

First evaluation of visual information improvement for welders using the angle dependant selective darkening property of the liquid crystals protection filters in a multilayer setup

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Zusammenfassung:

Um beim Schweißprozeß die Sicht der Schweißer auf den Schweißprozeß zu verbessern bzw. überhaupt erst zu ermöglichen werden die Schweißschutzhelme mit Filtern ausgerüstet, durch die das einfallende Licht abgedunkelt wird. Die Arbeit untersucht die Frage, welche Vorzüge ein selektive Abdunkelung gegenüber einer gleichmäßigen hat. Der begangene Weg benutzt Anordnungen von jeweils zwei Flüssigkeits-Kristallen. Erste Ergebnisse zeigen, daß der Schweißer auf diesem Wege deutliche bessere Sicht auf die Umgebung des Schweißstrahles erlangen kann.

Abstract — the welding process became automated in the last years in many industrial fields but nevertheless there are still many welding processes that can not be automated. For the processes where the automation is not possible the human skills and visual sensing are still playing an important role.

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To improve the welder vision, the welding helmets evolved from using darkly tinted glass to the actual state of the art protection filters that are automatically darkening when exposed to the welding arc. The actual filters darken homogenously the view over the work area and they limit the vision of the whole scene and not only close to the arc. Thus, the idea of selectively darkening of the view emerged, and to selectively darken the very bright area around the welding arc, but attenuates all other area less. The ideal selectively darkening filter will have less or no darkening in the filter area distant from the arc, which can render them visible to the welder, and a high darkening in the filter area corresponding to the arc area.

Usually the actual filters are built using two liquid crystals protection filters glued together, because any of these filters present a non uniform dependency between the light transmission and the view angle. The purpose of this study is to determine if this property of the filters can be used to build a selectively darkening filter and to determine the improvement of the visual information on the welding scene.

1 INTRODUCTION

In the industrial environment of our days, even with the high scale of automation, the welder still plays a very important role. Many welding processes of the industry were automated but there are still many processes where the automation is too expensive or impossible, e.g. ship building, bridges, huge structures, locomotives and others. In those processes the skills of the welder are very important. The most of the research in this direction is focused to improve the characteristics of the filters, sensors and circuits of the actual modern welding helmets [1]-[5]. The most advanced welding helmets on the market lack a high contrast view of the welding environment's surroundings. Those helmets allow enough light to pass, in the clear state, by which the welder gets a good view onto the environment and can easily operate the welding machine or interact with the environment without removing the welding helmet. In the dark state the amount of light that is passing through the filter is highly reduced and the welder will get poor visibility of the complex welding scene being limited to distinguish only the welding arc (Fig. 1).

A very advanced welding helmet (TEREBES), based on high dynamic range cameras and a head mounted display, was developed [6]-[8]. The result of the

development is that the welder gets an improved view of the scene (Fig. 2) together with an augmented view offering information about the optimal position of the torch, and direct access to the welding machine parameters. The only impediment for mass production of this type of helmet is the fact that the technology is not mature enough yet. The production of such a helmet with actual technology would make the price prohibitive.

