NEXT GENERATION DISPLAY TECHNOLOGY: TRANSPARENT ORGANIC LIGHT EMITTING DIODES

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Abstract

Transparent displays have attracted significant interest as new generation display technology in diverse fields, such as glasses, automotive industries, or military technology applications. These applications need simultaneous projection or display of data and visibility of the surroundings through the device to reach transparent OLED, the colour of the emission layer materials, and the opaqueness of the metal thin film cathodes are the important aspects that have to be addressed. In the last few years, Transparent Organic Light Emitting Diode (TOLED) display got very big attention in terms of developing and improving its transparency to be able to make the background visible to the user as much as possible. In this paper, a review of some studies in the literature about Transparent Organic Light Emitting Diode (TOLED) has been made. Some information about prototype applications and technology has been given. Some factors are affecting by making the vision clear in the TOLED such as; haze, the distance between the TOLED display and the object behind it, illumination, transparency, and contrast. There are also some studies about using TOLED displays in vehicles. It recommended that transparency should be ideal and clear as well for the driver.

Keywords: TOLED, Contrast, Transparency, Illuminance, Haze, Vehicle Glass

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YENİ NESİL EKRAN TEKNOLOJİSİ: ŞEFFAF ORGANİK IŞIK YAYAN DİYOTLAR

Özet

Ekran teknolojisinin yeni uygulamalarından birisi olan şeffaf organik ışık yayan diyotlar, başta cam endüstrisi, otomotiv endüstrisi, askeri uygulamaları olmak üzere çeşitli alanlarda büyük ilgi görmektedir. Bu uygulamalarda emisyon katmanı malzemelerinin rengine ve metal ince film katotların opaklığı için cihazdan gelen verilerin eşzamanlı görüntülenmesine ve çevrenin görünürlüğüne ihtiyaç duyulmaktadır. Son yıllarda şeffaf organik işık yayan diyot (TOLED) ekran, arka plan kullanıcı için olabildiğince görünür kılmak için şeffaflığı geliştirme ve iyileştirme açısından çalışmalar yapılmaktadır. Yapılan bu çalışmada, TOLED ile ilgili literatürdeki bazı çalışmaların derlemesi yapılmış ve TOLED'in bazı prototip uygulamaları ve teknolojisi hakkında bilgi verilmiştir. TOLED'in görüş netliğini etkileyen bazı faktörler vardır. Bunlar; pus, TOLED ekran ile arkasındaki nesne arasındaki mesafe, aydınlatma, şeffaflık ve kontrasttır. Araçlarda TOLED ekranların kullanılmasıyla ilgili bazı prototip çalışmalar bulunmaktadır. Bu uygulamalarda ekranın şeffaflığı sürücü için ideal ve net olması gerekmektedir.

Anahtar Kelimeler: TOLED, Kontrast, Şeffaflık, Aydınlık, Pus, Araç camı

1. Introduction

A transparent display got a very big attention by considering it as advanced technology of displays in optoelectronics [1-3]. This technology may be used in many areas as it allows for the users to see through the screen while displaying images or videos on it at the same time [1,2,4,5], it works as a glass window [6]. This advantage gives the possibility to use it worldwide in many applications and industries such as defence technology, Internet of things (IoT) and vehicle industries [1,2,5]; to provide the driver with the related information according to the speed, directions, and some other specifications [7]. Nowadays, Liquid Crystal Display (LCD) and Organic Light Emitting Diode (OLED) display are used in some fields like television and computer screens [5]. Liquid Crystal Display (LCD) is facing some challenges in terms of transparency as it has to get a backlight and other optical components. In terms of TOLED display, the

transparency is related to the source of light emitting that should be as much as transparent to get the highest transparency for the display [5,8].

When people look at a Transparent OLED (TOLED) display, they will be able to see a group of background and front picture. Of course, the low transparency for the foreground image, the higher vision of it, but unfortunately the background image will not be clear for the user to see. It is a must to achieve a high transparency to get the maximum quality for the transparent display [1,9]. For the brightness of the background passed through TOLED display, there is a factor called transmittance factor [6], and the higher it is, the brighter the background. The transparent display's haze has also an effect, the lower the haze, the clearer vision of the background [10]. In the vehicles, there are two important elements that were considered, the readability and the legibility [7,11]. Readability refers to recognizing of the words, sentences, and paragraphs. Legibility expresses how easy it is to make the symbols notable [7,11].

