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Compensation of magnification variations in varifocal HMDs by using a virtual camera

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Abstract—Nowadays, we observe a steady increase of virtual technologies application. VR devices, i.e. HMDs, are still struggling with the VAC. It is possible to "implement" the accommodation mechanism in HMDs using a varifocal system. By using focus tuneable lenses, we can achieve high speed and smoothness of displacement of the virtual image plane. This solution involves also unfavourable changes of geometrical parameters of the projected image i.e. change in magnification. This can be solved by software modification parameters of a virtual camera. In this paper, the development of varifocal HMD is presented, including the method of maintaining constancy magnification.

Most commercially available VR goggles and AR goggles suffer from the vergence-accommodation conflict (VAC). They are designed in such a way that only the vergence mechanism is stimulated in the sense of virtual distance. The virtual image produced in common VR goggles is at a fixed position, usually about 1-2 meters away from the user. However, there are now devices that have varifocal optics [1] based on liquid crystal lenses, deformable mirror, Alvarez lens and others. Each of the listed methods has its own advantages and disadvantages. For example, some of liquid crystal lenses have a much longer response time than the time it takes the real eye to change its optical power, and they do not have a large optical power tunability range. The human eye can change its optical power at a rate of about 10D/s [2] and can focus the image of an object located at a distance from few centimetres to infinity. For medical applications, it is necessary to use accommodation stimuli that are as close as possible to those the user encounters every day in the real world. The malfunction of the accommodation mechanism causes discomfort in the perception of virtual space. For this reason, a varifocal system was designed on liquid lenses. Lenses of this type have a low response time of less than 1ms and a large optical power tuning range and 0.01 dioptres step. A picture illustrating image creation in varifocal HMD is shown in Fig. 1.

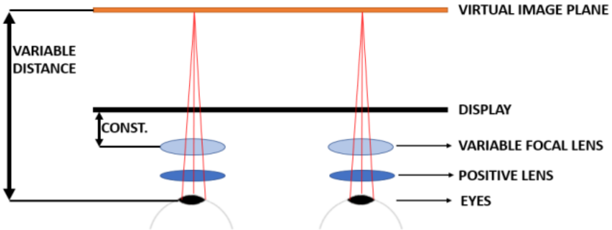

Fig. 1. Principle of virtual image creation in HMD.

The way to impact the position of the image plane in HMD is to change the focal length of the optics using focal tuneable lenses while keeping the distance between the optics and the display constant. Measurements of changes in the distance of the virtual image in relation to the optical power of the lens in the HMD system were made. The measurements were taken using a camera with a varifocal lens. The lens was calibrated to focus on an object at a given distance. A correlation was obtained between the setting of the optical power of the lens and the distance of the object. In this way it was possible to measure how far the virtual image is projected in the focal variable HMD system. A photo of this system is shown in Fig. 2.

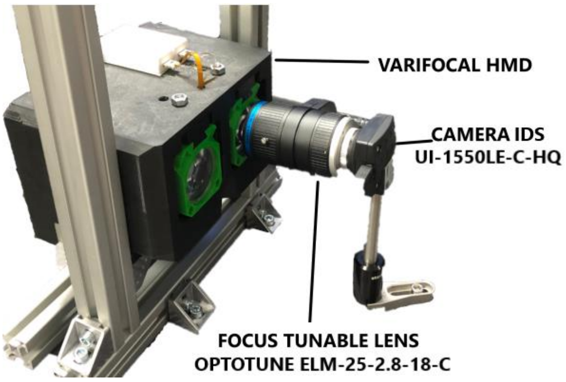

Fig. 2. Physical representation of the measuring system.

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Based on the measurement results, a correlation was obtained showing how the position of the virtual image changes as a function of the optical power of the electric tuneable lens, as shown in Fig. 3.

