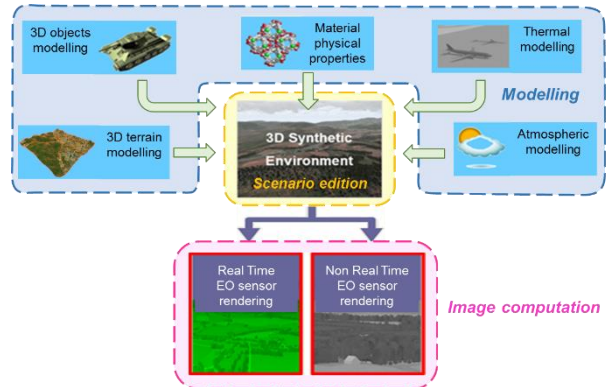


Figure 1. – SE-WORKBENCH-EO components

2. 'COCOTIER' OVERALL PROJECT DESCRIPTION

COCOTIER ('COncept de COckpit et Technologies Intégrées En Rupture' - 'Breakthroughs in Cockpits concepts and attached Built-in Technologies') is an aeronautic project supported by the French DGAC ('Direction Générale de l'Aviation Civile'). It focuses on the SPO requirements for Airliners (Single Pilot Operation). The project encompasses different situations that include from 'low-intensity' to 'high intensity' incidents the plane has to face:

- during its full flight (including taking-off and landing steps),
- or/and when taxiing.

One of the 'high-intensity' situations to deal with corresponds to the scenario when an aircraft is landing while a GNSS-denied situation occurs (Global Navigation Satellite System). This event may happen during the landing sequence (last kilometres before the TDZ contact (Touch Down Zone)) or just a few minutes before. A more drastic situation is the lack of GNSS data just a dozen of minutes before landing meaning here, when the plane is prepping to the final sequence (achievement of the alignment with the runway and the ILS beacon (Instrument Landing System)). In that case, for the COCOTIER project, an inertial-vision fusion module becomes a key-solution to help the airliner to land in a safer way. Indeed, when considering only the filtering of the on-board INS (Inertial Navigation System) measurements including the last coherent GNSS information in order to get the own Aircraft trajectory, this situation leads to a position drag effect. Consequently, these uncertainties are very risky for the landing sequence (misalignment with the runway). For this use case, we must notice that INS accuracies are very important to mitigate as best as possible the resulting position drag values before landing.

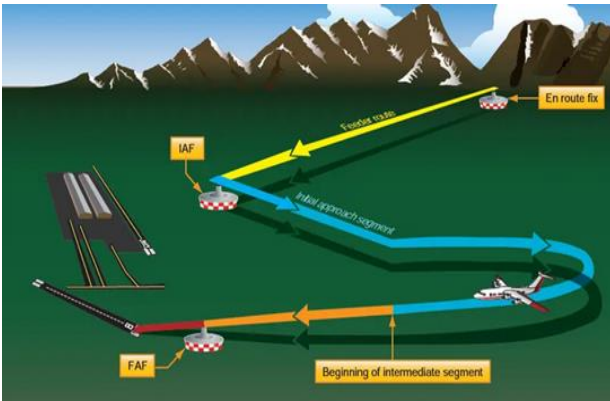


Figure 2. – Approach without a designated IF (Intermediate Fix) from an IAF (Initial Approach Fix) to a FAF (Final AF)

Safran Electronics and Defense (SDS) and OKTAL SE take part of the COCOTIER project. The previous 'high intensity' scenario (GNSS-denied during landing) is particularly under study. For the System Performances analysis, SDS provides:

- The ATLAS electro-optical sensor suite and their attached physical models provided by SDS Optronics Experts for simulation aspects. ATLAS includes different cameras operating in various wavelengths: LWIR (Long Wave Infra-Red), SWIR (Short Wave IR), NIR (Near IR) and visible wavelengths ('Voie Jour' (VJ) for 'Day Light Channel'). The objectives are to assess the pros and cons of each wavelength selection. They correspond also to get the achievable benefits (Detection range, localization accuracies...) by combining in a coherent way raw data retrieved from each sensor. In one hand, Image Processing extracts from frames the runway features and the navigation lights features (PAPI (Precision Approach Path Indicator), threshold lights...). In the other hand, the module fusion handles these dedicated data (object position and associated morphological features) and combines then with INS output to filter in a better way the Airliner position and attitude.

