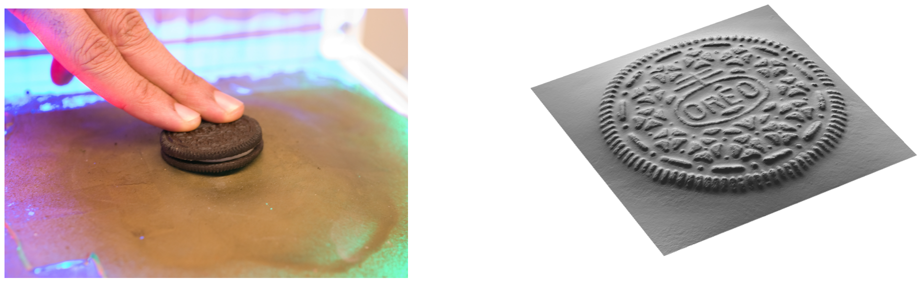
An interactive "retrographic sensor" for touch, texture, and shape

Alvin Raj, Micah K. Johnson, Edward H. Adelson*
Massachusetts Institute of Technology



(a) (b)

Figure 1: *(a) A cookie is pressed against the skin of the retrographic sensor. It is illuminated from below by three colored lights and is captured by a standard USB camera. (b) Using photometric stereo, we estimate the cookie's shape at interactive rates.*

1 Introduction

Retrographic sensing is a novel method for measuring surface texture and shape. It uses a sensor made of clear elastomer with a painted skin to non-destructively change an object's reflectance characteristics. When an object is pressed into the sensor, the painted skin conforms to the shape of the object. Viewed from behind, the object appears as a shaded surface and the shape of the surface can be estimated using photometric stereo techniques. In previous work [Johnson and Adelson 2009], we describe a method for reconstructing high-resolution 2.5D surface data from a single image of the sensor. In this work, we demonstrate an implementation of the system that runs at interactive rates.

2 Technical details

The sensor is made of a clear thermoplastic elastomer (TPE), which is both strong and elastic. The elastomer can be dissolved in common solvents and formed into arbitrary shapes, though we typically keep the shape as flat as possible. The reflective paint is made from a mixture of TPE, dissolved in a solvent such as toluene, and reflective pigments. This technique creates a reflective skin with the same strength and elasticity as the body of the sensor. The paint is applied to the elastomer using an airbrush.

The properties of the sensor determine the types of surfaces that can be measured. In particular, the thickness and hardness of the elastomer directly influence how the reflective skin deforms as an object presses against it: a soft and thick sensor is useful for measuring objects with deep concavities, while a firm and thin sensor can measure near-microscopic surface texture.

The choice of BRDF of reflective paint also has a large effect on the performance of the system. To measure deep objects, we have found that diffuse BRDFs and oblique illumination are necessary because they reduce ambiguities at extreme surface orientations. But diffuse paints typically blur the fine surface detail. To see this detail (i.e., small variations in surface normal), we need specular paints. Specular paints, however, cause problems with extreme angles, thus there is a tradeoff between depth and detail.

To capture images from the retrographic sensor, we position the slab of elastomer on a sheet of glass and arrange colored lights (red, green, and blue) below the glass facing the sensor. The lights are arranged in an equilateral triangle below the sensor. We use an Imaging Source DFK 31BU03 Color CCD USB camera positioned below the sensor.

The system is calibrated by imaging an array of spheres with known diameter. The spheres allow us to learn the relationship between object geometry (i.e., surface normal) and RGB color at every pixel. We build a lookup table to represent this mapping. For the interactive implementation, we use the normals learned during calibration directly and skip the surface normal refinement step described in [Johnson and Adelson 2009].

The system receives real time video input from the camera which is processed frame-by-frame. To counter non-uniform lighting from the close proximity of the three light sources, we process a constrained region of 512×512 pixels on the sensor. We look up the associated normals for each pixel, then solve the resulting Poisson system of equations, additionally imposing a Dirichlet boundary condition so that the edges of the 512×512 region has zero height. The resulting height map is turned into a 3D mesh, which we light and render with DirectX. At present, our system runs in Windows XP on a 2.4Ghz Core 2 Intel processor with 2GB RAM and a GeForce 8600 GTS video card with 256 MB RAM, at a frame rate of approximately 20 fps.

3 Conclusion

The retrographic sensor allows realtime capture and display of surface texture and shape. It may be useful in studying the interaction between human skin and soft materials in the context of food, cosmetics, or clothing.

References

JOHNSON, M. K., AND ADELSON, E. H. 2009. Retrographic sensing for the measurement of surface texture and shape. In *IEEE Conf. on Computer Vision and Pattern Recognition (CVPR).*

*email: {alvin,kimo,adelson}@csail.mit.edu

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