Tracking Water Droplets Under Descent and Deformation

Caleb Brose*
Dept. of Computer Engineering

Martin Thuo†
Dept. of Materials Science
Iowa State University

Jeremy W. Sheaffer‡
Dept. of Computer Science

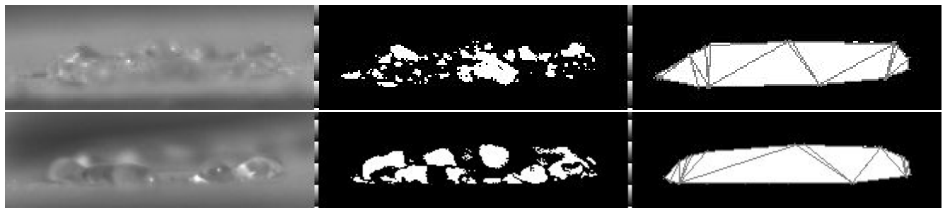

Figure 1: *On the left, two droplets of water interacting with two different hydrophobic surfaces. The middle shows the detected droplets as per foreground detection. On the right are triangulated convex hulls.*

We present a system for tracking the movement and deformation of drops of water in free fall and collision. Our data comes from a high-speed camera which records 60,000 frames per second. The data is noisy, and is compromised by an unfortunate camera angle and poor lighting which contribute to caustics, reflections, and shadows in the image. Given an input video, we apply techniques from image processing, computer vision and computational geometry to track the the droplet's position and shape. While our tool could monitor the movement of transparent fluids in a more general environment, our data specifically depicts water colliding with hydrophobic materials. The output of our processing is used by materials scientists to better our understanding of the interactions between water and hydrophobic surfaces. These interactions have direct application in the materials engineering of next generation printing technologies.

Tracking the motion of a moving object in an otherwise static video is a well understood problem with many, fairly trivial solutions; however, when the object in question is a droplet of water, the problem becomes less straightforward. This stems from properties of the water itself; the transparent drop is a lens, passing rays near the center of the drop—as observed from the point of view of the camera—through unperturbed, making the water difficult to differentiate from the background, while refracting rays through most of the body and reflecting rays near the perimeter. Even given this issue, since the shape of the falling drop is static and we can easily calculate its motion, tracking the droplet in free-fall is still a simple endeavor.

The goal of our task is to discover properties of the micro interactions of water in contact with various hydrophobic surfaces. It is here, in this interactive space where behavior is less regular and predictable, that the issues mentioned above become challenges. Ideally, we would have bright, omnidirectional, ambient illumination; however, in practice our scenes are lit by a spotlight near the camera, adding caustics and shadows to the mix, grainy video footage creates noise issues, and a poor choice of camera angle adds anisotropy; nor is the surface itself microscopically isotropic, so we can make no safe assumptions about symmetry, but anisotropy imposed by perspective compounds the other difficulties.

We begin by calculating a background image from which we will discern the water. We do this by taking the pixel-wise average of the lower half of several frames at the start of the video and combining the resultant, noise-reduced half-image with a similar half-image calculated from the top half of several late video frames. We then track the falling droplet over this background through five phases:

1. Appearing: The droplet is entering the frame from above. Once entirely in-frame, the droplet transitions to falling.
2. Falling: The droplet is in free-fall. For practical purposes, the droplet is perfectly round; it is small enough that surface tension is much larger than the force induced by air resistance, so the drop is round to the limits of our ability to measure. Drop volume in "cubic pixels" can be estimated with high accuracy (frame-to-frame variance very close to zero) in this state.
3. Contacting: As the drop makes initial contact with the surface it is most difficult to track. The drop casts a dark shadow and dramatic caustics, with which it intersects in the feature space. It then begins to oscillate between expanding and contracting phases as it dissipates energy.
4. Expanding: The drop is spreading out over the surface and becoming thinner. Our algorithms look for a horizontally "larger" drop in subsequent frames.
5. Contracting: Surface tension pulls the drop back together. Our algorithms look for horizontally"smaller" drops.

By—falsely!—assuming isotropic expansion and contraction, we can estimate the volume of the droplet in the last two stages by integrating the cross section of the convex hull of the droplet's profile over pi. This gives us a bound on error which stays within about $\pm 10\%$. This error, while worse than we desire, is sufficiently low as to allow our materials science collaborators to draw conclusions about the incident surfaces.

Going forward, we intend to acquire more video sequences with better lighting, more and better camera angles, improved depth of field, and additional features that convey ground-truth size measurements. These will simplify the video stream analysis and enable us to produce much better, and more physically-based, data to drive the materials science research.

*cmbrose@iastate.edu
†mthuo@iastate.edu
‡sheaffer@iastate.edu

SIGGRAPH 2015 Posters, August 09 – 13, 2015, Los Angeles, CA.
ACM 978-1-4503-3632-1/15/08.
http://dx.doi.org/10.1145/2787626.2787651