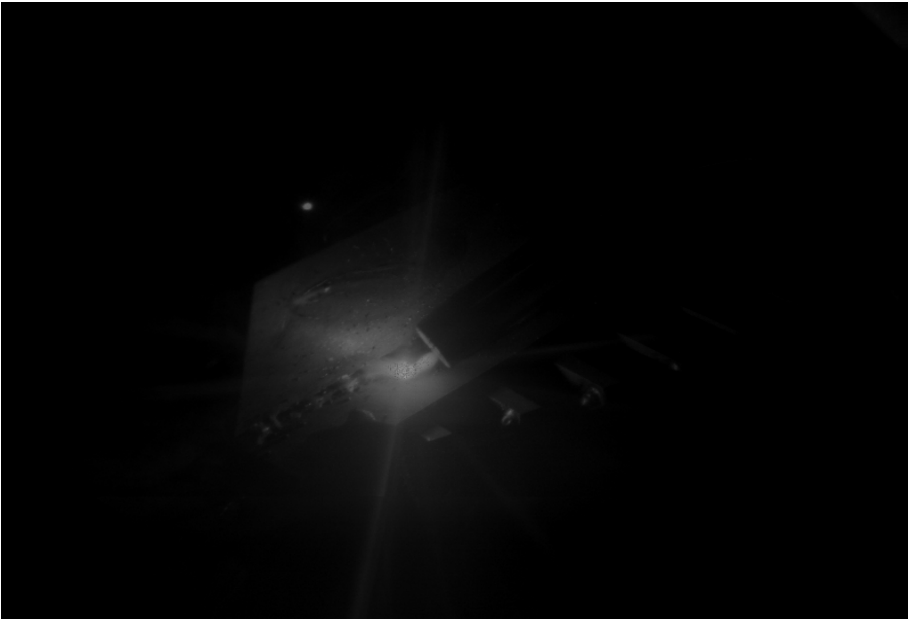


Figure 1: Welding scene view during dark state



Figure 2: Welding scene view using TEREDES welding helmet. Courtesy: Hillers, Aiteanu [6].

Because of these disadvantages a different approach is needed to provide a better view onto the welding environment scene to the human operator.

A common known problem of the liquid crystal protective glass shields used for many years in building the welding helmets is the optical angular effect. There has been a lot of effort invested for reducing this effect [3], [5] in the welding filters in order to obtain homogenously dark view. In our approach we use this rather negative angular effect of the liquid crystals to build a selective darkening welding filter, in other words to take advantage of angular effect and not to reduce it.

2 BACKGROUND

In reaching the goal of building a selective darkening protection filter for welding, two behaviors of the filter are playing an important role. The first one is the optical angular dependence of the twisted nematic (TN) liquid crystal and the second one is defined by the quality of the image observed when recorded using a static filter for the bright area of the image.

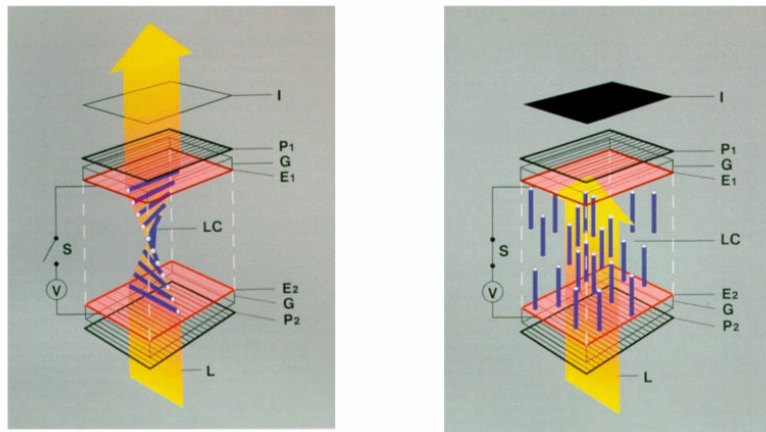


Fig. 3. Twisted nematic effect in a liquid crystal cell. Courtesy: M. Schadt, Wikipedia Contributors [9]

Starting with the first aspect, the main advantage of the TN liquid crystals consists of the fact that they are not current-driven and do not require high operating voltages in comparison with the liquid crystals based on the dynamic scattering effect which require 0 to 40V for operating and the power consumption is considerably higher. These advantages make the TN liquid crystal suitable for embedding in a

welding helmet. The twisted nematic effect (Fig. 3) succinctly speaking can be explained as follows: in the off state (clear state) if no voltage is applied, the incident light (L) will pass through the P2 polarizer and as a result we will obtain a polarized light wave, the resulting light being guided through the liquid crystal (LC) which will rotate the plane of the light with 90° and will pass through the crossed polarizer P1. During the on state (dark state), if a voltage is applied, the electric field will force the molecules to align and as a result the polarized light coming out from the P2 polarizer will not be rotated with 90° and the P1 polarizer blocks the light wave.



