Advanced stereo projection using interference filters

Helmut Jorke
Arnold Simon
Markus Fritz

Abstract — Stereo projection using interference filters is an advanced wavelength multiplexing approach that specifically takes into account the nature of the human eye, which is characterized by three types of color receptors. Accordingly, the filters used to code image information for the left-eye and for the right-eye image have three narrow bands each. Wavelength multiplexing represents a modern approach by overcoming earlier drawbacks in the color reproduction of image-separation methods such as anaglyph technologies. Unlike polarizing technologies, there is no need of polarization reservation or a restraint to the projection technology.

Keywords — *3-D stereo, 3-D, stereo projection, wavelength multiplexing, interference filter.*

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1 Introduction

Stereo-imaging techniques cover a wide range of applications in science, medicine, simulation, education, presentation, entertainment, and gaming. A common feature of these techniques is the high degree of realism experienced when image content is provided in a most natural way; namely, in a way that the viewer perceives two independent images for the right and left eye.

In order to optimize the sensation of realism and, thus, to really approach the claim of visual high fidelity, the stereoscopic principle needs to be supplemented by the optimization of some residual image-quality parameters, such as the definition of the image, the channel separation between the left and right image, the homogeneity of the image, and the degree of fidelity in hue reproduction.

In this paper, we want to explain the basic approach of stereo projection using interference filters and show the present status of this technique regarding those parameters which are crucial to stereo imaging in real visual high fidelity.

2 Basic approach

Visualization by wavelength multiplexing codes results in image information in different spectral ranges. A well-known representative of the wavelength multiplexing approach is the classic anaglyph approach were the entire wavelength range of visible light (400–700 nm) is basically subdivided into two ranges (red and cyan, the complementary color to red). Using narrower wavelength bands, however, the number of images shown in parallel can be significantly enhanced. The situation resembles the situation in wireless communication technology, where, for instance, in the very-high-frequency (VHF) range, there is a place for a multitude of different carriers.

On the other hand, the visual processing of light in the human eye is characterized by the presence of three receptor types which are associated with the primary hues blue, green, and red. Sensitivities of these receptor types versus wavelength are depicted in Fig. 1. Thus, in order to avoid wavelength multiplex schemes that conflict with the human-eye construction, image information of one image has to be coded in three narrow bands in parallel. These narrow bands have to be placed such that the first band lies within the sensitivity range of the blue, the second within the sensitivity range of the green, and the third within the sensitivity range of the red receptor type. For each of these narrow bands, the available band width is defined by the bandwidth of the respective receptor type (Fig. 1). Additionally, the bandwidths are also limited by the slope of the filter edges.

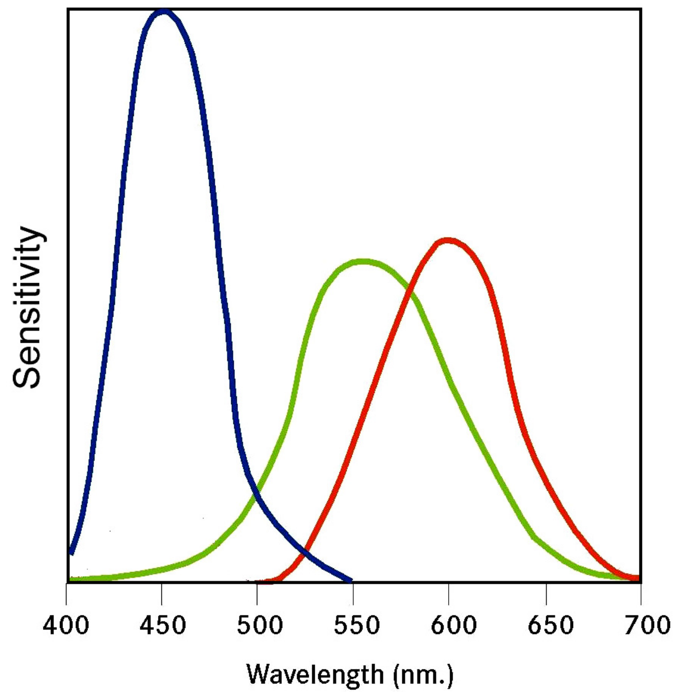

FIGURE 1 — Typical sensitivities of the receptor types for blue, green, and red in the human eye.

