Visualization of Surface Tension Using Multiple Light Sources

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Image/ Video 1

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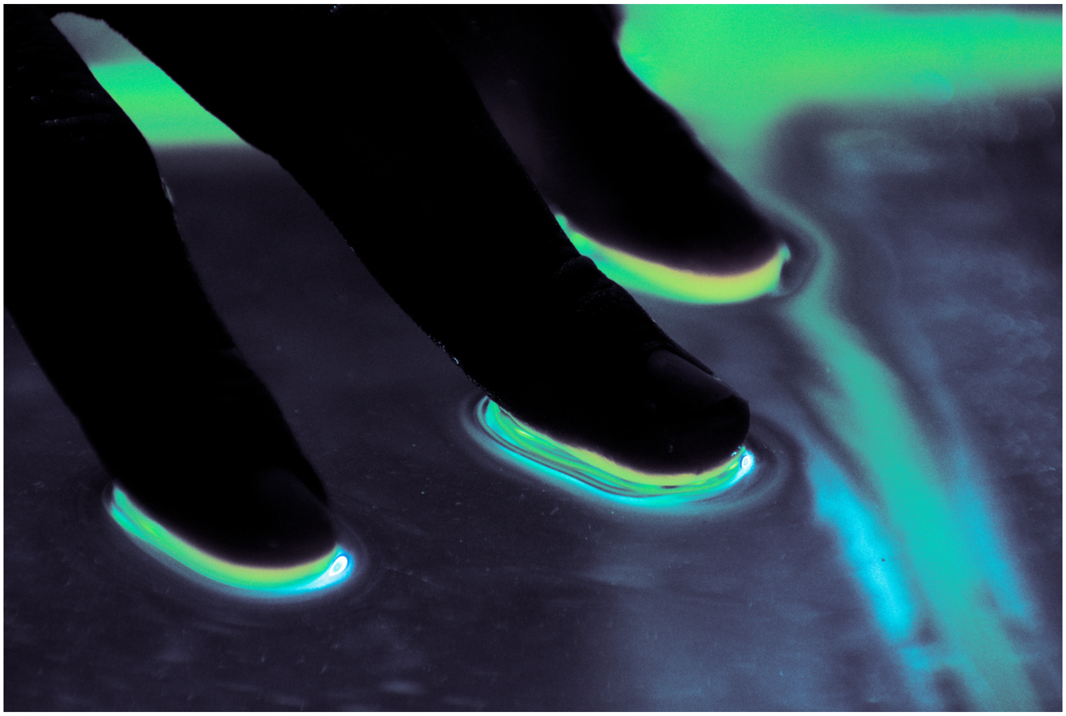

Figure 1: Visualization of Surface Tension

For the primary Image/ Video submission, students were tasked with capturing a snippet of fluid phenomenon. Early on I had decided to work with my fellow classmates William Watkins and Isaac Martinez in order to tinker with fluid physics and dial in a useful photography setup that was capable of capturing the experiments we had decided upon. William checked out external LED lights from the department and Isaac helped with camera positioning along with lighting, and framing/ additional lighting advice was provided courteously by my roommate Joshua Greenburg. Initially, I had planned to capture an image of an object splashing into water, but noticed that our lighting setup allowed for a unique visualization of surface tension that I then set out to capture. Figure 1 depicts the photo taken by myself with the intent of visualizing the surface tension of a pool of water when acted on by an external body– Josh's fingers.

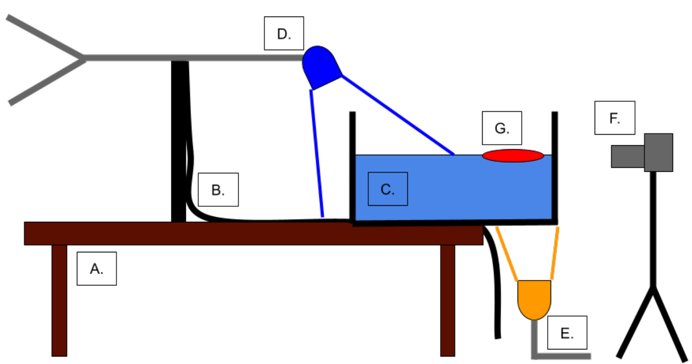

Figure 2: Experimental Setup for Figure 1

Figure 2 shows the experimental setup used to take Figure 1. The elements labeled out are described as follows:

A.) Wooden table used as base.

B.) Black plastic tablecloth used as backdrop for image.

C.) Glass fish tank containing 5 gallons of water (approximately filled halfway). The fish tank is clear on all sides, including the lower panel.

D.) Blue LED lamp shining into fish tank at an 60 degree angle, preventing reflections from the glass from appearing in the image. The stand supporting the light was balanced on a separate table leg to provide elevation.

