



2015 International Conference on Virtual and Augmented Reality in Education

## Use of PDLC Film for Improving Visualization of Contents in Holographic Display under Different Illumination Scenarios

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### Abstract

Pepper's ghost effect has been used since its beginnings at the second half of XIX century to generate 3D projections of virtual people in real environments. Nowadays this effect is used by 'holographic' displays for the projection not only of virtual people but also of objects and even animations that can interact with real objects. Marketing and product presentations are some of the most used applications for these displays. Nevertheless, another interesting application has been explored recently: knowledge transfer for both industrial and educational purposes. Regardless the application there is a little problem with these displays: when they are used in a high-illuminated place the contents projected are lost. That is the motivation for this project, which seeks to evaluate the use of a PDLC film (that allows to control its transmittance) to minimize these problem. Action research methodology is being used as a guideline for planning and executing the actions required in the project. The results were satisfactory; achieving an improvement in the visualizations of the contents displayed using the PDLC film.

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Peer-review under responsibility of organizing committee of the 2015 International Conference on Virtual and Augmented Reality in Education (VARE 2015)

*Keywords:* Holographic display; Pepper's ghost; PDLC; maintenance process; mobile devices

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<b>Nomenclature</b>
PDLC Polymer Dispersed Liquid Crystals

## 1. Introduction

Since its beginnings, Pepper's ghost effect has been used for generating 'three-dimensional' projections of virtual objects or people in a real environment. First what was sought was a more realistic experience for cinema and theater spectators. More recently, this effect is used for bringing back to life famous artists for concerts. Another application is the development of 'holographic' displays that are widely being used for products presentation, since virtual animations can be made to interact with the real products.

At Tecnológico de Monterrey, under the framework for a new education model, contents are being produced for using 'holographic' displays as a tool for both knowledge transference and products presentation. Figure 1 shows a holographic display, fabricated with students' help, and its components.

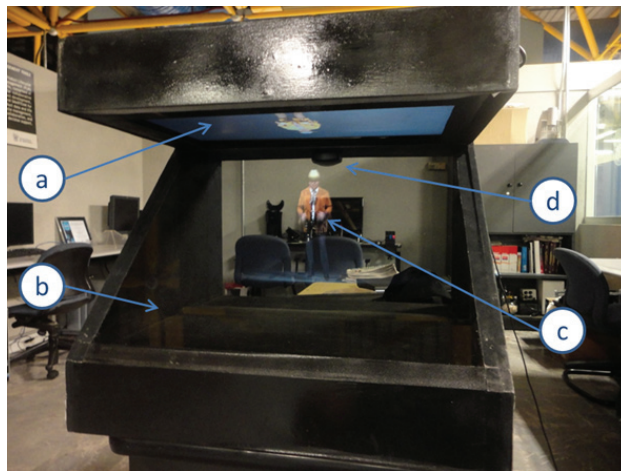


Figure 1. 'Holographic' display. a) Projection source, b) Reflective surface (45° inclined glass), c) 'Holographic' projection, d) Lamp (for better appreciation of real objects behind the glass)

These 'holographic' displays present a problem when they are located in a place with high illumination: the projection is weak and the spectator cannot see the contents as expected or, in the worst case, the projection is completely lost. This is the motivation for this project, which attempts to study the effect of using a PDLC film adhered to the glass for improving visualization of the contents under different illumination levels. The intention of the PDLC film is to vary the transmittance of the glass so it is possible to have distinct levels of transmittance for comparison.

## 2. Background

### 2.1. First displays

The last decade of XIX century and the first two of XX century the experiments and patents related to Pepper's ghost effect, as already stated, were oriented to give the cinema spectator a more realistic experience, 'removing' the screen and offering three-dimensional pictures in motion. Two apparatus called Alabastra and Kinoplastikon caused great attraction because of the illusion of virtual singing and dancing artists in a real stage. The great advantage over

the theatre was that the performances could be indefinitely reproduced without relying on the real artists' availability.

Figure 2 shows the Alabastra configuration. This was produced by Oskar Messter and it consisted of a transportable stage, ten by thirteen by ten feet [1]. The projection size generated with this apparatus was about 30 inches.

