A Multiple-View Geometric Model of Specularities on Non-Uniformly Curved Surfaces

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ABSTRACT

The specularity prediction task in images, given the camera pose and scene geometry, is challenging and ill-posed. A recent approach called JOint LIght-MAterial Specularity (JOLIMAS) addresses this problem using a geometric model under the assumption that specularities have an elliptical shape. We address the most recent version of the model, Dual JOLIMAS, which is limited to planar and convex surfaces where the local surface's curvature under the specularity is constant. We propose a canonical representation of the JOLIMAS model that is independent of the local surface curvature. To reconstruct our model represented by a 3D quadric, we use at least 3 ellipses fitted to specularities and transform their shape to fit a planar surface and simulate a planar mirror which does not distort the image of the reflected object. After reconstruction, we project the 3D quadric into an ellipse and transform it to fit the current local curvature of the surface on a new viewpoint. We assessed this method on both synthetic and real sequences, and compared it to the previous approach Dual JOLIMAS.

CCS CONCEPTS

• **Computing methodologies → Computer vision**; *Mixed / augmented reality*;

KEYWORDS

Specular reflection, local curvature, specularity, prediction.

1 INTRODUCTION

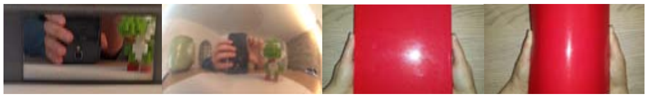

Figure 1: Mirror images of a 3D scene in two cases: a mirror surface (left pairs) and a specular one (right pairs). The 3D objects (a plastic statue and a smartphone for the mirror and light source for the specular surface) are deformed similarly according to the local surface curvature. In a specularity prediction process, these deformations have to be taken into account.

Many AR applications attempt to capture the lighting conditions of the current environment to further understand the scene and increase realism. It is important to simulate specular reflections on virtually added objects since they are essential in the perception of an object material and geometry. In practice, this process is difficult due to the dependency of the visual appearance of specularities to the geometry/material of the surface, the light sources and the camera parameters (pose, aperture, exposition time). As opposed to global illumination or local illumination model reconstruction, the specularity prediction problem can be represented as a multiple-view reconstruction problem [2]. This method reconstructs, from ellipse shaped specularities, a 3D quadric whose perspective projection matches the outline of the specularity for new viewpoints. This approach is limited to planar and convex surfaces and does not allow any local curvature changes on the surface under the specularity. In this paper, we bring two main contributions to the geometric modeling of specularities. Firstly, a canonical representation of the model which reconstructs a 3D quadric from ellipses fitted to the specularities by transforming their shapes according to the local curvature. We warp the specularity's shape appearing on a curved surface to simulate a specularity on a planar surface. This process is done because the reflected image (ellipse) of our 3D quadric on a planar spe

cular surface is undistorted similarly to an image reflected by a planar mirror. Secondly, for a new viewpoint, by perspective projection of the 3D quadric, we obtain ellipses which we then warp back to the surface according to the local curvature. These transformed ellipses fit the specularities.

2 RELATED WORK

We can divide the state of the art in three main categories.
Global illumination. These methods aim to solve the rendering equation which describes the total amount of light emitted from a point on a surface along a particular viewing direction, given a function for the incoming light and a BRDF. They are efficient but rely on a heavy initialization step and on static scenes.
Local illumination models. These include directional and point light sources. However the number of parameters needed to predict the specularity and the limitations of the light source types (especially for extended light source) limit their applicability.
Geometric modeling. Considering the specularity as a 3D object is a recent idea coming from the JOLIMAS model [2]. By reconstructing a fixed 3D quadric from ellipses fitted to specularities on planar or convex surfaces, the specularities are predicted by perspective projection of the 3D quadric on a new viewpoint. This approach is similar to ones using Structure from Motion with mirror images. Considering that a specular surface has a mirror-like behavior, the specularity has its shape affected by the local curvature

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of the surface in the same way a 3D object is deformed by a curved mirror as seen in figure 1. In the recent Dual JOLIMAS [2], the curvature has been included to some extent by computing virtual cameras (symmetric of the real cameras) according to the brightest point of the specularity which is the point of perfect reflection in the reflection law. For cases of non-uniform curvature, [2] fails to predict the specularities since the change in the specularity shape due to the local curvature is not included.

We propose to include the curvature information by using a transformation step of the specularity before reconstructing the 3D quadric in a canonical form independent of the curvature. The inverse transformation is then computed to the ellipse projected by the 3D quadric to predict the specularity on new viewpoints.

