

RECENT IMPROVEMENT OF THE "FAST" VERSION OF SE-WORKBENCH-EO

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ABSTRACT:

SE-Workbench-EO is the international wording for CHORALE set of tools. CHORALE has been used by DGA for more than 20 years and has been recently improved to meet the needs of DGA MI, in the frame of HardWare in The Loop (HWIL) applications dedicated to IR seeker assessment. CHORALE enables to compute the same infrared spectral images according to two modes. The first one is slow and based on ray tracing. The second one is fast and based on Open GL, GPU shaders and CUDA. This paper focuses on the fast branch called SE-FAST-IR and describes the recent evolutions.

After an introduction to SE-Workbench-EO, the first part of this paper concerns the way to use CHORALE (SE-Workbench-EO).

Formerly, to get fast rendering in SE-Workbench-EO, it was mandatory for the users to pre-compute several data. In the current version, this "compilation" is done lazily (when needed) and transparently for the user.

Besides, SE-FAST-IR was formerly limited to one spectral band (such as SWIR, MWIR or LWIR). It is now possible to compute two/three separated bands during the same run, which is very useful for dual band sensor simulation for instance.

The second part of this paper deals with improvement of physical realism of this simulation. One important limitation of former SE-FAST-IR rendering was the flickering of objects smaller than the pixel to render. This limitation has now been by-passed.

Another limitation is the combination of highly wavelength dependent media. In the former SE-FAST-IR version, spectral management was not precise enough. A new method has now been introduced in order to get closer to the ray tracing physical accuracy. Validation results that are presented in this paper show good results, even in the worst cases.

A new type of physical texture typology has been introduced and called "material cover". Correlatively to this new texturation mode, the Wang-Tiling algorithm has been introduced, which enables to create a large variety of textures sharing the same Physics.

1. SE-Workbench-EO

The SE-Workbench is a multi-sensor battlefield modeling workbench mainly used by:

- Defense agencies as French DGA, German BWB, South Korea MoD, Singapore DSO/DSTA and Swedish FOI
- Research centers as ONERA, IOSB Fraunhofer Institute
- Industrials in and out of France as MBDA FR and UK, Dassault, LG, Samsung, Rafael...

SE-Workbench-EO concerns the infrared sensor simulation. SE-Workbench-EO can be associated to SE-Workbench-RF to perform Electromagnetic Radio Frequencies. SE-Workbench-RF has been used for many years by several MoDs in a consistent way (typically for sensor fusion assessment) and starts to be used by DGA now.

The SE-Workbench is made of several components, as described hereafter. It is basically made of two parts. The upper part concerns the Synthetic Environment "construction". The second part concerns the "exploitation" and more precisely the signal rendering associated to the modeling of the sensors treatments. This paper puts the focus on the real time rendering in the infrared domain i.e. the computation of the scene radiance.

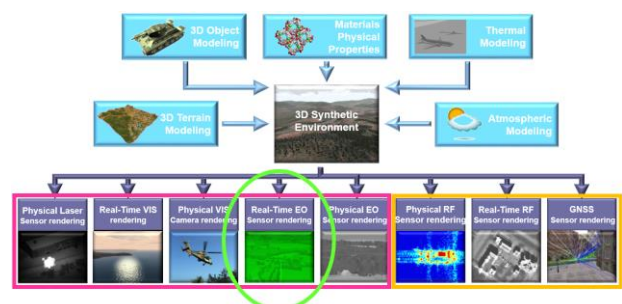


Figure 1. SE-Workbench components

The red left rectangle gathers the rendering modules in the ElectroOptics domain when the orange right rectangle gathers the rendering modules in the Radio Frequency domain.

This paper focuses on the SE-FAST-IR infrared rendering module that is encircled in green.

2. Ergonomics improvement

2.1. No more pre-computations

Formerly, to get high rendering performances (for instance from 30 Hz to 300 Hz) it was mandatory for the CHORALE users to pre-compute several

data. Each object of the Synthetic Environment was supposed to be "compiled", meaning prepared, with respect to wavelength, material, atmospheric configuration, orientation, altitude ... In the current version, this "compilation" is done "lazily" (when needed) and transparently with regard to the user.

