Enhancing Field of View for Virtual Reality Headsets with Peripheral LED strips

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Abstract

This study investigates the enhancement of presence in Virtual Reality (VR) experiences by addressing the limited field of view (FoV). We introduce a novel LED-based solution, featuring LED strips on the user's periphery, stimulating peripheral vision for an extended FoV. The LEDs adapt to the virtual environment using a custom compute shader, conveying information about the virtual environment. We place participants ($n = 10$) in a virtual home with colorful lights and measure the improvement in presence via a user survey. Our findings demonstrate an overall decrease in presence with the simulated periphery, but indicate a future direction to improve the technology.

Figure 1. The addressable RGB strip in the headset

1. Introduction

The development of Virtual Reality headsets, in particular, display technology, has been rapid. Many aspects of display technology are critical to improving the immersive experience of Virtual Reality, such as field of view, contrast ratios, focal depths, pixel density, etc. However, much of the research in this area has been focused on new display technology using new solutions, which can typically be expensive to manufacture as they require new processes. Furthermore, many advancements require entirely redesigned headsets, requiring consumers to purchase new devices to utilize the new technology. This paper will present an improvement to virtual reality display technology using existing technologies to improve significantly the immersive experience of any virtual reality headset.

Nearly every headset on the market makes use of a facial insert to interface between the headset and the user's face. Addressable LED strips can be attached to the insert to improve the periphery experience. While there have been other implementations of this design, this approach will account for the cost of materials and use across multiple headset designs. The purpose of this study is to investigate an approach that emulates the peripheral experience of previous works but is more easily implemented in consumer headsets.

The primary objectives of this study are twofold: (1) to develop an inexpensive augmentation to the FoV that could be easily implemented across a range of VR headsets, and (2) to enhance the presence of the VR experience for users, thereby improving immersion and overall enjoyment. This paper describes the implementation to achieve the first objective and conducts a user survey to evaluate the second objective.

2. Previous Works

In this section, we provide a brief overview of previous works and the technologies that have attempted to address the limitations of the field of view in VR headsets, and how they relate to our novel LED-based solution.

2.1. Directly-related Works

These works are directly related to this study; each directly attempts to address limited field of view.

Wide Field of View Displays One of the most straightforward approaches to increasing the field of view in VR headsets is by designing wide FoV displays. There are several works which all investigate new lens, display, and headset technology, such as Rakkolainen et al. [3] or Bang et al. [1]. While this approach significantly improves the immersive experience, it requires completely redesigned headsets, which can be costly for both manufacturers and consumers.

Peripheral Light Devices There is a very similar paper related to our proposed approach in Xiao et al. [5]. This paper proposes a peripheral light display that uses a variety of light sources surrounding the display to simulate peripheral vision. The LEDs were directly attached to the edges of the lenses and in a matrix in the periphery of the HMD. Although this method showed promise in enhancing the user's sense of presence, it required additional, custom hardware and did not provide a cost-effective solution.

2.2. Indirectly-related Works

There are other approaches to the limited FoV problem in VR that may not directly enhance the FoV of VR headsets, but overcome computational or physical challenges in headset display technology that allows for larger FoV HMDs.

Foveated Rendering Foveated rendering is an approach that has been explored to indirectly address FoV limitations. There are many approaches to foveated rendering[4]. In general, the technique optimizes the rendering pipeline by prioritizing high-resolution rendering in the foveal region, while reducing the resolution in peripheral areas. This technique can be combined with new display technology to enable computationally efficient wider displays, but does not directly address the limited FoV in VR headsets.

Light Field Displays Similarly to foveated rendering, light field displays have also been proposed as a potential solution for indirectly improving FoV in VR headsets. Lanman et al. [2] presented a light field display that generates multiple perspective views of a scene, simulating a more realistic viewing experience. Since then, there have been numerous other approaches to light field displays [6]. While this technology shows potential for enhancing the immersive experience, it requires complex hardware and may not be suitable for mass-market VR headsets due to its high cost.

Our proposed LED-based solution builds upon these previous works by providing an inexpensive and easily implemented augmentation to the FoV. Unlike other approaches, our method can be applied to existing VR headset designs without requiring significant hardware modifications or additional cost. Furthermore, by using addressable LED strips, our solution offers a more seamless peripheral experience compared to sparse displays, making it a promising avenue for future research and development.

3. Methodology

In order to evaluate the effectiveness of our novel LED-based solution for enhancing the field of view and presence in virtual reality experiences, we placed participants in a carefully chosen virtual environment. The environment allowed us to study the interactions of users with the LED augmentation and gather valuable data through surveys to understand their perceptions and experiences.

