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Electronical correction of misalignments between optical grid and pixel panel on autostereoscopic displays

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Abstract

Large-area displays and an especial sharp image quality are built by gradual increasing pixel density. This trend is predestinated for the field of autostereoscopic 3D displays. Though it is hardly possible to adjust the optical grid against the pixel panel, due to micrometer scaled structures. This paper presents a method to locally correct adjustment failure by reallocating the image information in fine steps by adapting existing methods. It is possible to use the applicable methods at single-user, multiview as well as integral-imaging displays, and it enables an adjustment to the observer positions. With the correction method developed by us, local misalignments can be detected in a test image, which arranges the individual stereo channels on an HSV-color cycle by color coding. The test image will be detected and measured by a photo-spectrometer in a preselected position. We also demonstrate the generation of a resulting correction-map, which contains the position, offset or shift value as well as the shift direction of the affected subpixels. The effectiveness of this correction method was proven by measurements and also determined its working scope.

Introduction

Today, color displays can be built with a very high resolution, due to a continuous increasing pixel density. That makes an immersive viewing experience possible. These super high-resolution displays show digital photos at full resolution on a desktop display. The commercial exploitation has already reached 5K and prototypes have even 8K or 16K resolution at video frame rates. For the first time this development creates a possibility to design autostereoscopic 3D displays that provide sharp images per view comparable with full HD in 2D presentations. For a commercial use case, the optical grid and the pixel panel need to be merged by bonding to be dimensionally stable. As the size of the subpixel structures decrease, down to the micrometer range, it becomes more and more difficult to align optical beam splitters and display panels. Local mismatches are inevitable. It means that in addition to the task to avoid temperature drift to achieve temporal stability of the 3D image, alignment accuracy also needs to be achieved. The basic construction of spatial interlaced autostereoscopic 3D displays consists of a subpixel layer *MB* and of an optical image splitter *SE* with a specific distance *a*. The image splitter can be located in front or behind the subpixel layer. These 3D displays can be classified into multiview, integral-imaging and single-user displays. These sub-classes are only differentiated by their emission characteristics [1]. In multiview as well as in integral imaging 3D displays, several views I_α will be arranged side by side in an image strip. The intention of such an arrangement is that an image strip will emit in different view directions through one image splitter element. These views are only differentiated by a horizontal offset of the rendering camera or by different camera angles, because of using a look-at-point. At nominal distance *ND* this results in side by side arranged stereo rhombi that exclusively comprise the image content of the correspondent view [2].

In a single-user 3D display, two stereoscopic partial images of a scene are homogenously written in the available subpixels of an image strip. This results in an optical separation of partial images, due to the image splitter in front of the pixel panel [2]. The emitted light rays of left and right image content also converge at nominal distance *ND* and form two side by side arranged stereo rhombi. The resulting sweet spot positions are adaptable to the position of observer eyes by appropriate procedures [3][4]. The adaption of the 3D-representation by means of image processing procedures is implemented by reallocation of image information. Reserve subpixels are necessary for this reallocation, enabling to adapt the position of the stereo rhombi to the viewer's position. All classes of 3D displays with an image splitter have in common that stereo rhombi are repetitively visible in neighboring areas. Because of increasing panel resolution, it is possible to construct large-area displays. On the other hand, small displays also will be a more high-resolution to enable a close-up observing of details like small text and high-resolution photos. These displays can be used to build high-resolution autostereoscopic 3D displays. The dramatic reduction of structure sizes results in a new challenge in mounting and alignment of the image splitter towards the pixel layer. Thus, only slight tolerance variations can cause a substantial increase of crosstalk which results in dramatic degradation of image quality. At our recently presented, iterative brightness shifting procedure for single-user displays the effort is very high, due to the need of a multitude of sequentially evaluated camera shots [5][6]. The camera shots of the faulty display image are necessary to calculate and correct optical addressing errors [3]. Other correction procedures for a compensation of errors on lenticular raster screens also register the image error by a camera shot and create a mathematical model [7][8]. In contrast, we present in this work a correction strategy that comprises both approaches and which is applicable for all types of autostereoscopic displays.