In the new SE-FAST-IR version, it is no more necessary to know, before loading the scene and the scenario, the complete list of materials to be used, neither to know the spectral bands to be used during the simulation. This illustrates the "lazy" concept. The material and the spectral band analysis is simply done "on fly", when necessary.

Historically, several versions, over more than fifteen years, have been necessary to reach this current state and high level of performance.

In 2002, the first version of SE-FAST-IR needed a specific compilation of the 3D scene to produce radiances for a given spectral band (typically SWIR, MWIR or LWIR bands). The rendering was performed by OpenGL. An Open GL exponential law of fog was parameterized and used to simulate the atmospheric transmission.

In 2007 the OpenGL code has been replaced by "shaders". The "shader" is basically a piece of code that runs directly on the GPU, using graphics memory and graphics processor power, but with a reduced set of instructions. In that version, self-emission of surfaces (Black Body law) and reflection of sun/moon irradiance, associated with sky/ground radiance, became uncorrelated.

The 3D scene was still compiled for the given sensor band so that the physical materials and textures, the material being defined both for emission/reflection and for thermal characterization (used for predicting temperatures). In that 2007 version, sky/ground radiance was directly issued from SE-ATMOSPHERE/MODTRAN radiative transfer computations. Light source characterization, based on intensity diagram definition, has improved the quality of representation of lights. In that version, a classified texture could only address 4 physical materials.

In 2010, the limitation to 4 went to 8 materials. A simplified model was introduced for the sea representation and for cloud layers. That time, a new model has been designed to put Physics on particles systems.

In 2012, there was no more limitation in the number of materials for classified textures. Thermal shadows management became operational. A 3D Swan model of sea surface, associated to wakes, foam and white caps appeared.

In 2014, external compilation of thermal states was no more necessary. Besides the OpenGL limitation concerning the number of light sources was definitively bypassed.

In 2016, a sky dome representation was added to SE-FAST-IR in order to represent the stars in the sky at the good position and with the good spectral radiance.

In 2017, many improvements have been performed, which are described in this paper.

2.2. Multi-band capability

Besides, SE-FAST-IR was formerly limited to one spectral band (such as SWIR, MWIR or LWIR). It is now possible to compute two/three separated bands during the same run.

SE-FAST-IR can either output multi-band images (one per spectral response), or sum the result obtained for each spectral response.

For display, SE-FAST-IR always sums the results for each pixel, and radiance gain is applied to the sum.

The following images show SE-FAST-IR in visible, SWIR, MWIR and LWIR domains:

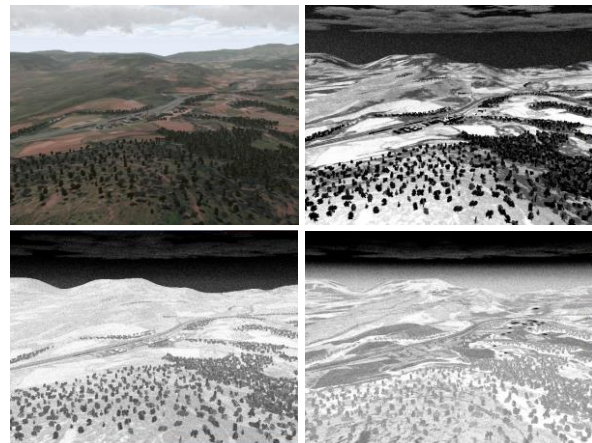


Figure 2. Multi-band capability of SE-FAST-IR

3. Physical realism improvement

3.1. Sub-pixelic rendering

One important limitation of former SE-FAST-IR rendering was the flickering of objects smaller than the pixel to render (for instance a far range incoming missile). In this new version, the intrinsic aliasing due to Open GL graphic board has been bypassed using a dedicated method based on GPU mip mapping.

The method that is now natively implemented in SE-FAST-IR is based on identification of objects (targets) that can be smaller than the pixel in the image. A dedicated rendering is performed for these objects using a larger local resolution. Then this rendering is integrated within the global image. Various tests have been performed to control the intensity values especially using comparison with SE-RAY-IR that has no limitation of accuracy.

