Improving Radiance simulation workflow with process of anti-aliasing and tone-mapping to enhance users' experience in VR environments

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Abstract

Recently, the use of VR is developing and spreading to be used for different applications: among them the evaluation of luminous environments and their characteristics by potential occupants for visual comfort assessment. Here, an improved simulation workflow based on Radiance use is presented to enhance the visualization quality in lower resolution VR HMDs devices and consequently users' immersion experience. The method is based on the use of equirectangular projection, digital signal anti-aliasing processing and tone-mapping trough 'normtiff' Radiance command. Results demonstrate that the method increases the photo-realism of the model, improving users' experience.

Highlights

- Radiance workflow update applies for physically-based rendering used in study of subjective impressions of space and light.
- Digital signal anti-aliasing processing (spatial and post-process) is proposed to increase the quality of physically-based rendering with equirectangular projection.
- 'normtiff' (Radiance's command) is applied to tone-map high dynamic range images according to the low-resolution Oculus Quest 2 (VR) technical specifications.
- Results offer VR 3DoF omnidirectional stereoscopic experiences that increase users' immersion in subjective impressions of space and light.

Introduction

The last decades show substantial efforts in the development of virtual reality (VR) applications in different disciplines. The availability of mature technology, affordability of VR head-mounted displays (HMDs), and capabilities of simulation tools to generate physically-based rendering are factors responsible for this growth.

Currently in the field of lighting, especially daylight, there is an important trend in the use of VR immersion systems (Zhang et al., 2020; Bellazzi et al., 2022). In this environment, the use of photographs (Cauwerts 2013; Newsham et al., 2010) and rendered images (Mahdavi and Eissa 2002; Newsham et al., 2005) are the most widely used resources in the investigation of subjective impressions of space and light.

The main challenge lies in obtaining research results that are valid, reproducible, and generalizable from digital to physical environments (Bellazzi et al., 2022). A key factor is the creation of digital environments that provide an experience indistinguishable from that experienced in the physical world. For this, interactivity is important (Newsham et al. 2010) and the immersion that is achieved through the VR HMDs, which makes it possible to isolate conflicting stimuli in the observer's peripheral vision (Kuliga et al. 2015).

The validated and consolidated simulation tool in the lighting field is Radiance (http://www.radiance-online.org/) (Ward, 1994). Radiance allows the predictive calculation of luminances and illuminances in interior spaces based on the stochastic Monte Carlo method and backward ray tracing. As a computer graphics generation tool, Radiance offers high degrees of physical realism and photorealism. This means that it provides the same visual stimulation as the physical world scene (how the material behaves) and the same visual feedback (how the material looks), respectively (Ferwerda, 2003).

Unlike other software, this tool offers physically-based rendering and wide-field-of-view stereoscopic image generation, which can be used for *three-degrees-of-freedom* (3DoF) VR experiences. The *degrees of freedom* refer to the movement of a rigid body within space. 3DoF VR experiences describes a stationary mode of user interaction with the virtual environment where they have the ability to roll (X axis), yaw (Y axis) and pitch (Z axis); but they cannot move in space. This last case corresponds to 6DoF.

State of the art

The Radiance workflow allows you to generate wide-field-of-view stereoscopic physically-based rendering through three projections: angular sphere map, cube map, and equirectangular (Moult, 2019). The cube map projection is the most used in the subject, however it presents limitations in artificial stereoscopic effect. This is not constant in all directions. This is due to technical and software limitations mentioned in a recent article (Chamilothori et al., 2019). On the other hand, the equirectangular projection offers an artificial omnidirectional stereoscopic effect, but it is rarely used in the field of lighting.

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Its diminished use is related to technical limitations in the treatment of distortion artifacts (aliasing) and its slight distortion in the polar zone. In this context, this work focused on the generation of 3DoF VR experiences for the study of subjective impressions of light and space, proposes the use of equirectangular projection and interventions in the Radiance workflow. The objective is to improve the quality, definition and compatibility of the simulator output images for their correct visualization in lower resolution VR HMDs devices.

Method

The methodologies are divided into 3 main blocks: (1) Equipment, (2) Visual stimuli: physical environment and (3) Visual stimuli: virtual environment.

