SE-RAY-IR improvements : an advanced illumination approach for infrared rendering of outdoor scenes

Antoine BOUDET, David PRATMARTY, Paul PITOT and Thierry CATHALA
OKTAL Synthetic Environment

ABSTRACT :

SE-RAY-IR is the physical ray tracing software from OKTAL Synthetic Environment that constitutes the core of the CHORALE workbench for the French Ministry of Defense. It enables the computation of high realistic images in visible and infrared spectrum based on complex scenarios. Its physical model takes into account the thermal emission of materials, the contribution of sky irradiance without occlusions, diffuse and multiple specular reflections.

The software gives good results according to the used physical model. However, it suffers from some limitations. As many ray tracing algorithms, it formally used a simple material model based on a canonical decomposition of the bi-directional reflectance distribution function (BRDF) in more or less diffuse and specular components. SE-RAY-IR also offers an advanced rendering algorithm, called Photon Mapping, in order to handle complex multiple reflections. This is well suited to render confined scenes (i.e. building interiors, engines...) and is the best in order to simulate light focalisations (i.e. caustics) that could create unexpected hot points (useful for infrared signature simulations). This technique strongly raises the realism of simulation, unfortunately, it cannot be used directly for outdoor scene rendering. Actually, the simulation of very extended light sources (like the sky dome) leads to an enormous memory consumption that cannot be supported by most computers.

In this paper, we describe the evolutions of SE-RAY-IR. The first evolution concerns an improvement in the description of physical materials using a BRDF model which describes complex materials (from user defined analytical models to measured data sets). The second improvement concerns the rendering algorithm. We propose a highly configurable hybrid approach which takes the best suited method for each simulated phenomena among a set of literature rendering methods. Then our hybrid approach benefits from their respective advantages. It enables the computation of highly realistic simulation of outdoor scenes, taking into account sky light multiple reflections, extended sources and glossy reflections.

INTRODUCTION

Visible, infrared, electromagnetic or acoustic sensor systems are usually difficult to simulate due to the complexity of the required synthetic environment modelling. The OKTAL-SE suite of software (SE-WORKBENCH [13]) enables the creation of realistic multi-spectral synthetic environments. The priority of the software is to provide physically accurate 3D databases and databases of physical materials. The usage of ray tracing and 3D graphic board techniques for the scene analysis enables the generation of high quality scenes of complex scenarios.

SE-RAY-IR is part of the SE-WORKBENCH software suite. In the infrared spectrum, the workbench provides both simplified real time (SE-FAST-IR [12]) and advanced non real time (SE-RAY-IR) rendering. The second is used for studies and validates the results of the first one.

SE-RAY-IR uses a ray tracing model in order to compute high realistic images in visible and infrared spectrum based on complex scenarios (3D scenes, atmospheric and thermal conditions, sensors, trajectories). In this paper, we briefly present SE-RAY-IR and its place in the SE-WORKBENCH suite in section 1. In section 2 and 3, we respectively study the models used in the current version. In these two sections, we first present the considered model, then we discuss it in order to show its limitations and justify the improvements that are in the process of being developed and that are going to be released next year. Section 2 contains the discussion concerning the material model, and section 3 contains the discussion about the advanced illumination (currently based on the Photon Mapping method). In section 4, we propose some preliminary results in order to give an idea of the level of physical realism we will attain in the next version of SE-RAY-IR.

1 SE-RAY-IR PRESENTATION

SE-RAY-IR comes as the advanced simulation tool for the visible and the infrared spectrum. Its results are used for both studies and validation of the real time simplified tool SE-FAST-IR. SE-RAY-IR is integrated in the SE-WORKBENCH suite which provides all tools necessary to feed the ray tracing software with scene and materials description, trajectories, scenario ...

