Predicting the Light Spectrum of Virtual Reality Scenarios for Non-Image-Forming Visual Evaluation

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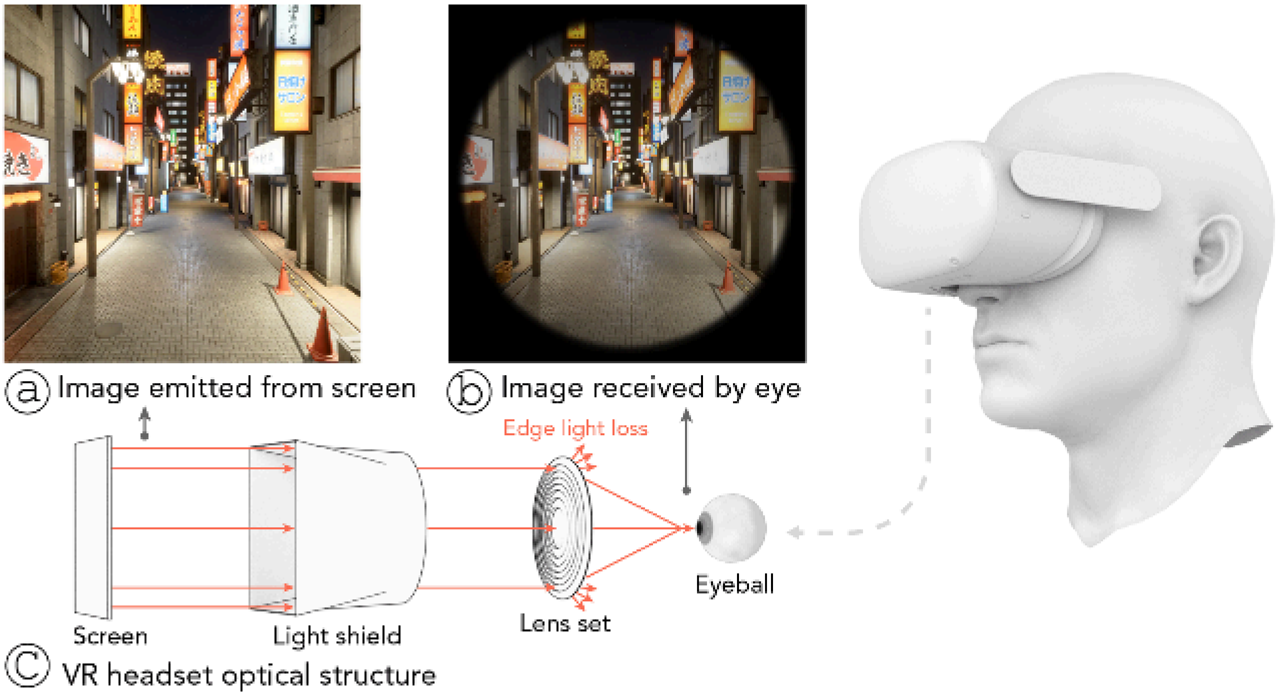

Abstract: Virtual reality (VR) headsets, while providing realistic simulated environments, are also over-stimulating the human eye, particularly for the Non-Image-Forming (NIF) visual system. Therefore, it is crucial to predict the spectrum emitted by the VR headset and to perform light stimulation evaluations during the virtual environment construction phase. We propose a framework for spectrum prediction of VR scenes only by importing a pre-acquired optical profile of the VR headset. It is successively converted into "Five Photoreceptors Radiation Efficacy" (FPRE) maps and the "Melanopic Equivalent Daylight Illuminance" (M-EDI) value to visually predict the detailed stimulation of virtual scenes to the human eye.

Tags: Virtual Reality, Human vision, HCI

1 Introduction

Virtual Reality (VR) offers a highly immersive simulated environment. While developers have made great efforts to create virtual content, the VR device usage still leads to an unsatisfactory experience and physical side effects with. The average session time of VR headsets is reported to be 21 minutes *(Alsop, 2022)*, with visual fatigue being one of the main barriers to longer session times *(Souchet et al., 2022)*. Recent studies reveal the existence of a non-image-forming (NIF) visual pathway in the human eye in addition to the imaging vision system for colour perception,

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which synchronises the biological clock and influences hormonal secretion by sensing external light-dark cycles *(Schmidt, Chen, et al., 2011; Schmidt, Do, et al., 2011)*. NIF visual stimulation has a strong correlation with the triggering of visual fatigue *(Askaripoor et al., 2018)*. In order to precisely control stimuli, it is important to evaluate the effect of VR on the NIF visual system in the human eye. Quantifying the NIF stimulation of VR headsets will help to reduce digital eye strain (DES), increase usage time and eliminate sleep disorders caused by nighttime use. VR systems will therefore have the ability to better simulate reality. Not limited to entertainment, the fields of medical research and training will also be enhanced.

