Can we Invert a Local Reflectance Model From a Single Specular Highlight with Known Scene Geometry and Camera Pose?

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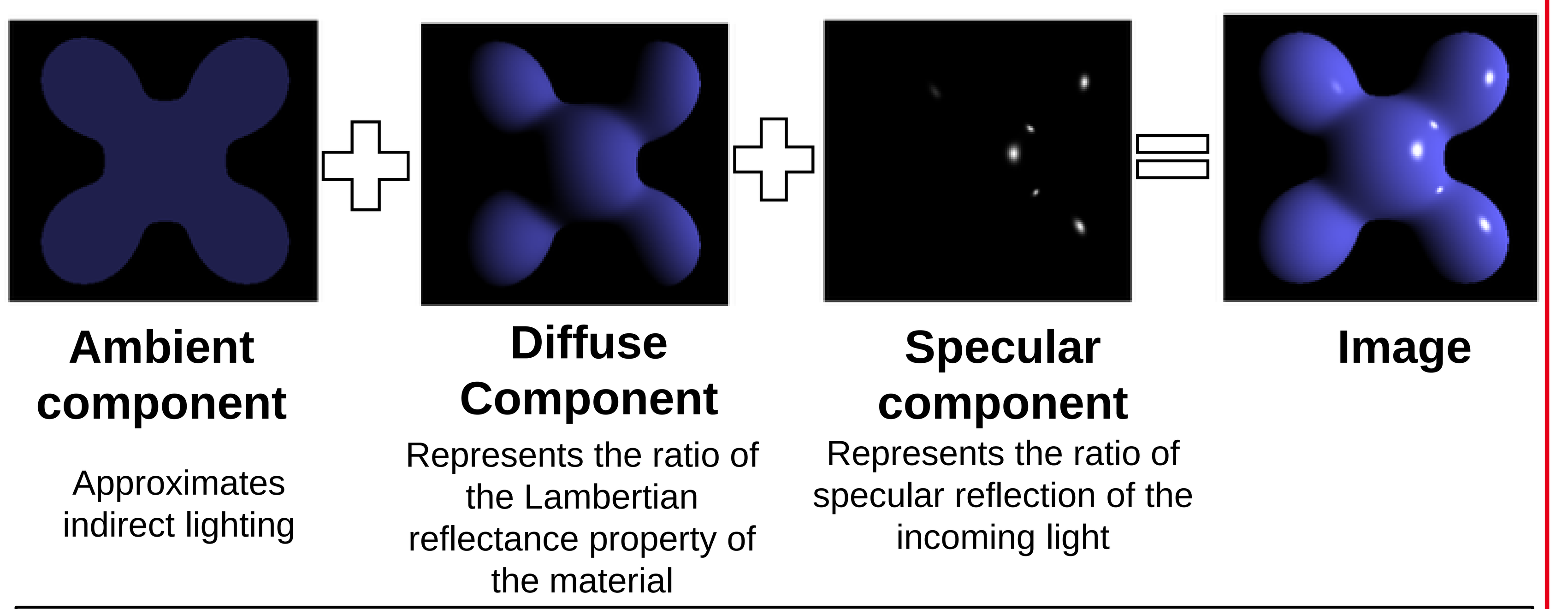
Introduction

- **Context:**
  - Inverting a local reflectance model.
  - Estimating the unknown parameters of the model based on an observation of the scene.
  - Inverting local reflectance model is important in rendering realistic images in Augmented and Diminished Reality.

- **Key observation:** Multiple specularities in the scene can be associated to one or multiple light sources but each single specularity is only associated to a single light source
  ➔ What is the solvability of the local reflectance model inversion when using an image region containing a single specularity?

Local reflectance model:



- **State-of-the-art:** Previous work propose several computational approaches for the local reflectance model inversion but the solvability of the problem depending on the nature of the input data is not investigated.