E.) Yellow LED lamp shining directly vertically into the fish tank.

F.) Nikon D3400 Camera mounted slightly above water level within fish tank.

G.) Approximate FOV of camera; location where water was touched to produce Figure 1.

Surface tension is a complex problem that is sought to be modeled and understood by countless researchers, especially when numerous external forces and disturbances are added. In the case of the selected image, the system can be modeled under relatively simple conditions. For example, the fluid is standing still, meaning that there is a constant pressure throughout the fish tank, and no external forces acting immediately at the interface. One such desired property is the curvature at the interface, which would allow for calculations of force or other physical quantities acting upon the fluid. Findings from Popinet (2017), can offer some insight into the mathematics behind numerical methods covering surface tension, including curvature. One such equation estimating curvature is given by a height-function method, which relies on discrete observation of fluid displacement as a function of the boundary in question. Given an interface, $y = h_y(x)$, the curvature defined by this function is described in Equation 1:

$$k = \frac{h_y''}{\sqrt{1 + h_y'^2}} \tag{1}$$

The higher derivatives of the interface help define the tangent lines formed by the bending water as the fingers contact the surface. Using this equation, if another photo were taken showing the amount which the finger dips below the surface normal, one could calculate the curvature of the water at this point of interaction.

A higher-order derivation of this scenario is explored in Coquerelle (2015), that delves into a fourth-order curvature computation of flows subjected to surface tension. Does the setup in the image meet the appropriate criteria to be analyzed? Coquerelle (2015) claims that the critical criteria for computation are the following:

- Consistent numerical discretization of the pressure and surface tension terms
- Rational computation of surface's curvature

Coquerelle (2015) continues to write that a rational computation or the curvature includes minimal deviation along the surface, and minimal variation along the surface normal. Adhering to these criteria shows that the setup used to achieve Figure 1 would be valid to explore numerical method approximations for the surface tension of water.

Initially, I attempted to take a picture of the fingers with just the blue light shining in the water, but later realized that I could include the orange light since the underside of the fish tank was also clear. The visualization technique used in this image was the process of having multiple colored light sources. As the light from the upper blue bulb (item D.) illuminates the water within the tank, the light from the yellow bulb shines from directly below. The blue light fills the water within the tank due to internal reflection, and at the angle that the camera can see the yellow light is not directly observable. However, when the subject's fingers touch the surface of the water, the surface tension of the upper boundary layer begins to bend around the external body. This bending of water causes a lensing effect, such that the light is deflected at an angle that becomes visible by the camera. The experimental setup was contained within my garage, allowing for a pitch-black environment. The only lights utilized were the two LED bulbs described in D and E– no built-in flash was utilized. This allowed for the fingers to stay in shadow, and for the focus to be on the converging lights at the boundary.

This image was taken with a Nikon D3400 DSLR camera, using a 70-300mm f/4.5-6.3 zoom lens. The photo was taken with a focal length of 270mm at aperture f/6. The shutter speed was 1/250s, at ISO 3600. The goal of the framing of the image was to have the lensing caused by the finger be the primary focus, with the background being out-of-focus. The FOV of the image spans a region 3.5x2$\frac{1}{3}$ inches (at 6000x4000 pixels), and the subject was approximately 20 inches away from the lens. The raw image is depicted below in Figure 3:

Figure 3: Original Unedited Photo

After taking the initial photo, I decided to make a number of digital alterations to highlight the fluid physics. I reduced the intensity of the red channel, which darkened the fingers significantly. I also played with the RGB curve to change the overall highlights by reducing the mids and bringing out the brighter tones. Lastly I desaturated the blue water to gray to really highlight the color brought out by the orange lighting.

In conclusion, this image reveals the way that water bends when contacted with an external force, which is described as surface tension. I am very happy with the way that it turned out, especially once the digital editing was applied. I believe that the fluid physics are shown quite clearly, especially compared to how they would have been if there were not a secondary light source placed below the fish tank. I was successful in fulfilling my intent with this image, and it turned out better than I expected! I believe that if I were to redo the setup, I would try to control the background particulates more closely, as one can see dust particles that settled into the water, along with some artifacts from the backdrop that was used. In a future experiment, perhaps additional photos could be taken from below, since the glass was clear.

References

Stéphane Popinet (2017) https://hal.archives-ouvertes.fr/hal-01528255/

Coquerelle M, Glockner S https://www.sciencedirect.com/science/article/pii/S0021999115007548?casa_token=9tFBU_aC07MAAAAA:48tB2ABu4IT3FtI2qg5-o6qJuwa1X0Z0fOsE6be4wKKQ4QspEWs5ruS8SVmbTuUcBJE70QJjlA#br0100