2. Some Effects on TOLED

Transparency, haze, illuminance, and contrast have some effects on TOLED. Two different types of combination of the background and foreground are shown in Figure 1. It shows that to meet the people's demand, it required to make a proper transparency, luminance, contrast, and haze for TOLED display, as the quality of vision is a very important item. Not only the illumination is a very important factor in TOLED, but also the ability to consider the suitable transparency for an application is important. The contrast in TOLED display is directly related to the illuminance and transparency. TOLED displays are considered as two sections, showing the photo and breakthrough of background. The background has an ambient illumination for sure, for that, TOLED's contrast is changeable according to surrounding illumination alteration.

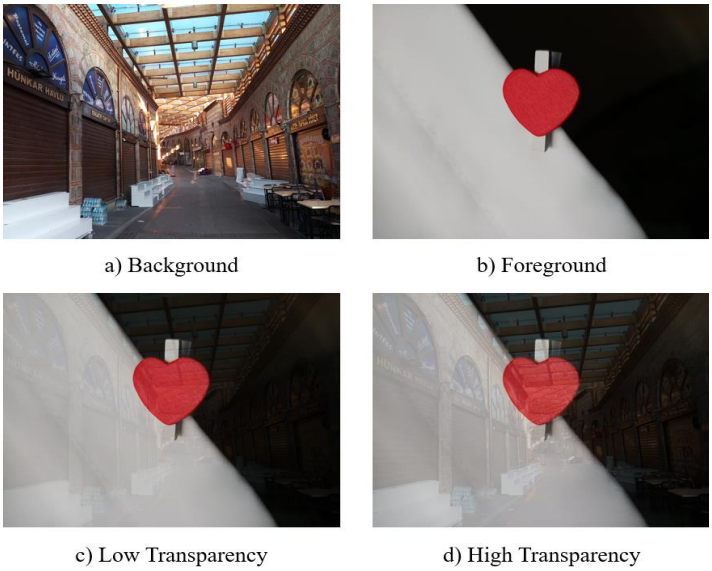

Figure 1. Combination images of low and high transparency; (c) combination of background and foreground with low transparency. (d) combination of background and foreground with high transparency. [Adapted from reference 4].

In Figure 2, haze and transmittance factor's effects on perceived see-through level (PSL) can be noticeable [12].

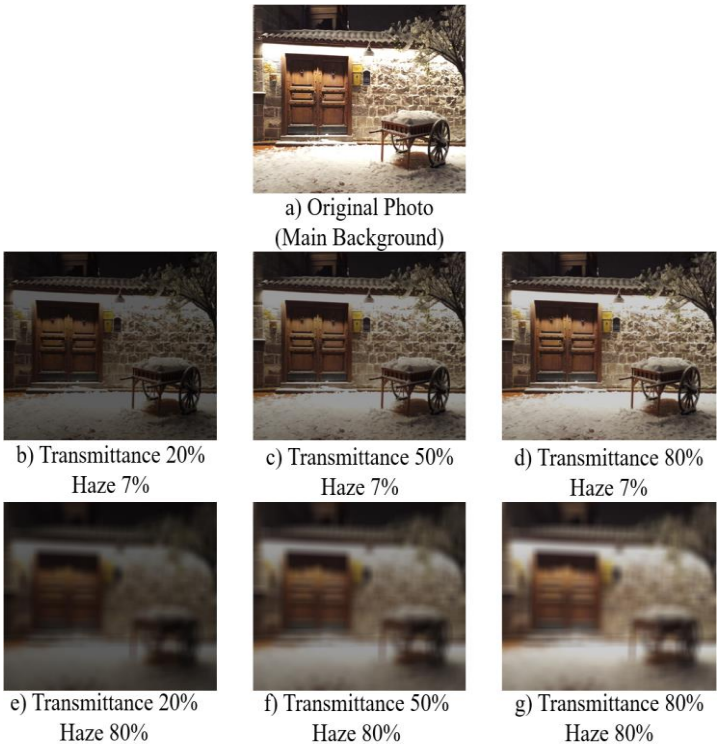

Figure 2. Some samples of the background photos passed through TOLED according to alter values of haze and transmittance. [Adapted from reference 6].