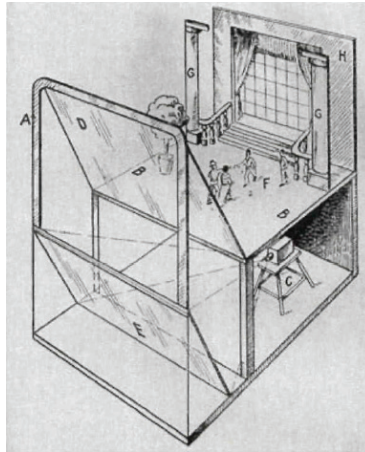


Figure 2. Configuration of Messter's Alabastra [2]

Kinoplastikon, patented by Karl Juhasz and Franz Haushofer, was similar to Alabastra, but its main difference was the full-size projection of the artists. By 1930 there were almost 250 Kinoplastikon theaters in the United Kingdom, Russia, France, Italy and North America [1].

With the beginning of WWI not only the Kinoplastikon performances stopped [3], but also did all the experiments related to Pepper's ghost effect [1].

## 2.2. Modern displays

Today's commercial 'holographic' displays are mostly oriented to marketing or to the demonstration of new products because of their capacity to show virtual objects and animations interacting with real objects. Available displays can produce a great variety of projection sizes, using different projection sources, from mobile devices (smartphones and tablets) to projectors or LCD/LED screens.

## 2.3. Basic Optics principles

Objects' reflection is the principle behind the Pepper's ghost effect. When a light beam is directed to an object surface it splits into two waves: one is transmitted through the object body and the other is reflected [4, 5], as shown in Figure 3. The angle in which the beam gets to the surface is the same as the angle between the reflected wave and the surface, this occurs because the light looks to travel by the shortest optical trajectory and can be mathematically demonstrated (Fermat principle) [4, 7]. This is the reason why the reflective surface is placed at 45° from the projection source. If this angle is different to 45° the projection will appear leaning backward or forward, depending if the angle is lower or greater than 45°.

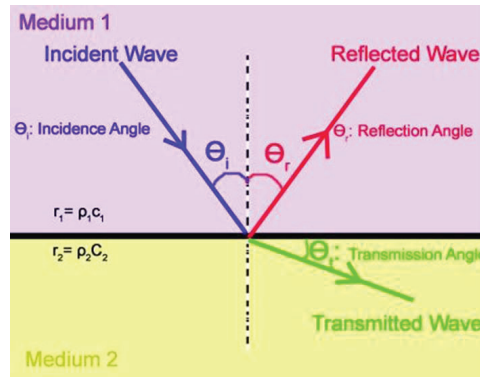


Figure 3. Illustration of wave reflection and refraction [6]

2.4. PDLC

Polymer Dispersed Liquid Crystals film s are basically three-dimensional structures composed by liquid crystal microdroplets dispersed in a polymer matrix [8]. Most of these films have the property of modulate light without using polarizers, which offers advantage in optical performance over polarized screens [9]. Figure 4 illustrates how PDLC films work.

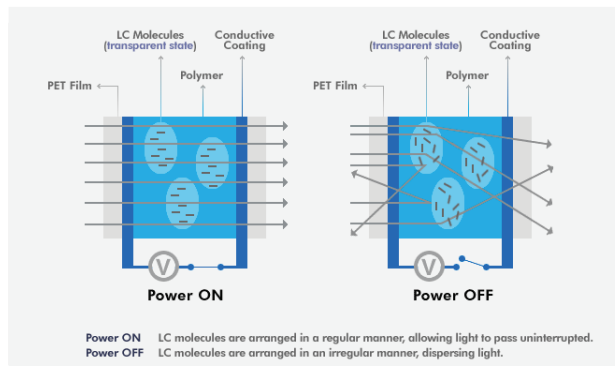


Figure 4. PDLC behavior under electrical stimulation

Transmittance of PDLC films can be continuously manipulated in function of the applied voltage [8, 10], but the operation voltage may vary depending on the film dimensions and the matrix configuration. This condition impedes the creation of a general model to predict the transmittance behavior of the films [9], i.e., the relations found in some studies may not be useful in most cases.

3. Methodology

The project follows the Action Research Methodology [11], illustrated in Figure 5.

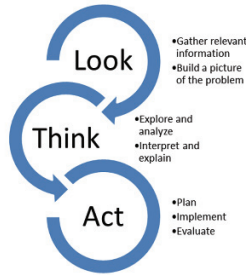


Figure 5. Action Research Methodology

### 3.1. Look

As first step, relevant information shall be gathered to understand the problem and then register the actual situation. Figure 6 shows the performance of the display under two different light conditions.

