Shape-from-shading driven 3D Morphable Models for Illumination Insensitive Face Recognition

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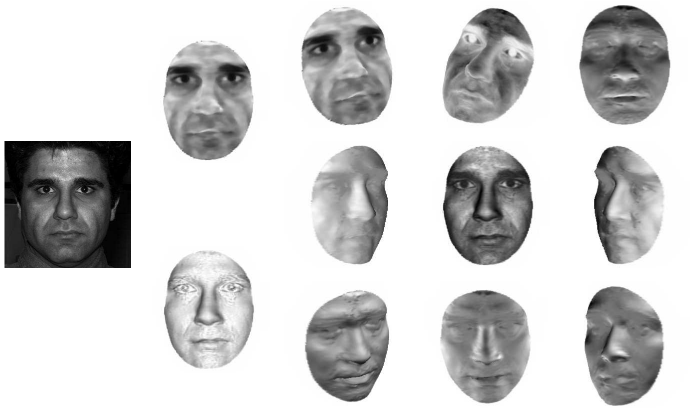

Figure 1: Given an input 2D image under frontal illumination (first column). The figure shows the estimated albedo map and bump map (second column) using the algorithm described in this paper. The last 3 columns show the spherical harmonic subspace derived from the estimated albedo and bump maps.

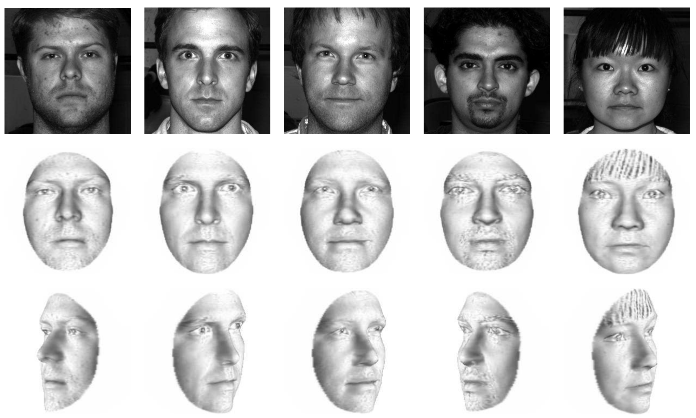

Figure 2: Shows images in a novel pose rendered with the estimated bump maps

In this paper we present a method for face shape and albedo estimation which uses a morphable model in conjunction with non-Lambertian shape-from-shading. We use surface normal and albedo estimates to construct a spherical harmonic basis which can be used generatively to model face appearance variation under arbitrarily complex illumination. This allows us to perform illumination insensitive face recognition given only a single gallery image. In contrast to other similar methods [1, 3], our aim is to retain the robustness and flexibility of using a statistical model, with the fine surface detail and discriminating features conveyed by irradiance cues. Our algorithm uses a morphable model to obtain a 3D face mesh and shape-from-shading to estimate a non-model-based surface normal map (bump map) and diffuse albedo map. The surface normal and diffuse albedo maps not are constrained by a statistical model and are therefore free to capture atypical, discriminating facial features. We present results on the Yale Face Database B and compare our method with state-of-the-art published results.

A morphable model allows us to represent a novel face using a linear combination of an orthonormal basis. Shape-from-shading enables us to modify an estimated set of surface normals such that they strictly satisfy constraints implied by the reflectance properties of the surface. Our implementation estimates morphable model shape parameters using an

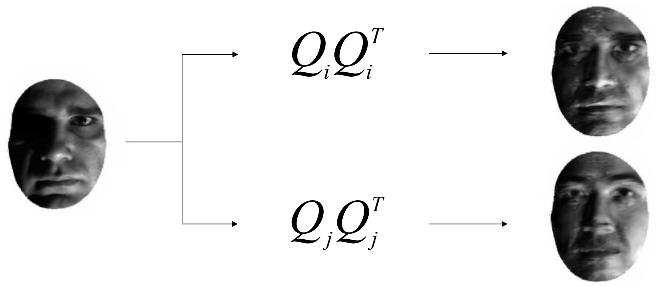

Figure 3: The figure explains the recognition principle. Given an input image (left column) of subject i, captured under lighting angles of $50° - 77°$. The right column shows the images projected onto the i^{th} spherical harmonic subspace (top) and the j^{th} spherical harmonic subspace (bottom). Note j corresponds to to a subject in the database disjoint from i

optimisation based on shape-from-shading constraints.

$$\mathbf{b}^* = \underset{D_M^2(\mathbf{b}) \leq D_{\max}^2}{\arg\min} \sum_p d\left(\mathbf{n}^p(\mathbf{b}), \Theta \mathbf{n}^p(\mathbf{b})\right), \tag{1}$$

where, $\mathbf{n}^p(\mathbf{b})$ is the pth vertex normal obtained from the 3D Morphable model. Θ is the rotation matrix that strictly enforces satisfaction of the image irradiance equation on the pth vertex surface normal. $\mathbf{b}^*$ is the optimum shape parameter vector that minimises the expression. $D_{\max}^2$ is the maximum allowable parameter vector length (as measured by the square of the Mahalanobis distance), which controls the trade off between fitting quality and shape plausibility. Optimum performance occurs when $D_{\max}^2 \approx n$ [2]. The objective function at iteration t of the optimisation is given in Algorithm 1.

Algorithm 1: Objective Function for Fitting a 3D Morphable Model using Shape-from Shading

Input: Light source direction $\mathbf{s}$, Viewer direction $\mathbf{v}$, input image I and shape parameters $\mathbf{b}$

Output: Albedo map ρ_d and bump map $\mathbf{N}$

Constrain the shape parameter vector length (1);
Obtain the p vertex normals $\mathbf{n}^p(\mathbf{b})$ from the shape estimate ;
Project vertices to image plane using orthographic projection to obtain vertex intensity estimates ;
Apply regularisation constraint on the diffuse albedo: $\rho_d^{(t-1)} = f(\rho_d^{(t-1)})$;
Update vertex normals according to sampled image intensities giving bump map $\mathbf{N}^{(t)} = \Theta \mathbf{n}^p(\mathbf{b})$;
Update the albedo map: $\rho_d^{(t)}(\hat{r}_p) = \min\left(1, \frac{I(\hat{r}_p) - \rho_s \cos^{\eta_s}(\theta_h^p(\mathbf{b}))}{\mathbf{n}^p(\mathbf{b}) \cdot \mathbf{s}}\right)$;

Detailed results and comparisons with other methods are provided in the paper. To conclude, we have shown how ideas from shape-from-shading and morphable models can be combined to perform illumination insensitive face recognition from a single gallery image.

[1] V. Blanz and T. Vetter. Face recognition based on fitting a 3D morphable model. *IEEE Trans. Pattern Anal. Mach. Intell.*, 25(9):1063–1074, 2003.

[2] A. Patel and W. A. P. Smith. 3D morphable face models revisited. In *Proc. CVPR*, pages 1327–1334, 2009.

[3] L. Zhang and D. Samaras. Face recognition from a single training image under arbitrary unknown lighting using spherical harmonics. *IEEE Trans. Pattern Anal. Mach. Intell.*, 28(3):351–363, 2006.