Satellite Image Contrast Enhancement Using Discrete Wavelet Transform and Singular Value Decomposition

Hasan Demirel, Cagri Ozcinar, and Gholamreza Anbarjafari

***Abstract*—In this letter, a new satellite image contrast enhancement technique based on the discrete wavelet transform (DWT) and singular value decomposition has been proposed. The technique decomposes the input image into the four frequency subbands by using DWT and estimates the singular value matrix of the low–low subband image, and, then, it reconstructs the enhanced image by applying inverse DWT. The technique is compared with conventional image equalization techniques such as standard general histogram equalization and local histogram equalization, as well as state-of-the-art techniques such as brightness preserving dynamic histogram equalization and singular value equalization. The experimental results show the superiority of the proposed method over conventional and state-of-the-art techniques.**

***Index Terms*—Discrete wavelet transform, image equalization, satellite image contrast enhancement.**

I. Introduction

SATELLITE images are used in many applications such as geosciences studies, astronomy, and geographical information systems. One of the most important quality factors in satellite images comes from its contrast. Contrast enhancement is frequently referred to as one of the most important issues in image processing. Contrast is created by the difference in luminance reflected from two adjacent surfaces. In visual perception, contrast is determined by the difference in the color and brightness of an object with other objects. Our visual system is more sensitive to contrast than absolute luminance; therefore, we can perceive the world similarly regardless of the considerable changes in illumination conditions.

If the contrast of an image is highly concentrated on a specific range, the information may be lost in those areas which are excessively and uniformly concentrated. The problem is to optimize the contrast of an image in order to represent all the information in the input image. There have been several techniques to overcome this issue [1]–[4], such as general histogram equalization (GHE) and local histogram equalization (LHE). In this letter, we are comparing our results with two state-of-the-art techniques, namely, brightness preserving dynamic histogram equalization (BPDHE) [5] and our previously introduced singular value equalization (SVE) [6].

In many image processing applications, the GHE technique is one of the simplest and most effective primitives for contrast enhancement [7], which attempts to produce an output histogram that is uniform [8]. One of the disadvantages of GHE is that the information laid on the histogram or probability distribution function (PDF) of the image will be lost. Demirel and Anbarjafari [9] showed that the PDF of face images can be used for face recognition; hence, preserving the shape of the PDF of an image is of vital importance. Techniques such as BPDHE or SVE are preserving the general pattern of the PDF of an image. BPDHE is obtained from dynamic histogram specification [10] which generates the specified histogram dynamically from the input image.

The singular-value-based image equalization (SVE) technique [6], [9] is based on equalizing the singular value matrix obtained by singular value decomposition (SVD). SVD of an image, which can be interpreted as a matrix, is written as follows:

$$A = U_A \Sigma_A V_A^T \tag{1}$$

where U_A and V_A are orthogonal square matrices known as hanger and aligner, respectively, and the Σ_A matrix contains the sorted singular values on its main diagonal. The idea of using SVD for image equalization comes from this fact that Σ_A contains the intensity information of a given image [11].

In our earlier work [6], [9], SVD was used to deal with an illumination problem. The method uses the ratio of the largest singular value of the generated normalized matrix, with mean zero and variance of one, over a normalized image which can be calculated according to

$$\xi = \frac{\max\left(\Sigma_{N(\mu=0,\mathrm{var}=1)}\right)}{\max(\Sigma_A)} \tag{2}$$

where $\Sigma_{N(\mu=0,\mathrm{var}=1)}$ is the singular value matrix of the synthetic intensity matrix. This coefficient can be used to regenerate an equalized image using

$$\Xi_{\mathrm{equalized}_A} = U_A(\xi\Sigma_A)V_A^T \tag{3}$$

Manuscript received July 27, 2009; revised September 18, 2009. Date of publication November 17, 2009; date of current version April 14, 2010.

H. Demirel is with the Department of Electrical and Electronic Engineering, Eastern Mediterranean University, Gazimağusa, via Mersin 10, Turkey (e-mail: hasan.demirel@emu.edu.tr).

C. Ozcinar is with the Department of Electronic Engineering, University of Surrey, GU2 7XH Surrey, U.K. and also with the Department of Electrical and Electronic Engineering, Eastern Mediterranean University, Gazimaðusa, via Mersin 10, Turkey (e-mail: co00048@surrey.ac.uk).

G. Anbarjafari is with the Department of Information System Engineering, Cyprus International University, Lefkoşa, via Mersin 10, Turkey (e-mail: sjafari@ciu.edu.tr).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/LGRS.2009.2034873

where $\Xi_{\text{equalized}_A}$ is representing the equalized image A. This task is eliminating the illumination problem.

