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Making defective LCD display pixels invisible

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Defective pixels can be made invisible by using an image processing algorithm based on characteristics of the human visual system.

Within active matrix displays, such as LCDs, each pixel has its own individual transistor that controls its transmittance (see Figure 1). Occasionally, these individual transistors will short, or otherwise malfunction, resulting in a defective pixel. These are often visible as 'bright' pixels, which appear as single or several randomly-placed red, blue and/or green pixel elements on an all-black background. They can also appear as 'missing' or 'dead' pixels, black dots on all-white backgrounds. For many applications, such as LCD TV, digital cinema, and desktop monitors, the existence of defective pixels seriously degrades the image quality. In medical-imaging applications, defective pixels can even influence the critical decision-making process and therefore result in a wrong diagnosis.[1]

State-of-the art manufacturing processes are capable of producing displays with an average of no more than one faulty transistor in two million. With ever-increasing resolution, the number of defective pixels in displays increases accordingly. Typically, LCD panels are being inspected after manufacturing and panels that have too many defects are rejected. This results in a lower yield and higher panel cost. Recently, techniques have been described that make it possible to partially repair[2,3] defective pixels by transforming a very visible bright defect into a less visible dark defect. However, neither rejection nor partial repair is a true solution. We have been working on a completely different approach where we focus on making defective pixels invisible to the user by means of an image processing algorithm.

Human observers perceive images by means of the eye, which is a complex lens system. Most lenses, including that in the human eye, are not perfect. As a result, when visual stimuli are passed through the cornea and lens, the stimuli undergo a certain degree of degradation or distortion. One typical degradation effect is the introduction of blur this means we do not perceive individual pixels, but a a low-pass-filtered combination of several neighboring pixels. Further, if one of those pixels is defective then it is possible to modify the pixel values in the neighborhood of the defect to compensate for it without any visible artifacts (see Figure 2). By accurately modeling the exact distortion of the human eye, we

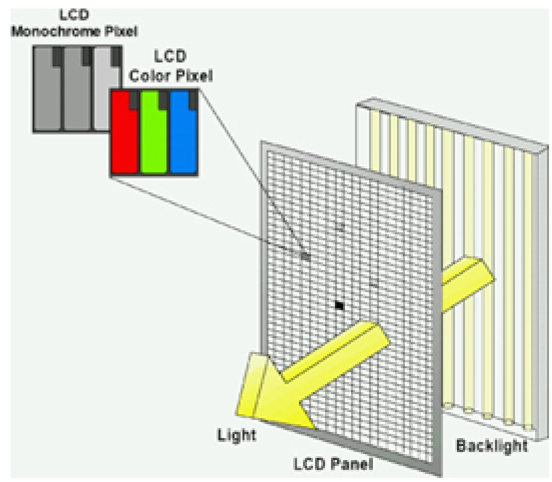

Figure 1. *An active matrix LCD works by blocking light that comes in from the back.*

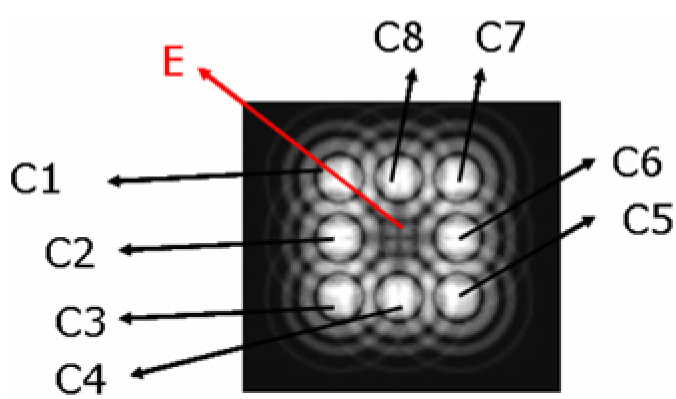

Figure 2. *Neighboring pixels can be used to compensate for a defect, as shown above.*

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-0,041	0,0892	-0,1719	0,0892	-0,041
0,0892	-0,252	0,4846	-0,252	0,0892
-0,1719	0,4846	-1	0,4846	-0,1719
0,0892	-0,252	0,4846	-0,252	0,0892
-0,041	0,0892	-0,1719	0,0892	-0,041

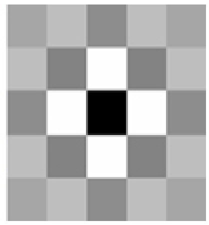

Figure 3. *An example of typical correction values.*

can calculate how the pixel values in the neighborhood of a defect should be changed to obtain this effect. The distortion of an optical system is typically described by means of the point spread function (PSF) that defines the image of a point source. Even with a perfect lens system this image will not be a point. This is because the lens has finite dimensions and therefore diffraction of light takes place at the edges. We use this 'diffraction limited' PSF as a basis to model the blurring effect of the eye. The PSF of a diffraction limited optical system is given by (in polar co-ordinates):

$$PSF(r') = \left[2 \cdot \frac{J1(r')}{r'}\right]^2$$

where $J1$ is the Bessel function of the first kind and r' is given by $r' = \frac{\pi D}{\lambda f} \cdot r$ and where D is the pupil diameter, f is the focal length, and λ is the wavelength of the light.

Next, we calculate the pixel correction values for pixels in the neighborhood of a defect ($C1 \ldots C8$) allowing us to make the defective pixel (E) invisible. Mathematically this can be expressed as follows:[1]

$$[C_1, C_2, \ldots, C_n] = \min_{c1,c2,\ldots,cn} \left\{ \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \begin{bmatrix} C_1 \cdot PSF(x' - x1'y' - y1') + \\ C_2 \cdot PSF(x' - x2'y' - y2') + \ldots + \\ C_n \cdot PSF(x' - xn'y' - yn') + \\ E \cdot PSF(x', y') \end{bmatrix} dx'dy' \right\}$$

This equation minimizes the effect of the defective pixel by changing the pixels surrounding the defect. In this formula the values $(x1', y1') \ldots (xn', yn')$ describe the location of the neighboring pixels relative to the defect. This equation can be either solved analytically or numerically. A typical solution is shown in Figure 3 where relative correction values for neighboring pixels are shown in case of a 'dead' pixel.

Figure 4 shows the performance of our masking algorithm applied to a 21 inch LCD and for a viewing distance of 40–60cm. On the left-hand side is the original eye response to the pixel defect (the visibility of the defect) without any correction. The right-hand side shows the response with our masking algorithm applied. These results clearly indicate that our algorithm is able to mask the defects very well. A psycho-visual test[4] also confirmed these results.

Producing displays without defective pixels or repairing defective pixels is not technically possible at this moment. We have developed a totally new approach to solving this problem.

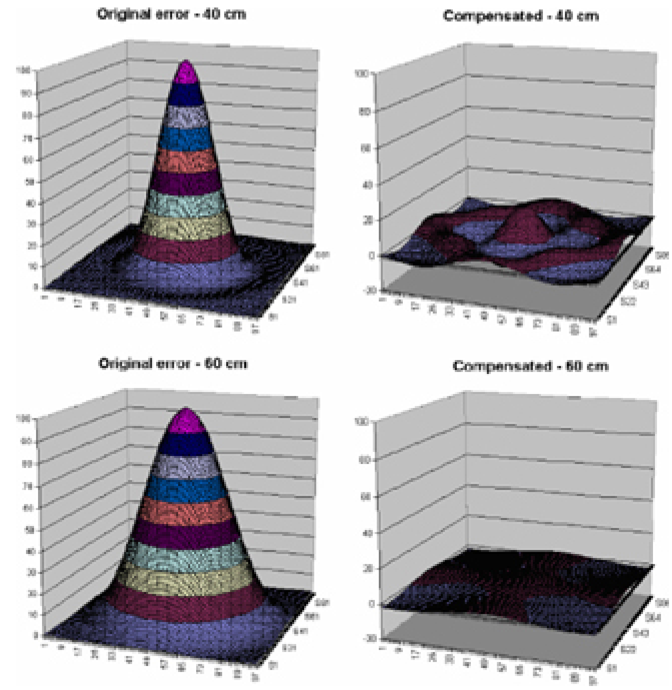

Figure 4. *Defect visibility is significantly reduced after compensation.*

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Tom Kimpe is the head of the Technology & Innovation Group of Barco Medical Imaging Systems. His main research activities are in the field of display technology and image processing. He has developed several techniques to improve image quality of medical display systems and has presented his results at several international conferences.

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