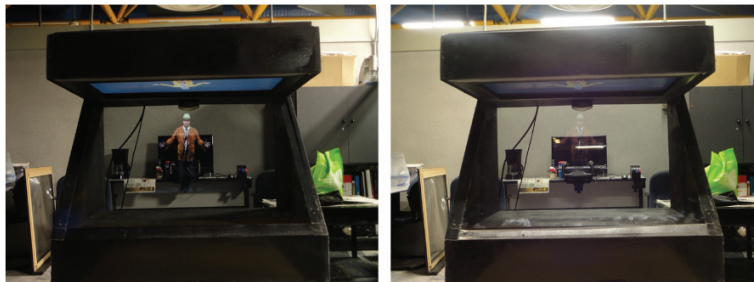


Figure 6. Display performance under 40 Lux (left) and 220 Lux (right)

### 3.2. Think

Once enough information is collected, the next step is to analyze it and identify aspects that would help to clarify and comprehend the nature of what is being researched. Figure 7 shows an Ishikawa diagram built with the information obtained and it helps to summarize the possible sources of the problem.

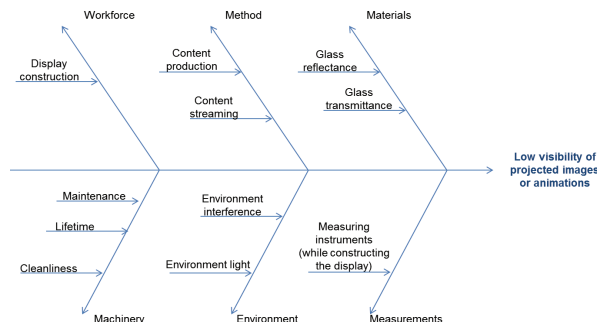


Figure 7. Main factors related to low visibility of projected contents in an 'holographic' display

### 3.3. Act

This last step consists of three phases: Plan, Implement and Evaluate.

#### 3.3.1. Plan

The actions planned for this project involved three variables: amount of light, in the place where the ‘holographic’ display is being used, transmittance of the glass (with PDLC film) where the pictures are projected and the background color.

Two illumination scenarios were proposed: 40 and 220 Lux, respectively. The light measurements were held by a Steren HER-40 Lux meter. Six transmittance levels were tested, obtained by applying different voltage. Two different background colors were used: black and grey.

The action plan for this project is illustrated in Figure 8.

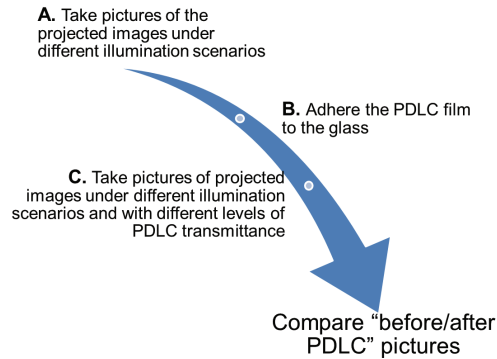


Figure 8. Action plan for experiments

#### 3.3.2. Implement

For step A, one picture was taken for each illumination level combined with each background color, at five different ISO levels. A 14 Megapixels camera was used to take these pictures, which has a CCD sensor and Carl Zeiss objective lens. The ISO levels used were ISO100, 200, 400, 800 and 1600. The lens aperture was set to  $f/4.5$ . Figure 9 show the distribution of the camera and the display. The camera was placed at 110 cm from the floor and at 75 cm from the display.



Figure 9. Equipment setup for picture taking

Figure 10 shows a flow diagram that indicates the proceedings of stage A experiments and Figure 11 shows the proceedings for stage C experiments. Figures 12 and 13 show some of the pictures obtained at 40 Lux and 220 Lux respectively.

