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

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ABSTRACT

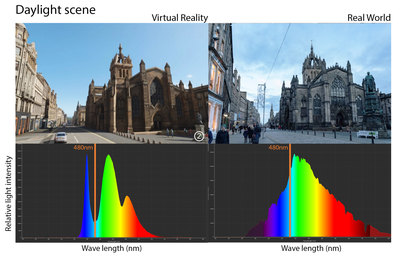
Virtual reality (VR) headsets, while providing realistic simulated environments, are also over-stimulating the human eye, particularly for the Non-Image-Forming (NIF) visual system. Therefore, it is crucial to predict the spectrum emitted by the VR headset and to perform light stimulation evaluations 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.

RESEARCH QUESTION

People want to be comfortably immersed in VR for longer periods of time.
But the fact is that they feel discomfort after less than half an hour of usage.

Daylight scene



The SPD of VR optics is different from natural light, leading to:

1. Obtaining painful experiences
2. Physical side effects
3. Permanent complications
4. VR Session time only 21mins

How can we **predict** and **quantify** the stimuli that VR headsets will cause to the human eye, as well as render it **controllable**?

Prediction → **Evaluation** → **Modification**

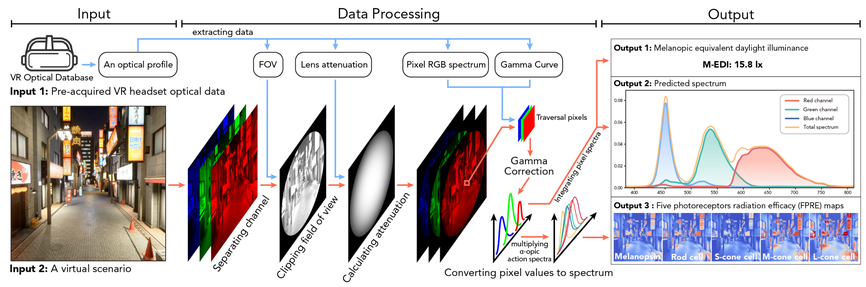
Predicting the real spectrum of VR scenes

Evaluating how VR scenes will stimulate the human eye

Reducing stimuli without compromising immersion

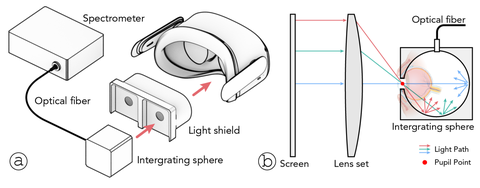
Reference:
1. An Overview of Eye Strain (Asthenopia) https://www.verywellhealth.com/do-you-suffer-from-asthenopia-or-tired-eyes-3421982
2. Forza Horizon 4 - Virtual Scene of Edinburgh https://store.steampowered.com/app/1293830/_4/

PIPELINE OF FRAMEWORK



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.

VR HEADSET OPTICAL PROFILE ACQUISITION



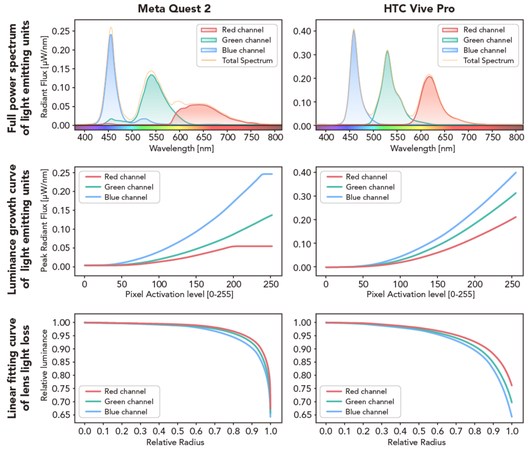
The setup of VR headset light measurement:
(a) illustrates the equipment setup for light acquisition from a VR headset using a spectrometer connected to an integrating sphere via optical fibre.
(b) shows a cross-sectional view of the acquisition light path. The integrating sphere's aperture is set at the same position as the pupil of the human eye to avoid capturing light not received by the eye.

VR optical data:
We measured ten sets of optical data from the Meta Quest 2 and HTC VIVE Pro as well as fitted ideal curves.

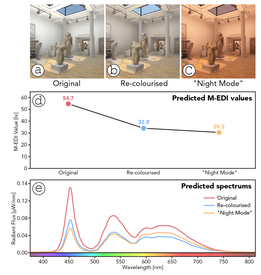
Top: the full power SPDs of three light (RGB) emitting units.

Middle: the luminance growth (gamma) curves of three light emitting units.

Bottom: the linearly fitted light loss curves for the lens set.



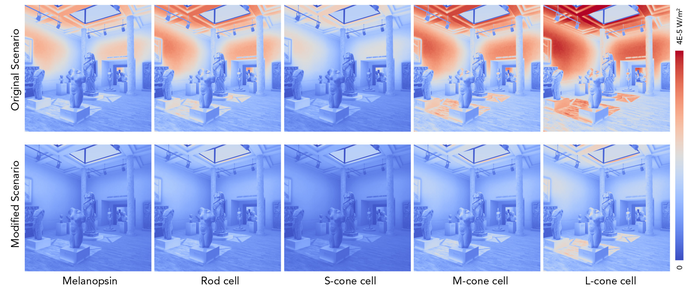
VR SCENE RE-COLOURISATION



In order to test the effectiveness of our approach in practical applications, we specifically design a user study on VR NIF visual stimuli. In particular, 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.

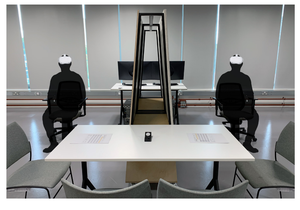
The overall aim is to explore whether the visual fatigue could be reduced without the user being able to perceive the scene modifications subjectively.

FPRE MAPS EVALUATION



Comparison of FPRE maps of the original and modified scenes. The comparison shows that the original scene has a higher level of activation of the eye photoreceptors. The modified scene maintains the irradiance of the original exhibits while reducing the visual stimulation at the walls and ceiling.

USER STUDY



Participants (n=46) were divided into two groups and experienced two scenarios in different orders. They were asked to measure visual fatigue differences before the start and after the end of the experiment.

Results:
The modified scene cause less visual fatigue.

Critical Flicker Frequency (CFF) test ($F(1, 45)=64.97$, $p<0.01$)

Visual Fatigue Scale (VFS) ($F(1, 45)=93.08$, $p<0.01$)

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.