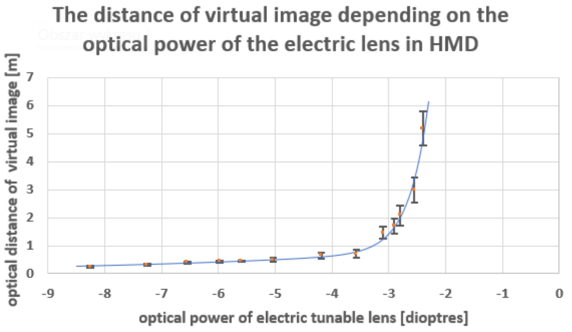


Fig. 3. Measurement of virtual image distance.

Based on the above results, we can conclude that there is a possibility to obtain a smooth adjustment of the distance to the synthesized virtual image. Changes in the optical power of the varifocal lens of the HMD optical path also affect the magnification of the observed objects in the virtual scene, as shown in Figure 4. The difference in the distance and magnification of the virtual image can be easily seen. The shorter the focal length, the farther away and greater magnification of the object becomes.

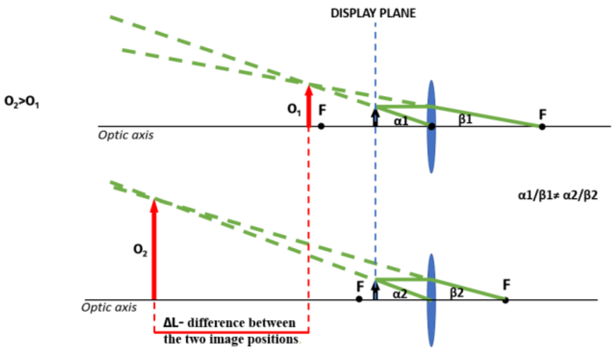


Fig. 4. This diagram shows how the image of an object placed in front of the focal point of a focusing lens changes. The black arrow represents the position of an object (in the display plane) and the red arrow represents the resulting virtual image. Two cases are shown, the first at the top with a short focal length and the second at the bottom with a long focal length.

An uncontrolled change in magnification causes the misperception of the accommodative stimulus. An object at a greater distance increases its angular size, which is unnatural for the normal visual process.

In the case of immersive VR environment perception, this is a very unfavourable effect. Maintaining a constant magnification of the virtual scene projected in the optical system described above can be achieved by configuring virtual camera parameters. This operation must be correlated with changes in the accommodative plane of the eye so as not to cause discomfort to the VR user. VR goggles with an adjustable distance of the plane of accommodation and simultaneous maintenance of a constant magnification require calibration of the system. This operation can be carried out using a camera. With a calibrated camera it is possible to directly measure the geometry of an object in the virtual scene formed by the optical system of the HMD device. Using this system, images were taken for different simulated image distances. Fig. 5 shows two measurement images compared to each other, showing an unwanted effect of changing the angular size of an object.

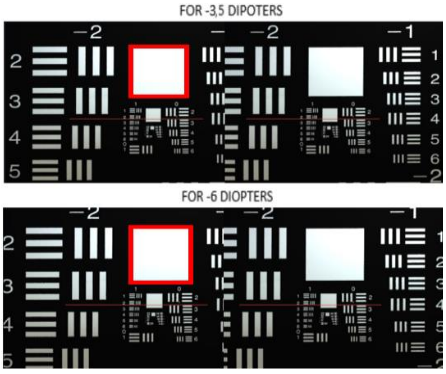


Fig. 5. Example of two virtual images of a constant angular size object projected on different distances Red boxes showing the same area of test plate, but the size of the second one is 7.2% greater.

Based on geometry analysis of images, the dependence of scaling objects in the virtual scene as a function of accommodation distance was estimated. The distribution of the data is approximately linear, so the results obtained were approximated by an appropriate function. The measurement data and their approximation are shown in Fig. 6

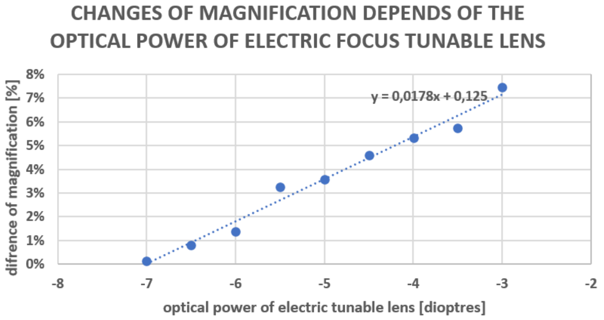


Fig. 6. Graph showing the dependence of magnification and optical power of a focal tuneable electric lens.

