# Simulation Method for LWIR Radiation Distribution Using a Visual Ray-Tracer

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*Abstract*—Infrared cameras with passive, uncooled sensor chips utilize the longwave-infrared (LWIR) range of the electromagnetic spectrum with wavelength between 8 and $14\mu$m for image generation. The reason for this is that every object is self-luminous at room temperature at that wavelength. Therefore, every surface acts as a source of radiation in an LWIR scenario. To gain an impression and to model the effects and circumstances in an infrared scenario, a simulation method is required. In the visual domain this task is accomplished by ray-tracing software, which allows the generation of synthetic images as well as the analysis of irradiance distribution in a given scene. In this paper we demonstrate a way to apply one of such ray-tracers to a LWIR scenario. We will also demonstrate an application of the proposed simulation method.

## I. INTRODUCTION

The bulk of an object's emitted radiation due to the movements of its atoms at room temperature are located in the second atmospheric window with a wavelength-range of 8 to $14\mu$m, which is called the longwave-infrared (LWIR) domain. Longwave infrared camera systems utilize this effect for image generation without the need of an active radiation source like light bulbs in the visual domain.

The maximum of emitted radiation varies with the object's temperature and moves towards lower wavelengths as temperature increases. This effect is called Wien's displacement law and is the reason that LWIR radiation is also known as thermal radiation. The amount of emitted irradiance in a certain wavelength-range $\lambda_1 - \lambda_2$ and at a certain temperature $T$ is given by Planck's law [1] as

$$M(T) = \int\limits_{\lambda_1}^{\lambda_2} \frac{2\pi h c^2}{\lambda^5} \frac{1}{e^{(\frac{hc}{\lambda k T})} - 1} d\lambda, \qquad (1)$$

where $h$ is the Planck constant, $k$ the Boltzmann constant and $c$ the speed of light in vacuum.

The second factor which influences radiation emission is the so called emissivity $e$. The emissivity is a material dependent factor and in general a function of wavelength. An object with a wavelength-independent emissivity of one forms the perfect emitter and is called a Black Body. Due to the conservation of energy and applying transmissivity $t$ and reflectivity $r$, it is obvious that

$$e + t + r = 1. \qquad (2)$$

Neglecting transmissive objects, we yield $r = 1 - e$. So every object in an LWIR scenario acts as a mixture of reflector and radiation source, where the ratio between emission and reflection is defined by the object's emissivity. This is the main difference between an infrared scenario and a visual scenario and must be considered when attempting to model radiation distribution in an LWIR scenario. In the following sections we will demonstrate how this task can be accomplished using a standard ray-tracing software originally meant for lighting simulation and synthetic image generation called RADIANCE.

## II. SELECTION OF A SIMULATION TOOL

The following two conditions must be met by a simulation tool suitable for the simulation of LWIR scenarios:
1) Physical correctness of the simulation results
2) Emissive- and reflective properties of objects can be mixed

Physical correctness means that simulation results must meet physical conditions rather than producing "good looking" images. Furthermore, it must be possible to specify the intensities of sources by physical units and quantities of radiance, i.e. $\frac{W}{m^2 sr}$. The emission of radiation of a certain object can then be calculated from its temperature and emissivity using Planck's law. The second condition ensures that the mixed reflective-emissive properties of an object in the LWIR domain can be considered.

The simulation of the propagation of light is done by analytical or numerical methods called ray-tracing and radiosity [2]. Their general aim is to simulate the light- or radiation-distribution in a given scenario based on the physical laws of photometry and radiometry. In general, these laws are the same for the visual and the LWIR domain, exept the above mentioned differences.

A very large number of computer tools exists in this field and many of these tools are even freeware, such as POV-ray, Blender or RADIANCE. A closer look at the available tools reveals that RADIANCE fullfills all the conditions specified above and its physical correctness in the visual domain has already been prooven well [3].

RADIANCE consists of a set of unix tools for scene generation, irradiance analysis and image rendering. It is licensed at no-cost and can be downloaded from *http://radsite.lbl.gov/radiance/*. RADIANCE scene descriptions are made of ASCII-files which contain all definitions for

Fig. 1. Schematic IRFPA Test Setup



Fig. 2. Radiative flux on DUT surface
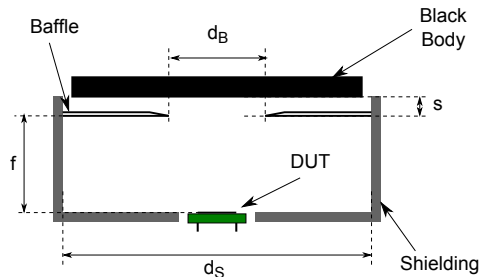
materials, sources and geometric objects [4]. It allows to mix-up two materials to generate a new one combining the features of both basic materials. At last a self-luminous material called `glow` is provided. Thus, all conditions needed for the simulation of LWIR scenarios are present.