Analysis of Misalignment Error

Today, image splitters are fixed by bonding, to get a rigid construction. This easily can result in a non-correctable tilt error of the image splitter. This becomes visible by slight deviations between the slope of the given interleaving pattern and the orientation of the image splitter. In addition, the surface of the display can have a slight waviness that results in irregular grid distances and error in parallelism. These irregularities, shown in Figure 1, result in inaccurate separations of views. Figure 1 shows an autostereoscopic 3D display with a parallax barrier *SE* and a slit width *L* that has a chosen distance *a* against the pixel layer *MB*. Behind every slit aperture there are corresponding image strips that consists of respectively 5 subpixels with a subpixel width *SP*.

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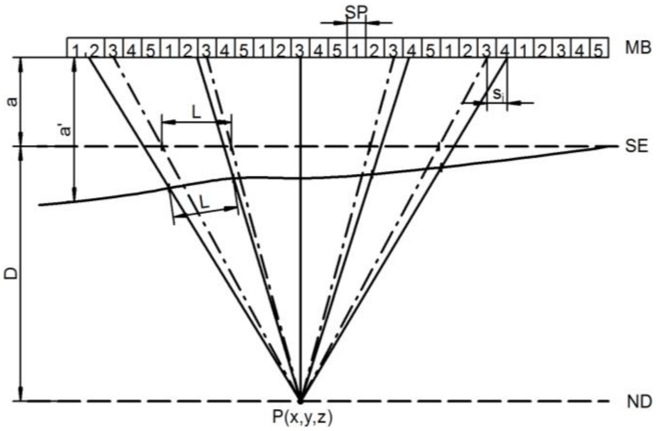

Figure 1: Defective emission on observing position P(x,y,z) by a deviation of the image splitter (continuous line) towards layer SE in comparison to an ideal alignment (dashed lines).

The views I_α are written to the subpixels in a regular order. With an ideal alignment of the barrier (dashed line) only view 3 is visible through every slit aperture at the eye position *P(x,y,z)*. The shown deformation of the parallax barrier (continuous line) results in a deviation of image content, recognizable at the observer position *P(x,y,z)*. The local divergence s_i is therefore different for every position on the display. The gradient of the error as a general rule is low-frequent and extends in x- and y-direction of display panel coordinates.

Creation of Correction-Map

For the detection of local optical mismatches to all views (1-5) a different color is allocated. These colors were chosen from the HSV color space as *hue* that is equally spaced to each other. Figure 2 shows the distribution of all views. The order of views corresponds to the position of the *hue* color circle, which is completely subdivided into equal parts.

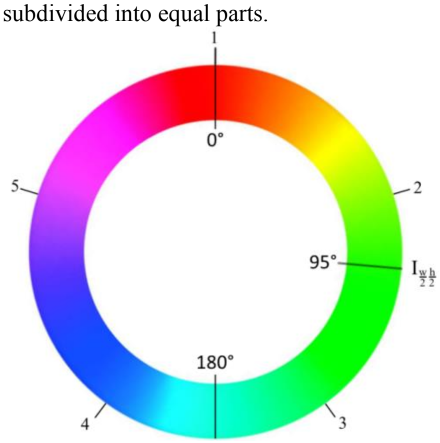

Figure 2: Hue-dimension of HSV color space in degree and as a normed value

For a precise localization of local mismatches a photo-spectrometer are centrally positioned to the middle axis at nominal distance *ND* in front of that 3D display. This setting is schematically shown by Figure 3. The used photo-spectrometer itself is a ProMetric PM-1200N-1. The resulting picture of the display surface is cropped from the overall image and geometrically corrected.