In this work, we propose a generic spectrum prediction algorithm for VR scenarios, which doesn't require any setup or additional optical equipment. The algorithm uses the imported pre-acquired optical profiles of various VR headsets, allowing developers to anticipate the spectrum the human eye will receive during the virtual scene construction phase. We also propose the 'Five Photoreceptors Radiation Efficacy' (FPRE) maps, which are generated by converting each pixel's predicted spectrum into irradiance values for the five photoreceptors, to visualise the regional activation of photoreceptors in the human eye by the virtual scene. In summary, our approach significantly reduces the cycle for evaluating the impact of VR on NIF vision. It eliminates the cost and complexity as well as establishes a reference with existing illumination standards. To the best of our knowledge, this is the first algorithmic implementation of spectrum prediction for VR head-mounted systems.

2 Related Works

A study by Kim et al. *(Kim et al., 2018)* compares the spectrum power distribution (SPD) of light from phone-based VR and AR screens and calculates the value of 'Circadian illuminance' (CIL) based on the melanopsin sensitivity curve. Another study by Wu et al. *(Wu et al., 2019)* uses an illuminance meter to assess the relative blue light emission of phone-based VR in the circadian action factor (CAF) value. The results of both studies suggest that phone-based VR causes more significant melatonin suppression, sleep-wake cycle disorder and eye fatigue than mobile phone use. The two studies were evaluated using only specific phone-based VR models; the results may not represent PC-VR and standalone VR headsets with higher performance and different optical structures.

3 Method

An overview of the method can be seen in Figure 1. The algorithm takes two inputs: optical profile obtained from the VR headset and a virtual scenario. The optical profile for the VR headset is evaluated separately and fed to the algorithm during runtime. At runtime, for a view direction the image is seperated into rgb-colour channels and processed to obtain spectrum values for each pixel in accordance with the field of view, light attenuation mask, pixel spectra and gamma curve obtained from the optical profile. In the last step, by using the spectrum values estimated at each pixel, full spectrum, M-EDI value and FPRE maps are evaluated.

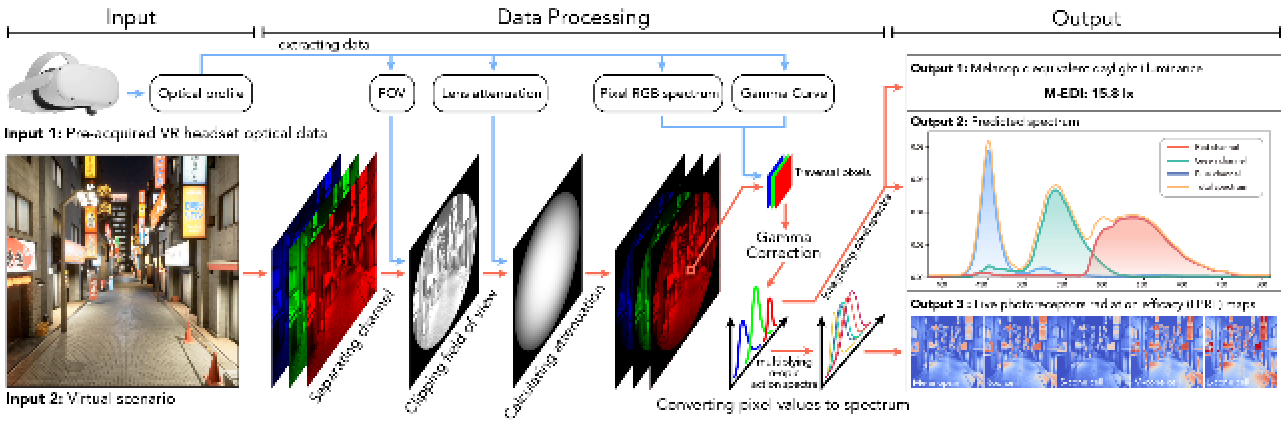

Figure 1: An overview of our approach. The algorithm first selects a viewpoint of the virtual scenario as the image input and imports the pre-acquired VR headset optical profile. Then, during the data processing stage, the image is channel split to obtain the monochromatic values of each pixel separately. The FOV and the lens edge-light-loss function described in the profile are extracted and overlapped with the three separate image channels. Lastly, the spectrums and luminance growth curves of the single-pixel red, green and blue light emitting units in the profile are extracted to iteratively calculate the spectrum of each pixel and then summed to generate the total spectrum. The M-EDI value and FPRE maps are subsequently calculated through the generated spectrum.

