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3-D VISION WITH CHROMADEPTH™ GLASSES

Christian Ucke, Physics Department, Technical University Munich, 85747 Garching, Germany, *ucke@mytum.de*

Abstract: Chromostereoscopy is a technique for converting color into stereoscopic depth. This phenomenon has been known for more than 100 years. Special glasses containing high-tech blazed gratings amplify this effect. These glasses enable the creation of normal' looking color images that can be viewed as two-dimensional images without glasses, but which jump into 3-D when viewed through the glasses. The physiological and physical background will be explained. Simple experiments will be shown with this inexpensive and easily obtainable device.

The human eye has a strong chromatic aberration. Between far red and deep blue there is a difference of about 2 dpt. If you look at a point light source that emits only red (750nm) and blue (400nm) light, you cannot see both colors simultaneously sharp. Normally you will see a red point and a blurred blue disc. This is the so-called longitudinal chromatic aberration. Blue light is refracted more than red light (chromatic dispersion of the eye media). Furthermore, the red point is not centered in the blue disc. This is due to the transversal chromatic aberration and occurs because the line of sight (line between the point source and the fovea; see Fig. 1, left side) does not coincide with the optical axis of the eye. With a simple experiment you can verify the longitudinal aberration. Through a cobalt glass filter look at a point light source that emits enough intensity even at the ends of the visible spectrum. Cobalt filters absorb almost all of the visible light. Only red and blue light can pass. You can see this with one eye or with both eyes open.

The longitudinal chromatic aberration has been known for long. It is used regularly by ophthalmologists to test visual acuity (red-green test). It is known also in the advertising industry. For example, red letters on a blue background must be avoided; otherwise, the accommodation of the eye will change between both colors, and the letters will appear unsharp and unstable.

The transversal chromatic aberration is difficult to see directly, but with two eyes you can see the effect that it causes. Imagine a red-blue point light source at a distance of several meters (Fig. 1). In reality red and blue characters printed on a black background or seen on a monitor display work much better. The blue and red light is refracted differently in the eye media. Imagine looking at the blue point. This means that the image of the blue point is directly on the fovea. Since red light is not refracted as strongly, the image of the red point is located in both eyes, a little to the side of the blue image on the temporal side. Our brain interprets this as if there are two light sources at different distances. The red source seems to be closer. The effect is small, and many people are never aware of it. If you know about the phenomenon, you may see it. The dashed lines in Figure 1 leads to the apparent image positions. This effect has been known as chromostereoscopy or color-stereo effect [1] for more than a hundred years. I have to mention here that the opposite effect is also possible: blue can appear closer than red. This depends upon the position of the fovea relative to the point of intersection of the optical axis with the retina.