3.1. Experimental Setup

The tests were performed using the Unity ”VR Beginner: The Escape Room” environment. This environment was chosen due to its rich visual features, including a variety of colorful lights, fireplaces, and characters, which provided a suitable setting to demonstrate the LED lights' effects on the user's periphery. The stylized environment also facilitated the investigation of the LED augmentation's impact on presence within the VR experience.

3.2. Procedure

Each participant was equipped with a VR headset featuring our LED-based solution and were then placed in the virtual home and asked to interact with the environment.

Following their VR experience, participants were asked to complete a survey containing questions related to their experience in the virtual environment. These questions were designed to gauge the effectiveness of the LED augmentation in extending the FoV and enhancing the presence in the VR experience.

3.3. Survey

Experience How many hours have you spent using VR systems in total? Provide a general estimate

1. None
2. Less than 5 hours
3. 5-20 hours
4. 21-50 hours
5. 51-100 hours
6. More than 100 hours

Comfort On a scale of 1 to 5 with 1 being ”No discomfort at all” and 5 being ”Very uncomfortable”, in general, what level of visual or physical discomfort do you experience during VR experiences?

Engagement On a scale of 1 to 5, with 1 being "Very low" and 5 being "Very high," how would you rate the level of engagement you experienced during the VR session? Base your answer only on the virtual environment itself and not the headset or extra LED augmentation.

Immersion On a scale of 1 to 5, with 1 being "Not at all" and 5 being "Completely immersed" how immersed did you feel in the virtual environment during the VR experience? Base your answer on the totality of the experience.

Presence On a scale of 1 to 5, with 1 being "Strongly Disagree" and 5 being "Strongly Agree," please rate your agreement with the following statement: "The VR experience provided a heightened sense of presence compared to other VR experiences I have had."

3.4. Survey Discussion

As discussed, the survey questions play a crucial role in understanding the effectiveness of our LED-based solution and its impact on the users' experience. By analyzing the responses to these questions, we can gain valuable insights into the user's perception of engagement, immersion, and presence during the VR session.

The engagement question serves to measure how engaging the game play was, irrespective of the augmentation. By comparing this information to responses to the immersion question, we can determine if the LED augmentation has had a positive or negative effect on the overall experience.

The presence question will determine the overall impact of the augmentation; this is the most vital piece of information captured by the survey which will determine the effectiveness of this study.

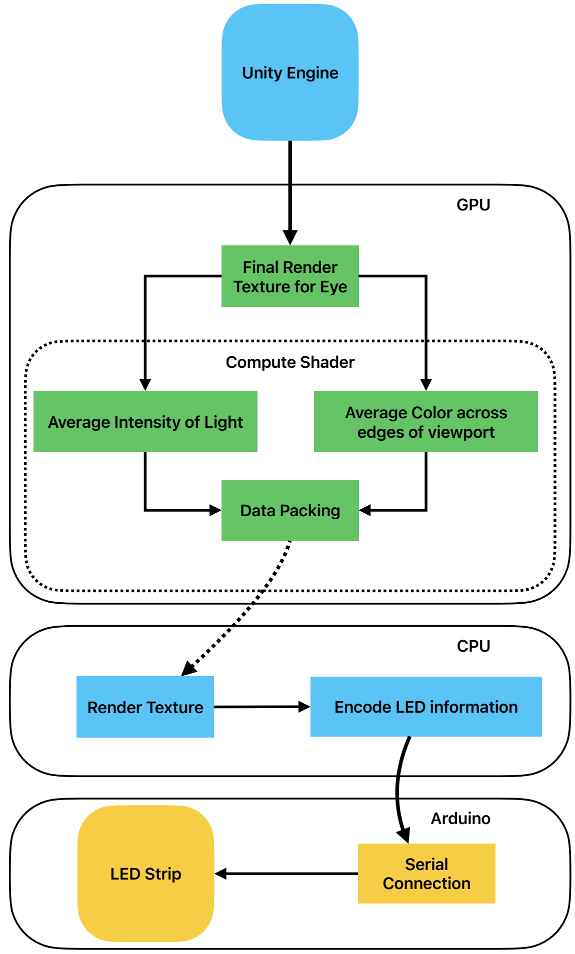

Figure 2. Calculating LED colors & intensity

4. Technical Implementation

The difficulty with such an approach is calculating the intensity and color assigned to the individual LEDs in the headset. Because this is primarily a proof-of-concept, this paper presents a compute shader for Unity Engine that will provide serial commands to a microcontroller for the LED strip (see Fig. 2). While this creates a particular dependency on the Unity Engine, there are other methods to access the display buffers from the headset to provide instructions to the LEDs without the need for an engine-specific implementation. The user surveys were conducted using the HP Envy G2 HMD.