The authors are with Infitec GmbH, R&D, Lise-Meitner-Str. 9, Ulm, Baden-Wurttemburg 89081, Germany; telephone +49-731-550-299-56, fax –61, e-mail: arnold.simon@infitec.net.

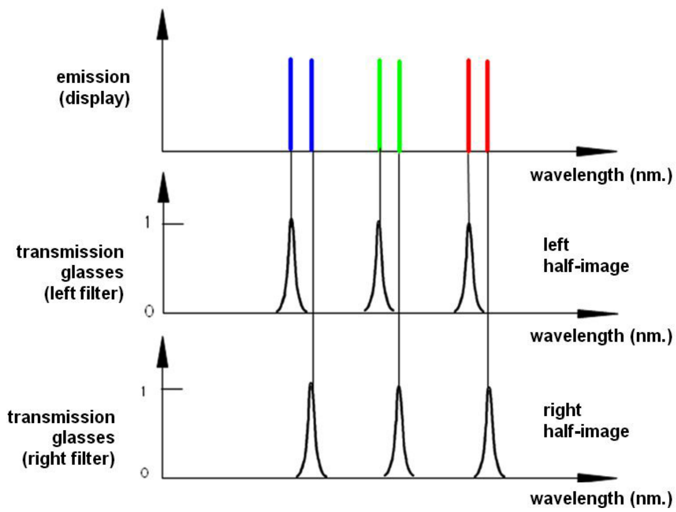

FIGURE 2 — Stereo-display principle using two wavelength emission triples and two matching complementary spectral-filter sets for the glasses.

To separate the image information again and to assign the correct image information to the respective eye, each eye has to be supplied with a narrow-bandwidth filter. This filter must have a triple-band characteristic to selectively transmit the narrow bands associated with the image content coded in these narrow bands. Using, for instance, two triples of narrow bands, stereoscopic images can be shown by wavelength multiplexing where each image is a full-color image (Fig. 2).

3 The Infitec system

To separate image content in wavelength multiplex systems, very narrow and selective filters are required. Conventional dye filters do not show the required selectivity. Instead, in practice, only very high-Q interference filters are sufficiently selective to fit the requirements of the wavelength multiplex visualization scheme for demanding applications. Interference filters normally consist of dielectric coatings deposited on a substrate. This substrate can be also curved glass substrate used for eyeglasses and can be mounted in any glasses frame. For those people who need corrective glasses, the coating can also be deposited on a corrective glass substrate.

In the conceptual approach, narrow-band filters are key elements on the side of the viewer. In practice, however, narrow-band filters are also key elements in the image-generating system. This is because through these filters, wavelength multiplex visualization systems can be realized by standard commercial digital projectors (Fig. 3), simply by installing filters in the path of light either inside or outside of the projector. Because of the importance of interference filters for these types of wavelength multiplex visualization systems, both on the side of the viewer and on the side of the image generator, the abbreviation Infitec (interference filter technique) was introduced and registered as a trademark for these types of stereo projection systems.