Zoom correction was implemented using tools offered by the Unity environment. Unity is a game engine in which you can simulate scenes in virtual reality. Using a virtual camera, you can freely configure the angular size of objects displayed in HMD. These cameras offer the possibility to modify many parameters of a displayed image. In this case, the FOV of a virtual camera was adjusted as shown on Fig.7. Changing the FOV of a virtual camera can be successfully used to achieve basic image correction to maintain constant magnification in the optical path of a varifocal HMD. More advanced correction could be implemented using software distortion modification. The software synchronization of electric lenses with the parameters of a virtual camera was performed in Unity.

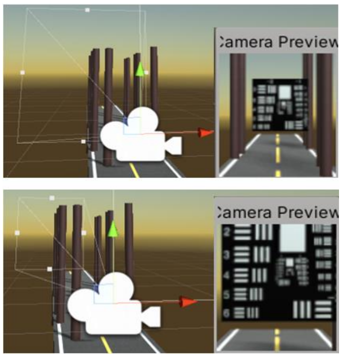
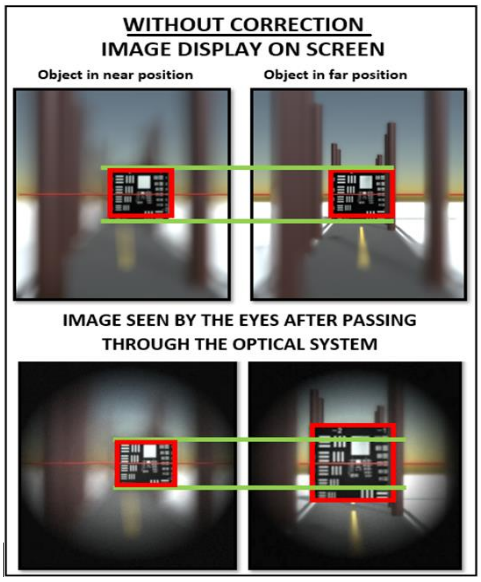


Fig. 7. Two example of a virtual camera in Unity with different FOV. Change of FOV affect the scene view by camera.

The result of image synthesis with and without correction is shown in Fig. 8

In the tests carried out, it was assumed that the object should maintain a constant angular size during observation regardless of the distance. In Fig.8, the green line shows the difference between the object size at near and far positions. For a better understanding of the solution in each case, it is also shown how the synthesized scene is displayed. The presented results confirm the validity of the correction.



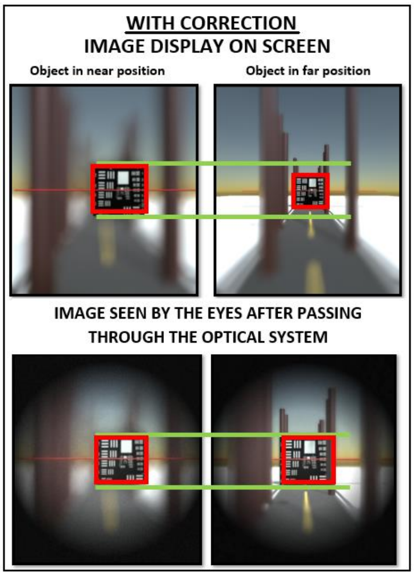


Fig. 8. Examplary image displayed on screen in a system with and without FOV correction for two simulated positions (far and near) of an object.

Simulated virtual reality in goggles should be as close as possible to the real perception of the world. Undesired changes in the size of objects caused by a variable uncorrected field of view can result in incorrect generation of the accommodation stimulus. High-fidelity reproduction of the accommodative stimulus gives the system the potential for future use in optometric research. The obtained results clearly indicate the possibility of developing VR goggles with desirable properties for vision diagnostics and therapy, especially in the aspect of possible fast and smooth modification of the accommodations plane in the range from near-point to far-point.

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