As shown in Fig. 2, there are three major components to the technical implementation. Firstly, there is a compute shader to calculate the dominant color in each region of the viewport. Secondly, there is control code which receives the color values from the shader, unpacks the necessary perimeter colors, and sends the information to a microcontroller connected to the RGB strip. Thirdly, there is the microcontroller driver code which displays the proper colors in the strips.

4.1. Control code

The control code serves two purposes. Firstly, it divides the calculates the distinct regions of the camera buffer to dispatch the compute shader to (Figure 3). It does not directly interact with the camera buffer, but rather just calculates the number of regions required and passes a reference to the camera buffer to the compute shader. Secondly, the control code receives the output colors calculated by the compute shaders, extracts the perimeter color values from the output buffer, and then passes those values to the microcontroller.

Figure 3. The camera's buffer is divided into distinct cells, from which a compute shader is dispatched per each cell

4.2. Compute Shader

Because each compute shader is dispatched per region, there is some difficulty in properly parsing the camera buffer and packing the output buffer. Based on the ID of the shader (each shader has a sequential ID based on the order it was dispatched in), the shader calculates the dominant color for that region. Once the dominant color is calculated, it is moved to an output buffer at index ID.

There are a few viable approaches to calculating the dominant color to send to the RGB strips. While a naïve approach such as averaging is suitable, during development we found it didn't visually match our expectations. Therefore, we developed an approach based on quantization of regions in the display, and selecting the most frequent quantized value, as show in Algorithm 1 (Appendix).

4.3. Microcontroller & RGB Strip

Material	**Cost**
Seeed Studio XIAO SAMD21	\$5.40
1 meter, 20 LED WS2812B RGB Strip	\$11.99
Misc. (capacitor & resistor)	\$0.01
Total	**\$17.40**

Table 1. Materials and Costs for the LED-based VR Headset Augmentation

The microcontroller used is the Seeed Studio XIAO SAMD21. It is based on the Arduino platform and hosts an ARM Cortex-M0+ CPU(SAMD21G18) running at up to 48MHz, with 256KB of Flash Memory and 32KB of SRAM. We found this microcontroller suitable because of its very small design; it only measures 20×17.5×3.5mm.

For the RGB LED strip, we used WS2812B Addressable strips. The WS2812B standard allows us to drive the strip from the SAMD21's power alone and a single data pin. A 220Ω resistor was placed in between the SAMD21's data pin and the strip, and a 500 μF capacitor on the 5v power & ground to protect the strip. This setup can be seen in Figure 4.

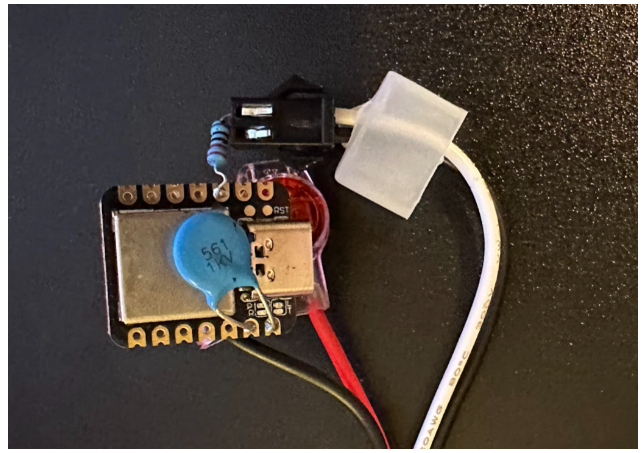

Figure 4. Microcontroller Wiring

Figure 5. RGB Strip in the headset insert

The RGB Strip is then inserted into the headset. Figure 5 shows the strip in the headset insert the strip in the headset.

Overall, we were able to achieve our proof of concept for approximately $17.40 pre-tax. This achieves our first goal of the study; creating a cost-effective version of the FoV augmentation that could be evaluated in our user survey.

5. Results

Implementation-wise, the proof of concept achieved the goal of extending the periphery of the display in a low-fidelity manner. The strips updated with the display and provided a minimal performance overhead. The following sections will discuss the results of the user survey, including the participant demographics and an analysis of the survey findings.

5.1. Demographics

A total of 10 participants (n=10) were included in this study. The distribution of hours spent using VR systems among the participants was diverse, from novices to experienced users (Table 2).

