VR Headset with Human-eye Resolution

Osku Sahlsten[1]

[1]Varjo Technologies Oy, Vuorikatu 20, 00100 Helsinki, Finland
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ABSTRACT

Varjo released world´s first human eye resolution virtual reality device, VR-1, in the beginning of 2019. This device has greater than 60 pixels / degree angular resolution on the center area of field of view. At the same time, the total field of view and peripheral resolution are similar to other commercially available VR devices on the market.

With current display manufacturing methods, it would be very hard to produce a single near eye display that offers 60 pixels / degree resolution over the whole field of view and is small enough to fit into the headset. In case of greater than 90-degree field of view, basically 6k x 6k panel would be required. With the high refresh rates of virtual reality applications, this would mean also very large data transfer rates and high rendering load on GPU´s. Varjo overcome these challenges by composing the single eye image from two different display sources, while minimizing the effect on total rendering load. High angular resolution is used on the area where it is mostly needed. Precise analysis of displays with geometrical- and optical adjustments is needed to blend the 2 separate images to a one uniform scene.

1. INTRODUCTION

1.1 Design principles of Varjo VR-1 virtual reality headset display system

Varjo VR-1 device is targeted to be used by professionals in multiple use cases and within many industry areas such as engineering, product design, training and research. In these demanding areas, it is important to distinguish small details and to be able to read even small text in virtual reality environment. To enable best possible experience in virtual reality, human eye resolution was selected as one of the device design targets.

The target for field of view (FOV) was kept in similar level than other virtual reality devices had. This meant 80-100 degree FOV. This figure is not close to the human eye total field of view (160 degrees horizontal and 150 degrees vertical), but was considered to be enough for good immersion without making device design and -manufacturing too complex.

There are also many other important display details that effect on the overall performance. Basic parameters such as contrast ratio, colour performance, response time and refresh rate have been improved a lot by display manufacturers. During past few years even some technology solutions specific for virtual reality needs have been implemented on displays. However, one thing that has been hard to solve is too low resolution. Panel resolution has typically a relationship to the display production methods and -processes and effect on the component yield. Electrical drive of high-resolution panels is also generating too big load for some host computers or to the hardware embedded in the headsets.

1.2 Resolution definitions

Display resolution is generally considered as a display panel resolution, like 1920 x 1080 pixels in standard Full HD panel. When panel physical dimensions are known, pixel per inch (ppi) figures can be calculated to enable easy comparison of pixel densities between different displays. However, when considering virtual reality device performance, more meaningful resolution metric is actually angular resolution. This explains the resolution as pixels per degree (ppd). Angular resolution is a result of the panel resolution and the optics generating the real FOV for user. If the panel is kept the same, large FOV optics make angular resolution smaller.

Typical human eye resolves 60 pixels per degree resolution, which is close to 1 arcminute (arcmin) angle separation between adjacent pixels and Snellen visual acuity of 20/20.

2. DESIGNING A HIGH-RESOLUTION DISPLAY SYSTEM

2.1 Constant high resolution on whole field of view

At first, a single display that could deliver 60 pixel per degree resolution in whole field of view was considered. With the 80-100 degree field of view target, this meant 5k x 5k or 6k x 6k resolution per eye. Such panels in suitable form factor were simply not available. Manufacturing processes and a cost structure suitable for volume production displays were considered to be impossible to solve. Extremely fast panel addressing techniques would have been needed to be develop. And when considering the typical virtual reality display refresh rate of 90Hz, the total data bandwidth from the host to the display would have been over 90 Gbps per following equation:

Data bandwidth per display = 6000 (Horizontal resolution) x 6000 (Vertical resolution) x 24 (bit depth) x 90 (refresh rate, per second) x 1.2 (data overheads) = 93 Gbps

This high data rate is very hard to transfer over any existing interface. Also, the system level power consumption would be very high. On the host side, rendering the virtual reality scene with resolution would cause very high loads for GPU´s.

2.2 Using high- and low resolution areas in FOV

Initial calculations proved that there is no available display technology offering high enough resolution fulfilling the targets. Next step was to consider a system that would be compatible with human visual system without over performing in the areas that are not important.

When considering human eye acuity, there is about 10 degrees field of view where vision is very sharp and about 3-degree foveal field of view where human vision system can resolve details even higher than 60ppd. Performance drops very steep in larger angles (See Fig.1).