Figure 4: Observed optical angular effect observed with a camera with the objective focused in the center of the LCD

While in the previous paragraph the twisted nematic effect was presented theoretically, in practice, a lot manufacturing factors will influence the functionality of the resulted hardware, which in our case is the welding filter. The rotation of the nematic molecules can be stopped to a greater or lesser extent by applying an electric field. The incidence angle of the ambient light will influence the light transmission because such TN cells present a strong asymmetry during the electrically active state (dark state) [3]. When the angle of the incident light increases in relation to the perpendicular on the filter, the filter will have regions with different shade levels, one being more transparent than the other. This optical angular dependency take place due to an incomplete molecular alignment with the applied

electric field [5], and the position and size of the regions will vary with the voltage (Fig. 4).

In our efforts to improve the quality of the acquired images during the welding operation different approaches were examined; one approach was to use one welding filter in the front of the camera in order to darken only the welding arc area.

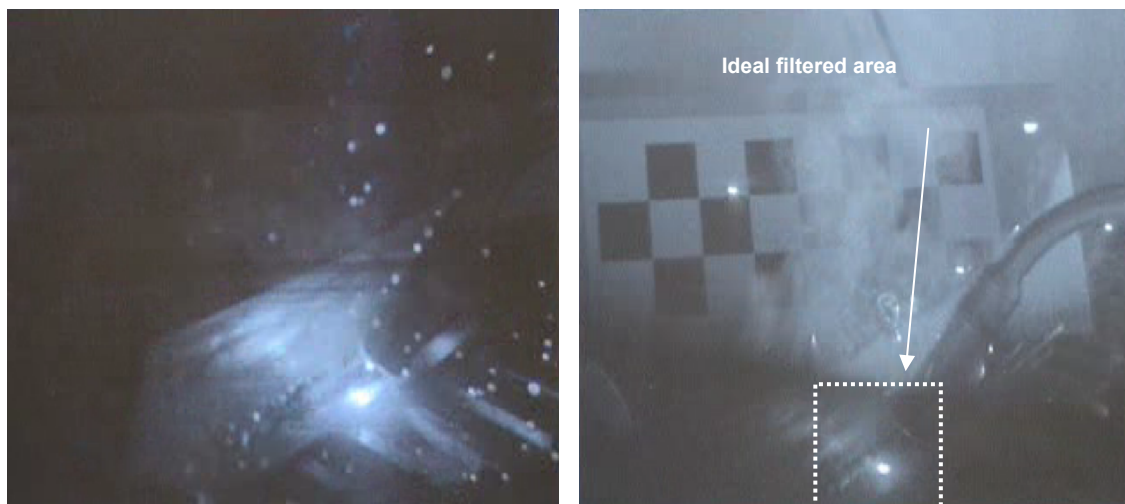


Figure 5: Welding images recorded a) without any darkening filter (left image) and b) using a small darkening filter at bottom in front of the optic (right image)

As it can be observed in fig. 5a, when without the usage of any darkening filter in the front of a high dynamic range camera (HDRC), the visible area is reduced only to a small area around the welding arc; the information about the environment can be merely distinguished. In fig. 5b, a darkening filter is used to darken only a part (the filter has the same width as the HDRC view and starting from bottom cover the 25% of the HDRC view height) of the HDRC view and the experiment was conducted positioning the welding arc in the area covered by the darkening filter. As can be observed for this experiment more environment details are visible without having a lesser extent of information in the welding arc area.

Based on the observations the idea is to use the TN liquid crystals device (LCD) which provides an increased optical angular dependency of the light transmission in order to build a filter that will darken especially the bright area of the welding scene view.

To achieve the goal in building a new darkening welding filter, a method combining the two behaviors of optical angular dependency of the light transmission and the selective darkening of the view is developed. This method uses a number of TN LCDs (with an increased optical angular dependency) which will be sandwiched

together. With the ability to control every LCD separately a selective darkening filter can be build. A HDRC detects the position of the welding arc (when the welding process starts). For the detected position the optimal voltages to selectively attenuate the filter will be calculated and applied to the sandwiched TN LCDs. To determine the voltages for different TN-LCDs a mathematical model for the angular dependent attenuation was developed. Based on this model an algorithm for the voltage distribution for a TN-LCD stack was developed. The algorithm calculates in real time, the optimal voltages needed to drive a set of 4 TN LCDs sandwiched together, with respect to a 2D given position of the welding arc.

