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Using specularities in comparing 3D models and 2D images ☆

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Abstract

We aim to create systems that identify and locate objects by comparing known, 3D shapes to intensity images that they have produced. To do this we focus on verification methods that determine whether a known model in a specific pose is consistent with an image. We build on prior work that has done this successfully for Lambertian objects, to handle a much broader class of shiny objects that produce specular highlights. Our core contribution is a novel method for determining whether a known 3D shape is consistent with the 2D shape of a possible highlight found in an image. We do this using only a qualitative description of highlight formation that is consistent with most models of specular reflection, so no specific knowledge of an object's specular reflectance properties is needed. This allows us to treat non-Lambertian image effects as a positive source of information about object identity, rather than treating them as a potential source of noise. We then show how to integrate information about highlights into a system that also checks the consistency of Lambertian reflectance effects. Also, we show how to model Lambertian reflectance using a reference image, rather than albedos, which can be difficult to measure in shiny objects. We test each aspect of our approach using several different data sets. We demonstrate the potential value of our method of handling specular highlights by building a system that can locate shiny, transparent objects, such as glassware, on table tops. We demonstrate our hybrid methods on pottery, and our use of reference images with face recognition experiments.

Keywords: Object Recognition; Illumination; Specularity

1. Introduction

An object's appearance varies significantly with viewing conditions. Lighting is a chief source of this variability. Current methods have made substantial progress in accounting for the effects of lighting on objects with Lambertian reflectance. However recognition of objects made of more complex materials, such as shiny or specular objects remains a challenging problem. When the specular effects are minor, existing Lambertian methods treat them as noise, and produce satisfactory results. However many real objects (some examples are shown in Fig. 1) are very specular and their appearance changes dramatically with even a minor change in lighting (Fig. 2).

We focus on modeling specular effects instead of treating them as noise. Such an approach has multiple advantages: (1) More accurate and realistic appearance models will improve the performance of object recognition systems. (2) Specularity appearance depends on surface normals, thus it contains information about the shape of an object. Though local it provides discriminative information that is essential for recognition.

Our contributions are to design:

- A simple model for specular highlights that allows us to use them as a positive source of information about object identity and location.

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Fig. 1. Images of real objects contain effects due to specularities, transparency, and interreflections.

Fig. 2. Strong appearance variation of specular objects. Top – objects that are part Lambertian, part specular under varying illumination. Bottom – transparent specular objects with different backgrounds.

- A model-based identification method that can identify smooth and textured objects that have mixed Lambertian and specular reflection. This method does not require explicit knowledge of Lambertian albedo, which is difficult to measure in shiny objects.
- A novel method for recognition of challenging objects made from specular and transparent materials such as glass, a problem that has not been previously addressed.

We use 3D models to allow us to account for the effects that lighting variation can have on the appearance of specular objects. 3D models can be acquired using stereo or structured light systems, if shiny objects are first covered with powder or paint to reduce their shininess. This however can result in noisy 3D models of shiny objects; consequently an important feature of our approach is its robustness to reasonable levels of noise in the model. We demonstrate this by using models built with commercial structured light systems.

In our current work we assume that the object is convex to prevent self-shadowing and interreflections. The object is illuminated primarily by a distant compact light source. This is true for many indoor settings and outdoors on a sunny day (our next step will be generalizing our method to multiple light sources). The camera and a compact light source are distant from the object. When dealing with glass objects we also assume that glass is thin to avoid interreflections. Currently we do not explicitly model interreflections, cast shadowing, and occlusions. However when these effects are minor, we treat them as noise. Using these assumptions, we derive an algorithm that we then test on real objects, achieving good results even when these assumptions do not precisely hold.

This paper focuses on *verification*, which we consider to be the core component of recognition and localization systems. This is the ability to judge whether a hypothesized position of a 3D object of known shape is consistent with a corresponding portion of a 2D image. Our algorithms