3 CANONICAL DUAL JOLIMAS

From Healy *et al.*'s method [1] of Shape from Specularity, some insights are given on a link between local curvature and specularity shape by the equation:

$$\kappa_n = \frac{\mathrm{d}\alpha}{\mathrm{d}s}\bigg|_{\mathbf{P_B}}, \tag{1}$$

with κ_n the local curvature in a given direction, $\mathrm{d}\alpha$ the change in angle of the reflected light source and $\mathrm{d}s$ the arc length on the surface at the brightest point of the specularity $\mathbf{P_B}$. The angle α is defined as $\alpha = \cos^{-1}(\hat{\mathbf{N}} \cdot \hat{\mathbf{H}})$ with $\hat{\mathbf{N}}$ the normal vector and $\hat{\mathbf{H}}$ the half-way vector $\hat{\mathbf{H}} = \frac{\hat{\mathbf{L}}+\hat{\mathbf{V}}}{\|\hat{\mathbf{L}}+\hat{\mathbf{V}}\|}$ between the light ray $\hat{\mathbf{L}}$ and viewing ray $\hat{\mathbf{V}}$.

In practice, equation (1) is hard to compute for non-parametric surfaces such as meshes. The arc length implies to compute geodesic distances which can be computationally expensive and inaccurate for sharp edges or rough surfaces which is often the case in a mesh. To simulate the local curvature computation, we compute limit angles on the outline α^i_{max} of the specularity using the surface normals $\hat{\mathbf{N}}$ and $\hat{\mathbf{H}}$ with $i \in [\![0, n]\!]$. The principle of our approach is to consider that these limit angles stay the same on the outline of the specularity for any curvature for each associated contours.

Canonical representation. To transform the current ellipse associated to a specularity, we compute the brightest point of the specularity $\mathbf{P_B}$ as in [2] and the tangent plane $T_{\mathbf{P_B}}(S)$ at this brightest point. We sample n vectors $v_i \in T_{\mathbf{P_B}}(S)$ starting at $\mathbf{P_B}$ in a range $[0, 2\pi[$. The choice of n depends on the specularity scale and shape. In practice, we fixed a value of 36 for both sequences in figure 3. When we reach the outline of the specularity, we compute a limit angle α^i_{max} using $\hat{\mathbf{H}}$ and $\hat{\mathbf{N}}$ at the point orthogonally projected on the surface S. The outline is detected using a binary mask of the ellipses in the image. We then use the same vectors v_i on $T_{\mathbf{P_B}}(S)$ until it reaches a point with the limit angle α^i_{max}. The warped ellipse is computed by fitting an ellipse with the obtained points. This process is illustrated in figure 2.

Specularity prediction. A similar process is used to predict the specularity outline for a new viewpoint. We compute the brightest point for the new viewpoint and project the 3D quadric which gives the specularity outline on the tangent plane $T_{\mathbf{P_B}}(S)$. We then compute the limit angles on $T_{\mathbf{P_B}}(S)$ and move the specularity contours on S until reaching the limit angle $T_{\mathbf{P_B}}(S)$ with S.

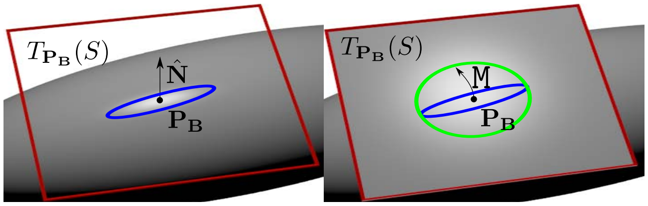

Figure 2: Ellipse transformation from its shape on a curved surface S to the canonical representation onto the tangent plane $T_{\mathbf{P_B}}(S)$ at the brightest point $\mathbf{P_B}$. From the fitted ellipse to the specularity (blue), we apply the transformation $\mathtt{M}$ to obtain the corrected ellipse (green) in the tangent plane $T_{\mathbf{P_B}}(S)$.

4 RESULTS

We show two examples of specularity prediction on a synthetic sequence as well as on a real sequence in figure 3. The JOLIMAS reconstruction is made with 6 frames and the prediction is done on the rest of the sequence. We can see the improvement in terms of position and shape fitting compared to [2].

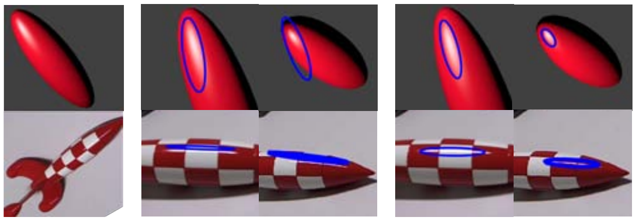
(a) (b) (c)

Figure 3: Specularity predictions on both synthetic and real sequences. (a) presents the object of interest: a synthetic ellipsoid (top) and a real rocket replica (bottom). Image pairs for each sequence showing specularity prediction results (blue ellipse) of [2] (b) and our approach (c). Our approach estimates the shape and position of the specularity substantially more accurately compared to [2].

5 CONCLUSION AND PERSPECTIVES

We presented a canonical representation of the Dual JOLIMAS model to handle specularity prediction for any surface curvature. An immediate application would be to do retexturing as in [2]. We could use the improved JOLIMAS model for inverse rendering as a good initialization for local illuminations models such as Blinn-Phong or Cook-Torrance. A study of the impact of the material (roughness, reflectance) on the specularity outline could greatly improve the genericity of the model.

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