Droplet Magnification of an LED Backlit LCD

By Davis Fogerty

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Professor Jean Hertzberg

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I. Introduction

This image was created for the introductory “get wet” assignment for the flow visualization course at the University of Colorado at Boulder. It is designed to get students familiar with process and challenges of capturing a flow phenomenon with a photograph. The course is designed for film majors, photography majors and engineers alike. It allows the non-technical disciplines to explore some of the physics and dynamics behind fluids and allows the engineers to find creative avenues to explore their knowledge of fluids. This image is an exploration of the basic functionality of a typical Liquid Crystal Display (LCD) screen. Droplets of water magnify individual pixels and sub-pixels. It also explores the contact angle of water droplets on glass and the blending of colors in the LCD screen.

II. Set-Up, Methods and Post-Processing

The set-up for this shot was fairly basic. Multiple shots were taken experimenting with camera stability and camera angles. Initially, the camera was mounted on a tripod directly over the screen although additional shots taken at a slight angle proved to be more aesthetic. No additional lighting was needed since the screen was already backlit and most of the room lighting was eliminated to reduce any noise from reflections in the shot. The camera used was a Panasonic Lumix DMC-TZ3 set to a macro mode for sharper focus at a close distance. A two-second timer was used to make sure the camera was perfectly still when the image was taken because even on the tripod movement occurred when the shutter was pressed. The camera settings were a 1/30 second shutter speed, an f-stop of 3.3 and an ISO of 200. No flash was used. The camera was about 7cm away from the screen.

The screen was cleaned with a glass cleaner although it is predicted that some oily residue was left behind. The screen and tripod were placed on a level surface. The drops were applied with a laboratory bulbed glass pasteur pipette. The sizes of the drops were varied in order to capture different effects. The quantity of drops in the image was also varied until a wide variety of effects was seen in the drops.

After the image was taken it was imported into a photo editing software, GIMP to be enhanced. The shadows and highlights were both increased to give the perception of depth in the image. The color temperature was slightly adjusted to make the screen in the foreground appear a more pure white. Finally the heal tool was used to eliminate some minor reflections of the glass screen that occurred from the small amount of external light in the room. Overall, there was minimal information lost in the post-processing of the image so the actual fluid phenomenon could be seen accurately.

III. Analysis

The screen used is and Apple iPad screen. It is an LED (Light Emitting Diode) backlit IPS (In-Plane Switching) LCD (Liquid Crystal Display) screen. An LCD screen uses two linearly polarized filters, one horizontal and one vertical. The liquid crystal is the layer between the two filters. The liquid crystal material has properties in between those of a liquid and a solid crystal. Its molecules can be oriented in a crystal-like manner to bend light when an electrical current is applied to it. When a pixel is illuminated, the LED light passes through the first vertical filter and is bent 90 degrees by the liquid crystal with current passing through it to then go through the second horizontal filter to the viewer. When a varied amount of electrical current is passed through the liquid crystal it changes its properties to allow more or less light to be bent and therefore get through the filters. The final stage of a liquid crystal display is the red, green, and blue filters over the sub-pixels to create a single pixel. For colors in between solid red, green or blue, the liquid crystal allows different amounts of the red, green and blue sub-pixels to be seen creating a full rainbow of colors. [3] White is created by fully illuminating all three sub-pixels as seen in

Figure 1. The smaller pointer looks as if it is on a white background but when the pointer is enlarged it can be seen that the white is actually composed of individual red, green and blue sub-pixels. The black pixels in the image are blocking the backlit light from shining through creating the appearance of black.

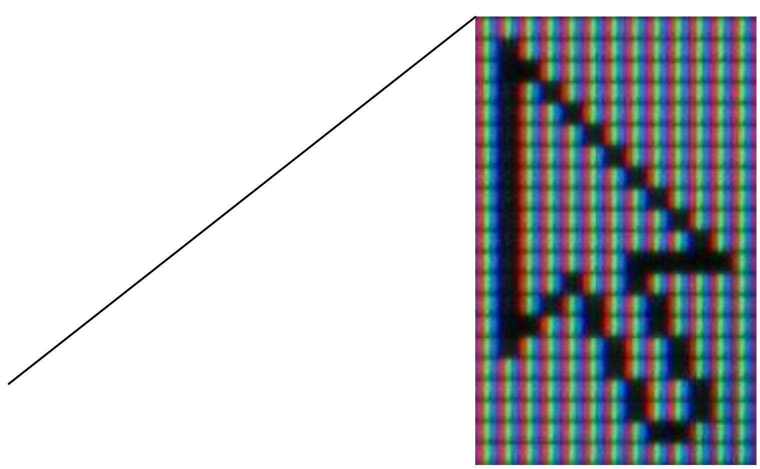

Figure 1 - LCD Close-Up

The individual sub-pixels can be seen through the droplet magnification as in Figure 2.