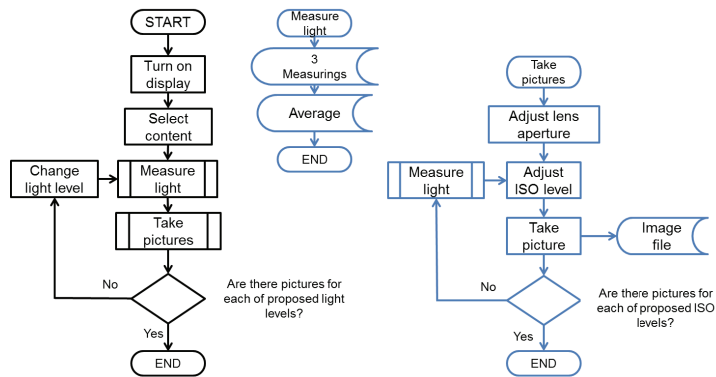


Figure 10. Proceedings for experiments of stage A

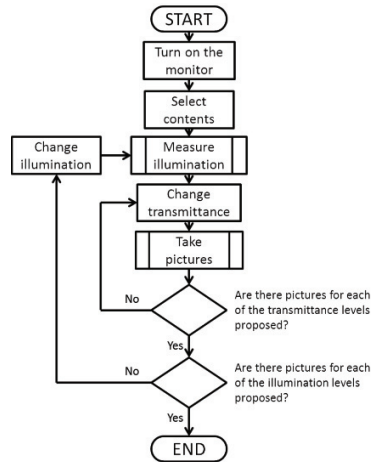


Figure 11. Proceedings for experiments of stage C

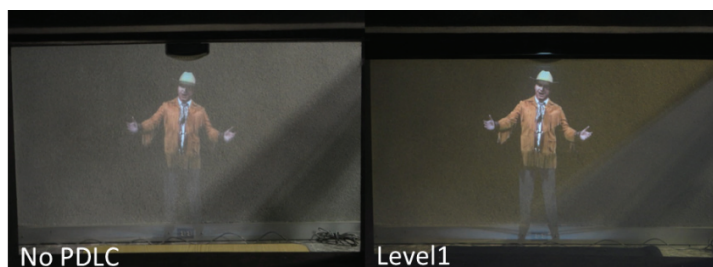


Figure 12. Pictures gotten at 40 Lux with grey background. Left picture is the one taken without the PDLC film (stage A). Level 1 refers to one the levels of transmittance of the PDLC (stage C)



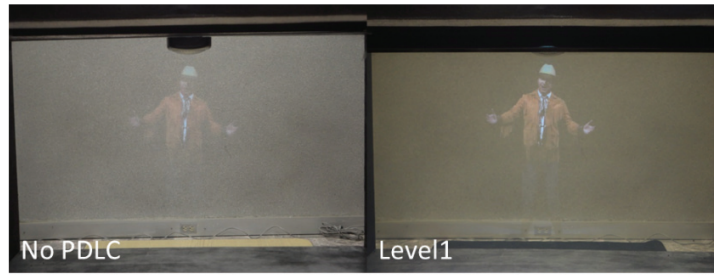


Figure 13. Pictures gotten at 220 Lux with grey background.

The histogram tool from Adobe Photoshop was used for the “before/after” comparisons (stage D). This tool shows the distribution of the pixels in the picture, arranged by their color intensity (RGB) in a scale from 0 to 255 [12]. For a more accurate study, only the pixels from the projected image were considered to create the histogram. The ‘magic wand’ tool was used to make this selection. Figure 14 illustrate this selection.

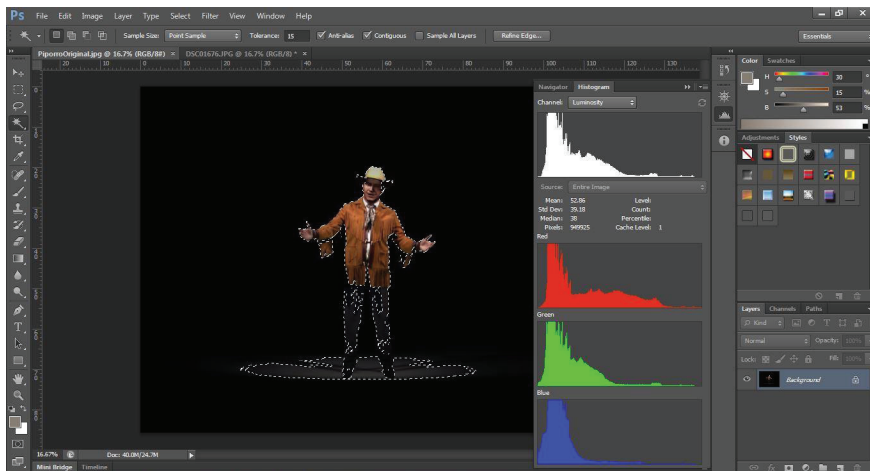


Figure 14. Selection of pixels in the original render image

### 3.3.3. Evaluate

All the histograms from all the pictures were compared to the histogram from the original render, and the average values were used to create graphs that demonstrate the differences between the image projected in the display without PDLC and the image with each transmittance level of the PDLC.

