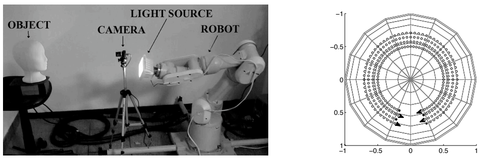
A method for improving consistency in photometric databases

Felipe Hernández-Rodríguez
felipe.hernandez@cinvestav.edu.mx
Mario Castelán
mario.castelan@cinvestav.edu.mx

Robotics and Advanced Manufacturing
Centro de Investigación y de Estudios Avanzados del I.P.N.
Ramos Arizpe, Coah., México.

Building photometric databases usually requires the gathering of images of a still object under different light source directions. During this process, unexpected artifacts such as noise, shadows, inter-reflections and other unwanted effects introduced by the sensibility of the camera may appear along the database, diminishing its consistency as a whole and therefore its suitability for the purposes of photometric analysis. This paper describes a method for improving photometric consistency in image databases acquired under photometric rigs. The main idea of our approach is to build and analyze a luminance matrix storing the reflectance behavior of each pixel under the different light source directions. To this end, we propose to fit sinusoidal functions to the singular vectors of this luminance matrix in order to improve its agreement with Lambertian reflectance. Experiments demonstrate that our method improves the photometric consistency of the database, providing stability for the purposes of photometric analysis of the database and surface shape recovery.

The data acquisition process for the photometric sampling database developed in our lab is described in Figure 1. A database of $k = k_1 \times k_2$ images of the observed object under k different light source directions was constructed, with k_1 azimuth angles and k_2 zenith angles of the light source direction vector.



(a) Experimental setting (b) Illumination patterns

Figure 1: **Data acquisition process scheme for the photometric sampling database.** In (a), the elements of the photometric sampling database acquisition scheme are shown, while (b) presents a projection of the light source positions, for four zenith and sixty-five azimuth angles. Separation between samples was 5°.

The photometric correction is based on the photometric sampling concept introduced by [1] that is related to the image irradiance equation for a Lambertian surface, that establishes the relationship of the surface normals $\mathbf{n}(u,v) \in \mathbb{R}^3$ and the light source direction $\mathbf{l}(u,v) \in \mathbb{R}^3$ to calculate the luminance for each pixel in the image: $i(u,v) = <\mathbf{n}, \mathbf{l}>$.

In accordance with the gathered images during the data acquisition process, the luminances of a pixel will draw a sinusoidal function if the illumination variations imposed around the object are circular, i.e., the different light source direction vectors are circles lying on the surface of a virtual sphere. The sine curve can be decomposed in the three parameters: amplitude ($\mathbf{A}$), phase ($\mathbf{B}$) and shift ($\mathbf{C}$) as $I(\theta) = \mathbf{A}sin(\theta + \mathbf{B}) + \mathbf{C}$, where $I(\theta)$ is the pixel luminance at each θ variation in azimuth.

The photometric correction commences by generating, for each pixel, a matrix $\mathbf{M}_{k_1 \times k_2}$ storing the k pixel intensity values recorded at each (azimuth, zenith) configuration pair. This matrix, which we refer to as the *luminance matrix*, contains the pixel reflectance history along the two main variations of the light source trajectory. For every pixel, the observed reflectance may be decomposed by the principal axis of the luminance matrix. The study of these axis allows identifying regions which best fit a sinusoidal behavior, i.e., close to a Lambertian behavior. The signal is finally corrected once the sine curve parameters have been calculated and the signal replaced with a sine function. We use SVD to decompose the luminance matrix,

$$\mathbf{M} = \mathbf{U}_{k_1 \times r} \Sigma_{r \times r} \mathbf{V}^T_{r \times k_2}, \quad (1)$$

where $r = rank(\mathbf{M})$. The column and row spaces of $\mathbf{M}$ are decomposed into the orthogonal basis $\mathbf{U}$ (left singular vectors) and $\mathbf{V}$ (right singular vectors), respectively. The singular values, contained in the diagonal elements of Σ explain the degree of retained variability in both right and left singular vectors. In our context $\mathbf{U}$ is related to the azimuth variations while $\mathbf{V}$ refers to variations in zenith.

Figure 2 shows a visual sketch of the light source trajectory variations over a surface normal of the mannequin and the human face. Since real images may include noisy variations in reflectance (i.e., bottom row in Figure 2), using least squares for calculating the three sine parameters (amplitude, phase and shift) may lead to poor estimations in the sought parameters, as behaviors departing from Lambert's law may occupy a large region of the singular vector.

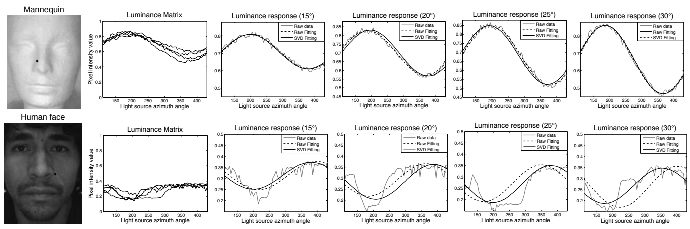


Figure 2: **Photometric correction for two different reflectance examples.** A mannequin and a human face are respectively shown in the top and bottom rows of the figure. For each case, the values in the luminance matrix for a single pixel (marked with a dark dot) are plotted in the second column. The rest of the columns depict sine fitting results on each vector of the luminance matrix.

To overcome this problem, we performed fitting using smaller fixed-sized signal periods starting from each point along the singular vector, then chose the phase, amplitude and shift parameters appearing in the majority of the cases. The fitting procedure is roughly illustrated by Figure 3. Once the sine parameters are estimated over each of the singular vectors, a new luminance matrix $\mathbf{M}' = \mathbf{U}'\Sigma\mathbf{V}'^T$ is generated to improve photometric consistency on the database. The new fitted columns of $\mathbf{U}'$ and $\mathbf{V}'$ contain the sine-fitted singular vectors from the original matrices $\mathbf{U}$ and $\mathbf{V}$ in Eq. 1.

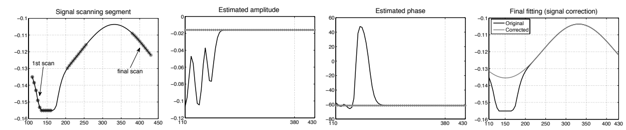


Figure 3: **The sinusoidal fitting procedure.** The figure illustrates the proposed sine fitting procedure, based on scanning sine segments through the singular vectors of the luminance matrix.

To determine the efficiency of the proposed method two different photometric databases was corrected to induce consistency, the photometric sampling database and the Yale B photometric stereo database.

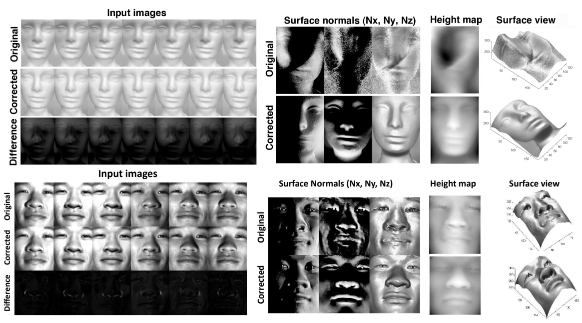


Figure 4: **Experimental results .** The figure presents original and corrected results for the photometric sampling database and the Yale B database.

[1] S.K. Nayar, K. Ikeuchi, and T. Kanade. Shape and reflectance from an image sequence generated using extended source. *Proceedings of IEEE ICRA*, 1:28–35, 1989.