The video above shows a short demo of real-time light stimulus identification using the FPRE map plugin in Unreal Engine 5.

4 VR headset Optical Profile Acquisition

As off-the-shelf and pre-released VR headsets have similar optical structures and fixed screen-to-eye distances, we, therefore, aim to establish a generalised method for acquiring optical data from a variety of different VR headsets and to produce the data as profiles for importing into functions

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for spectrum prediction. We will be measuring different models of VR headsets *(Dexter, 2022)* and sharing the profiles open source. Thus, developers can evaluate the impact of the current scene on the human eye in real-time, depending on the application, during the scene establishment phase, without the need for additional optical equipment. The equipment setup for performing the optical feature acquisition of the VR headset can be seen in Figure 2

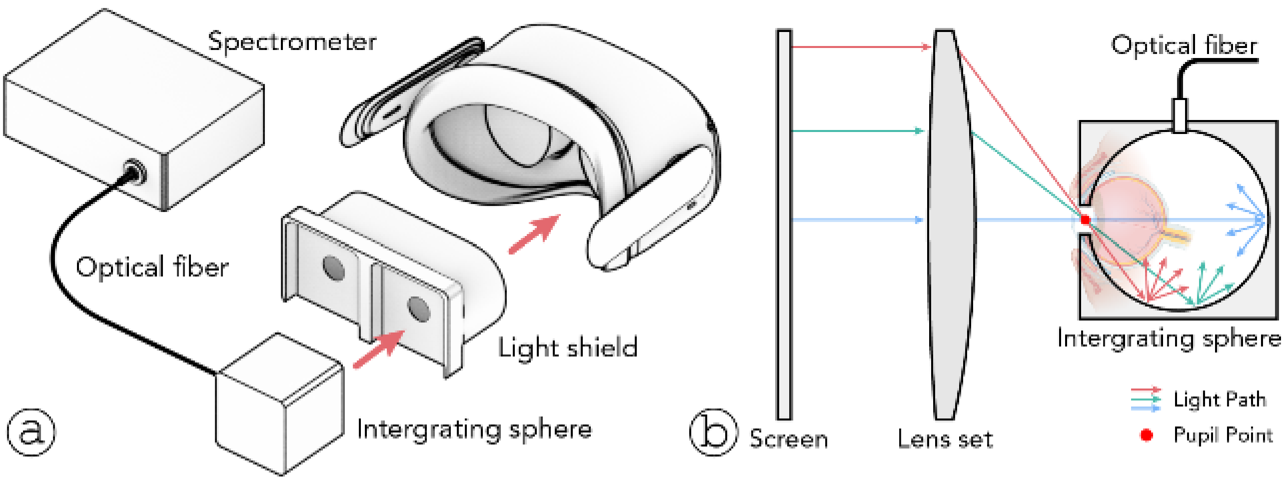

Figure 2: The setup of VR headset light measurement. (a) illustrates the equipment setup for light acquisition from a VR headset using a spectrometer connected to an integrating sphere via optical fibre. (b) shows a cross-sectional view of the acquisition light path. The diagram illustrates the principle of setting up the integrating sphere with a cross-sectional view of the human eye. The integrating sphere's aperture is set at the same position as the pupil of the human eye to avoid capturing light not received by the eye. Light path indication in three colours for better differentiation of light transmission.

5 User Study

In order to test the effectiveness of our approach in practical applications, we design a user study on VR NIF visual stimuli. This experiment selects a VR museum scenario, and a developer is invited to make lighting adjustments of the scenario partially to reduce the irradiance of the VR headset screen without affecting user perception, instructed by the spectrum prediction algorithm. The overall aim is to explore whether the visual fatigue could be reduced without the user being able to perceive the scene modifications subjectively.

Participants (n=46) were divided into two groups and experienced two scenarios in different orders. During the experiment, the participants are asked to wear VR headsets and undergo subjective and objective visual fatigue measurements after experiencing a virtual museum and the same scene with reduced irradiance guided by the spectrum prediction algorithm. The results show that the algorithm-modified scene caused less visual fatigue using the Critical Flicker Frequency (CFF) test (F(1, 45)=64.97, p <0.01) and the Visual Fatigue Scale (VFS) (F(1, 45)=93.08, p <0.01) *(Kuze & Ukai, 2008)*. Most participants were unable to perceive the difference through verbal reports.

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6 Conclusion And Future Work

In this poster, the spectrum prediction framework for virtual environments and the optical profile acquisition process for VR headsets are briefly described. Through a user experiment, the potential and effectiveness of our approach in practical applications is revealed. As future work, we will combine this framework with machine learning to design an automatic recolourisation method for VR scenes. The aim is to automatically reduce the light stimulation of the scene and maintain immersion.

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