ID de la contribución : **1**

Tipo : **Mini-oral**

gVirtualXray for X-ray imaging simulations and education

martes, 28 de octubre de 2025 16:30 (5)

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gVirtualXray is an open-source library designed to simulate X-ray images in real time using the power of the GPU. Its core relies on the Beer–Lambert law to model the absorption of photons by three-dimensional objects, such as polygon meshes. This project has received numerous awards and recognitions related to its use in education and *digital twins*, including the recent Dirk Bartz Prize for Visual Computing in Medicine and Life Sciences, granted among others to the authors of this presentation (Vidal, 2025).

Technical Foundation and Design

gVirtualXray is based on the following technical principles:

- Implemented in C++ and using OpenGL/GLSL, gVXR offers compatibility with both legacy and modern OpenGL implementations, without relying on deprecated functions.
- Employs the Beer–Lambert law model, in both monochromatic and polychromatic versions, ideal for emulating X-ray tube sources and synchrotron radiation.
- It is cross-platform: works on Windows, Linux, and macOS, and can even run on machines without GPUs, albeit with lower performance.
- Scalability is remarkable: from Raspberry Pi to supercomputers and cloud environments (such as Google Colab), and even Docker containers.
- Available as a core C++ library. To facilitate usage in other languages, there is SimpleGVXR, a layer that adds wrappers for Python, R, Ruby, Tcl, C#, Java, and GNU Octave.
- In addition, it provides a JSON configuration format to simplify simulation creation, especially in Python environments.
- Comes with demos, documentation, tutorials, and support through its website and repositories (SourceForge, GitHub).

Validation and Accuracy

Beyond its reputed use as a software product, gVirtualXray has been academically discussed in several publications such as Vidal et al. (2017) and Corbi et al. (2024). Moreover:

- Its accuracy has been validated against classical tools such as VXI, Geant4 (from CERN), and real experimental data.
- A recent comparative study against Monte Carlo (MC) simulations showed spectacular results: mean absolute percentage error (MAPE) of 3.12%; zero-mean normalized cross-correlation (ZNCC) of 99.96%; structural similarity index (SSIM) of 0.99; with execution times of milliseconds compared to days with MC.
- It was also evaluated with digitally reconstructed radiographs (DRRs), computed tomography (CT) slices, and real radiographs, confirming high-fidelity comparability.

Applications and Uses

The applications of gVirtualXray are diverse and multidisciplinary:

- Education: in medical simulators and teaching tools for particle physics and engineering (Corbi et al., 2019). This makes it an ideal educational tool, as it enables interactive teaching of X-ray physics, training in medical simulators (including virtual reality and haptic interfaces), generation of synthetic data for AI, safe experimentation without real radiation, and exploration of clinical and diagnostic scenarios, all with support for multiple programming languages and accessible web environments.
- Medical research: simulation of respiratory motion, CT artifacts, image reconstruction and image/image registration (Pointon et al., 2023).
- Materials science: micro-CT, artifact analysis, optimization in reverse engineering.
- Machine Learning: generation of synthetic images for training or optimization.
- Virtual reality and interactive environments: real-time simulation with deformations and animations.

Recognitions

As mentioned earlier, gVirtualXray has been presented and awarded at multiple events and conferences:

- Ken Brodlie Award at Theory and Practice of Computer Graphics (2009).
- Second place in Eurographics Medical Prize for medical graphics innovation (2009).
- Best Poster Award at dXCT (2022).
- Cosec Impact Award for advances in Digital Twins of XCT scanners, with a fully open virtual workflow (2023).
- The Dirk Bartz Prize for Visual Computing in Medicine and Life Sciences (2025).

Conclusion

gVirtualXray is a powerful X-ray image simulation library that combines scientific accuracy with speed, thanks to its GPU implementation. It is accessible to developers and researchers due to its cross-platform compatibility and wrappers in multiple languages. Rigorously validated and adopted in education, medicine, materials science, ML, and interactive simulation, the project remains active and recognized for its technical, scientific, and educational contributions. In the context of the V RSEF/IFIMED Conference, a brief and outreach-oriented presentation of the tool will be delivered, showcasing its potential and wide range of applications, with an emphasis on its educational use.

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Clasificación de la sesión : Monte Carlo

Clasificación de temáticas : Monte Carlo simulations