1. Equipment

The virtual reality headset used in this study is Oculus Quest 2, which uses a liquid crystal display with a refresh rate of up to 72 Hz and a resolution of 1832 × 1920 pixels per eye. The screen offers a 104° horizontal and 98° vertical field of view. The maximum luminance of the screen is 100 cd/m^2. The color space uses CIE 1931 xy primary color values: R (0.708, 0.292), G (0.170, 0.797), B (0.131, 0.046), and W (0.3127, 0.3290).

In the development and execution of this study, the Oculus software and modules XR Interaction Toolkit v2.2.0, XR Management v4.3.1, XR Oculus v3.0.2 and XR Openxr v1.5.3 for Unity Game Engine 2021.3.10f1 Silicon were used on a MacBook Pro Apple M1 Pro 16 GB - MacOS Ventura 13.2.1.

2. Visual stimuli: Real environment

In order to ensure the realism of the resulting scene, existing real space were used as a reference for the virtual environments. A typical office work with Visual Display Terminal (VDT) (Johnston et al., 2010) is selected as a case study *(Figure 1)*. Dimensions: 4.6 × 4.5 × 3.0 m (VR scene 4.1 × 3.1 × 3.0 m) *(Figure 2)*. To increase the realism of the virtual scene, some details were also modeled (color prints, air conditioning, furniture, library element, telephone, among others).

Figure 1: Case study - work office

The VR experience in this work, considering the type of task and the user's position, is *stationary*. This way of experiencing VR sitting or standing -without moving- creates a default zone for the surveillance system of 1.0 × 1.0 m around the user in the virtual environment. This enables virtual experiences in small spaces with high resolutions and better frame rates due to lower processing demands.

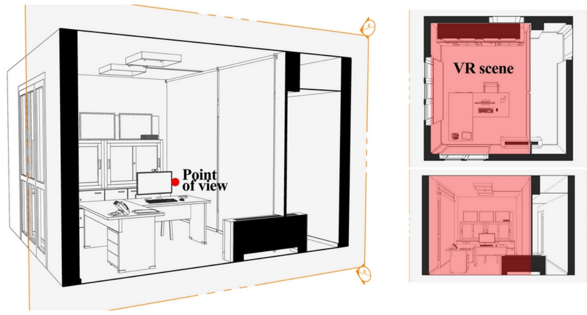

Figure 2: Work office 3D model with featured VR scene

3. Visual stimuli: Virtual environment

3.1. Generation of physically-based renderings

The test office was modeled in SketchUp and then exported via the Groundhog extension (Molina et al., 2018) to Radiance. The simulation and scene preparation protocol followed well-established and validated workflows to produce highly accurate views with Radiance, specifying material properties from spectrophotometer measurements (Ward and Shakespeare 1998); correct characterization of the artificial light source through Illuminating Engineering Society photometric file (*.ies) imported into Radiance; and the use of high precision representation parameters (Rockcastle et al., 2017).

The surfaces in the experimental room were measured with a Konica Minolta CL500A spectrophotometer and their properties were loaded into Radiance. 30 materials were characterized, the main ones of which are mentioned in the following (*Table 1*). In the same way, the images and prints found in space *(Figure 1)* were incorporated into the Radiance scene following a rigorous UV Mapping protocol.

Table 1: Materials reflectance values used in Radiance.

Type	Description and material (reflectance)
Space	Wall (*rho*=0.961); floor (*rho*=0.757) and ceiling (*rho*=0.96).
Curtain	Main (*rho*=0.768); roller blind cord (*rho*=0.676) and accessories (*rho*= 0.794).
Furniture	Desk (*rho*=0.767); chair (*rho*=0.135); card file drawer (*rho*=0.756); card file edge (*rho*=0.719); drawer pull (*rho*=0.007); top (*rho*=0.767) and laterals (*rho*=0.35).
Computer	Keyboard (*rho*=0.047); mouse (*rho*=0.04); monitor (*rho*=0.002); base monitor (*rho*=0.413) and webcam (*rho*=0.007).
Air-conditioning	Frontal part (*rho*=0.924); top (*rho*=0.812) and controller (*rho*=0.901).
Library	White paper (*rho*=0.842); yellow paper (*rho*=0.789); turquoise journal (*rho*=0.457) and black charger (*rho*=0.046).
Phone	Light gray (*rho*=0.317); gray (*rho*=0.073) and visualization (*rho*=0.073).