## 4. Results and Conclusions

Figure 15 shows one of the graphics obtained. The horizontal axis indicates the ISO level used to get the picture and the vertical axis refers to the pixels’ color intensity in a 0-255 scale. The closest the curve to the original render’s curve (blue) the better the visualization of the projected images is.



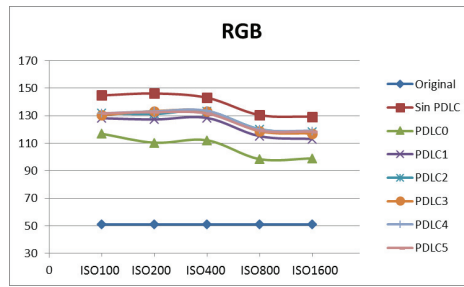


Figure 15. Average RGB vs ISO sensibility used to take the picture. Pictures obtained at 220 Lux illumination, grey background.

It can be seen that all transmittance levels (PLC0 to PDLC5) show a better projection that the display without PDLC film (red curve). The PDLC0 curve is the closest to the original, followed by PDLC1; nevertheless, with the PDLC0 level the effect of virtual objects interacting with the real environment will be lost because the film does not allow the light to pass through it, so the adequate level to operate the display will be the PDLC1. It cannot be seen a great difference between the other levels.

Additional tests were made to find out if the installation of the PDLC (back or front glass surface) will also influence into a better projection. The results for PDLC0 and PDLC1 levels are shown in Figures 16 and 17, respectively. As it can be seen, only at PDLC0 level there is a slight difference, but at the PDLC1 level the curves are almost exactly above each other and the same occurs at all other levels, so it can be inferred that there is no significant difference between installing the PDLC in the back or the front surface of the glass.

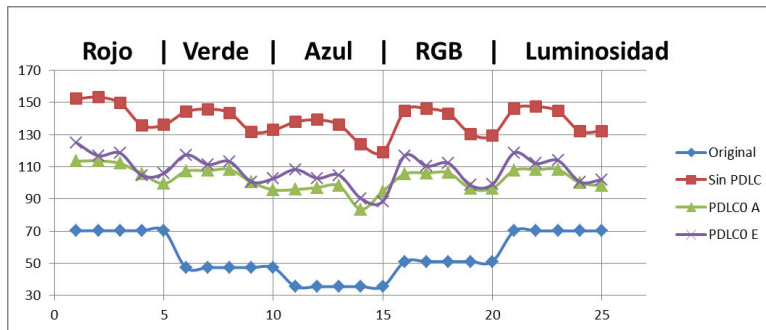


Figure 16. Differences in the projected image pixels' intensity between back (A) and front (E) installation of the PDLC.

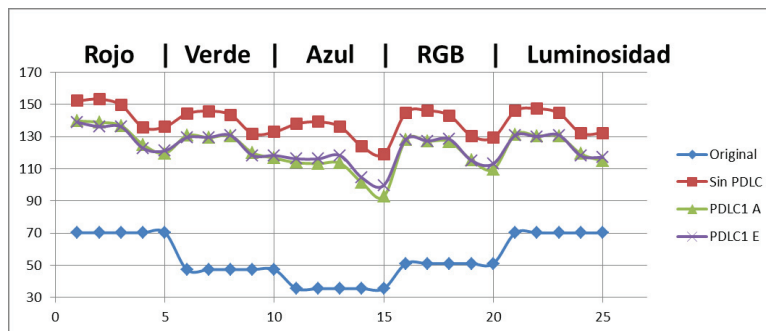


Figure 17. Differences in the projected image pixels' intensity between back (A) and front (E) installation of the PDLC.

## Future work

It is recommended to develop a similar study involving different kinds of ‘holographic’ displays, e.g. ‘holographic’ pyramid. Also, it would be a good idea to make a similar study including other factors that were considered constant for this project, such as the projection source technology (LED, LCD) and its image mode, i.e., brightness and sharpness.

## Acknowledgements

To B.A. Priscila López, M.Sc. Moraima Campbell, M.Sc. Juan D. Cabrera and M. Sc. Francisco Quiñones, responsible team for the event ‘Mujer Neoleonesa: Musa y Creadora’ for allowing both the participation in their project and the use of the animations and renders generated as case of study for the project described in this document.

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