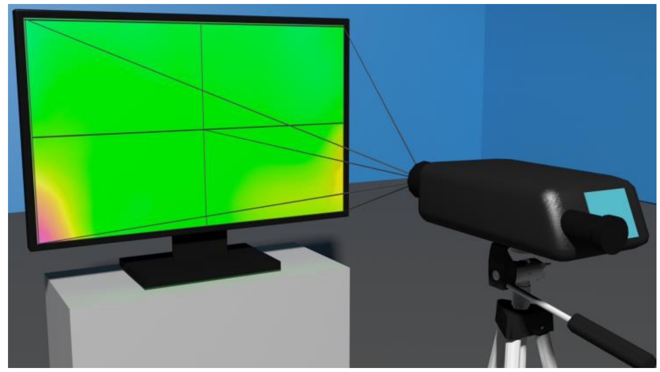

Figure 3: Setup to shot a colored mismatch picture with a photo-spectrometer for the correction Texture

As the distribution of local mismatches has a very low frequency, a median-filter can be used to eliminate high-frequent interferences of subpixel values that originate from noisy picture shots. Figure 4 shows a geometrically corrected and filtered shot I_α.

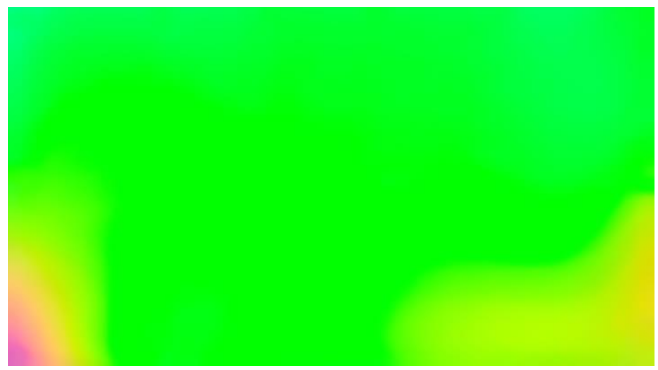

Figure 4: Image shot at nominal distance with a median filtering and a geometrical correction afterwards

As a reference point, the *hue* of the picture center point is chosen and a difference between it and $hue_{180°}$ is calculated. Equation (1) represents and describes the image matrix *I*. Subsequently, the *hue* of all pixels of the whole image will transform by summate the difference to the *hue* of every pixel. Figure 5 shows the result of the transformed image I_t.

$$I_{t_{ij}} = \left(I_{ij} + \left(360° - I_{\frac{w}{2},\frac{h}{2}}\right) + 180°\right) \, mod \, 360° \qquad (1)$$

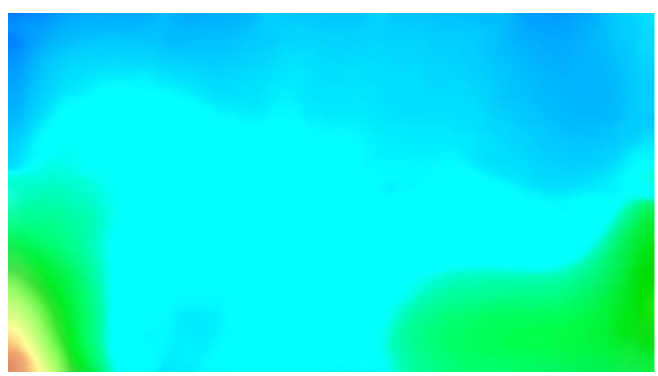

Figure 5: Image transformed to 180°.

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With the help of I_t it is possible to determine the shifting value I_S. This indicates for how many subpixels or views V, respectively the image content, needs to be shifted. The shifting direction I_D, which is described by equation (3), is dependent on the algebraic sign of the local shifting value I_S that is described by equation (2).

$$I_{S_{ij}} = \frac{I_{t_{ij}} - 180°}{360°} \cdot \mathrm{V} \tag{2}$$

$$I_{D_{ij}} = \begin{cases} 0, & I_{S_{ij}} < 0 \\ 1, & I_{S_{ij}} \geq 0 \end{cases} \tag{3}$$

Figure 6 represents the final correction map as a picture. The shifting value I_S was exemplarily written in the red color channel and the shifting direction I_D in the green channel. Theoretically, it is possible to choose other color keys.