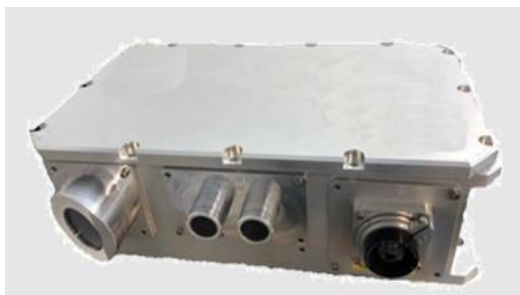


Figure 3. - ATLAS multisensory Box

During the study, wavelengths selection regarding weather conditions (clear or bad), Day/Night conditions are studied. The selection of features to retrieve stands also as an important part of the project (Image Processing Aspects). Performances assessment take into account:

- o True ATLAS data recorded by SDS during specific flight tests at Rouen Airport in France (sets of videos and associated position-attitude of the carrier)

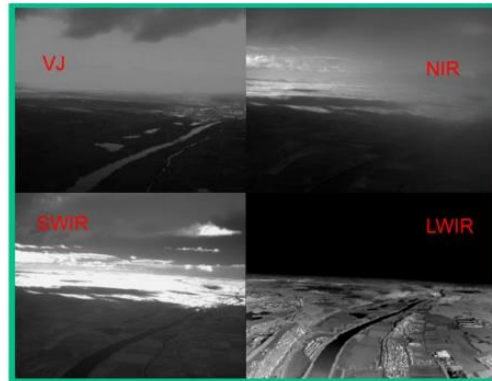


Figure 4. – Example of ATLAS multisensory Records

- o Simulated image sets provided by OKTAL SE. Previously, the simulation tool handling ATLAS records is fine-tuned. Tuning encompasses Rouen Airport mock-up (focus on aeronautic devices such as PAPI) and sensor models provided by SDS. That aspect that has not to be underestimated (refer to next chapters).
- An INS to get inertial data to fuse with electro-optical features retrieved from the ATLAS sensor suite. In the COCOTIER project, true INS record merge with true and/or simulated ATLAS image features (hybrid simulation configuration) to assess the full navigation module performances. Large-Dimension KALMAN Filters in 'tight' or 'loose' configurations are applied. SDS Navigation Experts have provided filtering models and strategies that are built-in in the SKYNAUTE equipment.



Figure 5. – SKYNAUTE equipment

- Flight trials at Rouen Airport (France – Normandy Province). A first flight campaign occurred in end 2020. A new one stand in end 2021. PIXAIR Company located at Rouen

Airport achieved the trials with the full set of SDS sensors on-board their own carrier. PIXAIR works also with SDS for other flight campaigns (Sense Avoid studies)



Figure 6. – ATLAS multisensory box integrated on the fore part of the PIXAIR airplane structure

A challenge in the Project is to combine both true data (INS) and simulated data (image synthetic environment). The interest of synthetic data is to embrace a large spectrum of input scenarios parameters: weather conditions, day/light conditions, modifications of Airport Devices (ILS beacons, approach lights switch on/off...) without not achieving various flight tests. Consequently, a derivate and direct challenge is to fine-tune the simulation tools w.r.t. true data to be enough confident with it and System Capabilities and Performances Analysis. Chapters hereafter stress on these aspects.

3. SYNTHETIC 3D MOCK-UP

3.1. Geometry

- In the frame of the COCOTIER project, OKTAL-SE and SED have decided to select a simple airport case with the ability to make experimentation on the field, rather than a complex and closed one. Rouen airport has been selected. Besides, the PIXAIR company is located in this airport, which has notably simplified airborne measurements and access to the airfield.

During 2 days, OKTAL-SE and SED have benefit from this full access.



Figure 7. – Measurement of the height of approach lights



Figure 8. – Measurement of a threshold light

As a first conclusion, it clearly appeared that the bias between the official Annex14 of OACI/SIA and the ground truth was not so chimeric.

Besides, airborne LiDAR measurement have been made by SED. These sets of 3D points have been used by OKTAL-SE to improve the height map of the airfield.

The 3D virtual mockup of Rouen Airport has been designed using SE-AGETIM terrain modeling tool. Several versions of this mockup have been generated up to converge with photo campaign and measurements.

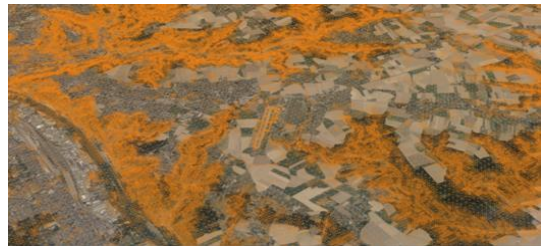


Figure 9. –Interest zone inside Environment zone



Figure 10. – Synthetic/real snapshot of the interest zone

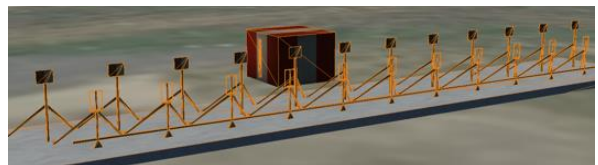


Figure 11. – High level of detail for the ILS system

3.2. Physical materials

Physical Material definition is the key of a realistic synthetic environment. SE-Workbench-EO includes a large library of physical materials both for radiative characteristic and for thermal data.

