Near-Field Photometric Stereo in Ambient Light

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Extended Abstract

Shape recovery from shading information has recently regained importance due to the improvement towards making the Photometric Stereo technique more reliable in terms of appearance of reflective objects. However, although more advanced models have been lately proposed, 3D scanners based on this technology do not provide reliable reconstructions as long as the considered irradiance equation neglects any additive bias. Depending on the context, such bias assumes different physical meanings. For example, in murky water it is known as *saturated backscattered effect* or for acquisition in pure air medium it is known as *ambient light*. Although the theoretical part covers both cases, this work mostly focuses on the pure air acquisition case. Indeed, we present a new approach based on ratios of differences of images where an exhaustive set of physical features are tackled while dealing with Photometric Stereo acquisition with considerable importance for the ambient light. To the best of our knowledge, this is the first attempt to recover the shape from Photometric Stereo considering simultaneously perspective viewing geometry, non-linear light propagation, both specular and diffuse reflectance plus the additive bias of the ambient light.

Contribution

We propose a new approach for the PS which allows 3D reconstructions that have data with a complete list of physical features that are not negligible when images are taken in outdoor scenes. We extend the model presented in [2] which includes perspective viewing geometry, point light source parameterization and Blinn-Phong specular reflectance [1], by considering non-negligible ambient light as an additional pixel-wise component ($A(x,y)$) to the usual irradiance model.

Theory

We assume the following irradiance equation for the i^{th} light source placed at point (ξ_i, η_i, ζ_i):

$$I_i(x,y) = \rho(x,y) a_i(x,y) \left(\bar{\mathbf{n}}(x,y) \cdot \bar{\mathbf{h}}_i(x,y,z)\right)^{\frac{1}{c(x,y)}} + A(x,y) \quad (1)$$

where ρ is the albedo, c is a material property in $(0,1]$ determining the shiningness and a_i is the light attenuation

We remark that in our irradiance equation, the ambient light $A(x,y)$ is considered as a pixel-wise unknown of the problem. By assuming that it is independent from $\mathbf{l}_i$, it can be cancelled out by considering the ratios of image differences, as described hereafter. With the aim to consider a readable ratio of images, we avoid as much as possible to write the dependencies of the functions from now on and we preliminary manipulate the irradiance equation as follows:

$$(\rho a_i)^c \bar{\mathbf{n}} \cdot \bar{\mathbf{h}}_i = (I_i - A)^c \approx I_i^c - c(I_i - A)^{c-1} A \quad (2)$$

where the approximation comes from truncating the Binomial expansion to the first two terms. This simplifies to (using $\gamma_i = \frac{a_i^c}{I_i^{c-1}}$):

$$I_i - cA \approx \rho^c \gamma_i \frac{\mathbf{n}}{|\mathbf{n}|} \cdot \bar{\mathbf{h}}_i. \quad (3)$$

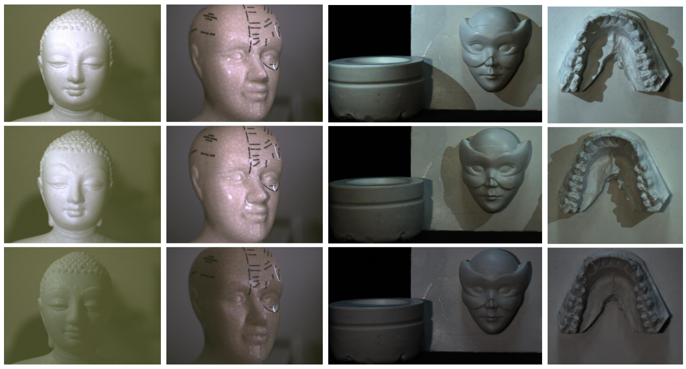
Now, we consider two pairs of irradiance equations, namely the i^{th}, j^{th} and the q^{th}, r^{th} in order to let the ambient light cancel out together with the albedo while taking ratio as follows:

$$\frac{I_i - cA - I_j + cA}{I_q - cA - I_r + cA} \approx \frac{\frac{\rho^c}{|\mathbf{n}|}\left[\gamma_i \mathbf{n} \cdot \bar{\mathbf{h}}_i - \gamma_j \mathbf{n} \cdot \bar{\mathbf{h}}_j\right]}{\frac{\rho^c}{|\mathbf{n}|}\left[\gamma_q \mathbf{n} \cdot \bar{\mathbf{h}}_q - \gamma_r \mathbf{n} \cdot \bar{\mathbf{h}}_r\right]}. \quad (4)$$

By considering the parameterization of the normal from [3], a variational problem for the unknown depth is obtained and solved alike [4].

Experiments

We evaluated the algorithm on various real data sets including marble Buddha statue(1(a)) , a shiny plastic head(1(b)), a plaster Arlequin mask(1(c)) and plaster print of teeth(1(d)).



(a) Buddha (b) Shiny head (c) Mask (d) Teeth

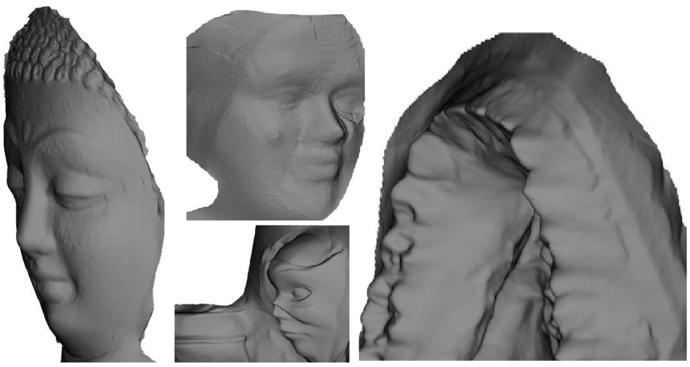


Figure 1: Two samples from each object (rows 1-2), the respective ambient light (row 3) and the corresponding reconstructions.

Conclusion

In this work we tackled the problem of PS under ambient light as well as an extensive set of additional realistic assumption (perspective view geometry, non-linear light propagation, specular reflection). A new approach based on ratios of image differences was presented that is able to remove any additive bias on images. The problem is then expressed as a quasi-linear PDE and is solved through a robust variational optimizer performing L^1 minimization. Experiments on real data verify that our approach achieves good reconstructions under significant ambient light, specular highlights and perspective deformation.

Future work includes porting to a GPU (as most of the calculations are performed on a per-pixel basis) to allow for real time acquisition.

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