3 MATHEMATICAL MODEL AND SIMULATION

For the design and development of the mathematical model first optical measurements of the light transmission were made in order to choose the right type of TN LCD. The results of the measurements describe the dependency of the light transmission function to the angle of the incident light. The results are used as input values for the optimization utility which determinate the voltage distribution of the TN-LCD stack.

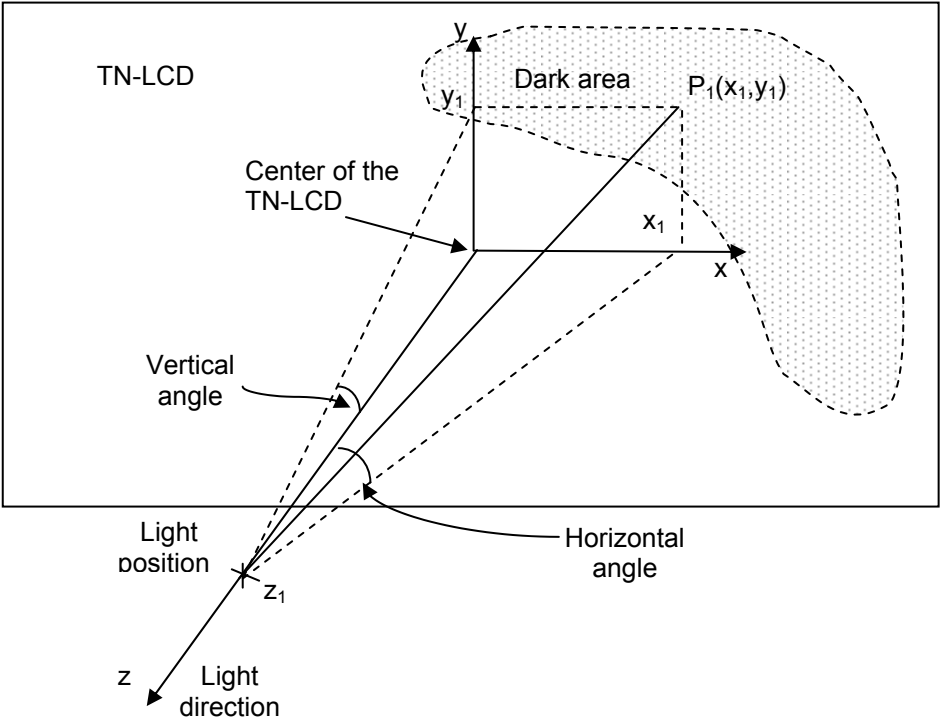


Figure 6: From angle coordinates to pixel coordinates

First the data provided by those measurements should be translated from the angle coordinates to the pixel coordinates of the screen in order to be able to represent graphically the mathematical model. As prerequisites, we considered a pixel to be equivalent with a square millimeter of the TN LCD surface and we know from the measurements the light and the observer position are at a fixed distance from the center point of the TN LCD. In order to calculate the shade level associated to a pixel P_1 first the values of the horizontal and vertical angle should be calculated; for this reason we draw the projections of that pixel on a coordinates system (xyz) centered in the centre point of the TN LCD representation (Fig. 6). Let's consider in for the explanations the light source at a known distance on the z axis (in the same way we can consider the observer position), the values of the projections are known also and, using them, we calculate the horizontal respectively vertical angles determined by the lines that connect the light source position and the projection of the pixel on the x respectively y axis.