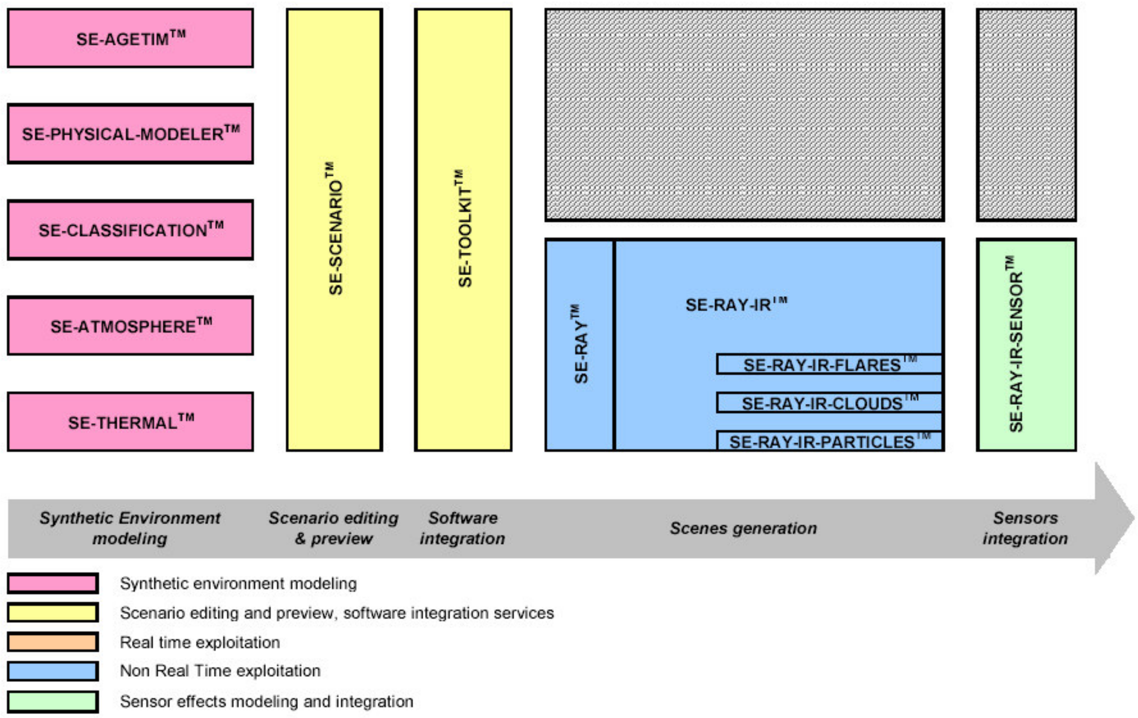

Figure 1 : SE-RAY-IR integration in the SE-WORKBENCH

SE-RAY-IR is a ray-tracing tool, it uses the same principle as every ray tracing algorithm [1]. However, one of the most important specificities of SE-RAY-IR is that it has an original concept due to the use of a physical model that computes images spectral small band per spectral small band. The spectrum is divided into bands of wavelength according to the sensor. This means that the radiative quantities of all scene materials are convoluted over wavelengths. Then all the radiance computations are done using these bands.

SE-RAY-IR also offers an advanced rendering algorithm, called Photon Mapping, in order to handle complex multiple reflections.

2 MODEL PRESENTATIONS AND DISCUSSIONS

The software gives accurate results. They have been validated using measurement campaigns. The model takes into account thermal emission, atmospheric condition for user defined 3D scenes.

However, it suffers from some limitations. The first limitation concerns the material definition. The second limitation concerns the memory consumption of the advanced rendering model (i.e. Photon maps) for outdoor scene- rendering.

These limitations come- from the fact that choices had to be made according to the hardware limitations concerning processing power and memory consumption. Actually, solving the real radiative model in complex environments should demand an infinite computing time. Some Monte Carlo methods typically used by physicists can give exact results with huge computing times. This is acceptable in physics, because most of the time, the results are computed only for simple study cases and for a limited amount of evaluation points. The interest of SE-RAY-IR is to extend these models to complex scenes. It seems evident that taking these models as they are is impossible. Some hypotheses have been taken at the creation of SE-RAY-IR in order to optimize computations. These hypotheses had a strong dependency on the hardware limitations. Hopefully, with the perpetual progress of computer processing power, we can now raise the complexity of our models in order to get rid of some hypotheses and then raise the realism of the simulation. For example, ten years ago, the computation of an image took about ten minutes whereas now it takes only a few seconds for the same image. As we gain a lot of computation time, we can solve some limitations of the SE-RAY-IR model.

2.1 MATERIALS

2.1.1 CURRENT MODEL

Materials are described by their radiative quantities i.e. self emitted radiance, transmittance, specular and diffuse BRDF. As many ray tracing algorithms, it formally uses a simple material model based on a canonical decomposition of the BRDF in more or less diffuse and specular components. Radiative data values are however described spectrally with an angular dependency (using textures).

2.1.2 LIMITATIONS

In the current version of SE-RAY-IR, materials are defined using OKTAL-SE modelisation file format (SDM). This does not give much flexibility to users. Actually, users can only define their own materials providing that they convert them into SDM format. In this case, depending on the model to encode, there could be a loss of data due to the conversion.