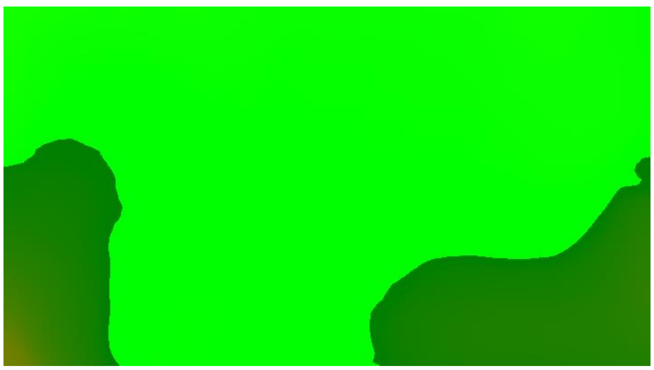

Figure 6: Final correction map of both shifting values by using the red color channel for I_s and the green one for the shifting direction I_D.

Method for Multiview and Integral-Imaging

For the correction of optical addressing errors the following procedure was used to gradually redistribute image contents. In a multiview display every view will be assigned to a correspondent camera angle. The image splitter could be a parallax barrier or a lenticular grid. The image content is arranged by following the grid slope and by building subpixel groups. The upper part of Figure 7 shows such an arrangement by using a lens grid, where the borders of lens elements are represented by white lines. The dashed black lines represent the center of the visible 3rd view from the center of the correspondent stereo rhombus in an ideal alignment of the grid. The lower part the picture shows a successive shifting of the lens grid projection to the right direction, which results in a content mismatch. This shifting situation is shown by continuous lines and they mark the visible content mismatch from the same observing position. The absolute value of local mismatches s can be smaller than the width of a subpixel, so that finely graduated local shifting of the image content is needed. Due to the discrete structure of the display matrix it is not possible to realize shifting values less than a subpixel width. For that reason the camera position is shifted instead. By that, the locally shifted emission directions that were induced by inaccurate assignment are corrected with altered subpixel content, resulting from the shifted camera positions. A shift of image content is possible by allocating the correction factor I_S on the correspondent camera angles of view's I_α. This correction factor can be a floating-point number. If the range of values of resulting camera angles $I'_\alpha = [0,\ V+1]$ exceeds or falls below a range, the modulo-function will be used.

$$I'_{\alpha_{ij}} = \begin{cases} I_{\alpha_{ij}} - I_{S_{ij}}, & I_{D_{ij}} = 0 \\ I_{\alpha_{ij}} + I_{S_{ij}}, & I_{D_{ij}} = 1 \end{cases} \tag{4}$$

The resulting transition views I'_α are described by equation (4). They were written into equivalent subpixels as shown in the lower part of Figure 7. It is not possible to avoid the observation of two neighboring subpixels, due to the misalignment of the image splitter, but with the method described above the correspondent view can be reconstructed. This is done in a rendering process, in the simplest case, by using a depth map. A gradual shift of camera angles leads to discontinuities in the image that are also recognizable as artifacts.

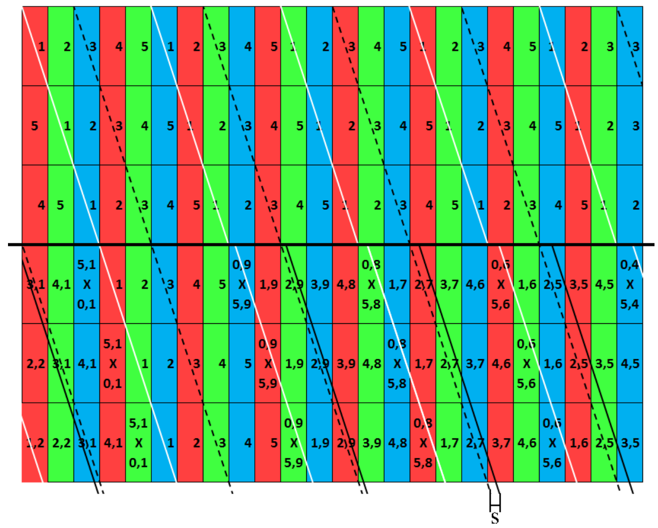

Figure 7: Successive, gradual, local shifting of image contents (continuous line) compared to the ideal case (dashed line).