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Luminaire	Zumtobel Square LED-Z42935396 55C7W (0.6 × 0.6 m) incorporated into Radiance with 'ies2rad' and calibrated in situ 3961ºK.

The 360º panoramic image format used was equirectangular projection. This projection has the main advantage of omnidirectional stereoscopy, unlike other projections. For example, the cube map projection widely used in this topic presents a reduced stereoscopy as mentioned by Chamilothori et al. (2019). This limits the areas of analysis of subjective impressions and immersion. The equirectangular projection only presents a slight deformation in the polar zone (>70º on the y axis). This turns out to be a partial limitation in 3DoF hover mode VR experiences as there is no subject displacement and points of interest are located in *maximum view* and *comfortable view* between 70º and -70º (on the y axis), and *peripheral zone* up to 110º and -110º (on the x-axis) (Chu, 2014) *(Figure 3)*. These specifications derive from Ergonomics, and in the case of exceeding these degrees we would be in conditions of hyper-extension or hyper-flexion that are not recommended.

The simulation parameters used are: (dt) .05 (dj) 0 (ds) .15 (dc) .75 (dr) 3 (dp) 512 (st) .15 (ab) 3 (aa) .1 (ar) 512 (ad) 4096 (as) 2048 (lr) 8 (lw) .005. These parameters were used in similar studies and present a good balance between image quality/processing time for a first phase of simulation and image rendering for VR (1-4 hours each) (Rockcastle et al., 2017).

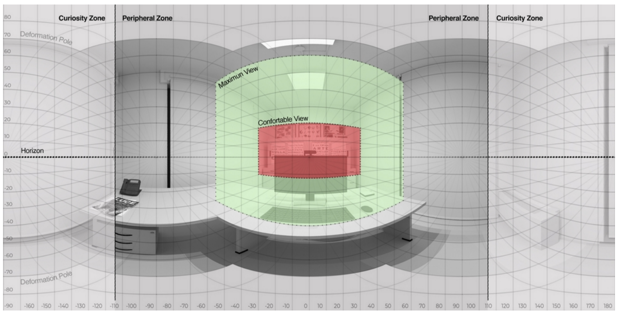

Figure 3: 360° panorama grid with Chu's ranges of motion and Alger's zones.

3.2. Validation

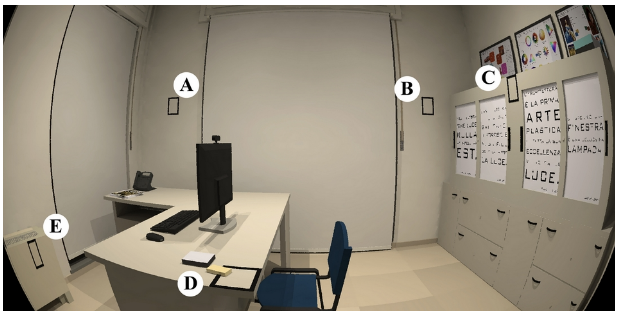

Figure 4: Image of the 5 reference points in the scene.

This section seeks to validate the virtual model of the office from 5 reference points. The luminance at these points was measured with a Hagner S1 luminance meter: A (112 cd/m2), B (108 cd/m^2), C (120 cd/m^2), D (161 cd/m^2), E (80 cd/m^2), and simulated with Radiance: A' (87.2 cd/m^2), B' (85.8 cd/m^2), C' (128 cd/m^2), D' (157 cd/m^2) and E' (74 cd/m^2). The statistic parameter used to compare the data sets (measured value and simulated value) is the root mean square error (RMSE). It was obtained RMSE average equal to 15.65.

3.3. Generic equirectangular projection

Radiance allows you to generate different 360º panoramic images through an angular sphere map, a cube map or equirectangular projections. In this work, it focuses on the equirectangular projection as it is the only one that currently offers omnidirectional stereoscopy in Radiance environments (Monteoliva et al., 2022).

Stereoscopic vision is a process inherent to the human being, consisting of obtaining a three-dimensional vision of the objects perceived through binocular vision. This process is obtained naturally in the human eye by simultaneously observing the same object from two different positions. That is, each eye sees a slightly different image of the object, resulting in depth perception.