Another limitation of the BRDF model is the decomposition of energy between so called specular and diffuse components. It is a problem when we have to do random sampling of the BRDF as we do in the Photon Map method. In this case, it would be better to have a material that is able to sample the incoming and/or outgoing hemisphere direction according to the repartition of energy in both specular and diffuse parts of the BRDF without explicitly decomposing the model.

2.1.3 EVOLUTION

Both these problems can be solved using the same approach. The first evolution concerns an improvement of the description of physical materials using a BRDF model which describes complex materials. In order to authorise, the user to define a BRDF model as complex as he wants without loss of data, the next version of SE-RAY-IR will offer a generic material interface providing a function for each quantity needed to describe the material (i.e.: self radiance, transmittance, BRDF ...).

This interface can be implemented by the user through a dedicated toolkit. With this interface, the user will be able to describe analytical models as well as to load measured data sets directly from his own format. Of course, backward compatibility with existing materials will be respected and our material description will be totally adapted to our advanced rendering methods. This means that SE-RAY-IR advanced rendering methods (presented in the next section) will take into account user materials without additional implementation from the user.

From a general point of view, the material evolution will enable the user to handle any kind of material from analytical models to measured data sets. It will take into account with a greater realism non perfectly specular or diffuse materials which we call *glossy* materials.

2.2 ADVANCED RENDERING

2.2.1 CURRENT ALGORITHM : PHOTON MAPPING

The photon mapping method [2, 11] was developed and validated in order to optimise the computations of multiple scattering effects in confined scenes (i.e. building interiors, engines...). In fact, these scenes are composed of closed spaces with little energy loss, and where light sources (even if extended) are small. The photon map method is a two pass method. It first propagates light particles (or photons) through the scene and stores their impacts in a temporary data structure independent from the geometry. Then a gathering pass is performed by tracing primary rays through the scene, and computing the radiance of their intersection with the scene using the density estimation of the k nearest stored particles. The method gives very good results for this kind of scene. Actually, as few photons are lost (no intersection with the scene) and photons multiple reflections are numerous, the number of photons to use is small (relatively. In most case, a few million photons are needed).

2.2.2 LIMITATIONS

The limitation of the photon map method is its memory consumption. Indeed, if the number of photons used is not sufficient, the method suffers from low frequency noise. This noise disappears when the number of samples (photons) tends toward infinity. Of course, we cannot use an infinity of photons, then we throw as many photons as we can store in memory.

We have already proposed a multi-pass approach in SE-RAY-IR in order to increase the accuracy of results by making a compromise between memory consumption and rendering time. Even if this approach gives results with a great accuracy, it has quite long computation times. In fact, in order to divide the error by two, the number of rendering passes has to be doubled.

The photon maps is well suited to render confined scenes and is the best in order to simulate light focalisations (i.e. caustics) that could create unexpected hot points (useful for infrared signature simulations). This technique strongly raises the realism of simulation, unfortunately, it cannot be used directly for outdoor scene rendering. The simulation of very extended light sources (like the sky) in vast scenes (about 20 km²) leads to an enormous memory consumption that can't be achieved by most computers.

Actually, in the current version, photons are emitted from light sources toward all the surfaces of the scene. In order to have a sufficient density on every scene surface, we have to store an enormous amount of photons, which cannot fit into most computer memory.
The second problem is that in the current version, light sources are considered to emit in all directions. Then, a lot of photons are lost (no intersection with the scene), which results in unnecessary computations that raises rendering time.

The third limitation is to take into account very extended light sources as the sky or the environment. In the current version, the sky is only taken into account considering that for any point of the scene, the whole sky is seen depending on the surface orientation. Sky occlusions are neglected. There is no multiple skylight reflections.

2.2.3 EVOLUTIONS

Our goal is to upgrade the current model of SE-RAY-IR so that it will be able to handle much more complex phenomena. At first glance, it looked like Photon Mapping was the best method to solve global illumination of a scene. Unfortunately, we saw in the previous section that the method can hardly be applied as is to outdoor rendering.

However, in state of the art image synthesis , a lot of methods have been suggested to solve the global illumination of scenes. Most of them are based on the principle of Monte Carlo integration [3, 5, 6, 7, 8, 9], as the Photon Mapping is. From a general point of view, each of these methods use raytracing in order to compute the samples needed to solve the rendering equation [4]. Of course, each of these methods has its own pros and cons. Actually, they give good results we used in the case they were designed for. For example, forward ray tracing (rays traced from the eye toward light sources) is better at handling direct lighting than backward ray tracing (rays traced from light sources), but the last one is better than the first at handling indirect lighting.

