ROOM IMPULSE RESPONSE ESTIMATION USING SIGNED DISTANCE FUNCTONS

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ABSTRACT

Several algorithms and approaches for Room Impulse Response (RIR) estimation exist. To the best of the authors knowledge, there is no documentation of accuracy, speed or even the feasibility of using signed distance functions (SDFs) in combination with sphere tracing for this task. Here a proof of concept with a focus or real time performance is presented, that lacks many features such as frequency dependent absorption and scattering coefficients, arbitrary source and receiver directives etc. The results are shown and compared to real room impulse responses recorded by [1]. The implementation happens mostly inside a compute shader, an example application is provided in the framework `TouchDesigner`. The application as well as all generated data and `Jupyter Notebooks` can be found on https://github.com/hrtlacek/rayMarchReverb.

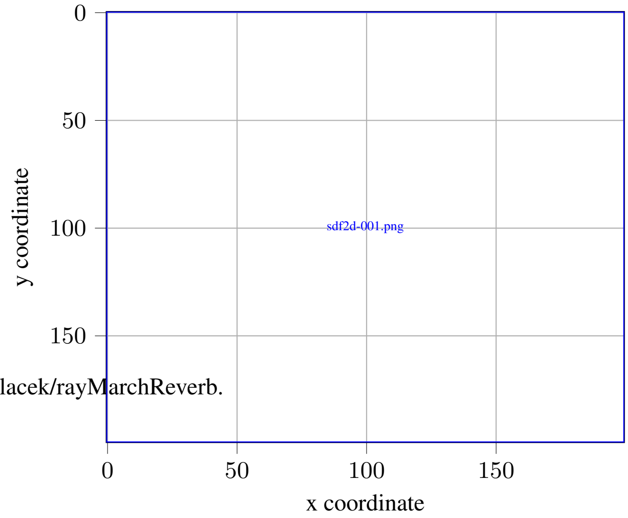

Figure 1: a two dimensional SDF. $F(x, y) = \sqrt{x^2 + y^2} - 1$ describes the unit circle.

1. INTRODUCTION

Sphere tracing [2] is extensively in the so called "demo scene" to render impressive 3D video demos via shaders in real time for decades. As a version of ray tracing that relies on the geometry being defined as so called signed distance functions (SDFs), it does not directly support the import of standard 3D Polygonal geometry. One of the advantages lies in the algorithm's potential improved speed in comparison to fixed-step ray tracing. SDFs describe implicit surfaces, via a function $f : \mathbb{R}^3 \rightarrow \mathbb{R}$. A function returns a negative value if the locus of the point is inside the geometry, a positive value if outside and 0 if on the surface. If defined carefully, the distance to the nearest surface is always known as the full geometry of the scene describes an ideally lipschitz continuous distance field in $\mathbb{R}^3$.

Since the distance to the nearest surface is always known, the step size of a ray tracing algorithm can be dynamically adjusted, resulting in fewer iterations along a ray, see figure

1.1. Previous Work

As shown in [1] there exist multiple approaches for estimating RIRs.

NVIDIA VRWorks™ Audio (introduced with the Pascal GPU architecture)

RIR Estimation

image sourcce method, wave based, raytracing.

Sphere Tracing

Defining SDFs is an active field of research and there are several projects that aim at easier construction of SDFs and integration in 3D frameworks such as https://github.com/Flafla2/Generic-Raymarch-Unity and [3].

1.2. Motivation

The reasons why sphere tracing in a compute shader for RIR estimation has not been documented until now probably lie in the relatively new introduction of compute shaders as well as in the difficulty of creating SDFs(in comparison to using existing 3D /CAD models and import them to polygon based ray tracers).

