

Accelerated Deterministic Simulation of X-ray Attenuation Using Graphics Hardware

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Abstract

In this paper, we propose a deterministic simulation of X-ray transmission imaging on graphics hardware. Only the directly transmitted photons are simulated, using the Beer-Lambert law. Our previous attempt to simulate X-ray attenuation from polygon meshes utilising the GPU showed significant increase of performance, with respect to a validated software implementation, without loss of accuracy. However, the simulations were restricted to monochromatic X-rays and finite point sources. We present here an extension to our method to perform physically more realistic simulations by taking into account polychromatic X-rays and focal spots causing blur.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Raytracing J.2 [Computer Applications]: Physical Sciences and Engineering—Physics

1. Introduction

The simulation of the X-ray imaging process is extensively studied in the physics community and different physically-based simulation codes are available. For transmission imaging, when the Beer-Lambert attenuation law can be considered as a sufficient description, ray-tracing is often used as a fast alternative to Monte Carlo methods [FDLB06]. Physically-based simulations are however often performed on the CPU, and even with a fast ray-tracing algorithm, interactive frame rates cannot be achieved.

In [VGF*09], we demonstrated that X-ray attenuation from polygon meshes can be efficiently computed on the GPU using OpenGL and the OpenGL Shading Language (GLSL). Performance significantly increased without loss of accuracy. The method has been deployed into a medical simulator for training fluoroscopy (real-time X-ray images) guidance of needles [VVH*09]. It makes use of polygon meshes that are dynamically modified depending on the respiration cycle of the virtual patient. The simulations were however restricted to monochromatic X-ray beams (i.e. incident photons have the same energy) and finite point sources.

We have now extended the simulation pipeline to take into

account focal spots that cause geometric unsharpness and polychromatic X-rays (i.e. incident photons have different energies).

2. Simulation Pipeline

The Beer-Lambert law relates the absorption of light to the properties of the material through which the light is travelling. For a polychromatic incident X-ray beam, it is:

$$N_{out}(E) = N_{in}(E) \exp\left(-\sum_{i=0}^{i < objs} \mu(E, i) L_p(i)\right) \quad (1)$$

with $N_{in}(E)$ the number of incident photons at energy E , $N_{out}(E)$ the number of transmitted photons at energy E . $objs$ is the total number of objects in the 3D scene. μ the linear attenuation coefficient (in cm^{-1}), which depends on: i) E , the energy of incident photons, and ii) the material properties of the object. $L_p(i)$ is the path length (in cm) of the ray in the i^{th} object.

We adopted the algorithm presented by Freud *et al* [FDLB06] in [VGF*09]. This is used as the foundation of the present work. It makes use of a modified version of the

Z-buffer, known as the L-buffer (for length buffer), to store the length of a ray crossing a given 3D object.

Additional loops (see gray boxes in Fig. 1) have been included in our simulation pipeline to implement Eq. 1. It is split into different rendering passes and uses frame buffer objects (FBOs) to store intermediate results (see [VGF*09] for details). Fig. 1 shows the full pipeline, taking into ac-

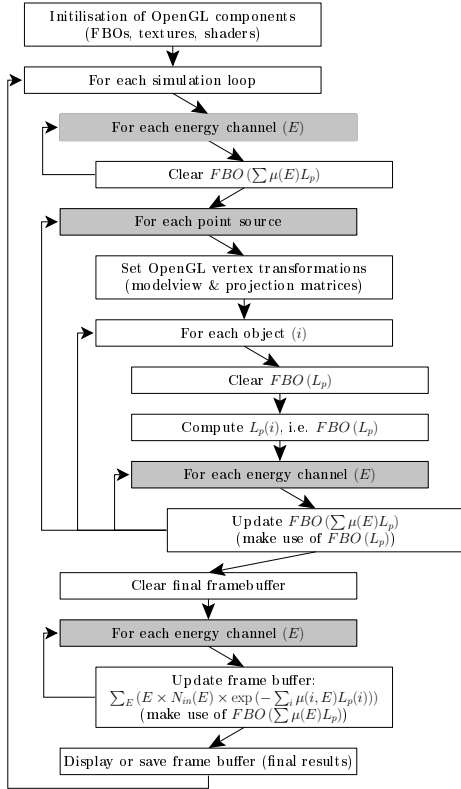


Figure 1: Simulation pipeline.

count the geometrical blur and polychromatic X-rays.

The shape of the source is modelled using a variable number of point sources (see Fig. 2 for examples). Each point is assigned a fraction of the total number of photons in the system.

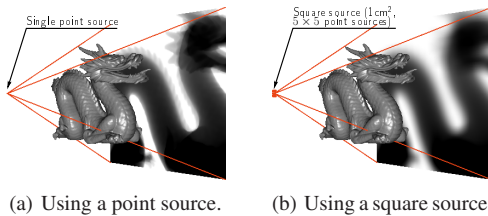


Figure 2: Simulations with different X-ray source shapes.

The incident beam is split into discrete energy channels. A 3D texture is now attached to the FBO used to store $\sum \mu(i, E)L_p(i)$. Each slice of the 3D texture corresponds to an energy channel (E). To produce the final image, the total

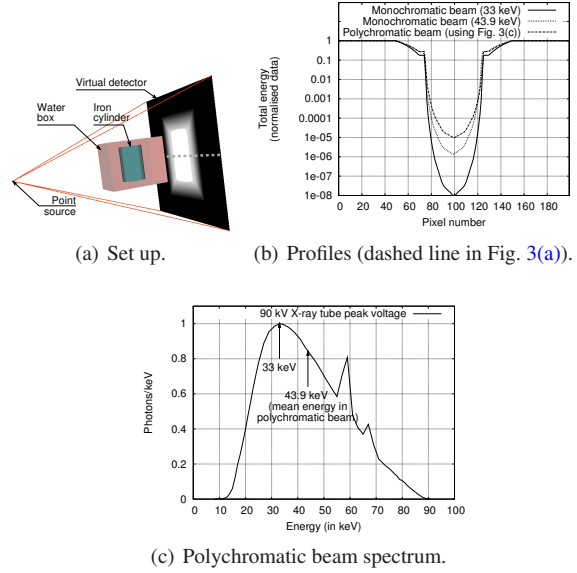


Figure 3: Incidence of the beam spectrum.

amount of energy received by each pixel is computed (see Fig. 3 for an example).

3. Conclusion

X-ray transmission images can be fully simulated on the GPU, by using the Beer-Lambert law with polychromatism and taking into account the shape of the source. Additional loops have been added to the simulation pipeline and the computation cost proportionally increases depending on the number of source points and energy channels. This is a useful development to improve the level of realism in simulations, when both speed and accuracy have to be retained.

References

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