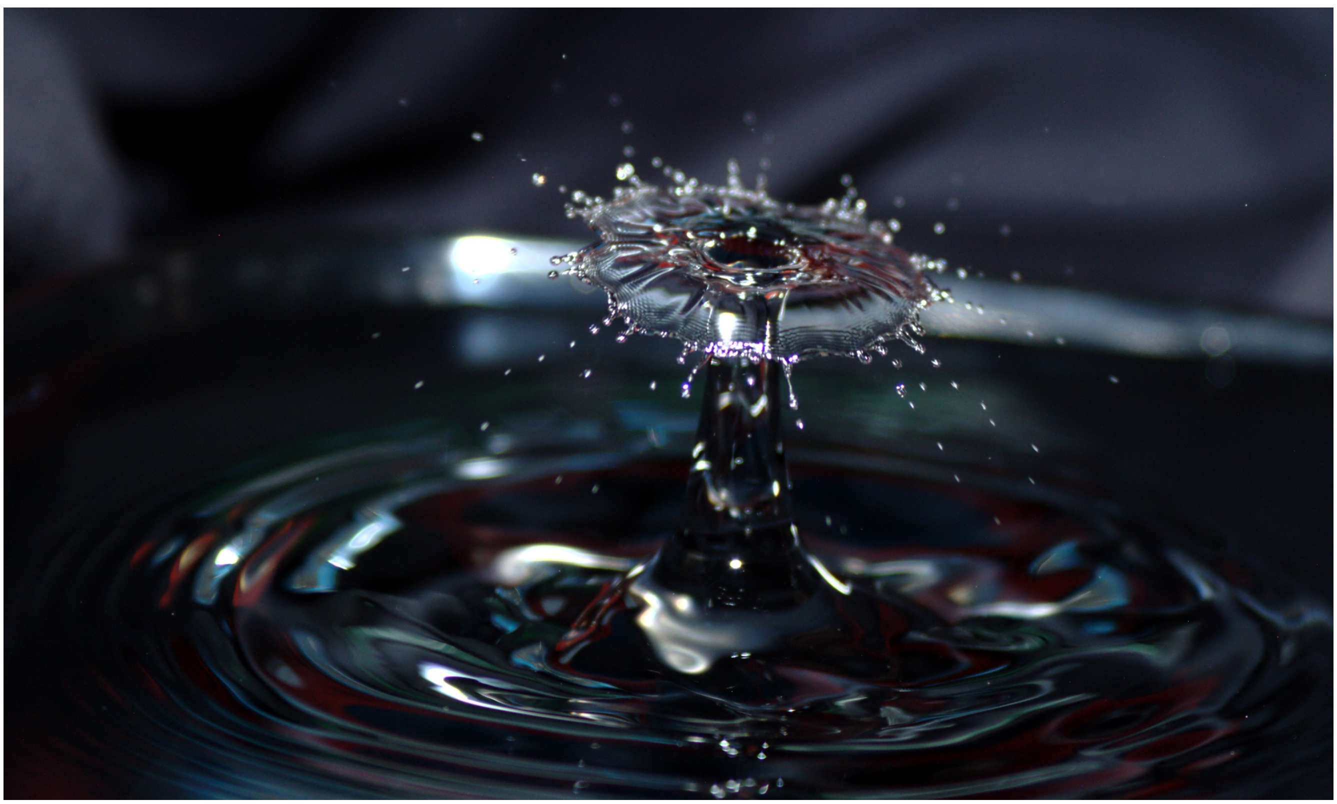
Water Droplet Collisions

MCEN 5151, Image #3

Wayne Russell



This picture was taken for the third group image in the Flow Visualization class at the University of Colorado. It was captured with the aide of Kelsey Spur, Paul Sweazey, Zach Wehner, Gabe Bershenyi, and Blake Buchannan. The goal of the project was to capture the beautiful and transient shapes caused by a water droplet colliding with the Worthington jet created by another drop in a consistent, reliable, controlled manner. By using a microcontroller to time the release of water droplets from a solenoid valve and a single flash, the goals of the project were met, although there is still room for improvement.

An ATMega 328P with the Arduino bootloader was used to achieve the desired timing. A simple program gave full control over all aspects of the process. By adjusting the length of time the solenoid was open, the delay between droplets, and the delay to release the shutter on the camera, creating a reproducible phenomenon was straightforward. Additionally, two LED arrays were used as flashes, allowing complex lighting from multiple angles and with any desired timing. Unfortunately, despite using five high-power LEDs (CREE MX6AWT-A1), neither array was bright enough to achieve a proper exposure, although this may have been due the 1.25 A current limit in the power supply. A larger power supply may have been able to drive each LED at it's maximum output. To provide sufficient light, a flash was mounted to a camera which had its shutter controlled by the microcontroller. A 7805 voltage regulator was used to drop the 12 V required by the LEDs and solenoid to 5 V. Additionally, a button was used to trigger the entire process. A schematic of the electronics is shown in Figure 1.

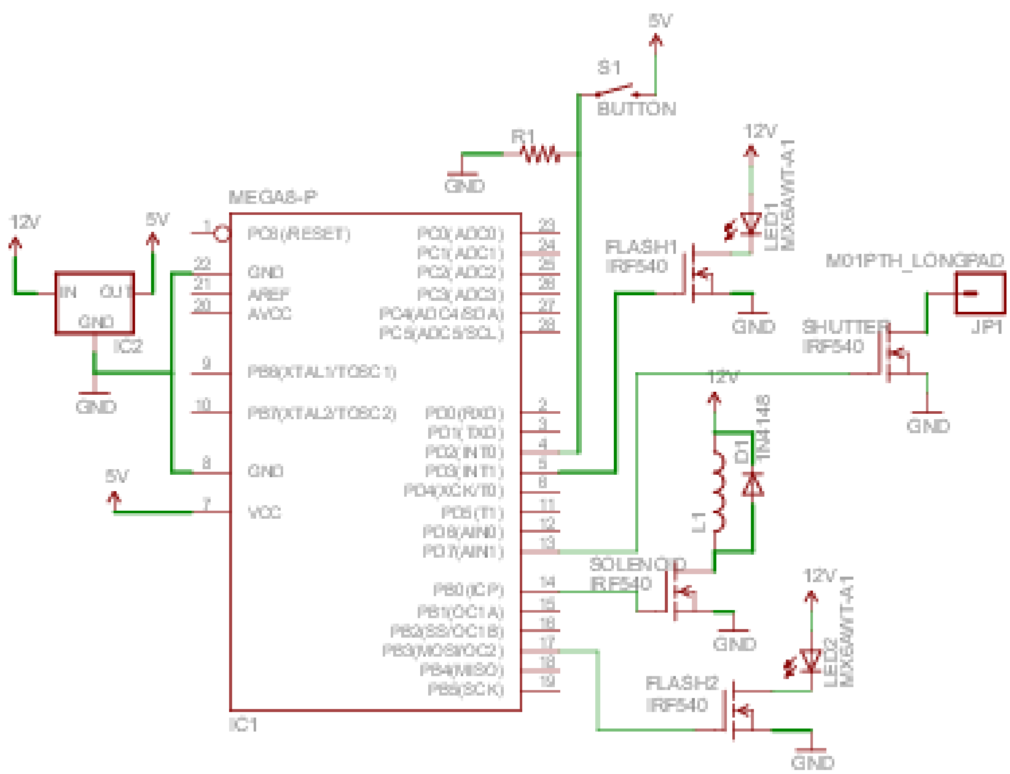


Figure 1: A microcontroller was used to control the shutter, solenoid, and two LED flashes.

A 3 mm diameter nozzle was attached to the valve. A small tank of water was held 20 cm above the valve. The nozzle was 43 cm above the bowl of water. A diagram of the setup is shown in Figure 2. Good results were obtained by leaving the valve open for 120 ms per droplet, with 30 ms between droplets. The flash was fired 202 ms after the second droplet. The timing is illustrated in Figure 3.