From this observation, we thought about using several global illumination methods based on Monte Carlo ray tracing and melting them together instead of using only one of them (i.e. Photon Mapping). The interest of integrating all these methods in one hybrid method is that we can use each method for what it is best forand only for that. Hence, we get rid of their disadvantages while keeping their advantages.

In the next version of SE-RAY-IR, we will be able to handle the following phenomena using our hybrid method:

- sky light occlusions,
- sky light multiple reflections,
- environment lighting,
- glossy materials,
- direct lighting of small extended light sources,
- indirect lighting of small extended light sources,
- solar cone,
- sun indirect lighting.

For each phenomenon, we use slightly different methods that are adapted according to the specificities of these phenomena. For example, we sample a small extended light source by tracing several rays to random points on its surface for the evaluation of direct lighting, and use the photon map to solve its indirect lighting. However, it's not possible for the sky because it is too wide. The number of samples to use for direct lighting could be enormous, and as we saw that Photon Maps are not really adapted to very extended light sources. Hence, we prefer to use a stratified sampling technique with multiple reflections in order to deal with direct and indirect lighting of the sky.

Of course, compared to the current version of SE-RAY-IR, taking into account these phenomena will demand more resources. Hopefully, we only propose this as advanced rendering options, and there will not be losses of performances for classic rendering.

Applying Monte Carlo methods directly gives good results, but is still time consuming. We use a special cache that enables us to compute only a set of necessary points and extrapolate to others. For example, in a 1024x1024 image, we have to compute only a fifth of the million pixels (depending on the scene complexity).

The future version of SE-RAY-IR will also authorize the user to define zones of interest where advanced rendering will be used. Actually, we are often interested in localised effects, for example the zone around a mobile (aircraft, tank...). Then advanced computation will only be done for a limited part of the image, resulting in a diminution of computing times.

3 PRELIMINARY RESULTS

Figures 2, 3 and 4 present advanced rendering of a complex scene using several atmospheric conditions. These are spectral images.

Figures 2 and 3 respectively use morning and midday atmospheric conditions for sunny weather. Figure 4 uses midday conditions for a cloud covered sky. For each case, the rendering was done using both the current and future version of SE-RAY-IR. In this scene, the only light sources are the sun and the sky.

As we can see, simulating advanced effects is more important for cloud covered sky. As a matter of fact, the radiance variation due to extended light source occlusions is very small in front of radiance received from the sun. Then when rendering sunny scenes, the user should adapt simulation parameters in order to optimise rendering times. Actually, the advanced rendering method is highly configurable, and the choice of better parameters can drastically reduce rendering times. For example, if accuracy parameters are too demanding, the computing time can increase exponentially without decreasing the error in a perceptible way. So a good knowledge of parameter influence is needed to obtain the best compromise between computation times and accuracy.

These renderings are in visible spectrum so that we can easily notice the realism given by our advanced rendering algorithm. However, the method is totally compatible with infrared rendering. The example in figure 4 is the more representative of the results in the infrared spectrum. Actually, the sun contribution in infrared spectrum is very reduced, then the very extended sources (the environment and sky) lighting effects are more important and noticeable in the image.

Figure 2: Visible rendering of a scene with a morning atmospheric file using the current version of SE-RAY-IR (left) and the future version with advanced rendering (right).

Figure 3: Visible rendering of a scene with a midday atmospheric file using the current version of SE-RAY-IR (left) and the future version with advanced rendering (right).

Figure 4: Visible rendering of a scene with a cloud covered atmospheric file using the current version of SE-RAY-IR (left) and the future version with advanced rendering (right).

CONCLUSION

In this paper, we have presented the SE-RAY-IR raytracing software that is part of the SE-WORKBENCH suite designed to enable de simulation of complex environment in the visible and infrared spectrum. We have explained the limitations of the current SE-RAY-IR model concerning the material model and the rendering algorithm. After a discussion, we have presented the improvements of these models and algorithm which are currently under development and which will be released next year. We have shown that this development strongly increases the realism of the simulation because they enable the computation of phenomena that were neglected by hypotheses due to limited hardware performance. Hypotheses that can be extended thanks to the constant evolution of hardware performances.

Taking into account these phenomena is a big advance in the realist simulation in synthetic environments. However, this is only a start and a lot more has to be done. For example, the rendering of participating media is the next step and should be integrated to SE-RAY-IR using the Photon Splatting method researched in our labs [10].

Rendering realism is of course linked with the rendering algorithm and the accuracy of modeling of the materials. But they are not the only constraints. Temperature history and thermal shadows are also extremely important. Thankfully, Oktal-SE provides SE-THERMAL and SE-THERMAL-SHADOWS in the SE-WORKBENCH in order to do this job.

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