The process for activating sub-pixelic rendering needs 2 steps:

- 1) Flag all the objects that need a specific rendering (using SE-SCENARIO):

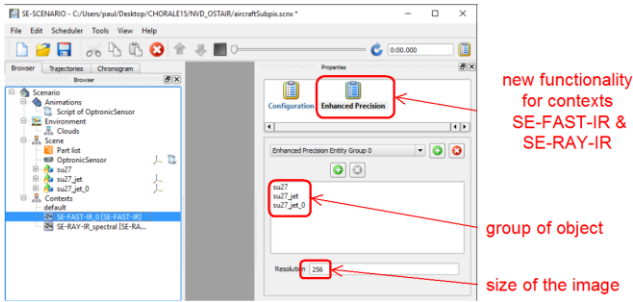


Figure 3. Configuration of targets

2) During the rendering: when the footprint of the objects is less than a specific value (for example 256):

- a) Computation of an image 256 x 256 = texture
- b) Mapping of this texture on a quad that replaces the objects (the automatic filtering of this texture being managed by the GPU mip mapping process in order to assume perfect merging of the super-sampled image within the origin image)

In the figure below the target is a fighter. Using a bounding box, the pixels attached to this target are identified in the origin image:

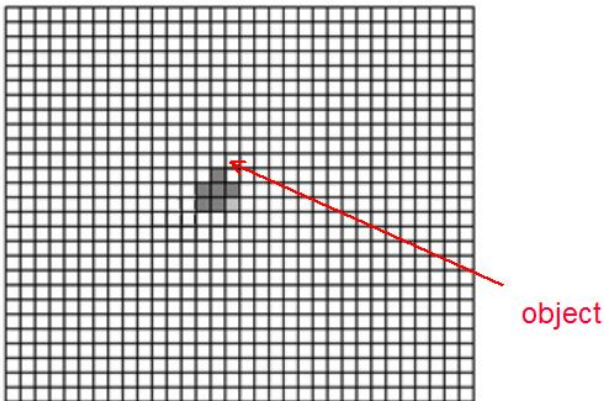


Figure 4. Sub-pixelic target

According to the apparent surface of the target, a dedicated "quad" is automatically created in the origin image:

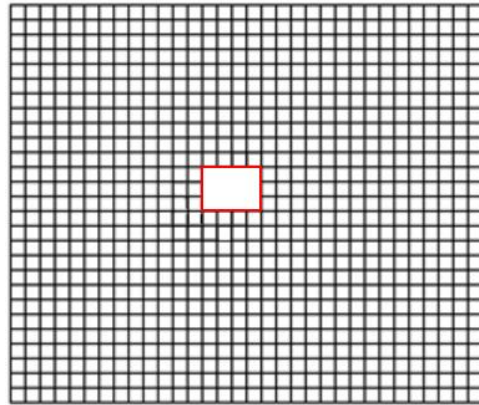


Figure 5. Associated quad to a sub-pixelic target

Then a high-resolution image is computed by the GPU in parallel to the origin frame computation:



Figure 6. Super-sampled target image

Finally, this super-sampled image is inserted into the quad and filtered by mip mapping:

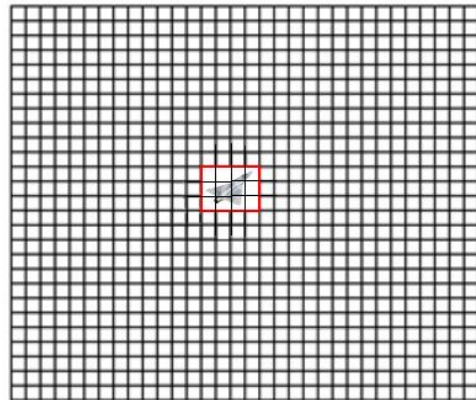


Figure 7. Super-sampled image merging

This new approach is fundamental for temporal analysis of detection algorithms performance using simulation. Many trials are on the road in DGA MI to check the detectivity continuity in time when a sub-pixelic object is getting closer from a simulated sensor in the frame of HardWare In the Loop applications involving infrared sensors.

3.2. Multi-spectral computation

Another limitation is the combination of highly wavelength dependent media. For example, within a pixel, the body of an aircraft, the plume of its

exhaust gas, the atmospheric segment to the observer and the spectral response of the sensor. With the spectral ray tracing approach, it is possible to compute a lot of spectral images within the spectral band of the sensor and to correctly recombine all the wavelength dependent attributes. In the former SE-FAST-IR version, based on Open GL, the under bands were limited to three (R, V, B). A new method based on Principal Component Analysis has been introduced in order to get closer to the ray tracing physical accuracy.