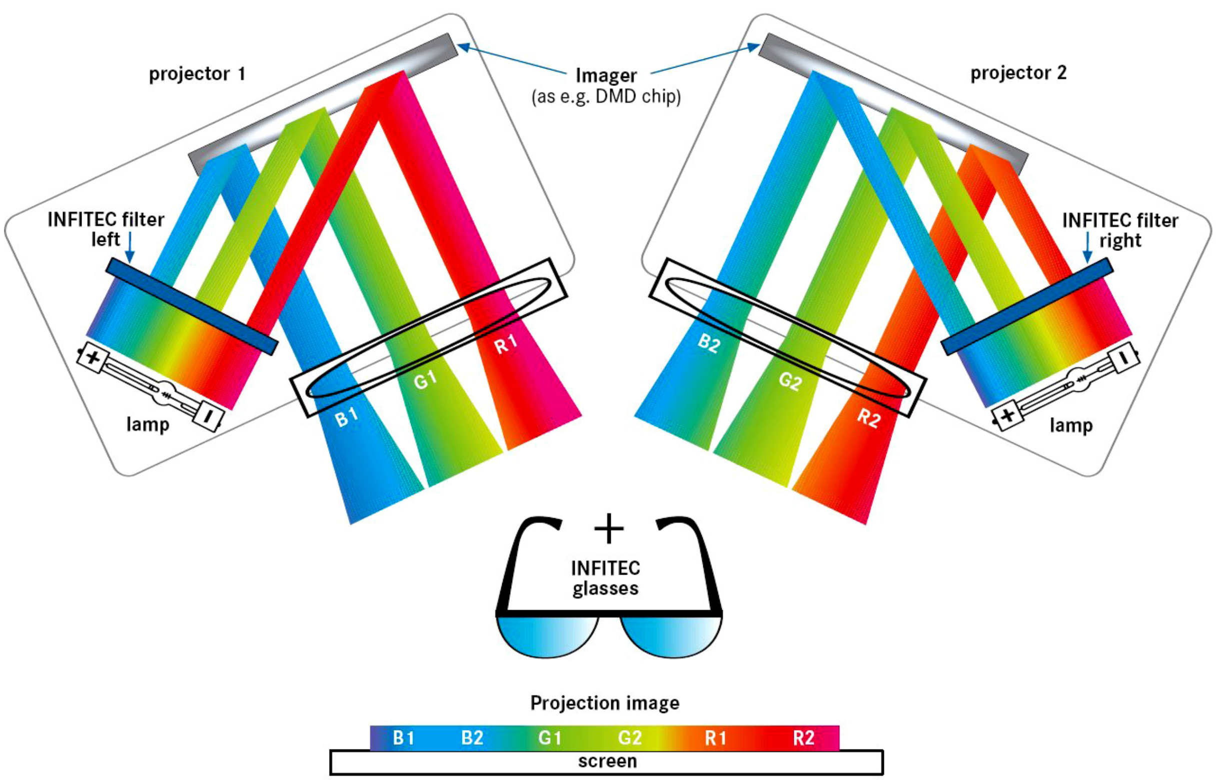

FIGURE 3 — Schematic set-up of an interference-filter technique (Infitec) system for stereo imaging using conventional digital projectors.

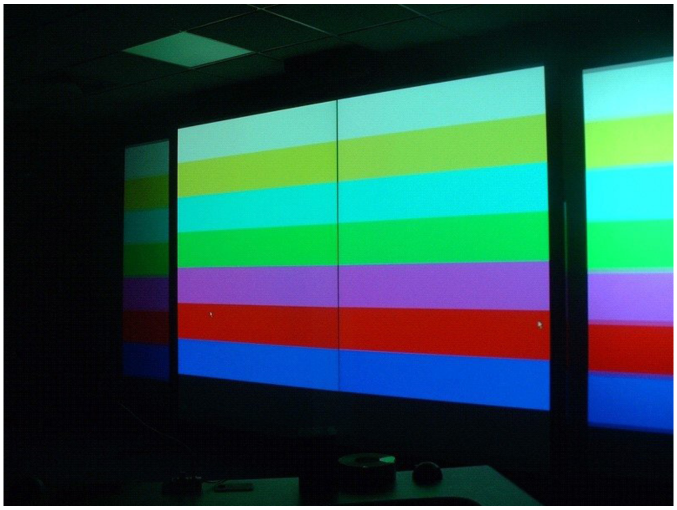

FIGURE 4 — Stripe of fundamental colors projected by a two-channel Infitec stereo system on a white screen.