This three-dimensional or stereoscopic effect can also be generated artificially. An environment with different angles (representing the left and right eye) is captured and viewed simultaneously, creating an impression of depth. To achieve this effect, the conditions are: (i) each eye must observe only the image that corresponds to it and (ii) the images must be parallel to the stereoscopic base, avoiding vertical parallax (Ordóñez López, 2011). The application of the stereoscopic effect within Radiance is possible using the 'rtrace' image rendering command and the '3d360.cal' function by Mark J. Stock (2014) ©.

3.4 Workflow update

3.4.1. Spatial anti-aliasing

Starting with preliminary considerations, Radiance can be used to create different types of 360º panoramic images through its 'rpict' and 'rtrace' image generation commands. The most used is rpict and it allows generating this type of images through cube-map and angular sphere map (monoscopic) projections. This command has the ability to control aliasing through spatial anti-aliasing from its native options -pixel sample jitter (-pj)-. From this parameter, distributed ray tracing performs smoothing by randomly sampling pixels. However, in the equirectangular projection this option is not available since it works with the rtrace image rendering command.

For 360º panoramic images with equirectangular projection, Radiance offers the functions 2d360.cal (monoscopic) and 3d360.cal (stereoscopic). Chronologically, 3d360.cal was the first function developed by Mark J. Stock (2014) © with definitions for the 360º stereoscopic equirectangular projection (over-under); modified by Greg Ward (2017) © and renamed in Radiance to 'view360stereo.cal'. On the other hand, 2d360.cal is a modification of 3d360.cal by Dion Moult (2018) © for a monoscopic image instead of a

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stereoscopic one. The following sections work only with the '3d360.cal' and 'view360stereo.cal' functions.

3.4.2. Post-process anti-aliasing

In the Radiance environment, post-process anti-aliasing is applied via the 'pfilt' program. This allows smoothing and scaling to be applied to a Radiance image. The program makes two passes on the image file to adjust the exposure to the correct average value.

3.4.3 Tone-mapping

The technical specifications of the Oculus Quest 2 device (https://developer.oculus.com/resources/oculus-device-specs/) are taken as a starting point: top luminance 100 cd/m^2; 2.2 gamma; white point D65; Primary CIE 1931 xy color values: R (0.708, 0.292), G (0.17, 0.797), B (0.131, 0.046), W (0.3127, 0.3290). Subsequently, the Radiance converter called 'normtiff' is applied to the tone map and converts the Radiance image to RGB TIFF.

To better visualize the results of the different processes proposed in this section 3.4, we work with 4 study areas (a1, a2, a3 and a4) *(Figure 7).* a1 is characterized by its vertical lines; a2, a3 and a4 for their diagonal and curved lines. Each of these zones presents a scale magnification of 1600% (zoom in). The aim is to improve the understanding and visualization of the impact of different interventions. As the output format of the images is in high dynamic range (*.hdr) to improve their visualization in the article, we work with the 'normtiff' command and its output is reduced to 8-bit black and white (grayscale) (*.tiff).

3.5. Generation of 360° immersive scenes

The software chosen for the management, configuration, creation and export of digital scenes to VR device is Unity Game Engine. Radiance physically-based renderings are imported into this platform.

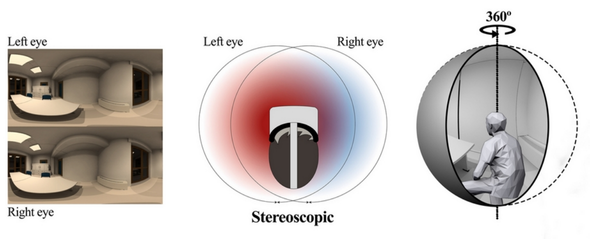

Figure 5: (a) Stereoscopic equirectangular projection of the scene, (b) Diagram to achieve the artificial stereoscopic effect and (c) Illustration of the equirectangular projection applied as a texture.

Unity is a cross-platform game engine that has been growing and expanding its compatibility with different platforms. Its particular use in this toolbox is through the so-called *skyboxes*. This resource allows the visualization of 360º panoramic images as a wrapper for a scene. The trick works by placing the view camera inside a sphere and mapping Radiance physically-based renderings as a texture to the interior of the sphere. This sphere is configured in a special way so as not to cast shadows or have lighting calculated to give the illusion that you are inside it, and thus see the environment around you *(Figure 5)*.

