# Imperceptible Color Modulation for Power Saving in VR/AR


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**(a) hardware setup** **(b) demonstration** **(c) temporal filter**

**Figure 1: *Demo setup.* a) We develop a hardware prototype OLED VR display to capture power measurements when displaying different images. b) Participants view a panoramic scene in VR with our filter turned on, and are encouraged to rotate freely to view the scene in a natural manner. c) Filter intensity is increased over 10 seconds. Image credits to VR Gorilla.**


## ABSTRACT

Untethered VR/AR HMDs can only last 2-3 hours on a single charge. Toward resolving this issue, we develop a real-time gaze-contingent power saving filter which modulates peripheral pixel color while preserving visual fidelity. At SIGGRAPH 2023, participants will be able to view a short panoramic video within a VR HMD with our perceptually-aware power saving filter turned on. Participants will also have the opportunity to view the power output of scenes through our power measurement setup.



## KEYWORDS

Color Perception, Power Consumption, Gaze-Contingent Rendering




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## 1 INTRODUCTION

While past works take into account the spatial [Patney et al. 2016] or temporal [Krajancich et al. 2021] aspects of human peripheral vision to decrease rendering workload and latency, they do not directly optimize power efficiency. Furthermore, color perception driven power optimization in HMDs is still relatively unexplored.

Motivated by the limited battery life in untethered VR/AR HMDs, we develop a gaze-contingent approach to power saving in VR/AR. We modulate peripheral pixel color only, and can save up to 24% on display power while maintaining high visual fidelity. We are motivated by two salient insights: 1) LED displays require variable power outputs to display different colors, and 2) human color discrimination is greatly limited in the periphery, especially during active vision. We combine these two ideas to shift peripheral pixel color in such a way that minimizes display power output while preserving visual fidelity. Details regarding modelling, optimization methods, user studies, etc. can be found in [Duinkharjav et al. 2022].

## 2 DISPLAY POWER SAVER

*Color Discrimination.* We conduct a pilot study within an HTC Vive Pro Eye to collect eccentricity-dependent color discrimination thresholds in the *DKL* color space. We recruited 5 participants (ages 20-32, 2 female). For 5 test colors and 3 eccentricities, we determine, through a series of 4-alternative forced choice (4AFC) psychophysical studies, an ellipse in color space that represents the set of colors indistinguishable from the test color. We then fit a radial basis function network $\Phi$ to predict, for an input test color and eccentricity, the corresponding ellipse parameters. Example model predictions are shown in fig. 2a.

*Display Power.* While the Vive Pro Eye device is neither an untethered device nor has an LED display, it is used for perceptual experiments and demo purposes due to its high eye tracking frequency. For power measurements, we develop a hardware prototype with the same display aspect ratio as the Vive Pro Eye. We measure the power output for a series of colors in *sRGB* using a current meter and regress a linear model $\mathcal{P}$ to the data, as shown in fig. 2b.

*Joint Optimization.* The color model $\Phi$ is parameterized by a single test color $x$ and eccentricity $e$ and returns ellipse parameters in *i-DKL*. The power model $\mathcal{P}$ is a function of color in the sRGB space, and returns the power consumption in mW. We compute the a pixel's color modulation by solving a joint minimization problem,

$$x^* = \underset{x \in C}{\arg\min}\, \mathcal{P}(x) \tag{1}$$

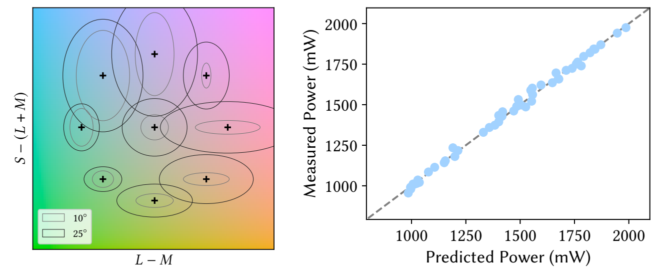
where $C = \{x \mid \mathcal{E}(x) \leq 0\}$ is the set of colors within an ellipse, $\mathcal{E}$, predicted by $\Phi$. This constrained optimization problem can be solved in closed form. As such, we can solve the optimization in real time using a compute shader to perform post-processing on the image displayed by an HMD.

## 3 RESULTS

We validate our filter by performing a perceptual study in which participants (ages 21-32, 3 female, 10 male) view a panoramic video with our filter or a naive baseline turned on. They are tasked with answering a two-alternative forced choice (2AFC) question, "did you notice any artifacts?". Across all test scenes, 16.7% of participants were able to detect artifacts with our filter applied, with about 20.8% power savings on average. We further develop a quantitative study by measuring power-saving on a diverse image dataset, ImageNet. Across a random subset of the dataset, we save 13.9% display power on average, with maximum power savings of 23.5%.

## 4 USER EXPERIENCE

Participants will be able to experience a short (approx. 20 second) panoramic video within an HTC Vive Pro Eye HMD, in a setup similar to fig. 1b. Users will sit in a chair and view the VR scene as they wish, allowing body rotation and active head/eye movements.




**(a) color discrimination model** **(b) display power model**

**Figure 2: *Modelling.* a) The color model predicts an ellipse of colors that are indistinguishable from a test color. b) We fit a linear model to predict power given color.**

During the duration of the video, our power-saving filter's intensity will be linearly increased in a temporal fashion, as visualized in fig. 1c, for a period of 10 seconds until it is applied with full intensity. The user's VR view will be displayed on a large screen to allow other attendees to view the effect of the filter, which will not be perceived by the participant wearing the HMD. The authors will ask participants if they noticed any artifacts as a result of the color modulation. To demonstrate the power saving capabilities, we will also display the power output for different displayed frames on our hardware prototype, shown in fig. 1a. The power saving ratio will be streamed on a monitor for the visualization of non-users.

Additionally, building upon our perceptual model, we propose and will demonstrate a compression scheme by encoding perceptually similar colors together. An efficient implementation of this scheme could reduce memory traffic in VR Systems-on-a-Chip drastically. We have implemented a preliminary compression shader that achieves over 90% compression rate. We show that this compression shader could comfortably run in real-time on a tethered headset (Vive Pro Eye), but runs below 30 FPS on a standalone headset Oculus Quest 2. The results suggest that dedicated hardware support is needed to harvest the benefits of our compression algorithm on a standalone headset.

## 5 CONCLUSION

We described the main details of the studies and models that were developed for our color perception-based power saver, as well as a discussion of what users will experience during our demonstration. We concluded with a description of the results of two evaluations conducted to validate our filter's perceptual fidelity and power-saving capabilities. We hope this work will inspire researchers to explore color-perception-based optimization in the future.

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