Method

- **Simplified local reflectance model:**

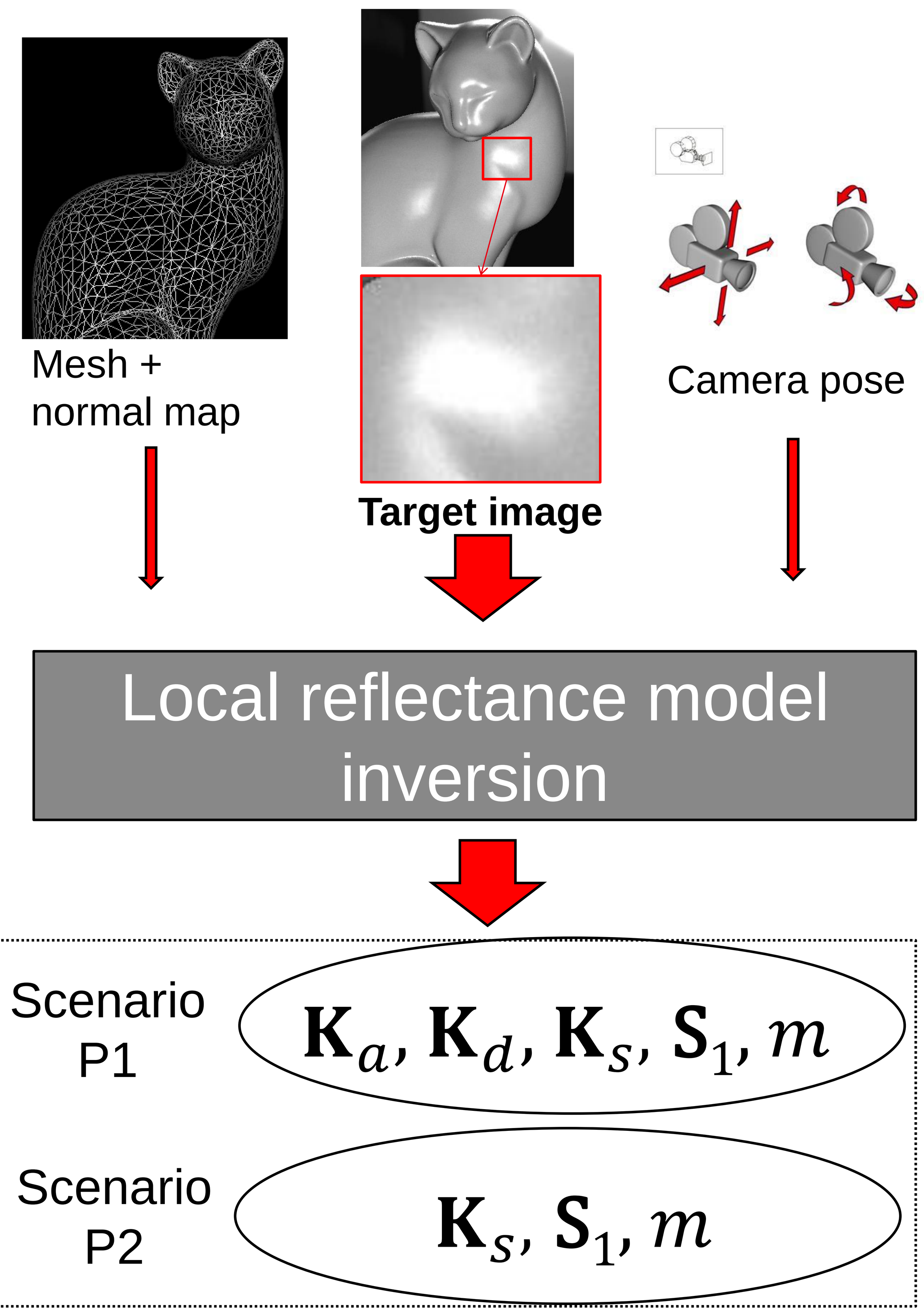
$$\mathbf{I}_e(\mathbf{P},\mathbf{S}_1,\mathbf{K}_a,\mathbf{K}_d,\mathbf{K}_s,m) = \mathbf{K}_a + \mathbf{N}(\mathbf{P})\cdot\mathbf{L}_1(\mathbf{P})\mathbf{K}_d + \mathbf{J}_s(\mathbf{P},\mathbf{K}_s,m,\mathbf{L}_1)$$

  - $\mathbf{I}_e$: intensity in point $\mathbf{P}$
  - $\mathbf{K}_a, \mathbf{K}_d, \mathbf{K}_s$: coefficient of respectively the ambient, diffuse and specular components
  - $\mathbf{L}_1$: direction of the light source $\mathbf{S}_1$
  - $\mathbf{N}(\mathbf{P})$: normal in $\mathbf{P}$
  - $\mathbf{J}_s$: specular component
  - m: surface roughness
- **Input:**
  - Image region containing a single specularity.
  - Camera pose and calibration (obtained by SLAM).
  - A surface mesh and itsnormal map (obtained by a 3D scanner).
- **Output:**
  - Position of the light source and its color.
  - The ambient, diffuse and specular coefficients
  - Surface roughness

- **Optimization:** Non-linear minimization (Levenberg-Marquardt) of the cost:

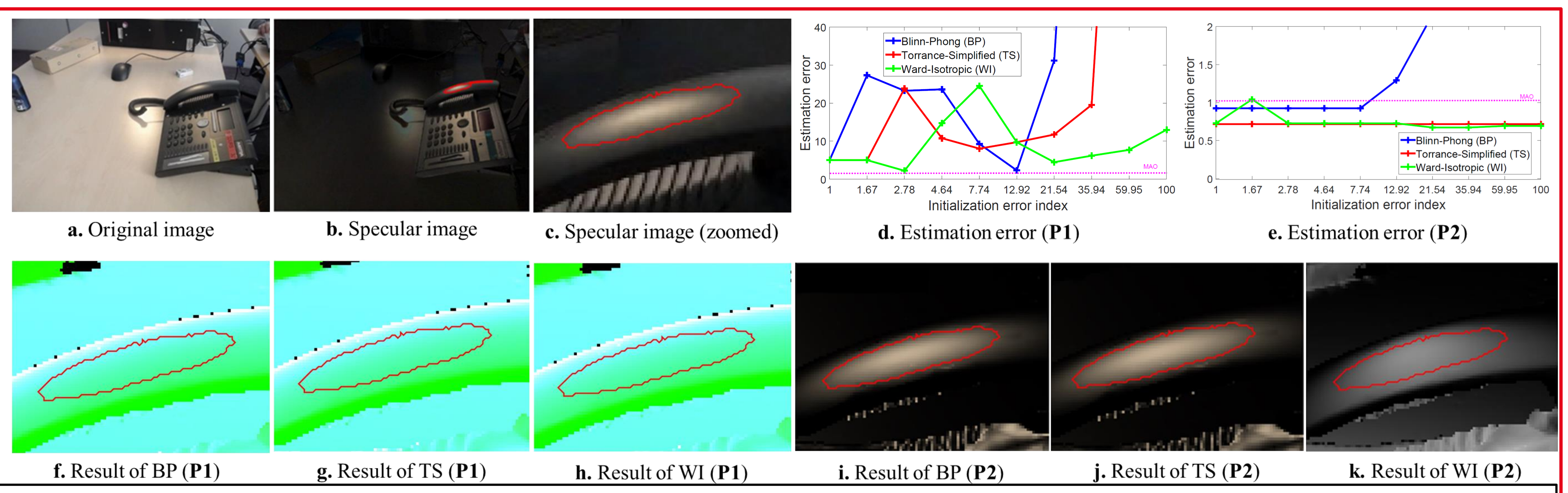
$$C^2_{\text{photo}} = \frac{1}{|\Omega|}\sum_{\mathbf{P}\in\Omega}\left(I^c_r(\mathbf{P}) - I^c_e(\mathbf{P},\mathbf{S}^*_1,K^{c*}_a,K^{c*}_d,K^{c*}_s,m^*)\right)^2$$

- **Scenario P1:**
  - **Input:** No specular-diffuse separation → Original image
  - **Output:** Estimation of $\mathbf{K}_a, \mathbf{K}_d, \mathbf{K}_s, \mathbf{S}_1, m$
- **Scenario P2:**
  - **Input:** Specular-diffuse separation → Specular component of the image
  - **Output:** Estimation of $\mathbf{K}_s, \mathbf{S}_1, m$



Experiments and Results

- **Data:**
- **81 synthetic images:** the specular-diffuse decomposition is obtained by generating the images using only the specular term.
- **4 Real images:** 3D reconstruction by the HandySCAN 3D scanner from Creaform. We use two polarizers, one in front of the camera and another in front of the light source to separate the diffuse and specular components.



a. Original image; b. Specular image; c. Specular image (zoomed); d. Estimation error (P1); e. Estimation error (P2); f. Result of BP (P1); g. Result of TS (P1); h. Result of WI (P1); i. Result of BP (P2); j. Result of TS (P2); k. Result of WI (P2)

- **Estimation error and Criterion of acceptance :** $E_g = \frac{1}{T_S}\|\mathbf{S}_1 - \mathbf{S}_1{}^*\|_2 + \frac{1}{T_K}\|\mathbf{K}_a - \mathbf{K}_a{}^*\|_2 + \frac{1}{T_K}\|\mathbf{K}_d - \mathbf{K}_d{}^*\|_2 + \frac{1}{T_K}\|\mathbf{K}_s - \mathbf{K}_s{}^*\|_2 + \frac{1}{T_m}\|m - m^*\|_2$
- We compute the weights corresponding to the independant numercial error associated to each type of term in the estimation error. This allows us to have an estimation error with terms at a common scale and to define the MAO : Maximum of Acceptance Offset.

Conclusion and Discussion

- Robust estimation of the specular parameters according to a simplified local reflectance model.
- The full reflectance model cannot be estimated directly from the original image.

➔ **Optimal approach:** a specular-diffuse decomposition + single specularity approach.
➔ This approach can be used without the need of any priors on the number of light sources since each specularity is computed separately.