As a summary, the main blocks of the methodologies and interventions proposed to the Radiance workflow are illustrated (*Figure 6)*.

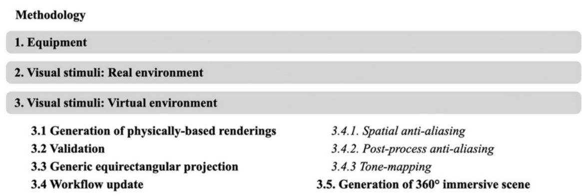

Figure 6: Illustration of the methodological approach used in the study.

Results

1. Generic equirectangular projection

To generate 360º panoramic images with equirectangular projection, Radiance offers two specific functions '2d360.cal' and '3d360.cal' for monoscopic and stereoscopic images, respectively (Monteoliva et al., 2022). To delve into these methodologies, the tutorial by D. Moult (https://thinkmoult.com/create-360-vr-panoramas-with-radiance.html) is recommended. Based on the workflow proposed by D. Moult (2019), '3d360.cal' is used in this first section. The result is 'test-room1.hdr' (A), a high dynamic range stereoscopic equirectangular projection image of the test room (stereoscopy setup: over-under) *(Figure 7)*. The resolution is 5760 × 5760 pixels (File size: 134.2 MB, Render time: 4 h 6 min). This dimension is the maximum recommended on the official website of the VR device (https://creator.oculus.com).

From this moment on, of the stereoscopic images, only the image corresponding to the left eye will be shown for reasons of space availability in the article.

As a result of the analysis of 'test-room1.hdr' we can mainly observe an aliasing in areas a2, a3 and a4 -known in other fields as jaggies-. This term refers to a distortion that can be seen clearly in the image on curves and diagonal lines *(Figure 8-A)*. This is due to the arrangement of the pixels that align point to point. This is not as noticeable in a1, since in horizontal and vertical lines the thousands of square pixels that make up the image line up perfectly next to each other.

Most of the time, it is possible to eliminate these distortions by increasing the screen resolution. Many devices today reach resolutions like 2K or 1440p (2560 × 1440 pixels), 4K or 2160p (3840 × 2160 pixels), or 8K or 4320p (7680 × 4320 pixels). However, this is not a solution for VR headsets in general and for the Oculus Quest 2 specifically; which has unchanging technical specifications of 1832 × 1920 pixels per eye -corresponding to the Head-Mounted Display (HMD) Viewer-. In a complementary way, the output image shows an over (right eye)-under(left eye) layout, inverse to that required by VR devices over(left eye)-under(right

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eye). However, this aspect will be developed in detail in the section 3.

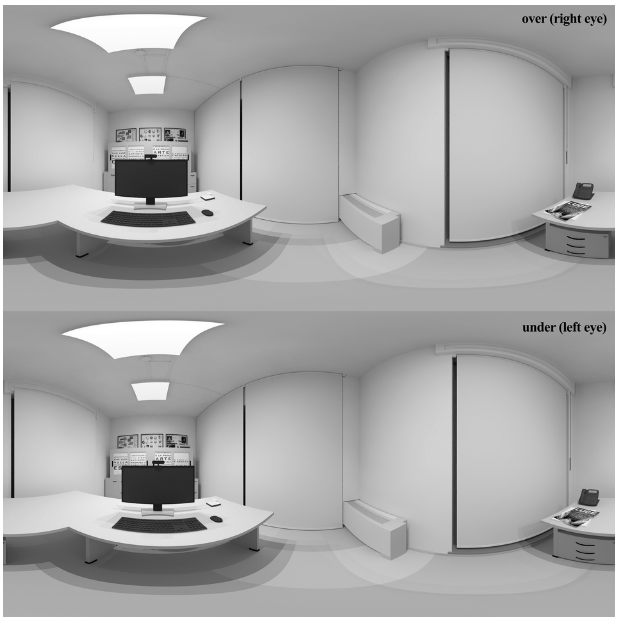

Figure 7: 'test-room1.hdr' 360º stereoscopic panoramic image.