When the radiative equation is solved using the ray tracing technique, the global spectral band is divided in a large set of very thin under-bands for computation. In that case, if "Int" is the integration operator, for a given thin under-band, considering several wavelength dependent functions f:

$$\text{Int}(f_1 f_2 \dots f_N) \cong \text{Int}(f_1) \cdot \text{Int}(f_2) \dots \text{Int}(f_N)$$

On the contrary, considering the whole spectral band:

$$\text{Int}(f_1 f_2 \dots f_N) \neq \text{Int}(f_1) \cdot \text{Int}(f_2) \dots \text{Int}(f_N)$$

This is the main problem to solve using real time technique and GPU pixel shaders. This is the key challenge for SE-FAST-IR.

To understand the spectral problematic it is interesting to introduce some wording first.

Five terms are basically evaluated with regard to wavelength:

- R(λ): sensor spectral response
- T(λ): atmospheric transmission
- L(λ): self-radiance
- M(λ): material data (emissivity, diffusion, ...)
- E(λ): scattered energy (BBL, sky radiance, ...)

Two classes of integrals on wavelength are to be evaluated to compute the infrared images:

- Int(R T L) → self-radiance
- Int(R T M E) → thermal self emission, reflection & scattering

Then we have to introduce some mathematical tools, which are very useful to manage spectral dependence. These tools are now implemented in SE-FAST-IR.

Let us consider several wavelength dependent functions f and a highly spectral dependent g function. We introduce the "split" approximation tool as defined here after:

$$\text{Int}(f_1 f_2 \dots f_N g) \approx \text{avg}(f_1) \cdot \text{avg}(f_2) \dots \text{avg}(f_N) \cdot \text{Int}(g)$$

with "avg": the average operator.

Let us consider the simple following example with one f function and the g function:

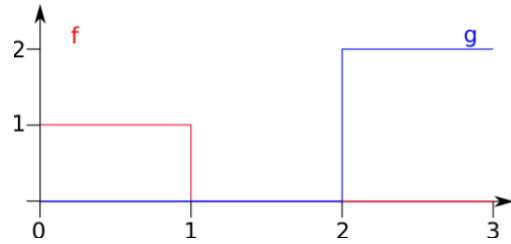


Figure 8. Example of spectral functions

$$\text{Int}(f g) = 0 \text{ and } \text{avg}(f) \text{Int}(g) = 2/3.$$

Note that if f were constant, this operation would be correct.

In order to minimize the errors due to the non-uniformity of these spectral dependent functions, OKTAL-SE has developed an approximation mathematical called 'projection'.

In the following equation, the T function is replaced by a T* function in order to make the approximation correct:

$$T_j(\lambda) \cong \text{sum}_i(w_{i,j} T^*_i(\lambda))$$

$$\Rightarrow \text{Int}(T f) \cong \text{sum}_i(w_i \text{Int}(T^*_i f)) = \text{Int}(T^* f)$$

Thanks to this "projection", it is possible to approximate thousands of similar T functions by interpolating a few well-chosen T* functions

This approach has recently been introduced in SE-FAST-IR to handle atmospheric transmission: it is called "model spectra". It leads to a very accurate approximation of atmospheric transmission spectra in practice using only 4 to 8 model spectra is sufficient, which is quite reasonable with regard to real time performances.

The following figure shows very nice results based on "projection":

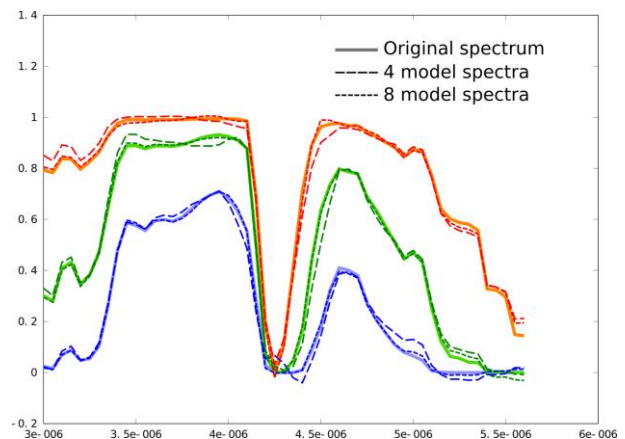


Figure 9. "Model spectra" versus original spectrum

Another method, "pre-modulation", has been introduced in order to take into account the "spectral response" of the sensor for the sensor modeling. This method aims at ignoring or damping unwanted parts of spectra:

