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Raising Awareness of the Impact of Artificial Light on Wildlife with Virtual Reality

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Figure 1: A view from the Virtual Reality application: the user can navigate a 3D city model and select from the perspectives of various animals.

ABSTRACT

This paper presents the development of an open-source Virtual Reality (VR) application designed to raise public awareness of the impact of artificial light on wildlife. The application allows the user to walk through a 3D model of “Bas de Siam” district of Brest city, while simulating the color and light perception from the perspectives of various animals, taking into account their sensitivity to specific wavelengths. This project aims to educate users about the effects of light pollution and promote a better understanding of the impact on wildlife.

Index Terms: Light pollution, Virtual Reality, Biodiversity.

1 INTRODUCTION

Public lighting has always played an essential role in our cities, contributing to the safety and well-being of citizens in urban areas. However, despite its importance, the impacts of public lighting are often underestimated and understudied.

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Artificial light, particularly that emitted by LEDs, has a significant impact on wildlife. To raise public awareness of this issue, we have developed a virtual reality application that allows users to view the world through the eyes of various animals. This open source application is designed to be both educational and immersive, offering a unique experience in understanding the differences in visual perception between species.

Several studies have highlighted the detrimental effects of artificial light on wildlife. For example, research by Gaston et al.[1] demonstrated that artificial light at night can disrupt the circadian rhythms of animals, leading to altered behavior and physiology. Similarly, Longcore and Rich [3] showed that light pollution can affect the reproduction and survival of various species, including birds, insects, and amphibians.

In this context, we are proposing a VR application which aims to develop a simulation of public lighting in VR, with a visual interpretation of how different light sources are perceived by a selection of animals. The code is open source and available on Github¹. This development is part of the Noz Breizh² project, which aims to study the sense of security during nighttime movements in the city and the impact of public lighting on biodiversity. One of the main objectives of this project is to create a realistic virtual environment that will allow researchers to observe and evaluate human behaviors in the presence of different urban lighting scenarios. Through virtual

¹<https://github.com/MaxSpur/SensiLumCERV>

²<https://nouveau.univ-brest.fr/chaire-noz-breizh/en>

reality, it is possible to recreate various night-time situations and precisely control the lighting parameters, thus providing an effective, flexible, and reproducible study platform.

2 SYSTEM OVERVIEW

We developed the system using the Unity game engine. It builds on a 3D model of the “Bas de Siam” district of Brest city, textured with photographs of the street and buildings at night. Public light fixtures are accurately modeled, and building windows also illuminate the scene using emission maps. Other modeled urban furniture includes trees, metro stations, bus stops, and benches.

Using Unity’s OpenXR³ plugin, the system supports a wide range of VR devices, including HTC Vive and Meta Quest headsets. Using conventional VR locomotion paradigms (rotation and teleportation), a user can freely traverse and explore the entire modeled part of the district.

A virtual panel that follows the user at a fixed distance contains the user interface, shown in Figure 1. It is divided into two halves: one shows the available animal vision modes and the other allows to select a lighting scenario. We have modeled the current street lighting as the *standard* scene. In addition, we have added a scene that replaces all street lights with colder and brighter LED lamps, one that replaces them with much warmer, almost red light sources, and one in which all lights are turned off and the buildings themselves have been dimmed — the main light source is the full moon from the skybox texture. All these scenes are stored as pre-rendered (baked) lightmaps that can be switched immediately by the user to quickly explore different scenarios without waiting.

Selecting any animal vision mode other than Human selects and turns on a post-processing filter on the whole scene except the interface panel that attempts to show what the scene might look like to the selected animal.

3 ANIMAL VISION APPROXIMATION

3.1 Spectral Sensitivity

We began by collecting relative spectral sensitivity data for each species (frogs, bats, passerine birds) from Longcore et al. [2]. Each dataset gives, for wavelengths roughly 320–700 nm, a series of relative sensitivity values. In parallel, we obtained human photopic and scotopic sensitivity curves from CIE. We merged the two human curves into a single aggregate sensitivity (by averaging and normalizing) so that its peak equals one.