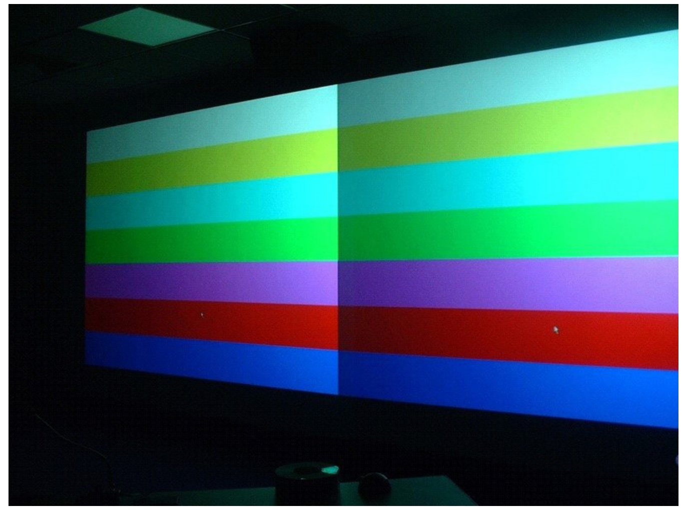

FIGURE 5 — Stripe of fundamental colors projected by a two-channel polarization stereo system on a non-depolarizing screen (silver screen). Luminance non-uniformity is due the directivity of the polarizing maintaining screen.

4 Image resolution

In Infitec systems, each image (left and right) shows, in principle, the full resolution of the basic projector used. Patterson[1] showed stereoacuity (the ability to discriminate small differences in depth) declines with decreasing spatial frequency. Very small disparities of only 20 arcsecs can be discriminated if the temporal frequency modulation is low. Therefore, the image resolution of 3-D display systems should be equal or better than those of 2-D displays.

5 Channel separation

Channel separation of the Infitec system depends on the selectivity of the wavelength multiplex filters. Channel separation determines the interocular crosstalk which affects the fusion limit and the subjective image quality. Yeh and Silverstein[2] compared the fusion limits, the stereoacuity, and the accuracy of depth judgments for red and white objects with differing ocular crosstalk. Due to the chromatic aberration of the used polarizing shutter glasses, the crosstalk was about 2% for red-colored objects and about 7% for white objects. This study proved that fusion limits for the red objects exhibiting less crosstalk was 6.19° compared to 3.66° for the white object if a stimulus of 2 sec was applied. Subjective judgments of the image quality concluded that the red objects appear sharper. The incidence of reported eyestrain and headaches was also less for the red objects.

Interocular crosstalk of the Infitec system is even significantly lower than the investigated red object of the Yeh and Silverstein study. However, up to now, stereo projection systems that use circular polarization filters suffer from extinction insufficiencies due to chromatic aberration of the polarizing system. Typical circular polarizing systems are optimized for the green spectrum (crosstalk <1%), but crosstalk for red color amounts to about 5% @ 600 nm. Current autostereoscopic displays are also reduced in their performance since crosstalk levels of 5% for two-view and over 20% for a 14-view lenticular-type autostereoscopic display have been measured.[3] Woodgate[2] recommends minimizing crosstalk to a maximum of 2% for high-contrast images, because a crosstalk level of 0.3% is reported to be visible.[5]

The crosstalk of the standard Infitec filters is below 1% for the entire visible spectral range. Maximum values are located at the spectral intersection of the two complementary filter ranges, whereas in most spectral ranges crosstalk is below 0.1%.

5 Image homogeneity

The Infitec system requires no special screen because the only condition which needs to be fulfilled by the screen is preservation of the spectral composition of the scattered light. This condition is fulfilled with all conventional white screens. Thus, highly diffuse scattering screens with a gain of unity can also be used. This holds for both the front and rear projection. Thus, Infitec opens a new way to show stereo images in a homogeneity quality normally known only from mono-projection. Hot-spot phenomena well-known from stereo imaging using polarization filters can be completely eliminated. This is illustrated in Figs. 4 and 5. Therefore, interference-filter technology is appropriate for 3-D presentation where the image is displayed on a curved wall (*e.g.*, Planetarium or historical buildings).