There are three values for the transmittance that were considered which are 20%, 50%, and 80%. Two cases for the haze percentage with 7% and 80%. It is obvious that when the haze is 7%, the vision is clearer while comparing it with a haze value of 80%, by considering the transmittance value in case (d) is higher than cases (b – c).

In terms of vehicles, the legibility gets influenced by illuminance, transmittance, and max luminance of TOLED display. Illuminance is referred to as the outside of the vehicle, the transmittance is the transmitted luminous flux over transparent displays and transparent displays' max luminance impacts the luminance scale of the on-screen text. The background and text contrast were selected in building the legibility valuation sample. Of course, the size and colour of text and/or symbols are important as well as they are influencing the on-screen contents' legibility of in-vehicle TOLED display. Aforementioned factors that are affecting the legibility are shown in Figure 3. As we see from Figure 3, (a) is the through-screen image, (b) is TOLED displays' on-screen content, (c) is the recognized photo according to illuminance alter, the background brightness be less when illuminance' value is low, and the right side is clearer than the left side as the brightness of on-screen is higher than the background. In case (d), the resulted photo according to transmittance alter, (e) is the resulted photo according to max luminance alter, (f) is the resulted photo according to the changing of size related to content [13].

Figure 3. The types of the different factors influencing legibility. (a) Background photo. (b) Contents of the transparent on-screen display. (c) Recognized photo in terms of illuminance alter. (d) Recognized photo in terms of transmittance change. (e) Recognized photo in terms of max luminance alter. (f) Recognized photo in terms of font size alter. [Reproduced from reference 7 with permission. Copyright 2019, Journal of Information Display].

3. Implementations and Methods

Illumination, transparency, and contrast values are hard to be selected as a specific value because the requirements are changeable for every application. As we noticed before, two factors were affecting the TOLED display which is haze and diffraction, and to develop TOLED display's visual quality, they must be removed. On the other hand, a big consideration must be shown on illumination, transparency, and contrast to achieve the aim of applications. In order to make a good structure of TOLED display,

transparency must be taken into consideration in terms of see-through and emitting. TOLED display that has the upper emission structure is being illustrated in Figure 4 [10].

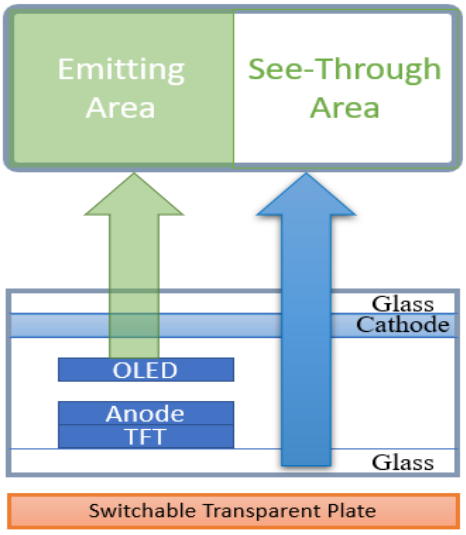

Figure 4. TOLED display with top emission structure. [Adapted from reference 4].

Human visual tests were performed to resolve the impact of haze and transmittance factor on the vision of background. The tests were done by using some photos with various values of haze and transmittance factor [12].

Sample photos showing various degrees of perceived see-through level (PSL) ought to be created before for human visual tests. As it is illustrated in Figure 5, the black and white patch's curve of luminance transition that is being displayed on a screen after transmission through a plastic transparent layer is measured.