Next, all curves were resampled to a common 2 nm grid spanning 400–700 nm. We linearly interpolated each species’ sensitivity onto that grid, then normalized so the maximum was one. The human aggregate curve on the same grid serves as our baseline: at each wavelength λ , we define the animal’s spectral gain $G(\lambda)$ as the ratio (animal sensitivity)/(human sensitivity). Outside a species’ measured range, $G(\lambda)$ is zero. These gain curves will be used to amplify or attenuate wavelengths of light in a postprocessing step to “translate” animal vision to human vision.

As these animals can perceive wavelengths outside the human-visible range, we could either cut these off for the gain curves, or map the animal range onto the human one. Simply cutting results in gain curves that are relatively similar between each animal, while mapping them results in more differentiated ones (see Figure 2). While this mapping distorts the animals’ color perception, this approach appeared useful to better highlight the differences in perception. We do not have access to the ultraviolet spectrum in Unity, and any kind of transformation between human and animal vision is arbitrary by definition.

³<https://docs.unity3d.com/Packages/com.unity.xr.openxr%40latest/>

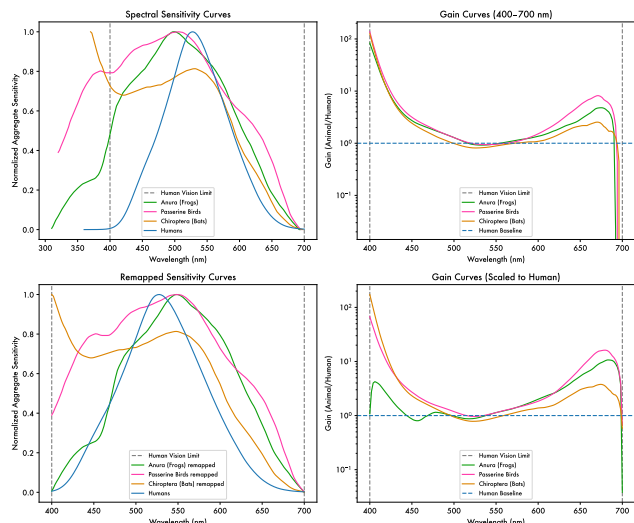


Figure 2: Spectral sensitivity curves for humans, frogs, bats, and passerine birds, adapted from [2], and the calculated spectral gain curves. The bottom row shows the animal sensitivities and gain curves mapped to the human visible spectrum.

3.2 Look-Up Table Generation

To apply these gain curves to translate animal vision into human vision, we need to generate Look-Up Tables (LUTs) that are applied by Unity in a post-processing step — a filter that all colors generated by the scene pass through before being displayed. These LUTs are stored as a three-dimensional texture. The challenge here is to find a process that maps spectrum (wavelengths) to colors components (red, green, blue), and back.

To build these 3D LUTs that preserve exact identity when $G(\lambda) \equiv 1$, we adopted a CIE-based pipeline. First, we load the CIE 1931 1 nm color-matching functions $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$ over 400–700 nm. We then solve a 3×3 linear system to express each “spectral primary” $P_R(\lambda), P_G(\lambda), P_B(\lambda)$ as a linear combination of $\{\bar{x}, \bar{y}, \bar{z}\}$. The constraints are that integrating $P_i(\lambda)$ against $\{\bar{x}, \bar{y}, \bar{z}\}$ yields exactly the standard CIE XYZ tristimulus values of pure sRGB red, green, or blue. By construction, forming the spectrum

$$S_0(\lambda) = rP_R(\lambda) + gP_G(\lambda) + bP_B(\lambda)$$

and then integrating S_0 to XYZ and converting back to sRGB gives exactly (r, g, b) whenever $G(\lambda) = 1$.

We then generated a $32 \times 32 \times 32$ grid of (r, g, b) points, where $(r, g, b) = (i/31, j/31, k/31)$. For each voxel:

1. Build $S_0(\lambda) = rP_R(\lambda) + gP_G(\lambda) + bP_B(\lambda)$.
2. Multiply by the species’ gain curve: $S_1(\lambda) = S_0(\lambda)G(\lambda)$.
3. Integrate $S_1(\lambda)$ against $\{\bar{x}, \bar{y}, \bar{z}\}$ to obtain a CIE XYZ triplet.
4. Convert XYZ to linear-sRGB via the inverse sRGB matrix, clip negatives to zero, then apply the standard sRGB gamma curve.
5. Store the resulting $(r', g', b') \in [0, 1]^3$ in the LUT.