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2. Anti-aliasing

The method for removing jaggies in the image is *anti-aliasing*. Digital filtering techniques based on sampling theory. Next, it is proposed to incorporate *spatial anti-aliasing* and *post-process anti-aliasing* into the workflow with the aim of improving distortions without losing the sharpness, quality and photo-realism of images obtained by Radiance physically-based rendering.

2.1 Spatial anti-aliasing

It is proposed to apply the spatial anti-aliasing method called *supersampling anti-aliasing* (SSAA) in the 'view360stereo.cal' function. SSAA is ideal for processing these photorealistic images, providing anti-aliasing that makes them appear more realistic. To do this, modifications are made to the function code in lines 32 and 33 to add some pixel sample jitter (1), suggested by G. Ward in the discussion forums (https://discourse.radiance-online.org).

(1)

px = (XD-1)/2 - $2 + 0.6(1-2*rand(3.5381*recno+17.385));*
py = YD-.5 - $1 + 0.6(1-2*rand(-1.568*recno+4.2874));*

As a result, a new image is obtained 'test_room-2.hdr', where the 4 areas are analyzed, and the results obtained are compared with the results of the previous section *(Figure 8-B)*. A partial improvement is observed in the analyzed areas, without yet reaching the expected result. It is important to highlight the importance of the 'view360stereo.cal' function. This function updates the one mentioned in Dion's tutorial (3d360.cal) and presents corrections in the equirectangular projection -visible in *(Figure 8-B)*- and arrangement over(left eye)-under(right eye), performed by Greg Ward (2017) ©. In the next section, an anti-aliasing post-processing is incorporated into the workflow with the goal of slightly blurring each pixel after the rendering process.

2.1 Post-process anti-aliasing

The proposal combines an over-sampling with a low-pass filter. Over-sampling involves working with an input image (input_test-room2.hdr) of higher resolution than the one required as output (output_test-room2.hdr). For the Oculus Quest 2 device, we work with an image resolution of 5760 × 5760 pixels, size derived from considering the resolution of the device (1832 × 1920 pixels per eye), field of view (horizontal FOV 104º and vertical FOV 98º) and layout over-under (1:1) stereoscopic output image.

The low pass filter is Gaussian. This removes high frequency (sharp) features oriented along the X or Y axis of the scan. The radius used is .6, the limit value expressed in the manual, in order not to lose sharpness, and it is combined with an over-sampling of 2 and 3. 'input_test-room2.hdr' is rendered in resolutions of 11520 × 11520 pixels (double) and 17280 × 17280 px (triple), for their over-sampling of 2 and 3, respectively. This returns: 'output_test-room2-ds2.hdr' *(Figure 8-C)* of 5760 × 5760 pixels (File size: 536.9 MB, Render time: 5 h 11 min) (2) and 'output_test-room2-ds3.hdr' *(Figure 8-D)* of 5760 × 5760 pixels (File size: 1194.4 MB, Rendering time: 6 h 6 min) (3).

(2)

pfilt -x /2 -y /2 -r .6 input_test-room2.hdr
> output_test-room2-ds2.hdr

(3)

pfilt -x /3 -y /3 -r .6 input_test-room2.hdr
> output_test-room2-ds3.hdr

Both post-process anti-aliasing have a noticeable impact on input_test-room2. However, when comparing both processes in the different areas *(Figure 8-C and Figure 8-D)*, factor 3 combined with a Gaussian radius of .6 is the one that achieves the best results. However, when testing the image on the VR device, a slight loss of focus is observed. This blur occurs mainly in the images located above the cabinet. For this reason, maintaining the factor 3 of over-sampling, a variation in the radius of the Gaussian filter is proposed. In this opportunity we work with .5 and .55. Proper balance is found in the .55 radius. For this reason, the output image 'output_test-

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room2-ds3.hdr' (with *r*=.55) is chosen (E) to apply the last adjustment phase.