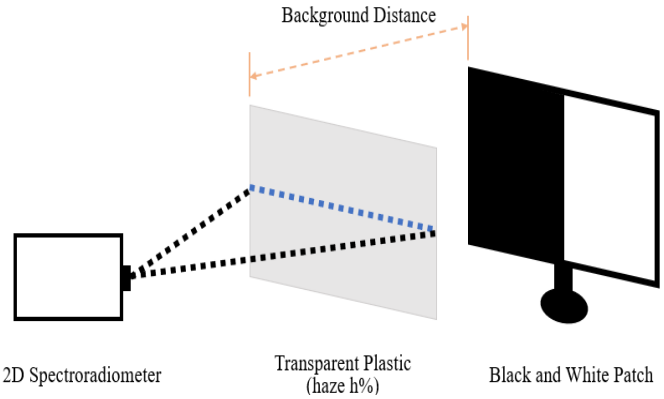

Figure 5. Measurement status for the luminance transition graphs. [Adapted from reference 6].

There are some graphs for various values of haze with constant transmittance factor as we see in Figure 6, the haze values 7%, 80%, and 99% respectively.

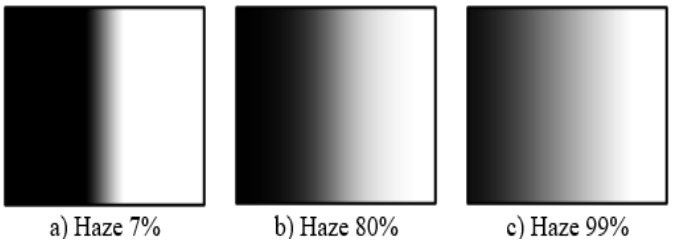

Figure 6. Samples of luminance transition graphs and resulted photos. [Adapted from reference 6].

In terms of vehicles, a simulation was made, and Figure 7 shows the examples of the simulation results. As we can notice, (a) shows the background scene and (b) shows the on-screen image, (c) illustrates the simulated image resulted under illuminance equal to 3000 lux [13].

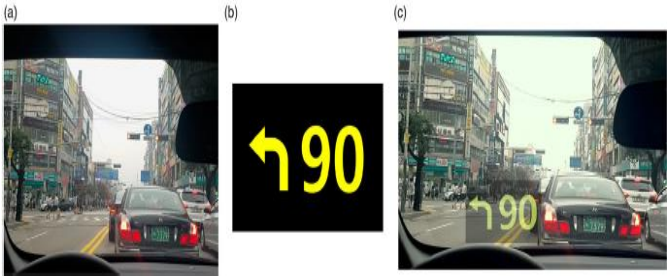

Figure 7. Examples of simulation results. (a) Background sight. (b) Photo of on-screen. (c) Combination of on-screen and background photos. [Reproduced from reference 7 with permission. Copyright 2019, Journal of Information Display].

Another note was that, while the contrast raises, the legibility raises too as it is illustrated in Figure 8 [15].