Figure 7: Simulated light transmission of the TN LCD, where α and β are the angles of the optical angular effect

Another problem that should be considered in the implementation of the mathematical model is the fact that the measurements conducted are using a set of discrete values for the horizontal and vertical angles and also for the voltages. In order to find out the intermediate values for the horizontal and vertical angle an interpolation method is used [10]. As concerning the intermediate values on the

voltage domain, the alpha blending technique is used [11]. Because those methods are simple and well known we are not going in further details about this subject.

The resulted graphic representation of the mathematical model (Fig. 7) for a TN LCD is describing very well the optical angular effect (Fig. 4). It can be observed that in the same way as in the reality, the graphical representation of the model has a smaller dark area comparing with a homogenously filter, located in the upper right for a controlling voltage equal to 5 V and the dark area is expanding and migrating to the center of the TN LCD when the voltage is increasing.

The model receives the measured light transmission values as input values; these values are not stored inside the model. By passing different input values to the model, it creates a simulation based on these input parameters. The simulation can present different migrations of the dark area compared with the one previously described (Fig. 4 and Fig. 7). This characteristic is of a great importance for us, because there are many types of TN LCD that present a different way of expanding and migration of the dark area. We have studied and measured the light transmission of a TN LCD where the dark area is migrating and expanding starting at the bottom left of the TN LCD, for small driving voltages, to the middle of the TN LCD, for higher voltages (similar to the TN LCD's from fig. 4 and fig. 7 but rotated with 180°), or starting at the bottom middle of the TN LCD and migrating to the center of the TN LCD, etc.

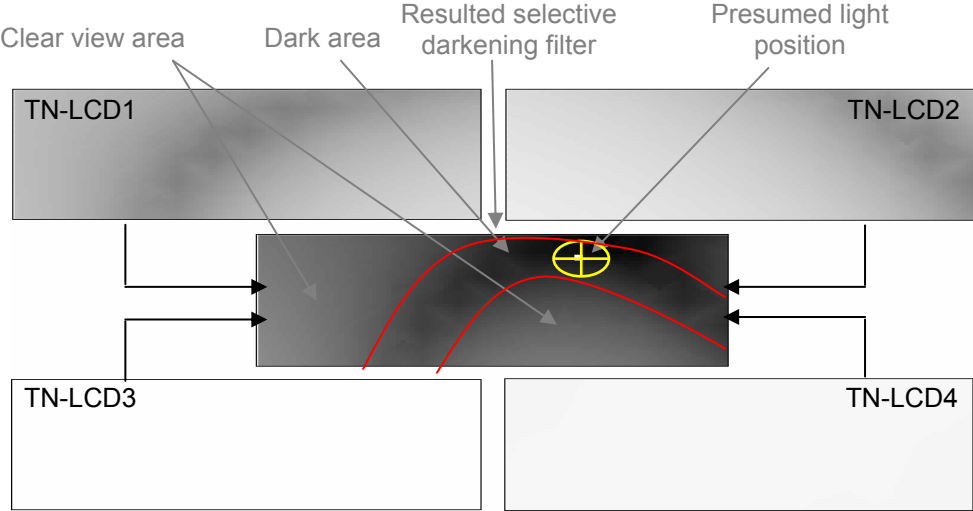


Figure 8: Simulated selective auto darkening

By using four different measurement results, for different types of dark area migration and expanding (top right migrating to the center, top left migrating to the

center, bottom left migrating to the center, and bottom right migrating to the center), we create a solution for a selective darkening welding filter. We presumed that the four TN LCDs are sandwiched (transparently glued) together and so are the simulated TN LCD models. For any presumed position of the light source (simulated welding arc position) on the 2D plane we determine the optimal voltages that should be applied to the TN LCDs, on one hand in order to obtain a targeted shade level in the light source area and on the other hand to maximize light transmission onto the surrounding area with a shade level of less than 60% of the shade level targeted for the very bright area, this reduced shade level area we will call from now on “clear view area”.

Figure 8 presents a simulated selective darkening welding filter obtained using four TN LCDs. We can observe the state of the simulated TN LCDs model associated with the four TN LCDs, the TN LCD that presents a dark area migration from the top left to the center and the one that presents a dark area migration from the top right to the middle will have a voltage applied and the other two will be switched off. It is necessary to use four TN LCDs in order to achieve a better coverage of the desired welding filter surface.