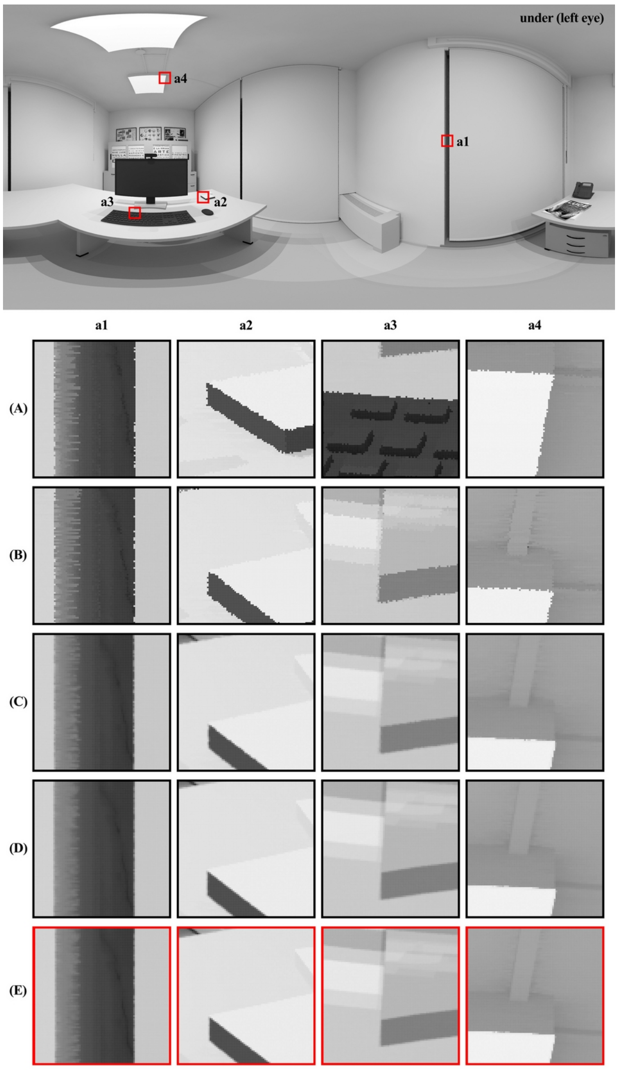

Figure 8: Study areas a1, a2, a3 and a4 in 3D model (left eye). Results of the generic workflow (A) and proposed anti-aliasing phases (B), (C) and (D).

3. Tone-mapping

The RADIANCE converter normtiff is applied to the tone-map and converts the RADIANCE image to RGB TIFF (4). This section retrieves the color information from the output HDR images (Figure 9), by not using the (-b) parameter in the 'normtiff' function. In this way the tonal values of 'output_test-room2-ds3.hdr' are reduced to the technical specifications of the device (see Section 3.4.3) and a compatible and adapted image is obtained (output_test-room2-norm.hdr). Complementarily, combined parameters of human contrast sensitivity (-s) and imitation of human visual response (-h) are applied.

The result is a stereoscopic Radiance physically based-rendering over-under -left eye-right eye-, calibrated and compatible with the technical specifications of the Oculus Quest 2 devices *(Figure 9)*.

(4)

normtiff -h -u -s -g 2.2 -d 32 -p .708 .292 .17 .797 .131 .046 .3127 .3290 output_test-room2-ds3.hdr output_test-room2-norm.tiff

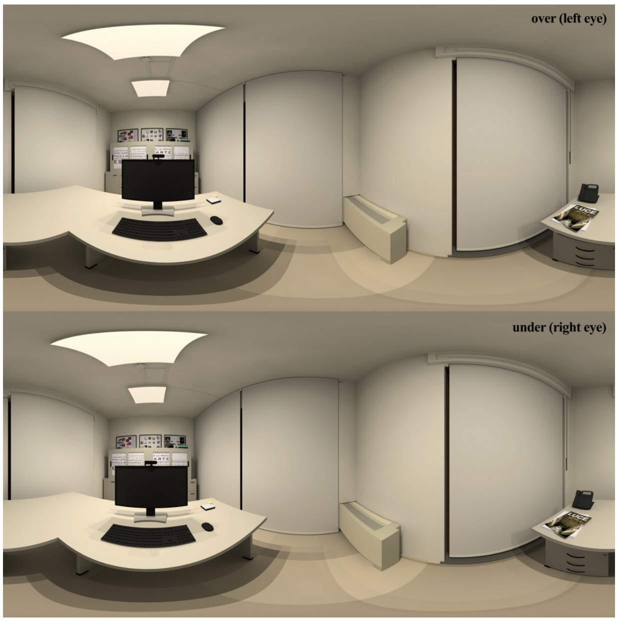

Figure 9: Tone-mapping image 'output_test-room2-norm.tiff'

Discussion

The digital signal processing proposed in the work improves the quality of physically-based stereoscopic representations with a wide field of view, their visualization and compatibility with the Oculus Quest 2 VR device. However, this proposal can also be extrapolated to other models and/or brands of VR devices on the market. This important versatility of the methodology is achieved only with the knowledge of the technical specifications of these products.