Actually, a SE-Workbench-EO material is an abstraction that offers the following services for radiative characteristic definition:

- Emission
 - o Emitted radiance
 - o Emitted intensity
 - o Emissivity
- Reflection
 - o Bidirectional Reflection Distribution Function
 - o Reflectance
 - o Diffuse reflectance
 - o Glossy (specular) reflectance
- Transmission
 - o Bidirectional Transmission Distribution Function
 - o Transmittance
 - o Diffuse transmittance
 - o Directive transmittance
 - o "Computer Graphics" transparency

Materials are associated via "texels" (texture element) that control every pixel of a given polygon. All these materials depend on wavelength and angles.

Besides several types of radiative data can be combined thanks to:

- Layered texture (to mix materials)
- Multi texturing (several texture for one polygon)
- Material Cover (texture of texture)
- Analytic materials:
 - o multilayer smooth dielectric materials
 - o HTSG
 - o Li-Torrance
 - o Sandford-Robertson

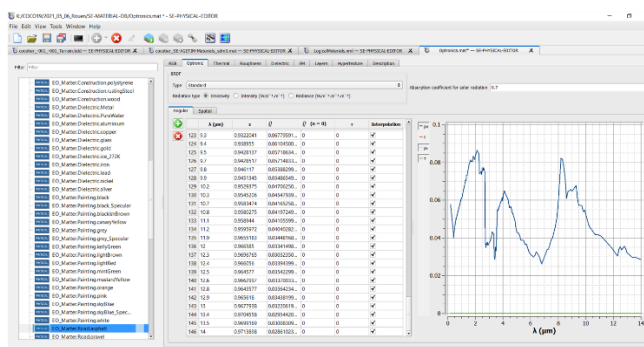


Figure 12. – Example of BRDF edition in SE-PHYSICAL-EDITOR

Finally, thermal data are needed to predict the temperature of the scene at pixel level.

The following parameters are used by SE-THERMAL product:

- thermal diffusivity
- specific heat

- front side convection coefficient
- back side convection coefficient
- front side air temperature
- front side air temperature
- wind speed
- mean value of absorption coefficient over the visible band on the front side
- mean value of emissivity over the LWIR band on the front side
- mean value of emissivity over the LWIR band on the back side
- thermal conductivity
- density.

3.3. Light sources

Light source modelling is very challenging. The associated physics is complex and the data sheets are not always up to date. New LED lights are very tricky for the infrared domain especially for LWIR. With classical incandescent or halogen lights the heat effect is very important. It is much less the case of LED lights.

In SE-Workbench-EO, a light is a special entity that is jointly considered as a 1-dimension point and as a volume with an apparent surface for the rendering. To avoid any risk of missing a light in an image, the raytracing casts a dedicated ray from the light to the sensor.

Then, the SE-RAY-IR physical model computes the associated radiance. SE-RAY-IR light source is a punctual entity described by:

- an illumination direction defined by its heading, pitch and roll angles
- an aperture along the X and Y axis
- a maximum range
- a material describing the lighting physical attributes
- a flag telling if the lighting can be seen
- a flag telling if the lighting illuminates the scene

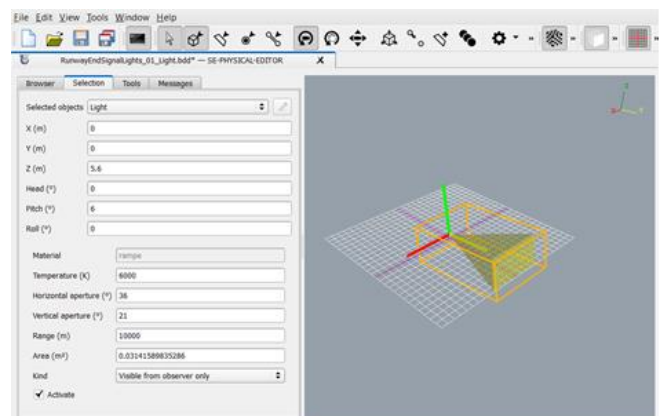


Figure 13. – Light parameterization using SE-PHYSICAL-EDITOR

SE-RAY-IR makes a difference between the ability to be seen (light point) and the ability to illuminate the scene (light source). In our case, for the runway and taxiway, lights are light points. The lampposts nearby the terminal are light sources.

Each runway and taxi lights are associated to a geo-specific geometry:

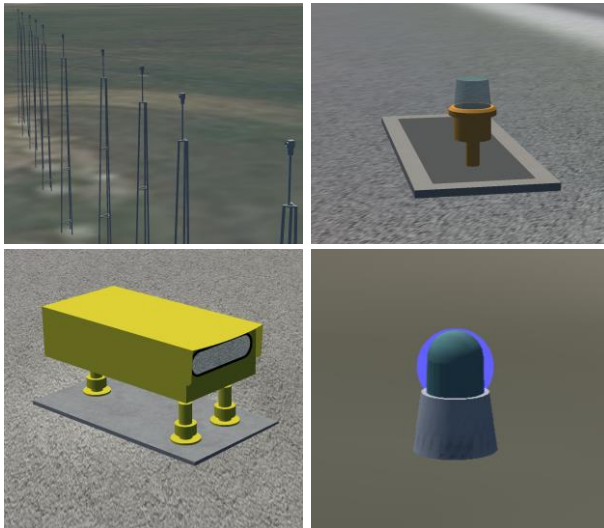


Figure 14. – Light geometry for approach, edge, PAPI, taxi

The geometry associated to a light behaves like a Level of Detail. For far distance observation, this geometry is perfectly transparent.