6 Fidelity in color reproduction

Infitec filters generate two different sets of primary colors for the left (A) and for the right eye image (B). Infitec filtering generates very narrow new primary colors (Fig. 6). So the two primary color sets are represented by larger triangles than the original triangle of the basic projector. However, the stereo system uses only one color gamut, which is defined by the intersection area of the both triangles A and

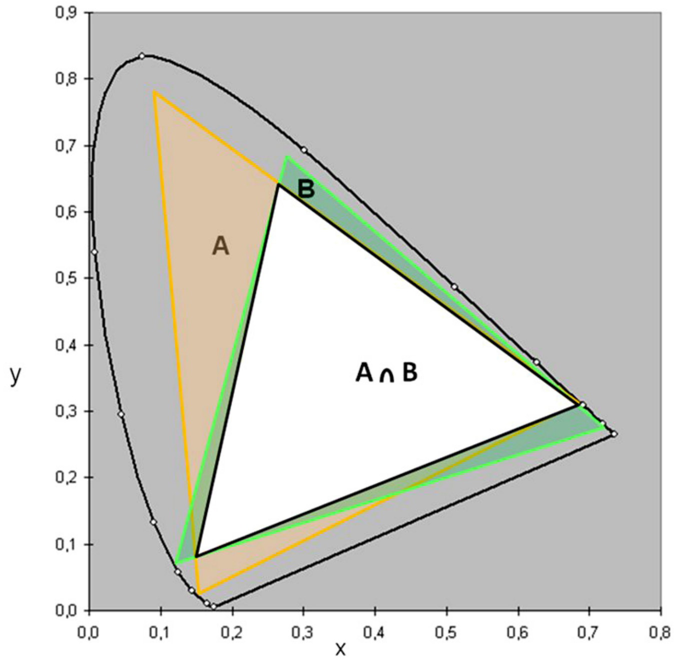

FIGURE 6 — CIE 1931 color gamut of the Infitec stereo system (A ∩ B) after color correction of the extended color gamuts A and B for the two conjugated filter sets.

B. Basically, for each filter gamut A and B, to each single primary a certain specific ratio of the two other primaries is added. Thus, a uniform color gamut for the two filter sets can be achieved. The color-gamut transformation algorithm reduces the enhanced gamut of the non-corrected triangles again approximately to the initial color gamut without interference filters.

The algorithm for this color conversion is a customary algorithm for calibrating colors in electronic-imaging systems. The parameters in this algorithm depend on the emission characteristics of the lamp in the projector and on the filter characteristics to generate the primary colors in the projector. Also, naturally, these parameters are strongly influenced by the Infitec filter characteristics. In practice, parameters need to be acquired for each projector type individually to get well-balanced colors.[5]

There are different ways to implement this algorithm. For applications which do not require interactive real-time rendering, data can be pre-processed using proper software. This holds for all 3-D video and 3-D cinema applications. For interactive 3-D applications, on the other hand, a fast electronics is required that processes image data in real time. This electronics is available in an analog version and in a digital version.

7 Conclusion and outlook

Conventional-stereo-display techniques by projection separate images for the left and right eye by (i) wavelength multiplexing (this is known also as the classic anaglyph approach using, for instance, red–green filters), (ii) polarization (linear or circular polarization), or (iii) time multiplexing (shutter glasses technique). Stereo projection using interference filters is an advanced wavelength multiplexing approach that specifically takes into account the nature of the human eye, which is characterized by three types of receptors, which are associated to the primary colors blue, green, and red. Correspondingly, the two filters used for the left and for the right eye have three narrow transmission bands, respectively. The three transmission bands B1, G1, and R1 of the filter type A for the left-eye image and the three transmission bands B2, G2, and R2 of the filter type B for the right-eye image are placed in the visible spectral range (400–700 nm) that (1) conjugated transmissions bands (B1–B2, G1–G2, R1–R2) are within the sensitivity range of the respective receptor and (2) conjugated transmission bands do not overlap.

Key features of present Infitec stereo-imaging systems are a superior channel separation, the compatibility with standard cinema screens for superior image homogeneity, especially in tiled display systems or on curved white screens. Stereo interference filter technology is compatible with any digital projection technology (LCD, DLP, and D-ILA).

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Helmut Jorke is CEO of Infitec GmbH. He has managed earlier DaimlerCrysler projects that subsequently lead to a spin-off the new company INFITEC GmbH in 2003.

Markus Fritz is COO of Infitec GmbH.

Arnold Simon is a consultant for Infitec GmbH.