1.2.1. Sphere tracing

As described above, ray tracing in general is in use. procedural by default deforming geometry

1.2.2. Implementation

It is possible to implement the chosen algorithm on the CPU and the GPU. A number of frameworks could be chosen for GPU accelerated computation such as OpenCL or NVIDIA CUDA. The

* Thanks to the predecessors for the templates

choice of a shader has the advantage of being more operating system independent and hardware independent. Compute shaders (in contrast to fragment shaders) make it possible to write to arbitrary output locations which is necessary for generating the actual impulse response from the measurement of timings. Since they are available since OpenGL 4.3 (August 2012) / OpenGL ES 3.1 they are both old enough have received broad support in other frameworks and relatively new in respect to first publications about sphere tracing. Another reason for the choice of compute shaders is their simplicity. In comparison to CUDA and OpenCL, shaders are easier to write and the GLSL(Graphics Library Shading Language) is more widespread.

2. GENERATION OF SDFS

3. SPHERE TRACING

For simplicity, deterministic equal-angle Ray Tracing is used in contrast to Monte Carlo or Equal Area Ray tracing (EART) [4].

low frequency pass

4. GENERATION OF IMPULSE RESPONSE

Advantage of compute shader. Maybe introduce cascaded Lowpass.

All figures should be centred on the column (or page, if the figure spans both columns). Figure captions (in italic) should follow each figure and have the format given in Figure 2. Vectorial figures are preferred. For example when using `Matlab`, export using either Postscript or PDF format. Also, in order to provide a better readability, figure text font size should be at least identical to footnote font size. To do so using `Matlab`, use the `subplot` command before plotting. If bitmap figures are used, please make sure that the resolution is enough for print quality. Fig. 3 illustrates an example of a figure spanning two columns.

5. RESULTS

compare to [1] compare to [5]

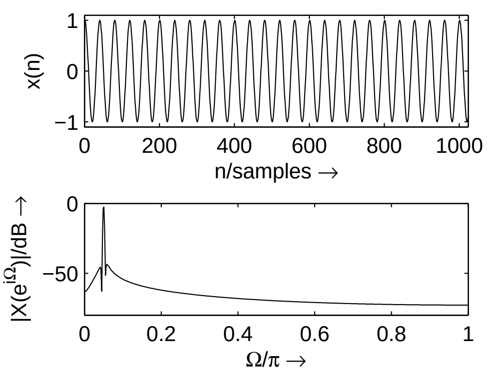

Figure 2: *Sinusoid in time and frequency domain. Short captions are centred, long captions (more than 1 line) are justified.*

5.1. Tables

As for figures, all tables should be centered on the column (or page, if the table spans both columns). Table captions should be in italic, precede each table and have the format given in Table 1.

Table 1: *Basic trigonometric values.*

angle (θ, rad)	$\sin\theta$
$\frac{\pi}{2}$	1
π	0
$\frac{3\pi}{2}$	-1
2π	0

5.2. Equations

Equations should be placed on separate lines and numbered:

$$X(e^{j\Omega}) = \sum_{n=0}^{N-1} x(n) e^{-j\Omega n} \tag{1}$$

where the sequence $x(n)$ in equation (1) is a windowed frame:

$$x(n) = s(n)w(n) \tag{2}$$

with a window function $w(n)$.

5.3. Page Numbers

Page numbers will be added to the document in the postprocessing stage, so *please leave the numbering as is*, that is, the first page will start at page DAFX-1 and the last page, at most, will have to be DAFX-8.

5.4. References

5.4.1. Reference Format

The reference format is the standard IEEE one. We recommend to use BibTeX to create the reference list.

6. CONCLUSIONS

This template can be found on the conference website. For changing the number of author affiliations (1 to 4), uncomment the corresponding regions in the template `tex` file. Please, submit full-length papers (max. 8 pages both oral and poster presentations). Submission is fully electronic and automated through the Conference Web Submission System. DO NOT send us papers directly by e-mail.

7. ACKNOWLEDGMENTS

Many thanks to the great number of anonymous reviewers!

8. REFERENCES

[1] Fabian Brinkmann, Lukas Aspöck, David Ackermann, Steffen Lepa, Michael Vorländer, and Stefan Weinzierl, "A round robin on room acoustical simulation and auralization," *The Journal of the Acoustical Society of America*, vol. 145, no. 4, pp. 2746–2760, Apr. 2019.