To avoid such artifacts, the image contents of adjacent subpixels of two neighboring image strips will be proportionately merged. This will happen, if the corrected partial images $I'_{\alpha 1}$ and $I'_{\alpha 2}$ are mutually multiplied with the fractional part of the local correction value I_S [9][10].

$$I'_{\alpha 1 X \alpha 2} = \begin{cases} I'_{\alpha 1} \cdot (I_s - \lfloor I_s \rfloor) + I'_{\alpha 2} \cdot (1 - (I_s - \lfloor I_s \rfloor)),\ I_D = 0 \\ I'_{\alpha 2} \cdot (I_s - \lfloor I_s \rfloor) + I'_{\alpha 1} \cdot (1 - (I_s - \lfloor I_s \rfloor)),\ I_D = 1 \end{cases} \tag{5}$$

Method for Single-User

For the correction of optical addressing errors as well as for the adaption of the viewing zones to the position of the observer, a procedure for single-user displays is needed. This procedure also has to provide means to overcome the discrete subpixel structure. Therefore, the image content of adjacent subpixels of left I_L and right I_R content, will be partially merged in relation to the local shifting value I_S. The dependencies for the principle shifting of the image content of adjacent subpixels I_{LXR} and I_{RXL} was specified in equation (6) and (7). If the shifting value I_S exceeds the width of a subpixel, the whole interleaving pattern will be shifted by the integer part of I_S. The fractional part of it will be used for the determination of the interpolation ratio of the content of adjacent subpixels.

$$I_{LXR} = I_L \cdot (I_s - \lfloor I_s \rfloor) + I_R \cdot (1 - (I_s - \lfloor I_s \rfloor)) \tag{6}$$

$$I_{RXL} = I_R \cdot (I_s - \lfloor I_s \rfloor) + I_L \cdot (1 - (I_s - \lfloor I_s \rfloor)) \tag{7}$$

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Figure 8 shows a shifting situation of left and right image content, where the shift value is $s = 0.25$, which is 25% of the subpixel width. The adjacent subpixels I_{LXR} and I_{RXL} in each case are located between subpixels of left (dashed line) and right (continuous line) image content.

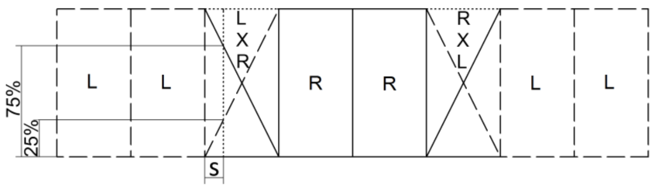

Figure 8: Linear shifting situation by 25% of a subpixel width

These procedures will be used to adapt the observing position in xyz-space as well as to correct optical addressing errors. Therefore the final shifting value I_S' can be understood as a summated superposition, depending on the shifting direction I_D. Equation (8) specifies the combination of global shifting value S_{xy} used for adaption and shifting value I_S used for the local correction [2][4].

$$I'_{S_{ij}} = \begin{cases} S_{xy} - I_{S_{ij}}, \ I_{D_{ij}} = 0 \\ S_{xy} + I_{S_{ij}}, \ I_{D_{ij}} = 1 \end{cases} \quad (8)$$

Results

In order to check the effectiveness of this procedure qualitatively by measurements, a multiview 3D display with a resolution of 5K and a lenticular grid were used. The grid was aligned manually by using round spacers at display edge. In the following, every view was allocated with a color correspondent to the colors of the HSV-color circle. Figure 9 represents a shot from a photo spectrometer at nominal distance *ND*. The local mismatches are clearly visible at the lower corners of the screen by a colored deviation compared to the color of display center point. This difference is an indicator for the magnitude of misalignment.