### III. GENERATION OF THE SCENE DESCRIPTION

The scene description, consisting of the various provided shapes, can be created manually or by a CAD-tool. Converters from many CAD formats to the `RADIANCE`-format are avail-abe (e.g. `dxf2rad` for the conversion of AutoCAD models).

LWIR materials can be created by mixing self-luminous with reflecting ones. The emissive part is handled by the `glow`-material [4]. Its radiance levels are given directly in radiometric units, i.e. $\frac{W}{m^2\,sr}$. An object' s radiance at a certain tamperature $T$ is given by Eq. 1. For $T = 30°C$ e.g. we yield $M = 152.4\frac{W}{m^2\,sr}$. Several material types with different reflective behaviours such as `metal` or `plastic` are provided. The `mixfunc` material allows to mix up two materials. So an LWIR-material can be created as follows from a reflecting (`m_reflect`) and an emitting (`m_emmitt`) material:

```
void mixfunc lwir_mat
4 e_emmitt e_reflect 0.95 .
0
0
```

The floating-point argument 0.95 specifies the emissivity for the new material. The obtained simulation results were validated by comparing them to analytical calculations for some basic scenarios. The comparison showed that the differ-ence between the simulated and calculated values is less than 1%. Repeated simulations of the same scenario show some noise in the result values. Reason for this is, that `RADIANCE` uses Monte-Carlo simulation methods, which are of statistical nature. The advantage of the Monte-Carlo Simulation is a reduction of the simulation time.

### IV. APPLICATION IN TEST-SYSTEM MODELLING

Fraunhofer IMS develops and fabricates Microbolometer based uncooled Infrared focal plane arrays (IRFPAs) as the first company in Germany and one of few ones in Europe [5]. Therefore, a test setup had to be developed to characterise the IRFPAs. Fig. 1 shows the schematic setup of the test setup, consisting of the Device-Under-Test (DUT), a shielding against IR-radiation from the environment, an optical baffle
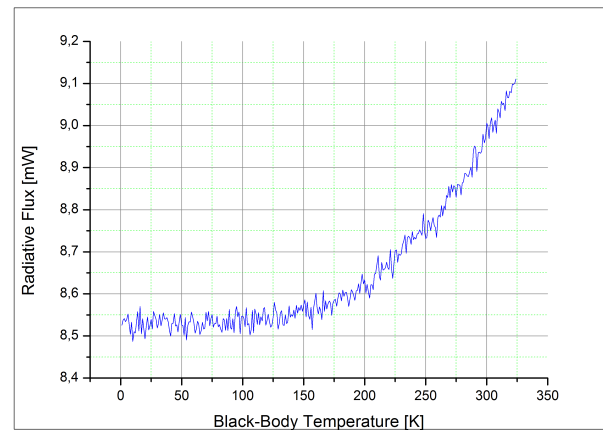
and the IR radiation source (Blackbody) for the generation of the test stimulus.

All components of the test-setup generate unwanted influ-ence on the DUT themselves. These effects can be quantified using the proposed simulation method. Fig. 2 e.g. shows the radiative flux on the DUT's surface as the temperature of the radiation source is varied. The active detector area of the DUT is considered to have the size of 1cm x 1cm. An offset of about 8.5mW is obvious, which is generated by the test-system components. With this method it is also possible to gain an impression on the homogenity of radiance levels on the DUT's surface.

It shall be mentioned that dynamic thermal effects, such as heating or cooling of the total scene due to the change of a source temperature by convection and conduction, are not considered with the proposed simulation method. These effects can also influence the radiative circumstances in an LWIR scenario.

### V. CONCLUSION

In this paper we presented a way to use the synthetic imag-ing system RADIANCE for the simulation of LWIR scenarios. We demonstrated a way to generate the scene description by mixing reflective and emissive materials, showed the physi-cal correctness of the simulation results and demonstrated a possible application of the derived method.

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