VR Experience	Number of Users
Less than 5 hours	3
5-20 hours	1
21-50 hours	2
51-100 hours	3
More than 100 hours	1

Table 2. User Experience Levels

In terms of comfort levels during VR experiences, our study sample consisted mainly of comfortable users. A significant majority of the participants, 70%, reported experiencing none to slight discomfort during VR sessions. This suggests that the majority of our study population had a relatively comfortable experience while using VR systems. The remaining 30% of the participants experienced varying levels of discomfort during their VR sessions (Figure 6).

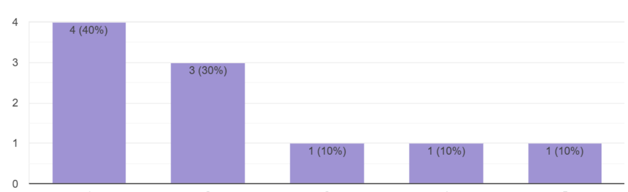

Figure 6. Number of participants who responded to **Comfort** Question

5.2. Analysis of Responses

To evaluate the effectiveness of the LED-based augmentation, we assessed the participants' level of engagement, immersion, and their agreement on the statement that the VR experience provided a heightened sense of presence compared to other VR experiences they have had.

Engagement	Immersion	Presence
3	4	3
5	3	3
5	3	3
5	3	2
4	2	2
3	3	2
2	2	1
4	3	3
4	5	5
2	2	2

Table 3. Participants' ratings for engagement, immersion, and heightened sense of presence

Overall, the level of engagement experienced during the VR session was mixed, with scores ranging from 2 to 5. Similarly, the immersion scores also varied, ranging from 2 to 5. When analyzing the agreement with the statement regarding the heightened sense of presence, half of participants disagreed with the statement, suggesting that the LED-based augmentation had a negative effect on the sense of presence (Figure 7). Similarly, immersion scores were low (Figure 8).

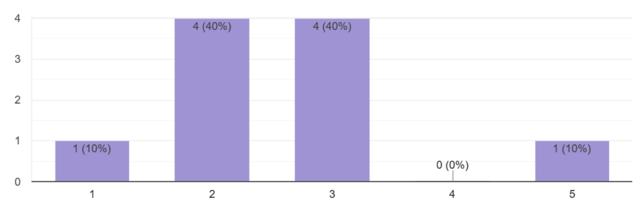

Figure 7. Participants' ratings for agreement with heightened sense of presence statement

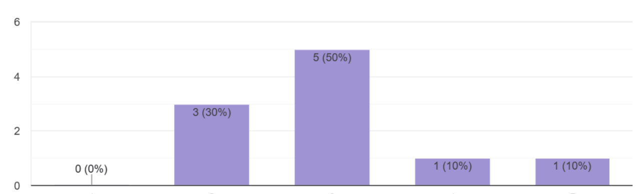

Figure 8. Participants' ratings for immersion

Participants in the study were encouraged to provide feedback about their experience with the LED-based augmentation. This qualitative data offered insights into the aspects of the augmentation that might have contributed to the mixed effectiveness observed in the quantitative data. The comments provided by the participants can be generally categorized into two main concerns: (1) the lights being distracting, bright, and too distinct, and (2) the colors not aligning well with the virtual environment.

Several participants reported that the LED lights on the periphery were too bright and distinct, causing them to be more of a distraction rather than an enhancement to their experience. These bright lights may have drawn the users' attention away from the immersive experience in the virtual environment, contributing to a diminished sense of presence. Moreover, the brightness of the lights could have also contributed to the discomfort experienced by some participants during the VR sessions.

Regarding the second concern, participants noted that the colors of the LED lights did not align well with the colors in the virtual environment. This discrepancy between the colors might have disrupted the continuity of the experience, making it harder for users to fully immerse themselves in the virtual world.

6. Future Work

Based on the feedback and results from the current study, several avenues for future work have been identified to improve the LED-based augmentation for virtual reality headsets. These improvements aim to enhance the user experience by addressing the concerns raised by the participants, ultimately leading to a more immersive and engaging VR experience.

Improve the color-matching algorithm The current algorithm for calculating the colors to be displayed on the LED strip can be refined to better match the virtual environment. One possible approach is to project the colors of each pixel in the virtual environment to the CIELUV color space. From this new projection, calculate the euclidean distance for each pixel to each other pixel, and find the most connected color. This method might provide a more accurate representation of the colors in the virtual environment and improve the overall experience for users. However, a naïve approach is computationally inefficient, so some heuristics would be necessary.