This workflow preserves the high-precision simulation environment (Radiance) and adapts it to the requirements of the new digital media. The Radiance system and its physically based ray tracing algorithm enable a high level of physical realism (how the material behaves) and photorealism (how the material looks). Although the focus of this article was not the accuracy of the simulator, this is a widely validated tool, and its potential can be seen in section *3.2 Validation* with RMSE < 16%. It is also important to highlight that this physical realism is computationally expensive (resources) and probably not necessary at all to reproduce visual perceptions, however, it is of great interest in our field of lighting quality research. In fact, it produces reliable physically based data (illuminances and luminances) as well as high-quality images (*.hdr). Therefore, it is appropriate to relate light perceptions to physical indicators. The stationary mode (3DoF) allows you to use the VR HMDs seated, similar to the activity carried out in the workspaces. It also provides the ability to experience 3D space without worrying about moving, display higher resolution images, and better frame rates due to reduced processing demand. Ideal characteristics

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for the study of subjective impressions of light and space.

The article offers a toolbox similar to that used in other works. However, it stands out for the use of equirectangular projection for the construction of 3DoF VR experiences. This projection allows stereoscopy in all directions (omnidirectional), a limitation that still exists in other projections -cube map-. These advances enable more immersive 3DoF VR experiences.

For the aliasing found in this type of projection combined with the limitations in the options of the rendering commands (rtrace) two interventions are proposed: spatial anti-alising and post-processing of anti-alising. Subsequently, through 'normtiff', the Radiance image (*.hdr) is adapted for output to a low resolution screen, considering the technical specifications of the VR device (color space, maximum luminance and high dynamic range compression). Finally, the human contrast sensitivity function is applied, obtaining a 360º stereoscopic output image adapted to the Oculus Quest 2 VR device.

The carefully calibrated VR is a technology capable of guaranteeing a satisfactory representation of the physical environment, becoming an effective tool to study the user's perception, reducing the time and costs that physical environments require. Currently, this technology makes it possible to evaluate user preferences in different lighting conditions, vary scene configuration parameters (type of source, intensities and CCT, among others) and observe the behavior of people in interaction with lighting controls and shading devices. However, there are still hardware and software limitations to reduce perceptual differences when comparing physical and virtual environments. This can be evidenced in detail in phenomena such as glare and high contrasts within the lighting field. These limitations have been already enhanced in previous research (Natephra et al., 2017; Krupinski, 2020; Abd-Alhamid et al., 2019). Nevertheless, the evolution of this technology suggests that these limitations will improve over time. For example, on the recent Meta Quest Pro (next model to the one used in this article), the display is more vibrant with a 30% greater color gamut and local dimming providing 75% greater contrast. Another aspect to be considered is that when increasing accuracy, computation time increases accordingly, but hopefully with further future developments of VR systems this will be solved as well.

Through these developments and its occupant-centered immersive approach, it seeks to help professional designers better understand the impact of light dynamics on subjective assessments of light and space.

Conclusion

Building on this methodology and ongoing international collaborative studies (Institute of Environment, Habitat and Energy, CONICET & Department of Industrial Engineering, University of Naples), it is planned to contribute new analyzes of subjective impressions of light and space in immersive virtual reality systems. To adequately recreate the human experience in the physical world, it will be necessary to delve into parameters such as user interaction and immersion in digital worlds. These advances are aimed at adapting validated methodologies to new challenges and formats of digital media (VR). This is a first step to build digital environments that are perceived as "physical", improving the VR experience and the knowledge about the subjective impressions of the users. Given that the proposed method improves the VR model photorealism, it is expected to obtain encouraging results about the sense of presence from future research comparing VR experiences with the real ones.

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