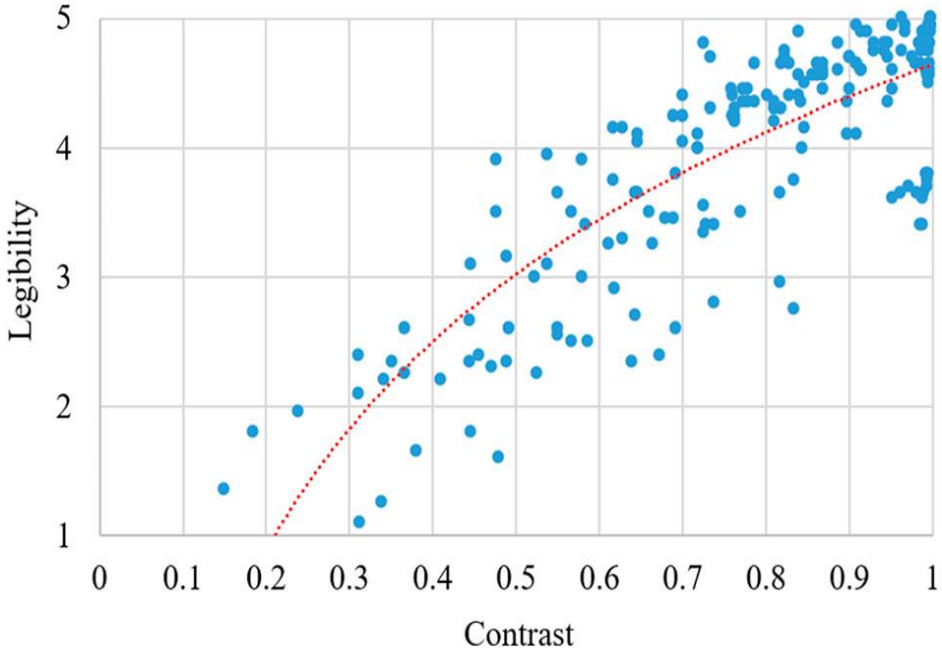

Figure 8. Red dotted line shows legibility vs. contrast. [Reproduced from reference 7 with permission. Copyright 2019, Journal of Information Display].

4. Results and Discussion

As we can see from Figure 9, the display of two cases (1, 2) is the same, that each has the same properties: transparency and luminance of the emitting zone. It is noticeable that cases have various contrast ratios because of the difference in illumination values. By comparing cases (1, 3), we will find that both of them are under the same illumination. Yet, the luminance of case 1 is higher than case 3. Besides that, case 1 has the almost double-contrast value of case 3. But in other words, it will be ridiculous to say that the vision of the first case is better in double than the third case. Moreover, the third case has better transparency than in the first case. As a result, it is hard to determine which one has the best transparency because it will depend on the application's purpose [10].

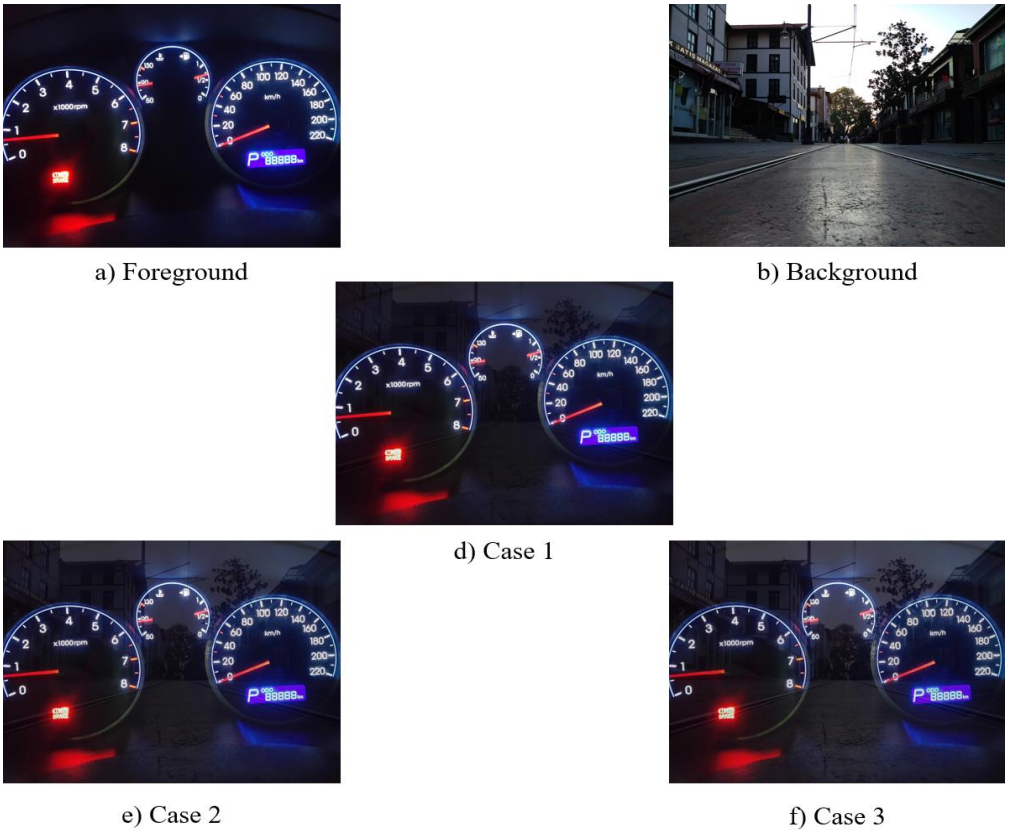

Figure 9. Some various cases. (d) Low transparency case with high foreground contrast. (e) Low transparency case with less foreground contrast. (f) High transparency case. [Adapted from reference 4].

