be taken at home with relatively inexpensive equipment and the algorithms involved are fairly common and implemented by multiple open source libraries.

When running this analysis on static images, we found that the hue angles of the two components were overall very stable for repeated samples of the same person, and were sensitive to changes in the color vectors brought on by discoloration of the skin due to disease.

The quantities obtained by taking the pseudoinverse of the two components were moderately stable, but error was introduced into the measurement by the presence of reflections. Various methods of compensating for the reflections gave mixed results for improving the stability of the quantities.

For analysis on images taken by a web-camera, hue angles continued to exhibit the same stability. This is expected behavior. Quantities, however, varied across subjects and across days for the same subjects. This may be an effect of the image acquisition process as no control accounted for lighting, pose in relation to the camera, nor for the physical condition of the subjects. It is interesting to note that the ratios did change in the same direction, however insignificantly, between baseline and flushed images. This matches with the result in the static image.

These results indicate that it is possible to detect changes in hue and in the ratio of the quantities of each component. While experimental data may not support the stabilization of the two pigment components, the methodology is fundamentally sound. As such, we have shown that *independent component analysis* is a viable method for decomposing images of skin into a usable data set for monitoring skin tone and, ultimately, the health of a given subject.

Further Work

Automation

For use in a live scenario within a home or apartment, image capture and processing will need to be automated. To automate image capture, facial recognition will be introduced so that trends for individuals may be recorded. For processing, a statistical distribution could be associated with the past and present hues of a user's face, and deviations could be calculated automatically. Machine learning algorithms have been shown to be effective in estimating the progression of the underlying disease based on how jaundiced the skin color was, and their use could be extended to cover not only changes in the color component, but also the quantities of each component. Trends over time could be observed, and estimations could be made about which deviations were significant, and which reflected everyday variability.

Variance in lighting

Future work also will need to address the normalization of the two color vectors to take into account the uneven distribution of the reflection (white) color vector between the two independent components. One method to be explored is systematically inducing variation in the distribution of the lighting between the three images. LED lighting can be easily controlled programmatically and synchronized with the image capture process.

Other areas of the light spectrum

Finally, infrared photography may provide a third dimension of information which could be integrated with the previous results. The amount of reflectivity, which increased error for our measurements, could also be analyzed for details about how oily the user's skin is or the presence of perspiration present.

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References

Chan, L.-S.; Cheung, G. T. Y.; Lauder, I. J.; and Kumana, C. R. 2004. Screening for fever by remote-sensing infrared thermographic camera. *Journal of travel medicine* 11(5):273–9.

Comon, P. 1994. Independent component analysis, A new concept? *Signal Processing* 36(3):287–314.

Hammond, P.; Hutton, T.; Maheswaran, S.; and Modgil, S. 2003. Computational Models of Oral and Craniofacial Development, Growth, and Repair. *Advances in Dental Research* 17(1):61–64.

Hyvärinen, a., and Oja, E. 2000. Independent component analysis: algorithms and applications. *Neural networks : the official journal of the International Neural Network Society* 13(4-5):411–30.

Liu, M., and Guo, Z. 2007. Hepatitis diagnosis using facial color image. *Medical Biometrics* 160–167.

Preucil, F. 1953. Color hue and ink transfer. *Their Relation to*.

Tsumura, N.; Haneishi, H.; and Miyake, Y. 1999. Independent-component analysis of skin color image. *Journal of the Optical Society of America. A, Optics, image science, and vision* 16(9):2169–76.

Tsumura, N.; Ojima, N.; and Sato, K. 2003. Image-based skin color and texture analysis/synthesis by extracting hemoglobin and melanin information in the skin. *ACM Transactions on ...* 770–779.

Viola, P., and Jones, M. 2004. Robust real-time face detection. *International journal of computer vision* 57(2):137–154.

Zhu, Z. 2004. Real time and non-intrusive driver fatigue monitoring. *Proceedings. The 7th International IEEE Conference on Intelligent Transportation Systems (IEEE Cat. No.04TH8749)* 657–662.