Rapid Classification of Surface Reflectance from Image Velocities

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Abstract. We propose a method for rapidly classifying surface reflectance directly from the output of spatio-temporal filters applied to an image sequence of rotating objects. Using image data from only a single frame, we compute histograms of image velocities and classify these as being generated by a specular or a diffusely reflecting object. Exploiting characteristics of material-specific image velocities we show that our classification approach can predict the reflectance of novel 3D objects, as well as human perception.

Keywords: specular flow, rapid surface reflectance classification, velocity histogram, material perception, spatio-temporal filtering.

1 Introduction

Identifying the surface reflectance of an object is a fundamental problem in vision. Reflectance provides important information about the object's material and identity, and given known reflectance, algorithms for shape reconstruction exist for both, diffuse and specular surfaces [1]. However, because of the strong differences in the image motion generated by specular and diffuse surfaces, unknown reflectance is a serious problem for these methods. Previous work on diffuse vs. specular reflectance classification has relied on specific assumptions and conditions, such as the tracking of surface features during known camera motion [2], known surface shape [3], the use of structured lights [4], color [5], or a specific reflectance model [6].

Evidence from human vision, however, suggests that monocular image motion across a few frames provides sufficient information to classify a surface as diffuse or specular, e.g. [7] showed that static objects with ambiguous apparent reflectance could be unambiguously classified as shiny or matte when in motion. Additionally, [8] demonstrated that it is also possible to generate reflectance illusions from motion: under certain conditions, rotating specular objects look matte (also see [9]). What aspects of specular motion explain both, the rapid material classification and the perceptual errors? Although specular motion patterns

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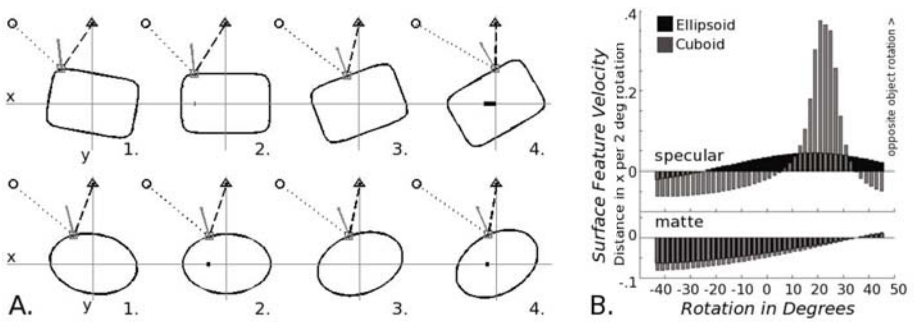

Fig. 1. Specular Velocity and Curvature Variability. A. Cross-sections through 3D scenes. The position of the 2D camera (triangle) and a point light source (circle) are fixed. We find the surface normal at the point on the object where the specular feature (square) will be visible to the camera. "Specular velocity" is measured as the distance traveled by the specular feature in x (indicated by fat black line) as the object rotates 10° counterclockwise around its origin. Consider the cuboidal cross-section: 1. The specular feature (sf) appears on a high curvature point and "sticks" to this region as the object rotates. 2. The sf moves some distance *in the direction* of object rotation. 3. The sf appears on a low curvature point. After a 10° rotation the distance that it has traveled, now in *opposite the direction* of object rotation, has nearly doubled. Compare this to the sf on the ellipsoid. **B.** Sf velocities for specular (upper plot) and surface feature velocities for diffusely reflecting (lower plot) objects per 2° rotation. See text for details.

can be quite complex, we will show that simple statistical measures on image velocities can be used to classify moving objects as specular or diffusely reflecting, without any additional assumptions or conditions. We will demonstrate that these classifiers can predict human perception, as well as the material of novel objects. Rapid methods for reflectance classification, such as the one proposed here, constitute an important step towards a fully automated vision system.

2 Specular Flow

The relative displacement of a specular feature or highlight due to camera or observer motion (or, conversely due to object motion relative to a stationary camera/observer), is negatively related to the magnitude of surface curvature [10,11], i.e. specular features "rush" across low curvature regions and "stick" to points of high curvature. In contrast, all points on a moving diffusely reflective surfaces stick. This suggests that the distribution of velocities across a moving object may contain important information about the object's material, because all specular surfaces with sufficient curvature variation undergoing a generic motion will have both low velocity "sticky" points and high velocity points, while diffusely reflective surfaces will have only "sticky" points. Moreover, except for rotations around the viewing axis, the flow generated by a rigid body motion will have a principle direction of motion.