The transmittance factor has various values according to Figure 10 (a,b,c). The variance between (a) and (b) is 20 which is the same between (b) and (c). Yet, the PSL variance is bigger between (a) and (b). Maybe this is happening because of the human visual system that is sensing the dark zones that have various brightness. When haze raises, PSL decreases because the object's blurriness raises, which is beyond the display, as haze raises [12].

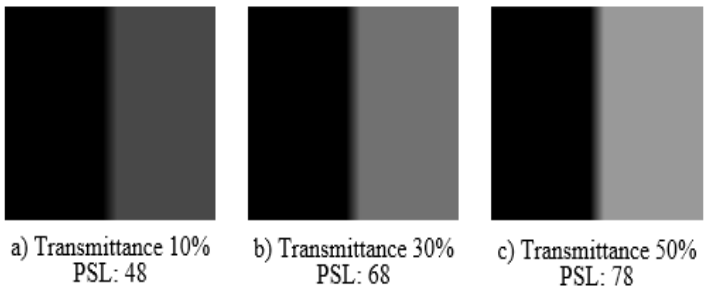

Figure 10. Various photos with values of PSL. [Adapted from reference 6].

Besides, in terms of vehicles, and after making the simulation and performing the study, they reached to a confusion matrix [13] which shows the possibilities of many cases and according to the score, the results will be grouped to the right categories which are Correct True Positive, Error False Negative, Error False Positive and Correct True Negative as shown in Figure 11.

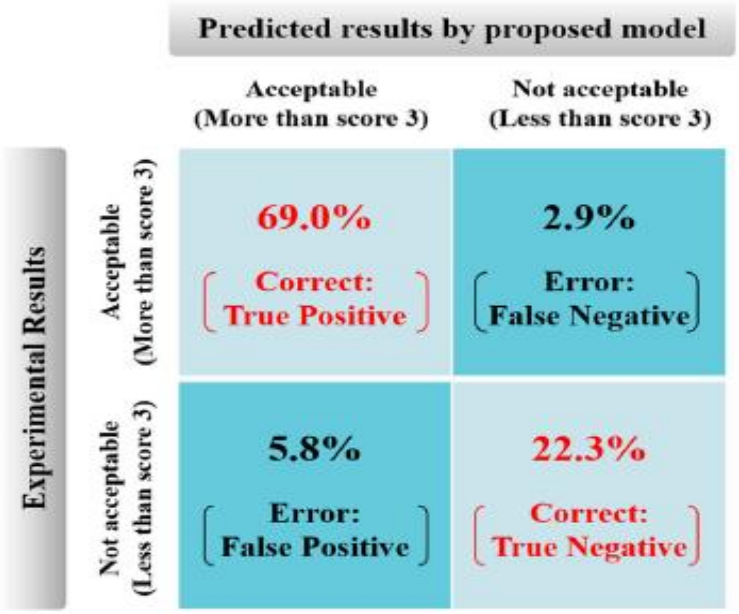

Figure 11. Confusion matrix and potential values for four various groups. [Reproduced from reference 7 with permission. Copyright 2019, Journal of Information Display].

5. Conclusion

The main aim of TOLED display is to show the background through it when the user's goal is to see what is behind the TOLED display. In this case, and in order to make the transparency and the vision clear for the user, there were some factors which considered as they are affecting the transparency and the vision such as haze, diffraction, illuminance, luminance, contrast, the distance between background and foreground, readability and legibility. Perceived see-through level (PSL) is suggested to illustrate the visibility of the object behind the display. In terms of vehicles, a simulation was done by considering illumination, transmittance, transparent displays' max luminance, and size of text and/or symbols. It was also specified that the legibility of on-screen contents of in-vehicle

transparent displays relies on the on-screen contents' colours as well as on display background.

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