4 CONCLUSION

Considering 27 position for the light source (welding arc position) on the simulated welding filter surface and we determine the percentage of clear view area size within

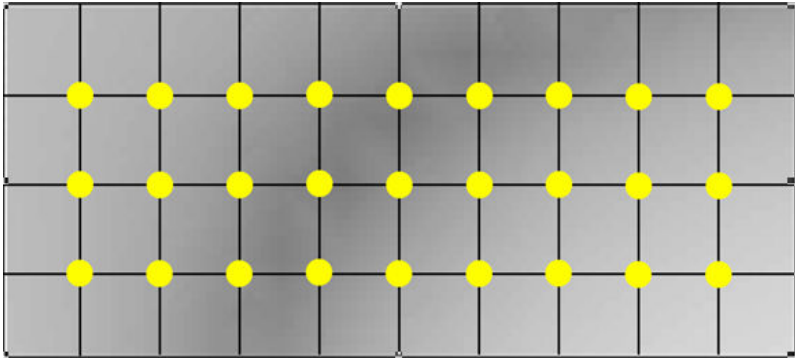


Figure 9: The light source position considered

the entire surface of the simulated selective darkening welding filter. The position of the light source are situated at the intersection of three equidistant horizontal lines with nine equidistant vertical lines, covering in this way the entire surface of the simulated selective darkening filter (Fig. 9).

| | Min [%] | Max [%] | Average [%] | Std. dev. [%] |
|------------------------------|---------|---------|-------------|---------------|
| Clear view area | 18.87 | 51.62 | 31.72 | 10.38 |
| Shade level of the dark area | 13 | 13 | 13 | |

Table 1: Clear view area as percentage of the filter surface

As it can be observed in the Table 1 and Figure 10 we have some position where almost half of the welder’s view is clear allowing him to get a better view on the surroundings, but we have some points where the results are not so impressive the welder getting only less than 25% of the entire welding filter as clear view area. Nevertheless for almost 60% of the points simulated results are show that the welder can get a better view on the welding arc surrounding, this results is considered to be satisfactory for going to the next step of hardware prototyping.

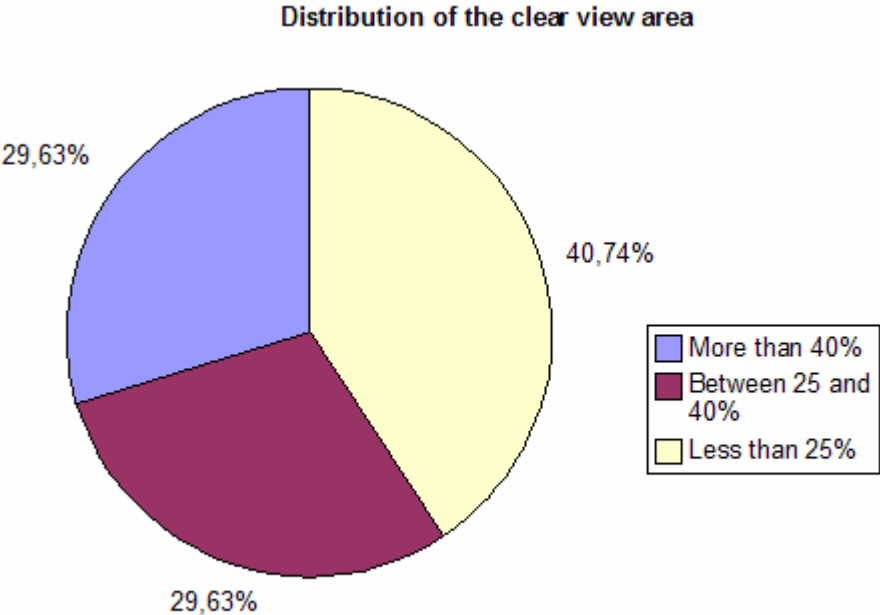


Figure 10: Clear view area percentage for the position of the light source considered

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