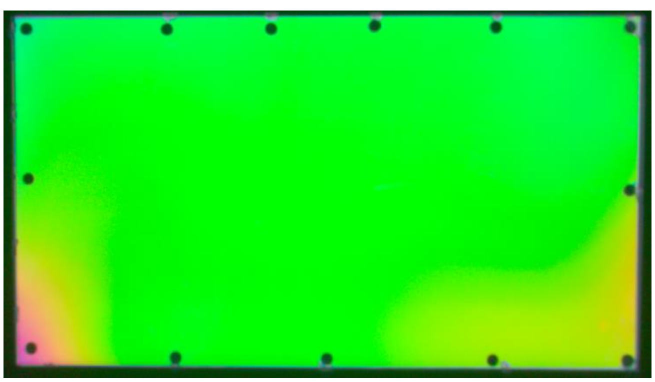

Figure 9: Photo spectrometer shot of a 3D display with locally optical mismatches at the edges, where every view represents a color in HSV-color space.

The shot shown in Figure 10 represents the same display after correction. The local mismatches of views at the corners were almost fully compensated. The quality of the correction is dependent on the shooting quality of the used photo spectrometer and the filtering technique used afterwards. With an ideal photo shot it could be possible to fully compensate the errors.

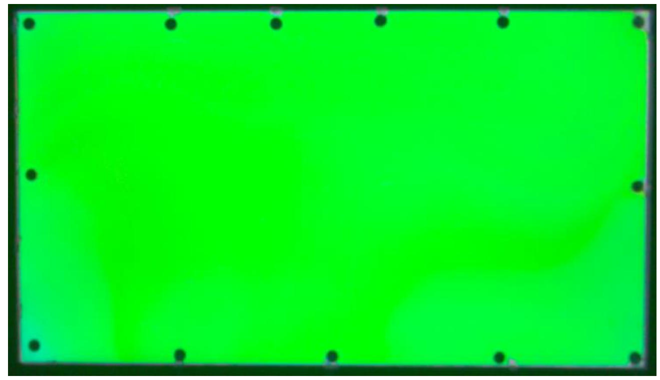

Figure 10: Corrected photo spectrometer shot of the same 3D display.

Conclusion

Correction procedures will be inevitable in the future, because of continuously increasing display resolutions and the consequential increasing precision requirements for assembly and adjustment. In this paper we could show how to compensate optical addressing errors with a comparatively low effort. It could be also shown that this procedure can be used in single-user displays, multiview displays as well as integral-imaging displays. The procedure is applicable in real time by using a graphics board with a correction texture. For the implementation of the interleaving procedure in hardware a lookup-table could be used. As a result costs for assembly and adjustment can be minimized.

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Author Biography

Silvio Jurk studied technical computer science at the University of Applied Science in Görlitz(2009) and computer science for media at HTW Berlin(2013). In 2008 he joined the Advanced Displays and Applications Group at Fraunhofer Heinrich-Hertz-Institute where he has been working on adaption procedures and display designs in the area of 3D displays. In 2015he changed to the Capture and Display Group. His current research interests include autostereoscopic 3D displays and image based technologies.

Mathias Kuhlmey studied computer engineering at TU Berlin (2014) and work for Heinrich-Hertz-Institute since 2011 as a research assistant. He developed a simulation environment for autostereoscopic displays besides mathematical modeling.

Bernd Duckstein after receiving his degree as a graduate engineer in communications engineering at the University of Applied Sciences of the Bundespost in Berlin, Mr. Duckstein joined the Heinrich-Hertz-Institute in 1986 as research associate. Working in the 3D autostereoscopy group, he worked on many hardware, software, content and measurement issues of autostereoscopic display systems.

René de la Barré received his diploma in 1978 and his PhD in 1993 from the University of Mittweida (Germany). He worked for 20 years in R&D of display industries. In 2001 he joined the Heinrich Hertz Institute. Since 2003 he led the 3D display research there. In 2015 he changed to HHI's Capture and Display Group. His current research interests are autostereoscopic 3D displays. He works in DIN, ISO and ICDM on autostereoscopic display topics.