The Light point radiance evaluation is directly achieved by the ray tracing. Depending on the apparent surface of the light point (light attribute in m^2) projected on the pixels grid, the light point can cover either several pixels or just one. When it covers several pixels, its shape is a simple disk. Unless the whole disk is included in the same pixel, the light point surface is always sampled as a 100×100 grid.

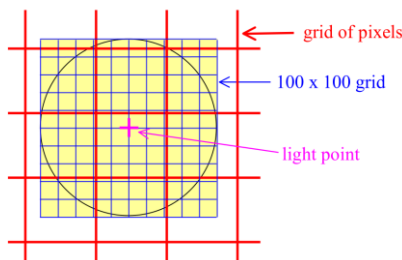


Figure 15. – SE-RAY-IR evaluation of the light point radiance

This ensures a good radiance estimate of the light point in each concerned pixel and also ensures the conservation of the global intensity.

A dedicated test has been made to check this consistency. The SE-SCENARIO test scene is made of a single light point object without any geometry. The light point is positioned at $(0,0,0)$.

The sensor is on a trajectory and “looks at” $(0,0,0)$. The first position of the trajectory is $(0,-1,0)$ and the last position is $(0,-100,0)$ so the sensor moves along the Y axis from the first position to the last position with a step of 1 meter.

A theoretical computation shows that the intensity of each image must be $930 \text{ W}\cdot\text{sr}^{-1}$. Less than 0.1% of error is obtained:

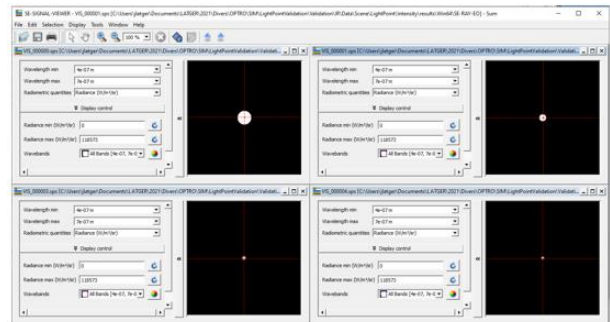


Figure 16. – Light radiance from 1, 2, 3, 4 m ranges

4. PHYSICAL MATERIAL TUNING

Compare simulation results versus experimentation in the real world is important to ensure that the simulator is trustable. Of course, it is not a warranty for all cases because a universal simulator is an unreachable mind view. But, if the simulation process rigorously applies physics laws - which is typical SE-Workbench mission statement – then it constitutes a good marker of validation.

Actually, it is impossible to mimic reality exactly. Synthetic scenes have not enough details. The key point is the physical materials parameterization. The generic SE-Workbench library of physical materials is not sufficient.

Thus, the methodology we have followed for this project has consisted in “tuning” the features to meet reality. The tuning is based on real ATLAS images. It concerns every feature of the synthetic environment. Here we insist on three features that are very sensitive for realism:

- Materials
- Runway lights
- Atmosphere

5. PHYSICAL MATERIAL TUNING

In this application, the system under test is the Image Processing whose mission is to detect the runway. Thus, the contrast of the runway and its vicinity is quite important. As a starting point, SED and OKTAL-SE have analysed several images, at several ranges in VIS, NIR, SWIR and LWIR bands. From these observations, some basic material BRDF (and emissivity) have been modified. Then the mixing (percentage) of these materials within a same texture of “classification” has been tuned, till

the result for each band was acceptable.

The main discrepancy was observed in NIR band. In the original synthetic image, the contrast of the radiance of the fields edging the runway is too low:

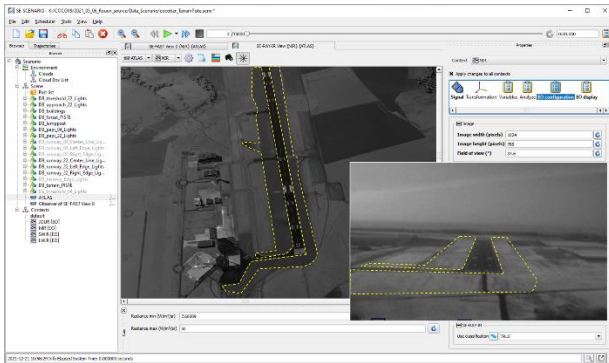


Figure 17. – Zones of material to be tuned

Thanks to SE-Workbench tools, the origin of this underestimation of the radiance can be explained. Actually, in the bad zone, the texture classification includes some asphalt material. We can check using SE-PHYSICAL-EDITOR:

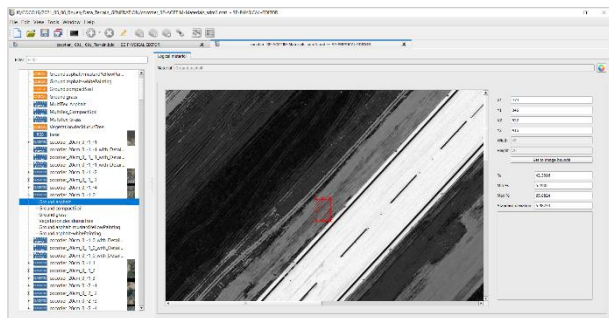


Figure 18. – some asphalt in the field

And asphalt material has a mean reflectance of 0,05 which is very low and explains the darkness.

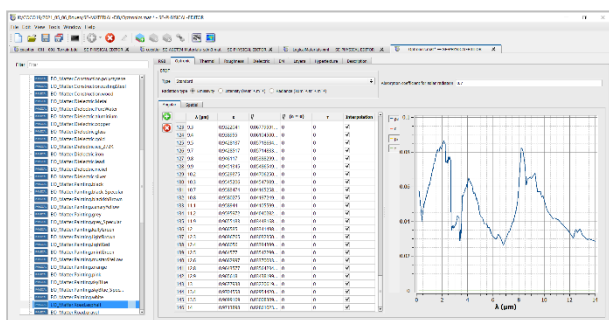


Figure 19. – asphalt BRDF

After tuning and a new classification we finally obtain a good result:

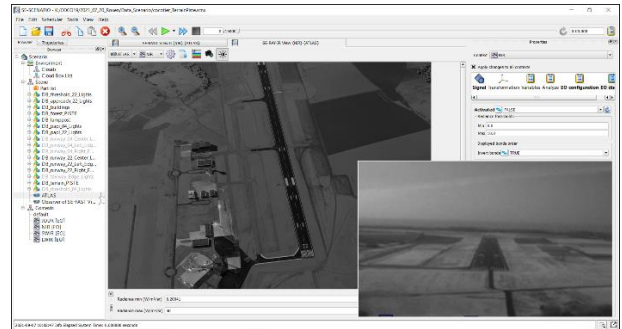


Figure 20. – Result after material tuning

6. LIGHTS TUNING

As already discussed, the light point modelling is much more sensitive than materials.

Actually, even if we have access to the datasheets of the sources, it is difficult to exactly predict their behavior, especially in LWIR.

The best way is to tune the lights models, starting with real images in each band.

Let us take the SWIR band and the case of the approach lights as an example. The SWIR Atlas sensor output is 14 bits.

We consider an image after sensor with no saturation:

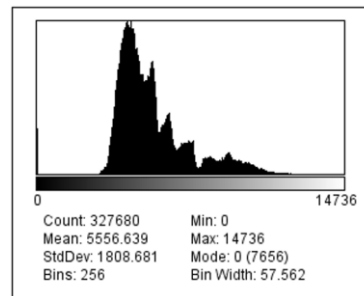


Figure 21. – SWIR Image histogram of the real image

After material tuning, we can trust in the radiance values computed by SE-RAY-IR.

We consider two reference materials in the simulated image. One is the asphalt of the runway. The other one is the white painting of the marks.

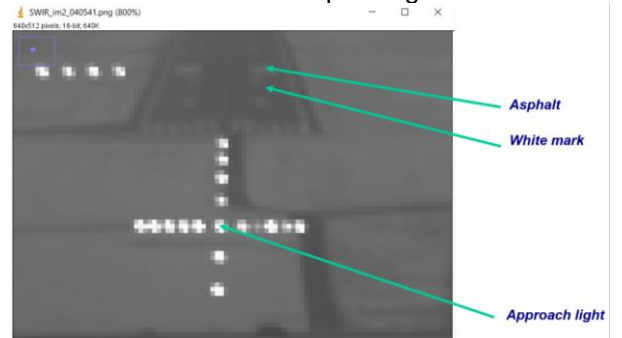


Figure 22. – Approach light in the real image

Since the real image is not saturated, we can measure the radiance of the light and of the two reference materials.

Doing the same operation in the simulated image,

and some solid angle computations based on the distance of observation, we can deduce the ratio to be applied to each light to fit reality. This is done using the apparent surface attribute of the light point.

OKTAL-SE has developed a dedicated tool to automatically control all the airport light points. This very practical tool will be integrated to the next releases of SE-Workbench.

7. ATMOSPHERE TUNING

Atmosphere modelling is all the more important as the weather conditions are more critical. The impact of attenuation and/or self-emission of atmosphere is a key driver of the probability of detection of the runway, in our COCOTIER application.