Figure 2 - Sub-Pixel Magnification

The rectangular red, green, and blue sub-pixels look similar to sub-pixels in

Figure 1. The difference between the magnification in

Figure 1 and the droplet magnification in Figure 2 is around the edges of the droplet when pixels are distorted from the varying curvature of the drop. These areas blend the sub-pixels together to create the other colors seen in the image such as yellow, turquoise and purple. This is even more apparent in [5]

Figure 44. The center of the droplet shows the magnification of a red sub-pixel. On the right side of the droplet there is a green sub-pixel. The combination of the red and green sub-pixels is the yellow color that is seen. On the left of the red sub-pixel is a blue sub-pixel and the combination of the red and blue creates the purple that can be seen. The turquoise is created between the blue and green sub-pixels as seen in the color wheel in Figure 3.

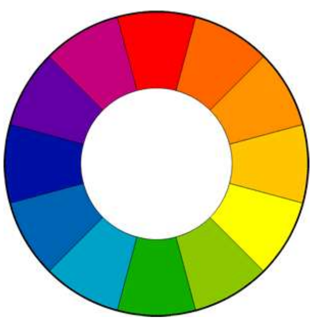

Figure 3 - Color Wheel [5]

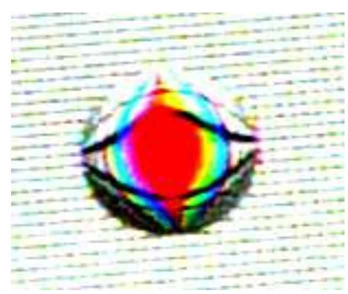

Figure 4 - Sub-Pixel Distortion

Even though most of the droplets are of varying size, some droplets of very similar size appear to be magnifying the pixels differently. This could be caused by the microscopic oily residue left on the screen after cleaning. The screen has an oleophobic coating that resists fingerprints but does not completely keep the screen from getting dirty. A perfectly clean screen has a contact angle of approximately 90°. Some contamination on the screen would cause that angle to decrease due to the increased wettability of the contaminated surface. As seen in Figure 55 when the contact angle decreases the focal length of the "lens" created by the droplet also decreases which results in a lower magnification. A perfectly clean surface has a higher contact angle, sometimes greater than 90°, which results in high magnification of the pixels.

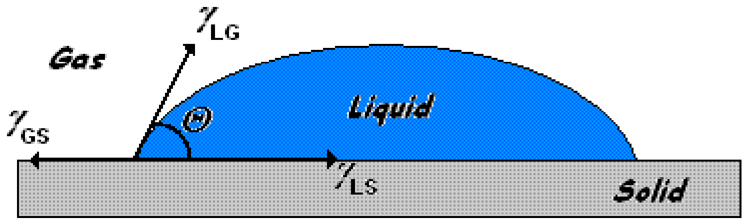

Figure 5 - Contact Angle [4]

A lower contact angle results in greater wettability of a surface and is determined by Young's relation.

$$\gamma_{GS} = \gamma_{LS} + \gamma_{LG} \cos\theta \qquad [2]$$

γ_{GS} is the surface tension between the solid and gas, γ_{LS} between the solid and liquid and γ_{LG} between the liquid and the gas, resulting in the contact angle θ. [2] The exact composition of the glass surface is proprietary information that Apple doesn't release but the base of the screen is glass. Visually, the contact angle appears to be right around 90° but varies slightly. The fluctuating contact angle may also be contributed to the inherent human inconsistency of placing the drops.

The screens In-Plane Switching (IPS) feature allows for viewing at a higher angle from a straight on view, without color distortion. This is important to the image since the shot was taken at an angle. A screen without IPS would appear darker and have inverted colors when viewed at an angle. Although the specifics of IPS are very complicated, an IPS screen can be identified using a linearly polarized filter. An IPS screen will appear black 4 or more times when rotating the filter. For example it will be black at 30º, 90º, 150º, and 210º rather than just at 180º like a normal LCD screen. The IPS in the screen allowed for a more accurate white background in the image.

IV. Conclusions

Overall this image reveals how almost any liquid in an everyday setting can be a window into the complex physics of fluids and open our eyes into the world of fluid dynamics. It doesn't take an expensive camera and a fancy lab to be able to photograph fluids in a visually stimulating way and even basic pictures can reveal fascinating fluid phenomenon.

Through this process I learned that photographing a fluid is extremely complex. Timing, lighting, focus, depth of field, contrast must be paid a tremendous amount of attention, more so than in typical photography. I have also discovered that the visualization of a fluid can be very beneficial in the understanding of that fluid. I was able to uncover the technology of an LCD screen using fluids while also creating a beautiful image.

If I were to study this topic in more depth I would investigate the specifics of the iPad screen and its composition. I would also try different fluids with higher viscosities to see how that changes the magnification of the droplet "lens." It would also be interesting to see how different colors in the screen would look under droplet magnification.

V. References

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