Rapid Inference of Object Rigidity and Reflectance Using Optic Flow*

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Abstract. Rigidity and reflectance are key object properties, important in their own rights, and they are key properties that stratify motion reconstruction algorithms. However, the inference of rigidity and reflectance are both difficult without additional information about the object's shape, the environment, or lighting. For humans, relative motions of object and observer provides rich information about object shape, rigidity, and reflectivity. We show that it is possible to detect rigid object motion for both specular and diffuse reflective surfaces using only optic flow, and that flow can distinguish specular and diffuse motion for rigid objects. Unlike nonrigid objects, optic flow fields for rigid moving surfaces are constrained by a global transformation, which can be detected using an optic flow matching procedure across time. In addition, using a Procrustes analysis of structure from motion reconstructed 3D points, we show how to classify specular from diffuse surfaces.

Keywords: Optic flow, rigidity detection, specular motion, reflectance classification.

1 Introduction

For some computer vision applications like shape analysis from motion, it is typically required to know the material and rigidity of the objects. For instance, there would exist some difficulties to track highly reflective objects like cars without knowing if the object appearance remains constant across frames. Hence, most algorithms usually have strong assumptions about both the reflectivity and rigidity. For example, structure from motion algorithms assume rigidity and it is difficult to extract the point motion information needed without diffusely reflective and patterned objects [1]. Although there are methods to handle both nonrigid structure from motion and shape from specular flow, these methods are derived under the assumption that the rigidity and reflective properties of the object are known [2,3,4,5].

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Detecting that an object is shiny and rigid would allow a tracking system to rely more on appropriate measurements and improve performance. Methods for rapidly classifying the reflectivity and rigidity of an object would provide the basis for automated recovery. Further, to be most useful, such methods should have minimal information demands. Ideally, we would like an assumption free, fast, image-based method for material and rigidity classification. In this paper we show how optic flow information from a single camera can be used to classify both rigidity of moving objects, and the reflectivity of rigid objects.

Previous methods for classifying material have largely relied on the ability to control the lighting in the scene, using multiple lights, structured lights, color, stereo, or combinations of these. For examples, see [6,7,8,9,10,11]. Oren and Nayar [12] develop a classification strategy to distinguish image points whose motions affected by specular reflectance from points behaving like diffuse reflectors based on caustic curves. To our knowledge, we are the first to suggest that rigidity can be classified for both diffuse and specular surfaces from optic flow information alone.

In this paper we develop an approach to classify the rigidity and reflectivity of a moving body using only optic flow information. Our approach consists of two parts. We show that rigidity produces characteristic transformations in optic flow that holds for objects with both diffuse and specular reflectance. We exploit this information to develop an optic flow matching algorithm for rigidity classification. We also show how an analysis of the consistency of structure from motion reconstruction can be used to identify diffuse rigid objects.

2 Rigidity from Optic Flow

To detect the rigidity of a specular or diffusely reflecting object from optic flow, we show a simple relationship exists between the optic flow fields at two time points for far-field environmental illumination and orthographic (or paraperspective) viewing. In particular, the flow fields generated by a rigid body motion that differ by a global transformation is derived below.

In order to derive a relationship between optic flow and rigid object motion, we assume that both the viewer and the environment are far from the object, approximated by orthographic viewing and illumination parameterized by direction on a sphere. These assumptions are not overly restrictive as [2] has shown that paraperspective is an exceedingly good approximation for most scenes. As shown in Fig. 1, the object surface $F(x, y) = (x, y, f(x, y))$ is represented as a function of image coordinates x, y, $\boldsymbol{n}(x, y) = S(\theta, \phi)$ indicates the surface normal at the surface point $F(x, y)$ with direction (θ, ϕ), S represents the mapping between spherical and cartesian coordinates, $\boldsymbol{u}(x, y)$ is the optic flow results from the rigid body transformation T. Because the viewing direction is $\boldsymbol{v} = (0, 0, 1)$, the mirror direction $\boldsymbol{r} = S(\theta, 2\phi)$ produces the image point at (x, y).

Rigid body transformation T can be applied to the surface F as $T\left[F(x, y)\right] = R\left[F(x, y)\right] + \boldsymbol{t}$, with R and $\boldsymbol{t}$ refer to the rotation matrix and the translation vector. This induces a motion field in spatial coordinates: