Measurement and Evaluation of the Applicability of Reflective Displays for Direct View Applications

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ABSTRACT

A measurement set-up is presented to analyse the applicability of reflective displays for direct view applications. Essential for this set-up is to simulate the different types of illumination caused by the environmental light. As an example the applicability of a reflective PNLC display is evaluated.

INTRODUCTION

Reflective displays are an important new display technology especially for mobile direct view applications. The energy consumption of these displays is low compared to classic LCDs because they don't require a backlight. Instead these displays use environmental light as a light source. The challenge for direct view reflective displays is that they have to be applicable (high contrast and brightness) in all environments and thus for all types of illumination.

Although there is already a standard for measuring side effects of environmental light in emissive displays [1], so far there is no standard for measuring the applicability of reflective displays. Because reflective displays only use environmental light the standards for emissive displays do no longer apply.

There are an infinite number of types of illumination produced by the environment. However the measurement set-up has to remain simple. The measurement set-up also has to give a better insight in the applicability of any kind of reflective display technology. This would make it a tool to determine the impact of changes in display technology on the applicability of the display and to compare different display technologies.

An evaluation of a reflective PNLC (Polymer Network Liquid Crystal) display was made as an example. The electro-optical principle of PNLC is based on the scattering of light [2]. The reflector of the display is a flat Al electrode.

PRINCIPLE OF THE MEASUREMENT SET-UP

All the different types of environmental illumination are basically made up of two types of light components: diffuse components and specular components. The measurement set-up will have to simulate these two types of components. Another important factor in the illumination of the display is the position of the observer. Contrary to the emissive displays the

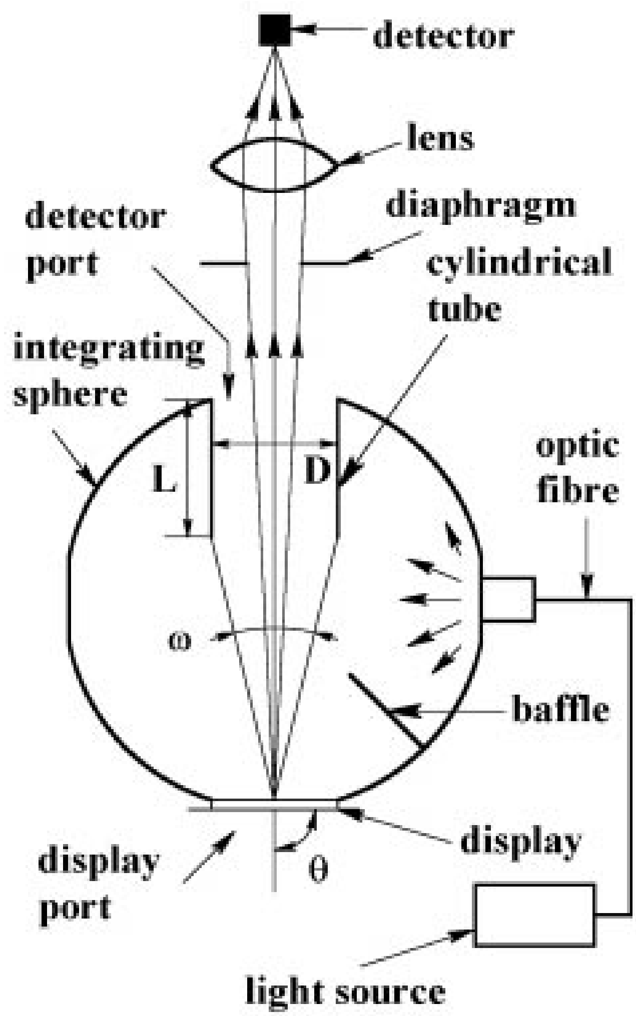

Fig. 1: Measurement set-up for diffuse illumination.

observer is on the same side of the reflective display as the illumination source. This means the observer can block the illumination of the displays partially or completely and have an important influence on the brightness and the contrast ratio of the reflective display. Other measurement set-ups don't take the observer into account [3]. In the case of diffuse illumination this is comparable with the situation of an ice bear looking at a reflective display in an uniform illuminated igloo. This is not a situation displays are generally used for. As a result a measurement set-up for diffuse and specular illumination was built (Fig. 1 and Fig. 2). Both set-ups have the influence of the observer incorporated as will be explained further on.

Fig. 1 illustrates the measurement set-up for diffuse illumination. The diffuse illumination is obtained by coupling light into an integrating sphere with an optic fibre. The display was placed at one opening of the sphere: the display port. Opposite to the display port is another opening in the sphere: the detector port. The detector port simulates the observer. Contrary to the diffuse and bright environment of the sphere the observer is considered to be dark. The detector port (observer) will resemble a dark area because the environment outside the integrating sphere is dark. The detector is at a distance from the detector port. By using a lens the detector only measures light coming from the display. The position of the observer is simulated by changing the dark area ω and the position of the display θ. By changing θ one changes the angular position of the observer to the display. By changing ω one changes the distance of the observer to the display. The closer the observer is to the display the bigger ω will be. In the set-up of Fig. 1 ω is changed by changing the diameter D (for small ω's) of the detector port or by inserting a cylindrical tube with length L (for big ω's) in the sphere at the detector port. The outside of the cylindrical tube has a white scattering coating. This limits the influence of the cylindrical tube on the uniformity of the diffuse illumination.

Fig. 2 illustrates the measurement set-up for a single source specular illumination. The measurements done with this set-up resemble to isocontrast measurements of LCDs with a backlight. This time the illumination source is a collimated light beam at the same side of the display as the detector. In the case of diffuse illumination the observer always blocks a part of the illumination. For specular illumination this is only the case when the observer is in the path of the light beam. This means that measurements with this set-up are only valid for situations where the observer is not in the path of the light beam.

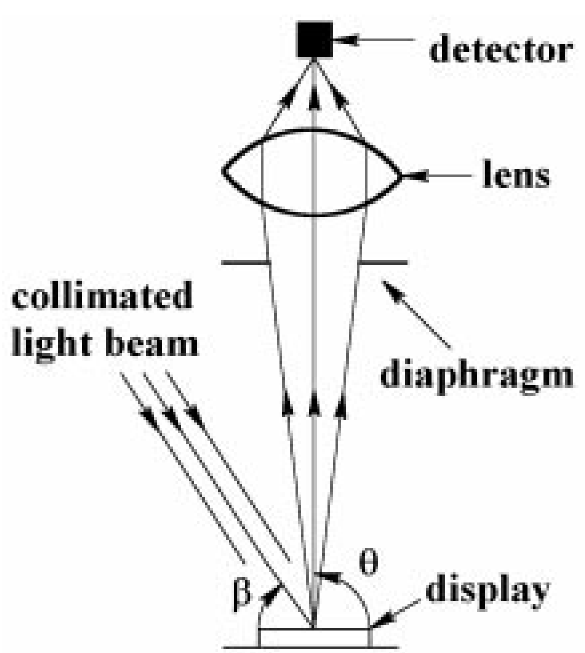

Fig. 2: Measurement set-up for specular illumination.

RESULTS

The measurements in Fig. 3- Fig. 6 are the results for the diffuse illumination of a reflective PNLC display. In Fig. 3 we see that the contrast of the display increases as the dark area increases. An ω=22.4° corresponds with the situation of an observer looking at a wrist watch keeping his arm stretched. This means that the contrast of the display will increase as the observer approaches the display. At the same time not only the absolute

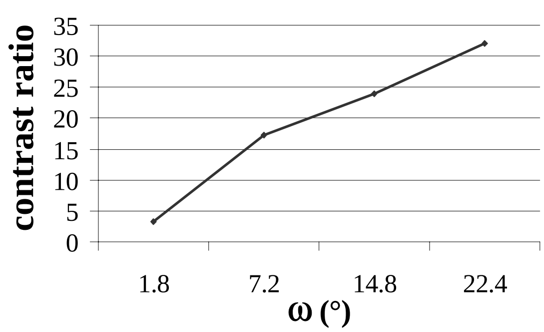

Fig. 3: Contrast ratio as a function of the dark area ω for diffuse illumination.

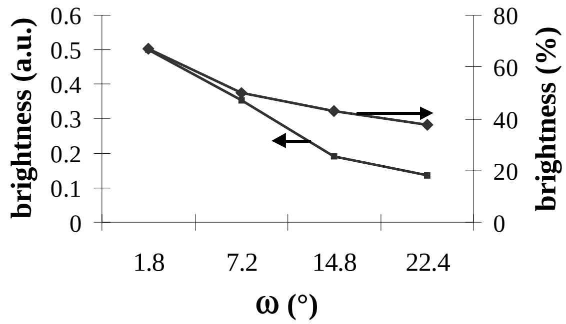

Fig. 4: Brightness as a function of the dark area ω for diffuse illumination.

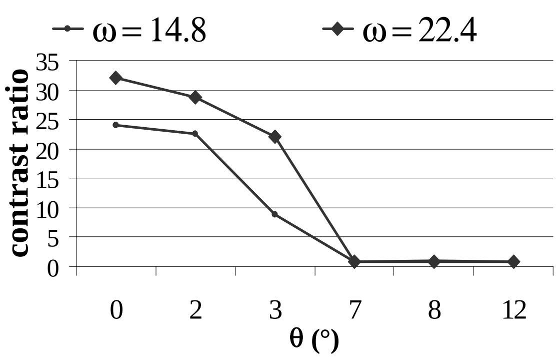

Fig. 5: Influence of the angular position of the observer to the display θ on the contrast ratio for diffuse illumination for a dark area ω = 14.8° and ω = 22.4°.

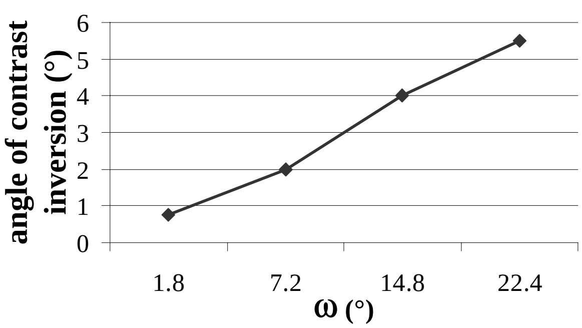

Fig. 6: Sensibility to contrast inversion for different values of the dark area ω for diffuse illumination.

brightness decreases (there is less incident light on the display) but also the relative brightness (the ratio of the display brightness to the brightness of a white standard for the same illumination) (Fig. 4). When the observer is closer to the display the contrast is less sensitive to a change in the angular position θ of the observer to the display (Fig. 5). The change of the angular position can cause an inversion of the contrast. This occurs when the light from the integrating sphere is reflected by the display on the detector in the transparent state of the PNLC. In this situation the normally 'dark state' of the display (PNLC is transparent) will be brighter than the 'bright state' of the display (PNLC is scattering). The angle θ for which the contrast is 1 is the angle of contrast inversion. This angle depends on the dark area ω (Fig. 5). Theoretically the contrast inversion occurs when θ = ω/4. This corresponds with our measurements (Fig. 6). The smaller the angle of contrast inversion is, the more critical the position of the display to the observer is. This is an important parameter for the ease of use of the display. Especially in mobile applications where the position of the display to the observer is not fixed.

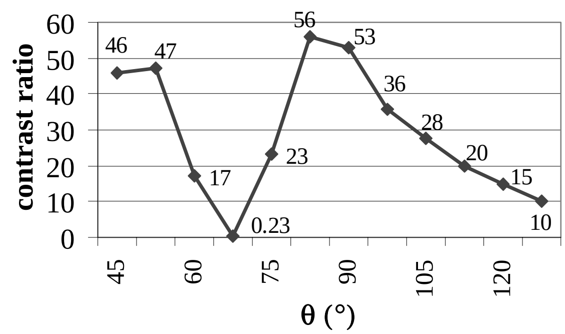

Fig. 7: The contrast ratio as a function of θ keeping θ+β=135° during the measurements.

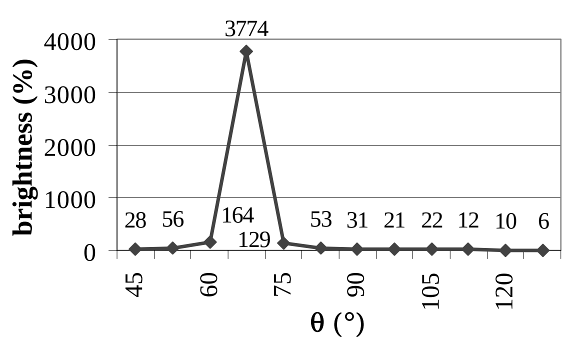

Fig. 8: The relative brightness as a function of θ keeping θ+β=135° during the measurements.

In Fig. 7 and Fig. 8 measurements for specular illumination are shown with θ+β=135° during the measurements. These measurements simulate the situation where the light source and the observer (detector) have a fixed position while the display rotates. For most values of θ the contrast ratio (Fig. 7) and the brightness (compared to a white standard) (Fig.8) have acceptable values. In the case the observer is looking almost perpendicular at the display (θ=82.5°) the contrast ratio is 56 while the relative brightness is still 53%. Only for $\theta=\beta$=67.5° contrast inversion occurs. In this case the observer sees the specular reflected light resulting in a high brightness (Fig. 8).

DISCUSSION

It is demonstrated that different types of illumination can lead to very different values for the contrast and brightness. This means that for direct view reflective displays it is insufficient to give the contrast and brightness for only one type of illumination. The position of the observer also has a big influence on the contrast ratio and the brightness. This is not only the case for the angular position of the observer to the display but also for the distance of the observer to the display.

The measurement set-ups of Fig. 1 and Fig. 2 do not exactly simulate all the possible different types of illumination. In reality the illumination of the display will be a combination of diffuse and specular illumination. If we would like to simulate all the types of environmental illumination then we would need an infinite number of set-ups because there are an infinite number of possible types of illumination. The importance of these measurement set-ups is that they give us an idea about the applicability of reflective displays. A good interpretation of the results will also have an important role in a good evaluation of the displays.

The results indicate that in the case of diffuse illumination a reflective PNLC display is best used for short distances between the display and the observer (a situation displays in mobile applications are normally used for). This results in a higher contrast ratio and a larger range of angles with no contrast inversion. The latter means that the angular position of the display to the observer is less critical resulting in a better ease of use. The angle for contrast inversion is a good indicator for the ease of use of a direct view reflective display in mobile applications. When the observer is closer to the display the display will be darker.

Reflective PNLC displays achieve high contrasts for specular non perpendicular illumination. This is an advantage for direct view applications but also for personal viewer applications. Because the illumination doesn't have to be perpendicular to the display the illumination system can be simplified. In the case of specular illumination contrast inversion only occurs when $\theta=\beta$. This is the position of the display where the observer also sees the specular reflection on the cover glass of the display. It is an advantage of PNLC that the maximum contrast occurs in a non specular reflection direction. Other display technologies like TN and STN require special electrodes [4] or have diffusing layers to obtain this effect.

If we compare the results of the contrast ratio with other reflective display technologies [5] and we take into account the high brightness we may conclude that PNLC is a good solution for portable applications.

CONCLUSION

The brightness, the contrast ratio and the angle of contrast inversion strongly depend on the type of illumination and the position of the observer to the display. This should be taken into account when making an evaluation of the display.

For mobile direct view applications PNLC has good values for the contrast and the brightness compared to other reflective display technologies.

ACKNOWLEDGEMENTS

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