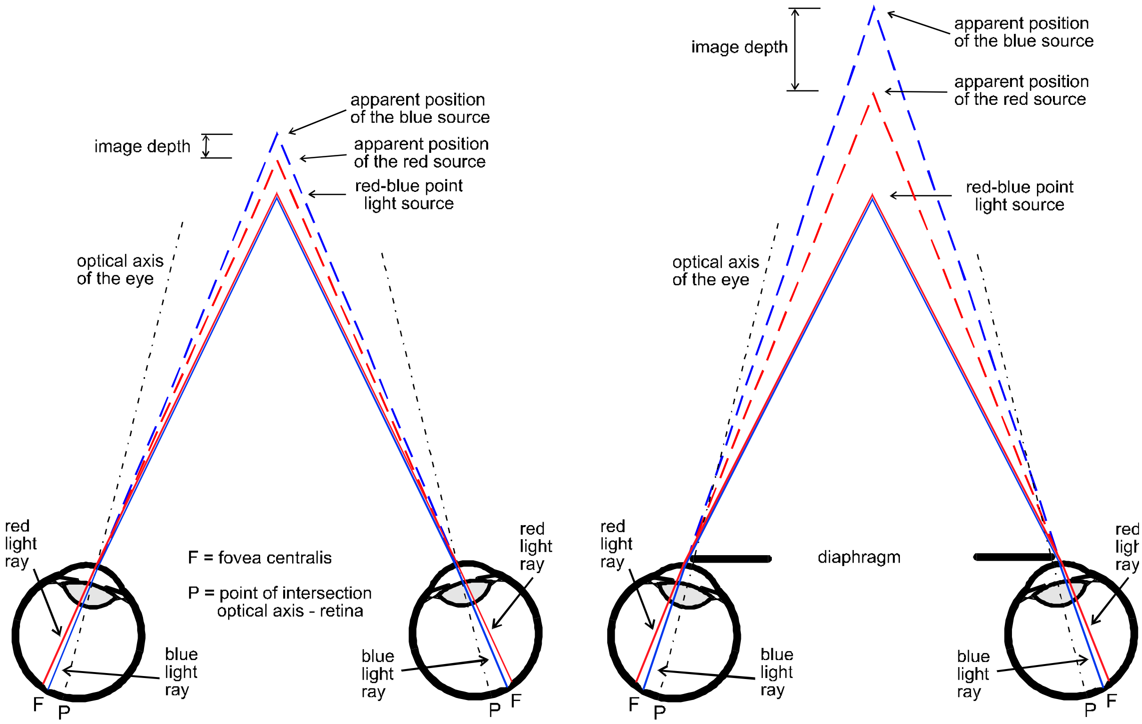

Fig. 1: On the left side there is a schematic drawing showing how light rays of different wavelengths enter into both eyes. On the right side there are diaphragms in front of each eye. Due to the stronger dispersion in the outer (temporal) part of the eye the angle between the blue and the red ray in the eye is bigger. Neither angles nor distances are in scale.

With a very simple 'finger-on'-experiment you can amplify the color stereoscopic effect. Hold your fingers as diaphragms in front of the inner (nasal) half part of each pupil (Fig. 1, right side). The light rays can pass through the outer (temporal) part of the pupil and will be refracted more strongly there. Therefore, the images of the red and blue source will have a slightly greater distance from one another on the retina. This means a stronger stereoscopic effect. With some training you can see this effect very well. You can even try to cover the outer parts of each pupil. A reverse color stereoscopic effect will occur.

If you position a prism in front of each eye with the base toward the nose (Fig.2), the distance of the source images on the retina is greater. Due to the dispersion in the prism, blue light will be refracted more strongly than red light. This means the stereoscopic effect (image depth) will be amplified. The prisms will also cause the optical axis of each eye to turn outward. This can lead to difficulties (double images, headaches) because the convergence of the eyes is strongly coupled with accommo dation. With so-called direct vision prisms, these problems can be avoided. This is described accurately in several patents [2]. However, in any case, prisms are not very comfortable in glasses and are relatively expensive.

Simple gratings diffract light. If you look through such a grating onto a point light source you will normally see multiple spectra, but with special, so-called blazed-gratings almost all the intensity can be diffracted into the first order spectrum on one side [3]. Blazed-gratings have been known in optics for a long time. Since about 1970 it has been possible to produce transmission blazed-gratings by holographic methods and etching techniques. These gratings are known as interference (holographic) gratings. The inventor of the basic principles of the ChromaDepth glasses, R. Steenblik, together with the Chromatek Corporation in the United States, successfully developed a technique for producing a very effective plastic transmission blazed-grating about 1990 [4]. In their own words „*The micro-optics in the 3D* TM *glasses are the highest precision optics ever mass produced. They are manufactured to a precision ten times more stringent than that required for making computer microchips*"[5].

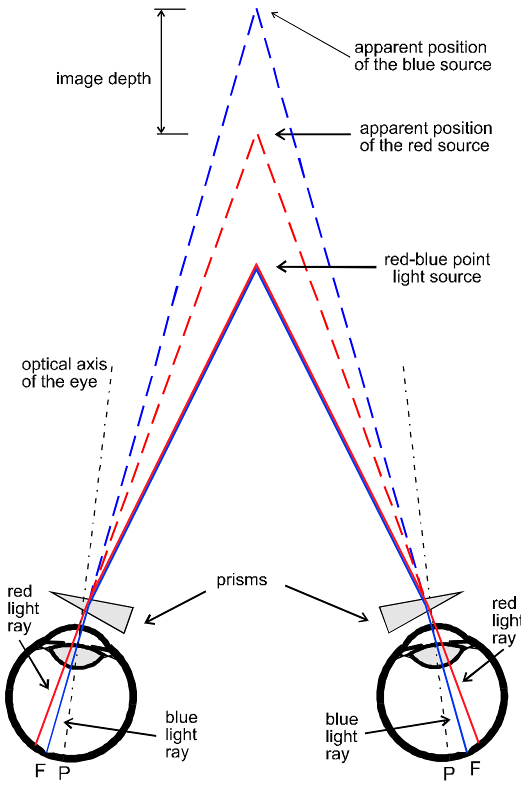

Fig. 2: Here are positioned prisms in front of each eye. Due to the dispersion in the prisms the angle between the blue and the red ray in the eye is bigger.