$$\text{Int}(R f g) \approx \text{Int}(R f) \text{Int}(R g) / \text{Int}(R)$$

$$\text{Int}(R g) / \text{Int}(R) = \text{Int}_R(g)$$

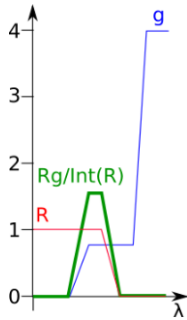


Figure 10. Example of "pre-modulation"

A set of new equations have so been implemented in SE-FAST-IR, which can be summarized by the following items:

Two classes of integrals on wavelengths:

- $\text{Int}(R \ T \ L) \rightarrow$ self-radiance
- $\text{Int}(R \ T \ M \ E) \rightarrow$ thermal self emission, scattering

Several mathematical tools:

- Split : $\text{Int}(f_1 \dots f_N \ g) \rightarrow \text{avg}(f_1) \dots \text{avg}(f_N) \text{Int}(g)$
- Projection : $\text{Int}(T^* \ f)$
- Pre-modulation : $\text{Int}_R(g)$

Specific approximations for each class in each implementation.

3.3. Material Cover texturation

A new type of physical texture typology has been introduced and called "material cover". It consists in using raster textures as direct (u, v) texture coordinate references to the nature of a given material indirectly characterized in term of radiative and thermal attributes.

3.4. Wang Tiling

Pattern repetition is a common artifact of conventional texture mapping techniques. This bad effect is often called the "ravioli" effect within our French community:



Figure 11. The "ravioli" effect

This effect is drastically biasing the image processing algorithms using synthetic images since these algorithms precisely search for repetition and correlation in order to perform detection.

"Mask" multi-texturation technique that is available in SE-Workbench and consists in combining a self repeated texture pattern with an independent

pattern that perturbs the first one in some dedicated locations, may be an answer to attenuate the problem of pattern repetition, by using a mask covering a large area mixing several small area texture patterns.

Wang-Tiling is another mapping technique that enables a texture to be mapped on a large area without any repetition of a pattern. The basic principle of the Wang-Tiling technique is the same as "dominos" game: a set of elementary square tiles matching to some others by a common side. Each time you have to place a tile, you have the choice to place on any free side one of the matching tiles you have. On a large area, each elementary tile can be repeated many times but each time in a different context.

Each tile side is associated to a "color". Actually the "color" wording must be understood as a "reference". Matching tiles share the same side or edge color.

In the figure below, a set of tiles have been prepared (in the left part of the figure) in order to populate the terrain (dashed line in the right part of the figure) with the convenient tiles. For example, a [up/blue, right/green; down/blue, left green] is needed and found in the prepared tiles:

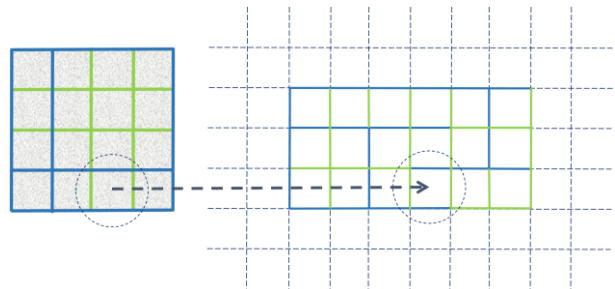


Figure 12. Example of 2 colors border selection

The Wang-Tiling technique that is used in SE-WORKBENCH is based on corresponding "corners" rather than corresponding "sides". The same corner colors on their sides. The implemented algorithm in SE-WORKBENCH can manage up to four different colors. The more colors you use, the more different elementary tiles you get.

For a two-color Wang-tiling you will get $2 \times 2 \times 2 = 16$ different tiles.

For a three-color Wang-tiling you will get 81 different tiles ($3 \times 3 \times 3$).

For a four-color Wang-tiling you will get 256 different tiles ($4 \times 4 \times 4$).