For each of the flight tests, SED has collected the broadcast main information such as time of day, ground air temperature, hygrometry and pressure:

Type of beacon UTC	Heure locale	Temperature	Point rose	Humidité relative	Visibilité	Nebulosité	Vent moyen	Direction	Vent rafale	Pression mer	Variation pression	Precipitation	Temp.
Catop	02h	23	1.8	71	13	60	11	20	20	1022.5	-1.87h	0.00h	0.00h
M (Catop 30)	02h30	23	2.1	71	10-10	60	11	20	20	1022.5	-1.87h	0.00h	0.00h
Catop	02h	23	2.1	71	10-10	60	11	20	20	1022.4	-1.27h	0.00h	0.00h
M (Catop 30)	02h30	23	2.2	71	10-10	60	11	20	20	1022.4	-1.27h	0.00h	0.00h
Catop	02h	23	2.2	71	10-10	60	11	20	20	1022.8	-1.27h	0.00h	0.00h
M (Catop 30)	02h30	23	2.2	71	10-10	60	11	20	20	1022.8	-1.27h	0.00h	0.00h
Catop	02h	23	2.7	71	10-10	60	11	20	20	1022.7	-1.27h	0.00h	0.00h
M (Catop 30)	02h30	23	2.7	71	10-10	60	11	20	20	1022.7	-1.27h	0.00h	0.00h
Catop	02h	23	2.7	71	10-10	60	11	20	20	1022.4	-1.27h	0.00h	0.00h
M (Catop 30)	02h30	23	2.7	71	10-10	60	11	20	20	1022.4	-1.27h	0.00h	0.00h
Catop	02h	23	2.3	71	10-10	60	11	20	20	1022.7	-1.27h	0.00h	0.00h
M (Catop 30)	02h30	23	2.3	71	10-10	60	11	20	20	1022.7	-1.27h	0.00h	0.00h
Catop	02h	23	2.9	71	10-10	60	11	20	20	1022.9	-0.27h	0.00h	0.00h
M (Catop 30)	02h30	23	2.9	71	10-10	60	11	20	20	1022.9	-0.27h	0.00h	0.00h
Catop	02h	23	2.9	71	10-10	60	11	20	20	1022.9	-0.27h	0.00h	0.00h
M (Catop 30)	02h30	23	2.9	71	10-10	60	11	20	20	1022.9	-0.27h	0.00h	0.00h

Figure 23. – Broadcast measurements

SE-ATMOSPHERE needs these input data in order to compute the radiative transfer of the atmosphere. The computation kernel is based on MODTRAN. SE-ATMOSPHERE computes for each altitude, LOS (Line Of Sight) and range, spectral values of atmospheric attenuation and self-emission that weight each ray traced by SE-RAY-IR to render the image.

In order to improve the model, SE-ATMOSPHERE automatically builds altimetric UIT profiles for temperature, hygrometry and pressure driven by the respective ground information.

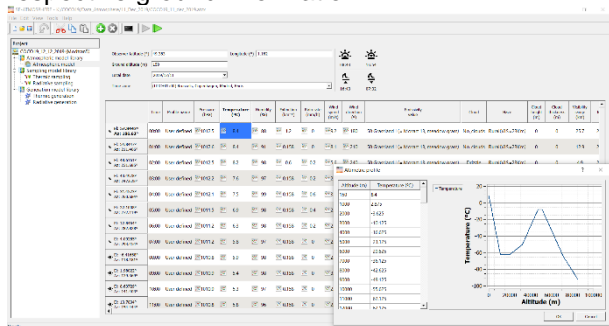


Figure 24. – Standard temperature variation with altitude

To fit the atmospheric simulation to measurements, the tuning has been concentrated on a cloud layer that has been added to the SE with two noticeable effects:

- Attenuate the solar irradiance in the sky

- Reduce the average radiance on ground.

The effect of a stratus cloud layer added to MODTRAN computation is obvious:

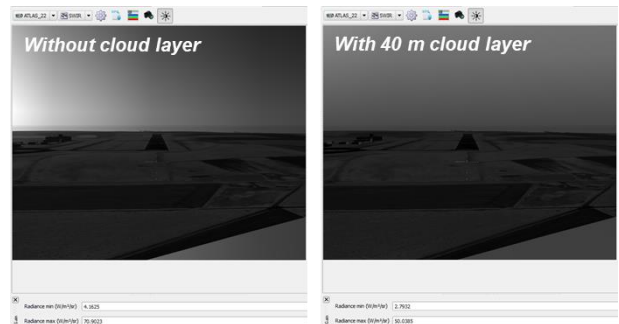


Figure 25. – Influence of the cloud layer in SE-Workbench

After several trials, the cloud layer thickness has been fixed to 10 meters:

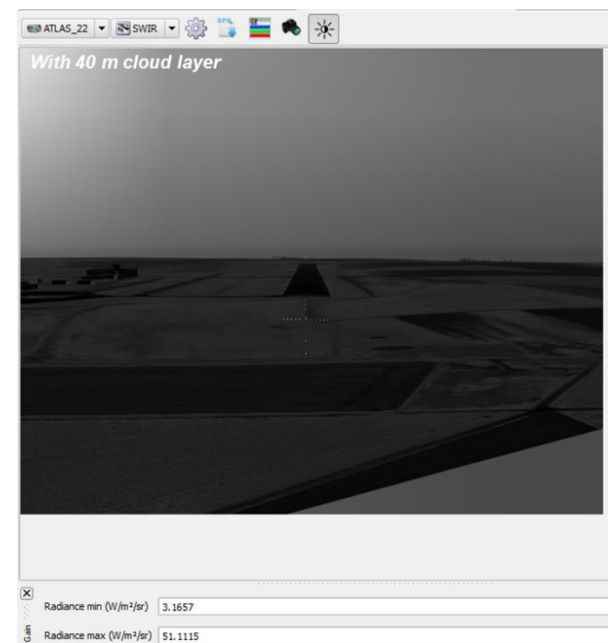


Figure 26. – Influence of the cloud layer in SE-Workbench

8. SENSORS MODELLING

The best simulation is the simplest simulation that gives good result. Good result depends on the frame of each application project. In other words, the simulation is accredited within each project context. In our case, the project is COCOTIER and the system is the Image Processing dedicated to runway detection for landing.

Each part of the simulation suit must be simplified. The previous chapters explain what is acceptable in terms of SE and rendering before sensor. The general simplification process is described in the following figure:

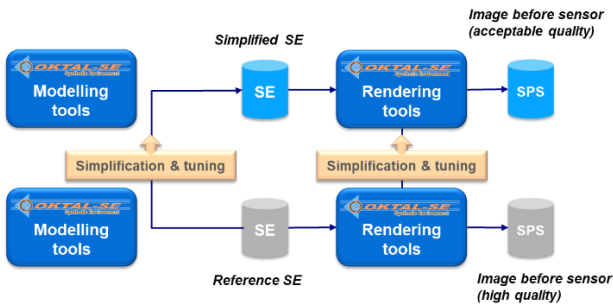


Figure 27. – simplification process: SE & rendering

We start with the more sophisticated and detailed SE as possible using the SE-Workbench modelling tools. Then we use these modelling tools for simplifying the SE (geometry, material, atmosphere, temperature) and process to the tuning thanks to real images feedback. Finally, we relax the level of accuracy of the renderers (resolution, wavelength sampling, antialiasing, recursion depth...) until the simplified rendering is acceptable.

This chapter focuses on the sensor model simulation. The general simplification of the sensor modelling is described in the following figure:

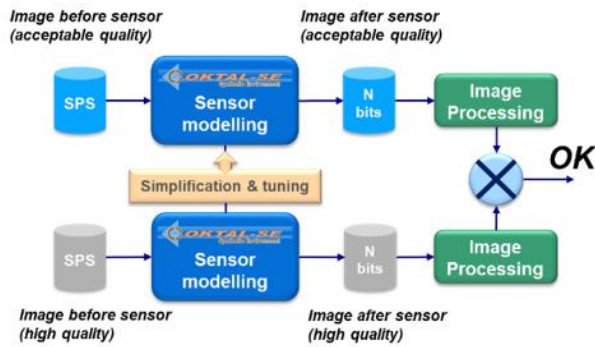


Figure 28. – Simplification process: sensor modelling

We start, on one hand, from the simplified but acceptable images and, on the other hand, from the high-quality images. We relax the level of accuracy of the sensor modelling (MTF, sensitivity model, NETD model ...) and feed the Image Processing for detection system from SED with both types of images. The criterion for simplification is the behaviour of this Image Processing system with regard to these two imagery fluxes. If no difference of detection is noticeable, then simplification is OK. The advanced modelling of the sensor is a dedicated SE-TK application of SE-Workbench. SE-TK is a set of C/C++/Python Application Programming Interfaces included in SE-Workbench. It is based on a SE-SCENARIO scenario file that stores all the needed information for computing the images before the sensor. Typically, a scenario agglomerates the static scene, made of terrain and objects, the trajectories of objects and sensors and the computation context of computation for each sensor (VIS, NIR, SWIR and LWIR Atlas monostatic sensors).

Once the image is loaded for a given date and a set of given sensors, the SE-TK-ADVANCED-SENSOR-MODEL applies several sequential models to mimic the sensor treatments. SE-Workbench-EO API is open, meaning that each user (here SED) can accept it as it is or overload the existing C/C++/Python that is delivered in source code. It is also possible for users to insert their private code. For instance, SED has the opportunity to add its own image distortion algorithm and its own statistical models of noise.