Calculate color regions based on physical LED positions Rather than using the perimeter values of the virtual environment, future implementations could take into account the position of the LEDs within the headset when determining the color regions. This would result in a more accurate and tailored color representation for each LED, ensuring a better synchronization between the LED strip and the virtual environment.

Diffusion layer/more LEDs To address the issue of the LED lights being too bright and distinct, a diffusion layer could be added over the LEDs to create a smoother and more subtle effect. This would help to better blend the LED lights with the virtual environment, resulting in a less distracting and more immersive experience. Additionally, incorporating more LEDs in the strip could provide a higher resolution of color information and improve the overall quality of the peripheral vision enhancement.

By exploring these improvements in future iterations of the LED-based augmentation, the technology can be better optimized to provide a more immersive and engaging virtual reality experience. As the field of virtual reality continues to grow, such advancements will be crucial in enhancing the sense of presence and overall enjoyment for users.

7. Conclusion

In this study, we presented a cost-effective solution for enhancing the sense of presence and immersion in virtual reality experiences by augmenting a VR headset with an LED strip. With a total cost of approximately $17, the proposed system aimed to offer an affordable and accessible means to improve user engagement in virtual environments. Although the results did not fully support the effectiveness of the current implementation, the insights gained through this research provide valuable information for future improvements. Overall, we achieved our first goal of the study, and have a direction for the second goal.

We believe that the proposed approach has the potential to significantly enhance virtual reality experiences once the identified issues are addressed. The participant feedback, combined with the suggested future work, provides a roadmap for refining the technology and optimizing its performance. By addressing the concerns raised by the participants, such as the brightness and distinctness of the LEDs, as well as the accuracy of the color representation, we expect to achieve a more immersive and engaging VR experience.

Our research has shown that a cost-effective LED-based augmentation for VR headsets, while not yet fully optimized, has the potential to enhance user immersion and presence. The feedback and results obtained from the study provide a strong foundation for future work, allowing for the development of improved iterations that can better address user needs and expectations. As virtual reality continues to evolve, the incorporation of peripheral vision enhancements such as the proposed LED augmentation will play a crucial role in elevating the overall user experience and sense of presence in virtual environments.

References

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8. Appendix

Algorithm 1 Compute Shader Pseudocode

function DOMINANT COLOR(InputTexture, OutputBuffer, TextureWidth, TextureHeight)
  $regionCount \leftarrow 6, 6$
  $resolution \leftarrow 8$
  $step \leftarrow \frac{256}{resolution}$
  $height \leftarrow 6$
  $width \leftarrow 6$
  $counts \leftarrow Array(resolution^3)$

  $y_{initial} \leftarrow id.y \cdot height$
  $y_{final} \leftarrow (id.y + 1) \cdot height - 1$
  $x_{initial} \leftarrow id.y \cdot width$
  $x_{final} \leftarrow (id.y + 1) \cdot width - 1$
  for $y \leftarrow y_{initial}$ to y_{final} **do**
    for $x \leftarrow x_{initial}$ to x_{final} **do**
      $normalized \leftarrow \frac{x}{TextureWidth}, \frac{y}{TextureHeight}$
      $color \leftarrow \text{SAMPLE}(InputTexture, normalized)$

      $quantizedColor.r \leftarrow \frac{color.r*255}{step}$
      $quantizedColor.g \leftarrow \frac{color.g*255}{step}$
      $quantizedColor.b \leftarrow \frac{color.b*255}{step}$

      $index \leftarrow quantizedColor.r*resolution+quantizedColor.g*resolution+quantizedColor.b*resolution$
      $counts[index] \leftarrow counts[index] + 1$
    end for
  end for

  $maxCount \leftarrow 0$
  $dominantColor \leftarrow 0, 0, 0$
  for $r \leftarrow 0$ to $resolution - 1$ **do**
    for $g \leftarrow 0$ to $resolution - 1$ **do**
      for $b \leftarrow 0$ to $resolution - 1$ **do**
        $index \leftarrow r * resolution + g * resolution + b * ColorResolution$
        $count \leftarrow counts[index]$
        if $count > maxCount$ **then**
          $maxCount \leftarrow count$
          $dominantColor.r \leftarrow r * step$
          $dominantColor.g \leftarrow g * step$
          $dominantColor.b \leftarrow b * step$
        end if
      end for
    end for
  end for

  $globalIndex \leftarrow id.y * regionCount.x + id.x$
  $OutputBuffer[globalIndex] \leftarrow \frac{dominantColor}{255.0}$
end function