In the following figure, the texture is a simple black & white drawing and uses a 2-colors constraints:

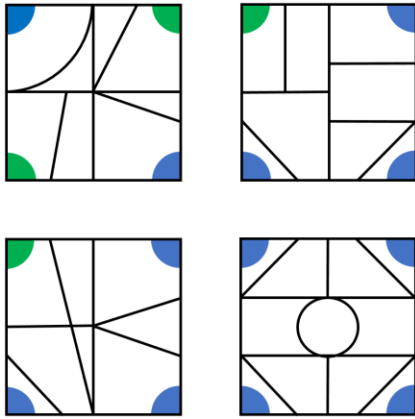


Figure 13. Example of 2 colors border creation

In the following figure, a winning combination is shown. The "game" consists in having circles (made of 4 quarters of circles) all with the same color. Note that there are 256! combinations of tiles i.e. 10^{507} combinations.

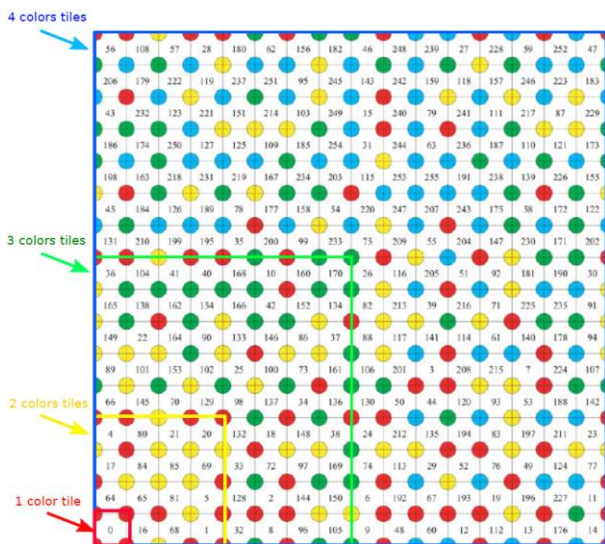


Figure 14. Wang-tiling texture structure, elementary Wang tiles for 2,3 and four colors

Generation of the Wang tiles consists first in extracting random tile corner samples from an input texture.

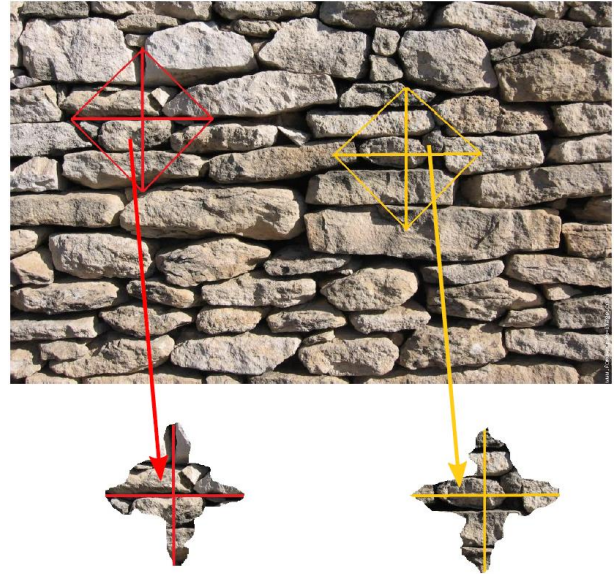


Figure 15. Wang-Tiling corner extraction for two colors

Assembling the corners in the Wang-tiling texture pattern produces the skeleton of the Wang-Tiling texture.

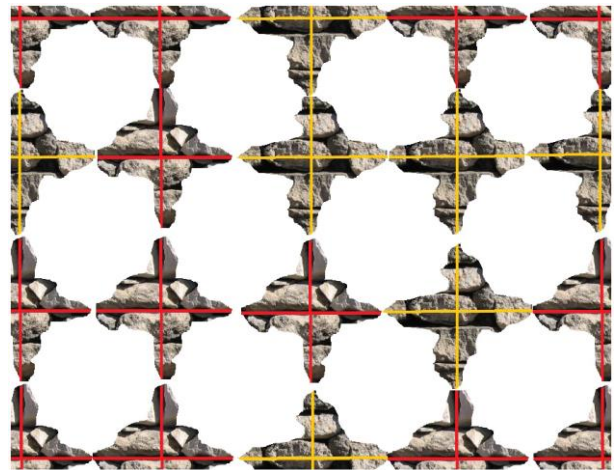


Figure 16. Wang-tiling texture structure with corner for two colors

The last step consists in filling the gaps between corners by extracting new samples from the original texture that match the gaps and reconcile differences on transitions.