When $G(\lambda) \equiv 1$, this procedure reproduces (r, g, b) exactly (up to floating-point noise). When $G(\lambda)$ follows a frog, bat, or bird curve, the LUT entry is the correct animal-tinted color.

Our post-processing shader samples the LUT at the pixel’s original sRGB color. When human vision is selected, the identity LUT

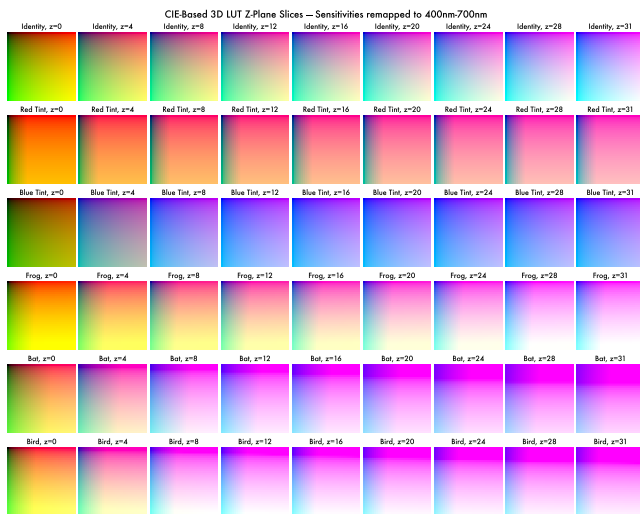


Figure 3: LUT slices of the gain curves of the selected species as remapped to the human-visible spectrum, plus the identity (gain=1, human) and a red and blue tint for comparison.

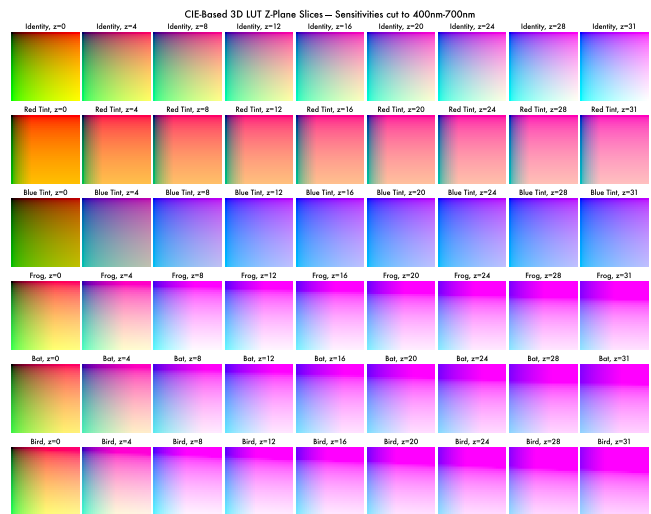


Figure 4: LUT slices of the gain curves of the selected species as cut to the human-visible spectrum, plus the identity (gain=1, human) and a red and blue tint for comparison.

could be used, or the post-processing being bypassed altogether. Otherwise, the selected animal’s LUT allows the scene to be viewed with the animal’s spectral sensitivity, or rather the sensitivity as mapped to the human-visible spectrum.

To verify correctness, we plotted several z -slices (e.g. $z = 0, 8, 16, 24, 31$) of each LUT (Figure 3 and Figure 4). The identity slices appear as perfect RGB ramps, and each animal’s slices show characteristic tinting. We also generated “average-over- z ” projections and diagonal ramps (where $r = g = b$) to confirm that pure grays remain unchanged for identity and shift appropriately under each gain curve. This CIE-based method thus provides both physical plausibility and real-time performance in our VR application.

4 CONCLUSION AND FUTURE WORKS

This open source virtual reality application represents an advancement in raising public awareness of the impact of artificial light on wildlife. By allowing users to see the world through the eyes of animals, it offers a unique and immersive educational experience. We hope that this project will inspire a better understanding of animals’ visual capabilities and encourage actions to reduce light pollution.

As future works we plan to investigate more species, and also possibilities of capturing and thus displaying the ultraviolet spectrum that is so far missing here, to more accurately show the animal vision.

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⁴<https://www.virtualys.fr/>

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