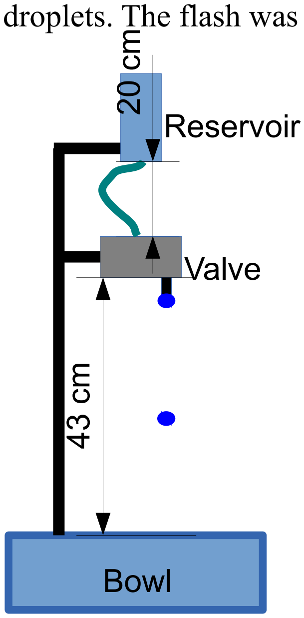


Figure 2: The physical setup was straightforward, with dimensions as shown.

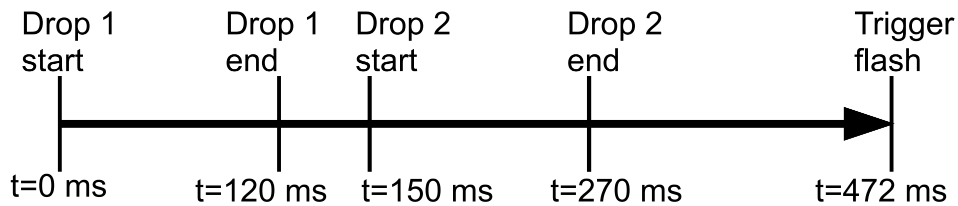


Figure 3: The use of a high-speed camera greatly simplified the task of determining the desired timing.

When an object strikes the surface of a liquid, a jet of the liquid is ejected into the air. In this case, a bowl of water is impacted by a droplet of water. This causes an air cavity to be formed. As the air cavity collapses, it causes a pressure gradient to form in the direction of the base of the jet. This causes particles to accelerate inwards. At the center of the jet, they are forced upwards, causing the water to rebound[1].

The velocity of the falling droplet can be shown to be

$$U = .54\sqrt{2*g*h} \quad (1)^{[2]}$$

where h is the height of the nozzle. In this case, the droplets reach a velocity of 1.6 m/s. The maximum radius of the cavity formed prior to the jet is

$$R_{max} = .76*\frac{U^{1/2}}{g}*d^{\frac{3}{4}} \quad (2)^{[2]}$$

where d is the diameter of the droplet. In the case studied here, R_{max} is 7 mm. Furthermore, the diameter of the jet can be estimated. The height of the jet is roughly 2 cm, which, by using equation 27 from Ogawa et al., gives a diameter of 2.7 mm. Although it is somewhat difficult to determine the height of the jet from the image (which was taken to showcase a consistent, artistic phenomenon, as opposed to the fluid dynamics), these estimates do seem to be close to the actual dimensions of the jet.

The image was taken with a Canon 400D digital SLR camera. The camera uses a 2.5 mm phone connector as a remote shutter release, which was connected to the microcontroller. This allowed the shutter for the 400D to be precisely timed. A flash was mounted on the camera. When the shutter on this camera was triggered, the flash fired. This allowed several other cameras to be used without needing to worry about precise timing; they were set with a long exposure in a dark room, and the short flash froze the motion of the droplets. The F stop was 5.6, with an ISO of 400. The focal length was 62 mm. The original image was 3,906 x 2,602 pixels, cropped to 2,942 x 1,683.

Minimal post-processing was done; the white balance and temperature were adjusted, a stray droplet that was out of focus was cloned out, and the contrast curve was slightly adjusted.

The goals of this project were achieved. Artistically pleasing collisions between Worthington jets and another water droplet were captured in a controlled manner with a high success rate. There are, however, many other areas to explore with such images. Using or adding other liquids, such as glycerin or milk, would open manifold possibilities for other interesting images. Using dyes would also add an interesting aspect. Additionally, the height of the nozzle could be changed or the water reservoir could have been pressurized. More interesting backdrops could have been used, illuminated and highlighted by slave flashes.

References

[1] Gekle, S & Gordillo, J M, *Generation and Breakup of Worthington jets after cavity collapse. Part1. Jet formation,* J. Fluid Mech. (2010), vol. 663, pp. 293–330.

[2] Ogawa, A, Utsuno, K, Mutou, M, Kouzen, S, Shimotake, Y, Satou, Y, *Morphological Study of Cavity and Worthington Jet Formations for Newtonian and Non-Newtonian Liquids,* Particulate Science and Technology, 24: 181–225, 2006