Figure 17. Wang-tiling resulting texture

Using the Wang-Tiling texture and the corresponding Wang- Tiling mapping, grid pattern repetition should be avoided.

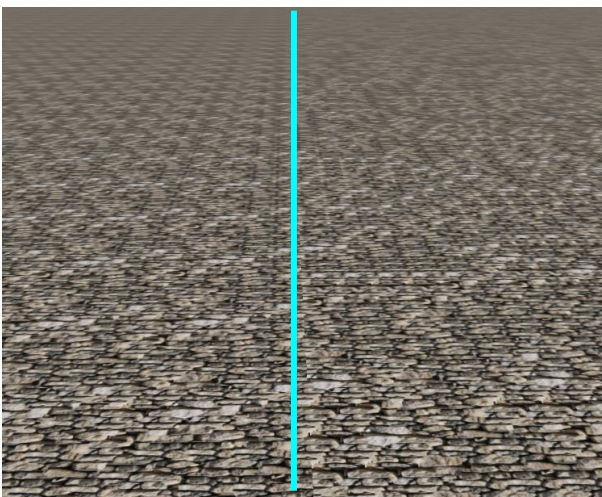


Figure 18. On left side standard texture mapping. On right side Wang-Tiling texture mapping (2 colors)

Dedicated GUI have been introduced in the SE-Workbench physical modelling tool SE-PHYSICAL-EDITOR to synthesize Wang-Tiling texture. The creation is done in three steps. The first step is the selection of the input texture file.

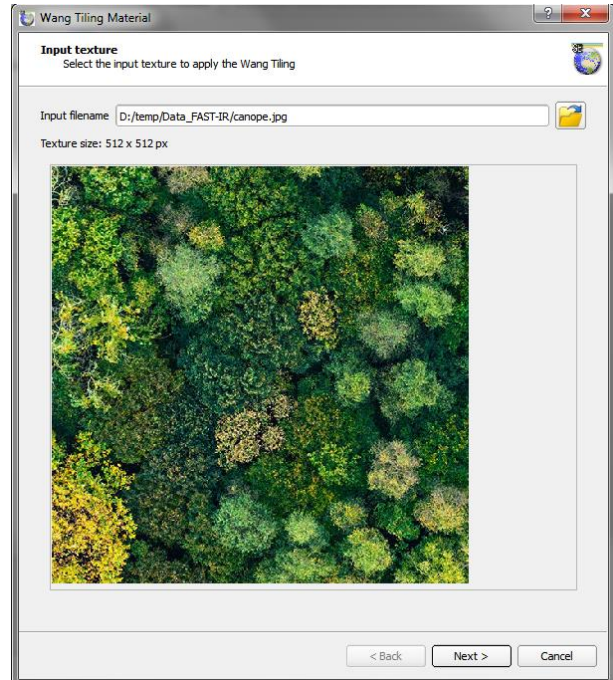


Figure 19. Origin texture

The second step is the settings of the Wang-Tiling parameters:

- The number of corner colors
- The tile size.

Finally, the user can see the progression of the tiling during the computation. Once the computation is done, the final texture is displayed as a set of tiles. All the tiles are selectable and can be generated again and again.

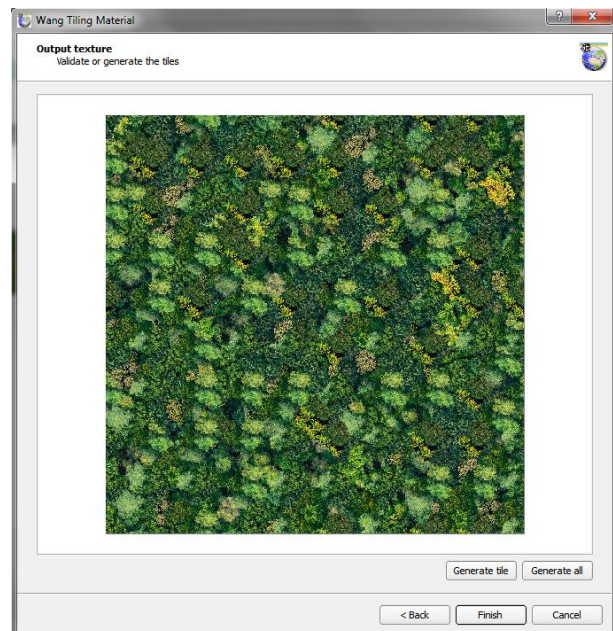


Figure 20: Wang-Tiling generation

The final rendering and the advantage of Wang-Tiling approach is obvious and illustrated by the two following figures:

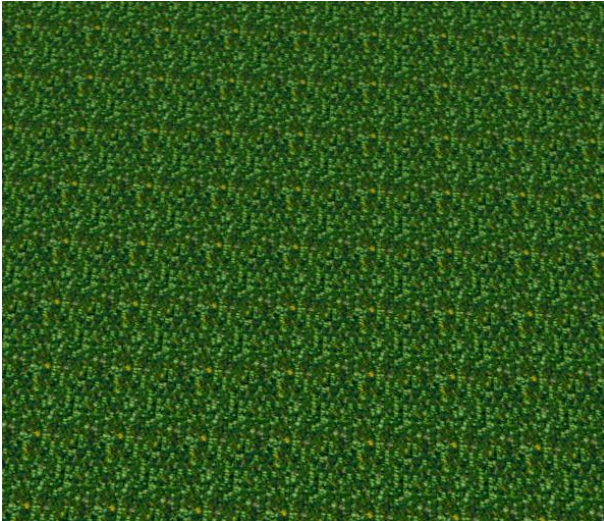


Figure 21. Without Wang-Tiling

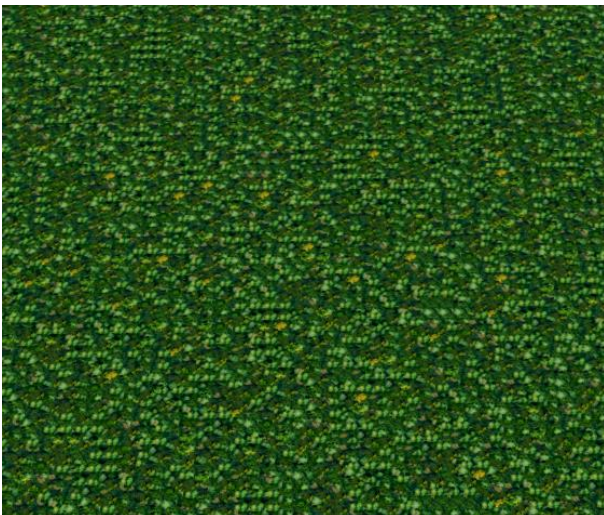


Figure 22. With Wang-Tiling

Note that this texturation mode using Wang-Tiling method is intrinsically carrying the physical classification i.e. that each texel refers to a dedicated physical material made of a complete set of spectral and thermal attributes. That way, provided the classification is correct for the origin sample, the whole Wang-Tiling huge texture is correct, which is a warranty of no room for manual errors.

4. CONCLUSION AND FUTURE WORK

The improvements presented in this paper are very important for SE-Workbench-EO promotion and position in the top international market.

They contribute to fill the gap between ray tracing spectral computation (that remains the reference simulation with regard to Physics) and real-time computation.

Real time computation is more and more required by customers dealing with simulation. The main application is closed loop application and especially HWIL application (e.g. SE-FAST-IR

producing virtual images for an infrared projector that illuminates a real infrared seeker inside a laboratory). In that case, there is no other choice than real time. Besides, parametric studies and deep learning applications are more and more demanding. They need more and more images. So, even for these open loop applications, the image time of computation must be drastically reduced, which emphasizes the interest for SE-FAST-IR.

One very important issue for the future is the "material cover" and associated Wang-Tiling approaches that enable to perform a quasi-infinite variety of physical materials. This is all the more important as customers ask for larger databases and with more details. OKTAL-SE is currently developing an add-on of SE-Workbench called WTS, based on procedural "on fly" computation of geometry, texture and Physics that aims at representing the whole earth (like GoogleEarth™) seen by a sensor. In that case, the "material cover" and associated Wang-Tiling approach is crucial to populate such a large surface.

5. REFERENCES

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