Joint Noise Level Estimation from Personal Photo Collections

YiChang Shih1*,2  Vivek Kwatra1  Troy Chinen1  Hui Fang1  Sergey Ioffe1
1Google Research  2MIT CSAIL

*Internship work at Google

Overview
Starting from a face image collection:
• Preprocess: geometrically and photometrically align the images with affine transform and color match

Two-stage optimization:
➢ Estimating \( \{ \rho_{ij} \} \): We take a patch-based method. We first find the patch correspondence between \( I_1 \) and \( I_j \), then find the best estimated relative noise \( \{ \rho_{ij}^* \} \) from the patch pairs.
➢ With \( \{ \rho_{ij}^* \} \), estimate \( \{ \sigma_i \} \) by constraining \( \sigma_i^2 - \sigma_j^2 = \rho_{ij}^* \)

Contributions
▪ Key observation: given two noisy images, the noise levels are correlated if they share the same underlying image content, since \( \sigma_i^2 - \sigma_j^2 = \text{var}[I_{n1}] - \text{var}[I_{n2}] \)
• We formulate the estimation as maximizing the joint probability distribution between all images’ noise levels
• The joint distribution is conditioned on the pair-wise relative noise levels \( \{ \rho_{ij} \} \). We use a two-stage optimization that first estimates \( \{ \rho_{ij} \} \), then \( \{ \sigma_i \} \)

Pair-wise Relative Noise \( \{ \rho_{ij} \} \) Estimation
▪ The two faces are not perfectly aligned
▪ We break down the image into patches, and estimate the patch-wise relative noise levels \( \zeta_{pq} \) by \( \zeta_{pq} = \text{var}[p_{1p}] - \text{var}[p_{2q}] \)
▪ Compute pair-wise relative noise by aggregating \( \zeta_{pq} \): \( \rho_{ij}^2 = \frac{\sum_{p,q} c_{pq} \zeta_{pq}}{\sum_{p,q} c_{pq}} \)
▪ \( c_{pq} = \exp(-\kappa_{pq} \|p_{1p} - p_{2q}\|^2) \), confidence that \( (p, q) \) is a true correspondence
▪ For computational efficiency, we selected the best 5 \( q \) s for each \( p \)

Absolute Noise Level Estimation with Global Optimization
▪ We estimate \( \{ \sigma_i \} \) conditioning on \( \{ \rho_{ij}^* \} \)
▪ \( \{ \sigma_i^2 \} = \text{argmin} \sum_{i \neq j} w_{ij} \| \sigma_i^2 - \sigma_j^2 - \rho_{ij}^* \|^2 \)
▪ Similarity between two faces \( w_{ij} \):
▪ Solving a linear system
▪ The system is under-determined, up to adding a constant number.
  - option 1: assign some images to be zero noise
  - option 2: assuming the collection contains clean images, assign the least noisy one to be zero. We use this one for evaluations

Results
• We show one example below with estimated noise levels and denoised result using BM3D + our method for noise parameter

User Study
• Based on BM3D denoised result, decide which one is preferable
• Ran on 71 images, each is evaluated by 3 users

Selected References

Acknowledgements
We thank MIT Graphics and Vision group for helpful discussion. We would like to thank the volunteers who participated in the user study.