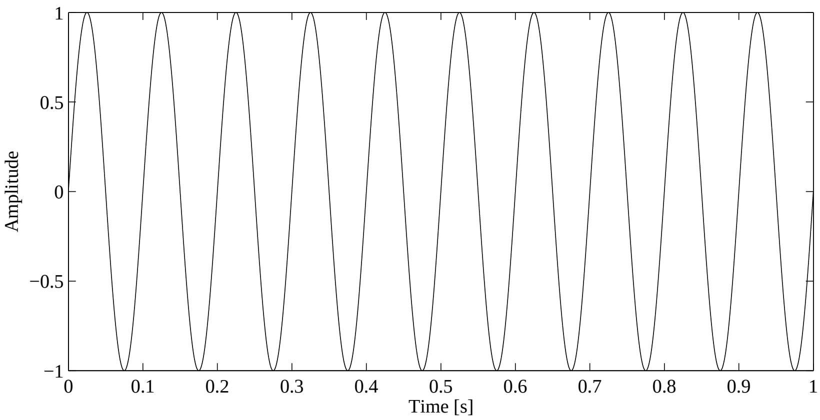

Figure 3: *A figure spanning two columns, as mentioned in Sec. .*

Table 2: *Basic trigonometric values, spanning two columns.*

angle (θ, rad)	$\sin\theta$	$\cos\theta$	$(\sin\theta)/2$	$(\cos\theta)/2$	$(\sin\theta)/3$	$(\cos\theta)/3$
$\frac{\pi}{2}$	1	0	$1/2$	0	$1/3$	0
π	0	-1	0	$-1/2$	0	$-1/3$
$\frac{3\pi}{2}$	-1	0	$-1/2$	0	$-1/3$	0
2π	0	1	0	$1/2$	0	$1/3$

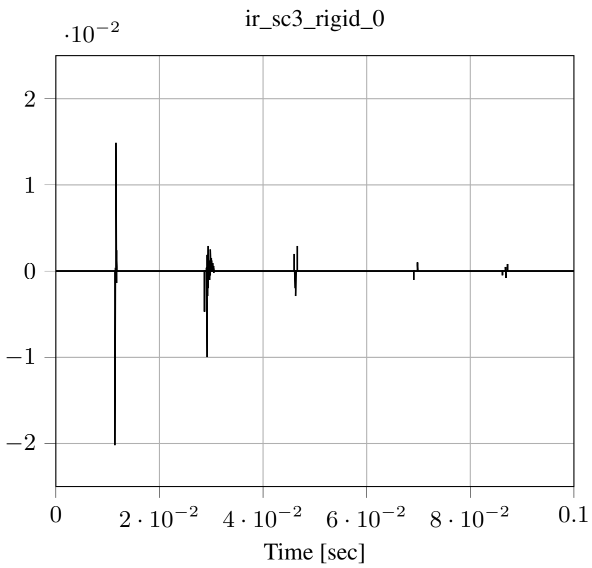

Figure 4: A PGF histogram from `matplotlib`.

[2] John C. Hart, "Sphere tracing: a geometric method for the antialiased ray tracing of implicit surfaces," *The Visual Computer*, vol. 12, no. 10, pp. 527–545, Dec. 1996.

[3] Patrik Lechner, "hrtlacek/TDraymarchToolkit v1.1," Feb. 2020.

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[5] Douglas R Campbell, Kalle J Palomäki, and Guy J Brown, "Roomsim, a MATLAB Simulation of "Shoebox" Room Acoustics for use in Teaching and Research," p. 4.

[6] Larisa Stoltzfus, Alan Gray, Christophe Dubach, and Stefan Bilbao, "Performance portability for room acoustics simulations," in *Proceedings of the 20th International Conference on Digital Audio Effects*. 2017, pp. 367–374, University of Edinburgh.

[7] Benjamin Keinert, "enhanced sphere tracing," 2014.

[8] Dirk Schröder, "Physically Based Real-Time Auralization of Interactive Virtual Environments," p. 231.

9. APPENDIX: MARGIN CHECK

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