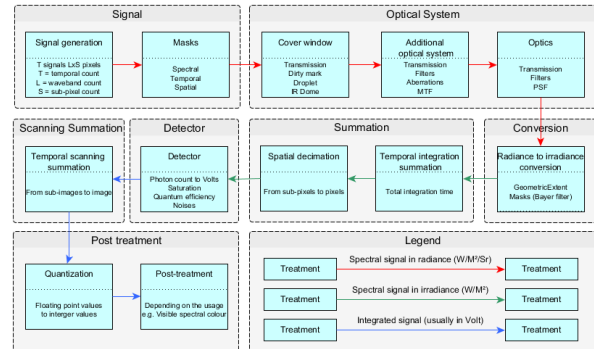


Figure 29. – Advanced sensor pipeline

The key feature of the advanced sensor model is a sampling process. In real world, everything is analogic. It means that photons have an infinite spectral accuracy that the spatial resolution is quasi-infinite and that time is continuous. Using simulation and ray tracing for rendering images, we need to sample wavelength, space and time. So, we start with a lot of wavelengths in the spectral band of each sensor (e.g. 80 wavelengths), with a higher image resolution than the sensor resolution (e.g. 5 times more pixels in X & Y) and with high time resolution (for instance 3 images during the integration time of the sensor that is much smaller than the camera frame period).

This is the “Signal Box” main function. The “Optical System” is decomposed into a specific optics (cover window, zoom...) and an intrinsic optics. SE-TK-ADVANCED-SENSOR-MODEL provides a theoretical model of Point Spread Function using Bessel’s functions, which constitutes the intrinsic model. In the “Detector” box, we provide for instance several models of noise, spatial temporal, additive or multiplicative.

These advanced sensor computations are very time consuming. The main interest is to validate the mandatory simplifications to be made before computing huge quantities of image.

9. METHODOLOGY

The objective of the COCOTIER project is to assess and accredit the current complex system under study dedicated to detect and locate the runway during landing for different flight use cases. System accreditation includes accreditation of the

associated twin Simulation Environment (SE) in order to make able and reliable the use cases verification (purpose of the paper).

Use cases include 'GNSS denied or not' occurrences but also various weather conditions for all seasons. In addition, they encompass capabilities to deal with configurations of indication lights emitters potentially switched on/off (for instance, Track Threshold light emitters).

Concerning SE Accreditation, we had to achieve previously the following primary steps:

- Verification
- Validation

Including the Accreditation step, we performed the full VV&A process (Verification, Validation and Accreditation).

OKTAL-SE, responsible of the SE modelling and rendering, has achieved the Verification process (refer to Chapter 3). The twin simulation is based on the SE-Workbench-EO which is a reference for various customers across the world (refer to Chapter 1). Of course, for the COCOTIER project, OKTAL-SE has developed a dedicated mock-up of Rouen Airport, selected as a reference airport for the COCOTIER project. Other airports mock-ups embracing different categories (International Airports including parallel runways) are next steps for further studies. Considering Rouen Airport, OKTAL-SE has led a topological and material study.

Associated to the Validation step, flight tests results have made it possible to tune different parts of the mock-up (refer to chapters 4 to 8):

- Materials (example of runway surroundings by selecting a finer raw material in the Material Database)
- Emitters Energy (Light Intensity tuning in different wavelengths by comparing sensor images from ATLAS platform with SE simulated images)
- Emitting sources dimension (example of the PAPI emitting surface in night conditions. The idea was not to model the full complex-emitting pod while keeping as well the sufficient level of modelling for the project. Modifications were driven by the observation of the ATLAS images, in other words, the real world to face)
- Sensors models. SED provided sensor models with a sufficient degree of representation of the real world for the different wavelengths under use.

All these parts of modelling focus on the objective to have a twin simulation whose confidence for the next module in the system architecture is stated (image processing to detect and track runway and emitters). To conclude, data is quite acceptable for use for the specific COCOTIER purpose, which consequently corresponds to its accreditation.

Today SED can affirm that this methodology is pertinent and we can apply it to many other use cases.

10. NEXT STEPS

We have presented a first level of improvement for Materials, Atmosphere, Lights. Improvement of these three items should be a focus point to be stressed on in the future.

Besides, many other items have not yet been fine-tuned:

- Trees and vegetation (according to seasons),
- Environment lights (cars, houses)
- Multi texturing,
- Clouds shadows (sparse cloud layer effects),
- Atmospheric diffusion,
- Wet effect...

In addition, the key point is the enrichment of the 3D mock-up with geo-specific details and besides modelling of other airports categories (for instance, international ones including longer parallel runways and taxiways). Nevertheless, we will respect the full VV&A process taking into account the customers' needs and the flight test records that is to say with compliance to the real world.

11. REFERENCES

1. Th. Cathala, J. Latger, Image simulation for HardWare In the Loop simulation in EO domain, OPTRO 2016
2. J. Latger, Th. Cathala, Multisensors simulation with SE-Workbench, OPTRO 2016
3. Thierry Cathala, Stéphane Barbé, Validation of SE-Workbench-EO In The Visible Spectral Band, OPTRO 2018
4. Jean Latger, Anthony Pajot, Thierry Cathala, Recent improvement of The "FAST" version of SE-Workbench-EO, OPTRO 2018
5. Julien Farjon, Dominique Maltese, EO/IR Sensor for UAV Detect and Avoid, OPTRO 2018