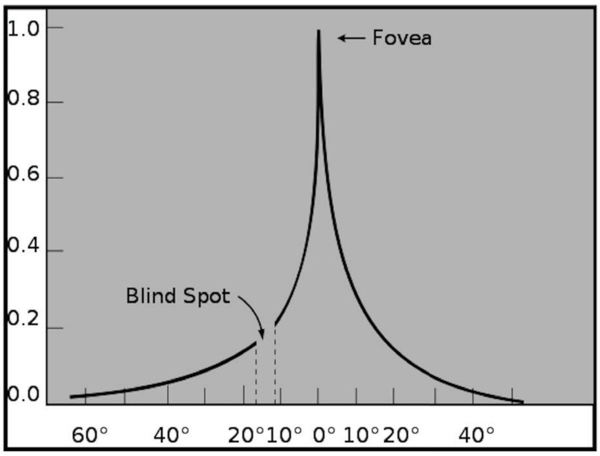

Figure 1: Human eye visual acuity plot

From display system design perspective, this means high resolution on the area where the center point of gaze is located and then gradually smaller resolution towards the edges of field of view.

It was decided that > 20 degree field of view should be a target for high resolution image. And in this area, higher than 60ppd resolution should be achieved. Area could be also larger to gain even better user experience. Resolution for low resolution area was selected to be in par with other available virtual reality devices, 10-15ppd. Visualization of the idea of this system is shown in the Figure 2.


Figure 2: Idea of high- and low resolution areas

3. IMPLEMENTATION

3.1 System development

It was understood that no single display technology alone can fulfill the requirements, but by combining two different technologies could make it. Normal glass-based OLED- or LCD panels were well available and suitable to generate the low resolution, large FOV image. Micro display technologies, such as OLED on silicon offered very high ppi figures (>3000ppi) and small form factor. This technology was selected to produce the high-resolution image.

In the selected concept, the images from two individual image sources needed to be combined. To form a uniform image from two separate images, a unique beam combiner was also designed. Target of this combiner is to pass through the low-resolution image and reflect the image of the high-resolution display. generating uniform virtual image with high resolution and lower resolution images. Unique lenses and optical coatings were also designed to minimize colour aberrations and to give flat spectral response for both optical paths.

In the final system, the high-resolution image is generated using 0.71” 1920x1080 micro-OLED. Peripheral image is generated by 3.5inch 1440x1600 AMOLED panel. Simplified optical architecture of VR-1 system is seen in the Figure 3.

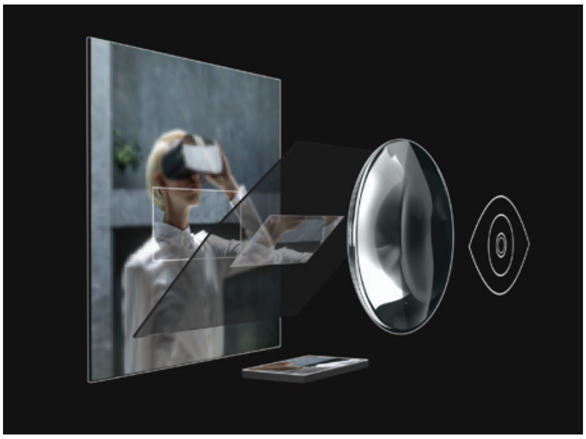

Figure 3: Architectural view of VR-1 optical components

3.2 Further optimization

As the display technologies for high-resolution and low-resolution images were different, careful adjustment of the images was needed. For this, dedicated optical measurement system was developed to characterize the displays. This was done for complete device with all optical parts and using high precision optical instruments. Based on the measured data, colour matching algorithms as well as algorithms to combine virtual images were developed. By implementing these, one uniform virtual image was achieved. Also display driving parameters were optimized for better overall performance.

4. RESULTS

A headset with described optical architecture was build and needed algorithms were developed. The details of algorithms and image combining methods are not covered in this presentation.

In the central region of VR-1 image, over 60 pixel per degree resolution is achieved and it is gradually going down towards the edges of field of view. This is similar to human eye acuity. With the designed image combination methods, transfer from the high-resolution region to the low-resolution region is not disturbing and it is very hard to identify where high-resolution area is changing to low-resolution area.

When comparing VR-1 to best commercially available devices from 2018 and 2019, the readability of text and details on the virtual reality scenes are remarkably better. There is no visible pixel pattern on the high-resolution image areas of VR-1. See Figure 4, where Varjo VR-1 is compared to another device with 1600p displays. Images of both devices are taken through their own optics.

Figure 4: Comparison of device with 1600p display (left) and Varjo VR-1 (right)

5. CONCLUSIONS

By using 4 separate displays in one device, Varjo designed and manufactured the VR-1 virtual reality headset. This device offers over 60ppd angular resolution in central area and 87-degree total field of view for good immersion. Display system is trademarked as Bionic Display™ due to high performance and design principles based on the human visual system.

Even VR-1 is offering the human eye resolution, it is not adding too much rendering load and it can be driven with widely available gaming laptops and desktop computers. The form factor of the device was also kept similar than in other available virtual reality headsets (see Fig. 5).

Figure 5: Varjo VR-1