In Figure 3 a cross-section through the left part of ChromaDepth glasses, seen from above, is shown. The grating has a saw-tooth profile with groove spacing of g ≈ 32 µm. The first order of the diffracted light (λ = 560nm; according to sin $\varphi = \lambda/g$) appears under an angle of $\varphi \approx 1^0$ on both sides of the grating normal. The prism structure also refracts the light to an angle of $\beta \approx 1^0$ (Snell's law), but only to one side. For this wavelength almost all the intensity is concentrated into one of the first orders of the diffracted light. For other wavelengths this is not fulfilled as well.

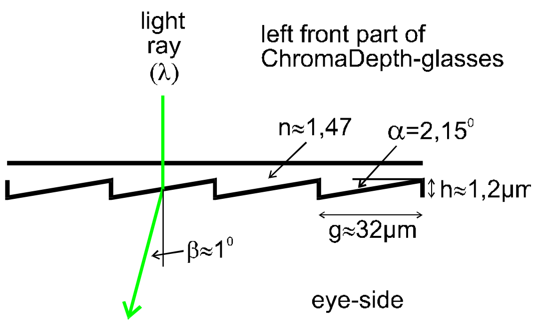

Fig. 3: A cross-section through the left part of ChromaDepth glasses.

Therefore, this grating acts similarly to a prism. If you replace the prisms through such gratings, you will also get the stereoscopic effect (Figure 4). A difference between the prisms and the ChromaDepth gratings lies in the different apparent positions of the real object. With the prisms, these apparent positions will appear behind the real object. With the gratings, these apparent positions will appear closer than the real object. A big advantage of the gratings is that the optical axis of each eye is turned slightly inward, which is much easier for the eyes to do. Another advantage is the greater dispersion due to the grating.

With a simple laser pointer you can visualize the effect of the blazed grating and also determine the groove spacing. Determining the refractive index and the geometrical dates of the saw-tooth profile is not as simple. With the help of colleagues I have determined the refractive index by measurement of a laser beam's reflection from the flat front surface of the glasses and the geometrical data with a force microscope.

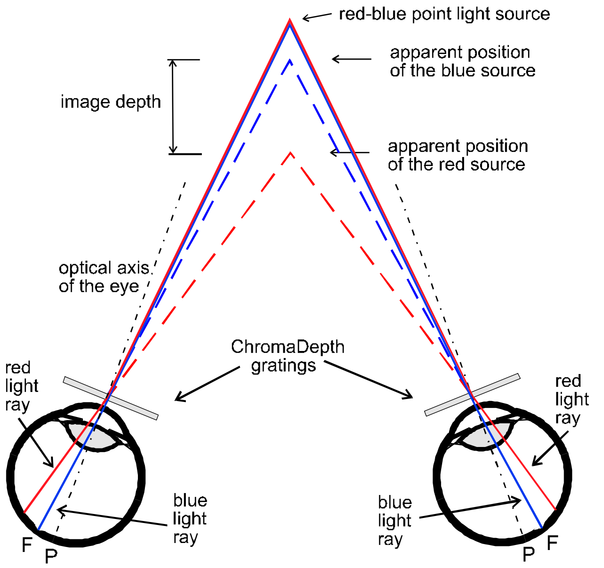

Fig. 4: Chromostereoscopy with ChromaDepth glasses

If both parts of the ChromaDepth glasses have a grating (C3D ™ Glasses since July 98; formerly ChromaDepth Standard Glasses), especially the vertical edges do not appear sharp. Therefore, there are glasses where the left part contains a grating and the right part only a transparent film (now HoloPlay ™ Glasses; formerly HD glasses; HD = High Definition). With these glasses the depth effect is halved but with the right eye you can see sharp.

Another experiment is the exchange of gratings in ChromaDepth Standard glasses: the left one into the right part and vice versa. This can only be done by cutting out gratings and thus destroying the original state. If you look through such glasses, all the depth information is reversed. The blue parts of an image will appear close and the red far away. An easier way to do this experiment is to hold the glasses so that you look through the left part with only the right eye and have nothing in front of the other eye. In this way you have reverse ChromaDepth High Definition glasses.

The big advantage of ChromaDepth glasses is that you need only one image and not double images, as in almost all other 3-D methods. But, of course, you have to be aware of the limitations in the use of colors.

ChromaDepth glasses are used in various areas, such as by the advertising industry, for special scientific purposes like photogrammetry, for painting 3-D images for children's toys and for laser entertainment shows. The Chromatek homepage contains many examples and even videos.

References

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