Nowadays, wavelets have been used quite frequently in image processing. They have been used for feature extraction [12], denoising [13], compression [14], face recognition [15], and satellite image super-resolution [16]. The decomposition of images into different frequency ranges permits the isolation of the frequency components introduced by "intrinsic deformations" or "extrinsic factors" into certain subbands [17]. This process results in isolating small changes in an image mainly in high-frequency subband images. Hence, discrete wavelet transform (DWT) is a suitable tool to be used for designing a pose-invariant face recognition system. The 2-D wavelet decomposition of an image is performed by applying 1-D DWT along the rows of the image first, and, then, the results are decomposed along the columns. This operation results in four decomposed subband images referred to as low–low (LL), low–high (LH), high–low (HL), and high–high (HH). The frequency components of those subband images cover the frequency components of the original image.

In this letter, we have proposed a new method for satellite image equalization which is an extension of SVE, and it is based on the SVD of an LL subband image obtained by DWT. DWT is used to separate the input low-contrast satellite image into different frequency subbands, where the LL subband concentrates the illumination information. That is why only the LL subband goes through the SVE process, which preserves the high-frequency components (i.e., edges). Hence, after inverse DWT (IDWT), the resultant image will be sharper with good contrast. In this letter, the proposed method has been compared with the conventional GHE technique as well as LHE and some state-of-the-art techniques such as BPDHE and SVE. The results indicate the superiority of the proposed method over the aforementioned methods.

II. Proposed Image Contrast Enhancement

There are two significant parts of the proposed method. The first one is the use of SVD. As it was mentioned, the singular value matrix obtained by SVD contains the illumination information. Therefore, changing the singular values will directly affect the illumination of the image; hence, the other information in the image will not be changed. The second important aspect of this work is the application of DWT. As it was mentioned in Section I, the illumination information is embedded in the LL subband. The edges are concentrated in the other subbands (i.e., LH, HL, and HH). Hence, separating the high-frequency subbands and applying the illumination enhancement in the LL subband only will protect the edge information from possible degradation. After reconstructing the final image by using IDWT, the resultant image will not only be enhanced with respect to illumination but also will be sharper.

The general procedure of the proposed technique is as follows. The input image A is first processed by using GHE to generate $\hat{A}$. Then, both of these images are transformed by DWT into four subband images. The correction coefficient for

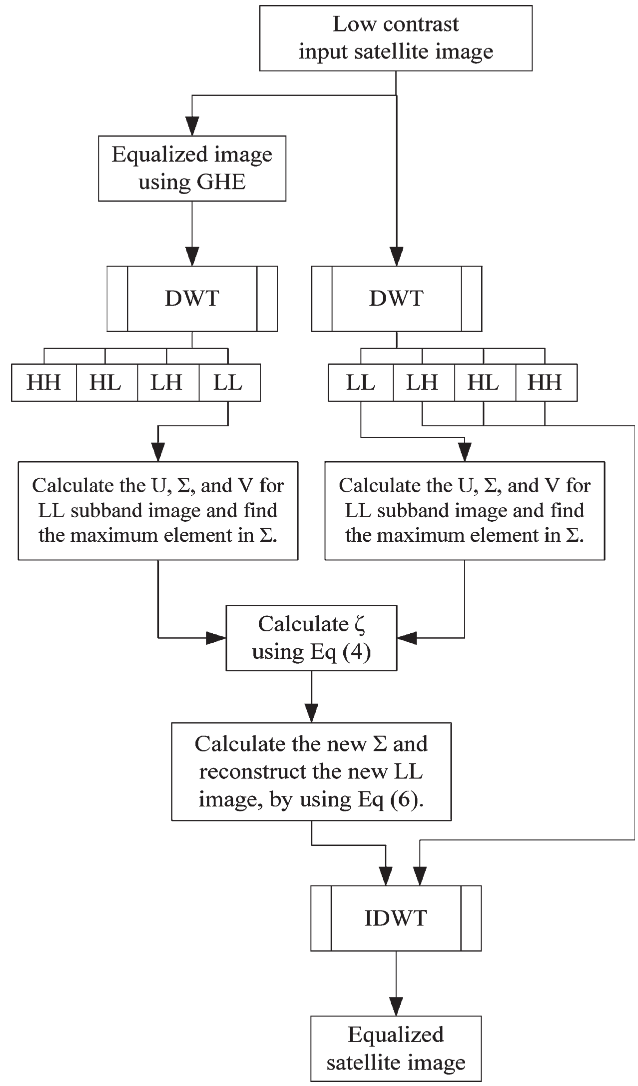

Fig. 1. Detailed steps of the proposed equalization technique.

the singular value matrix is calculated by using the following equation:

$$\zeta = \frac{\max\left(\Sigma_{LL_{\hat{A}}}\right)}{\max\left(\Sigma_{LL_A}\right)} \tag{4}$$

where Σ_{LL_A} is the LL singular value matrix of the input image and $\Sigma_{LL_{\hat{A}}}$ is the LL singular value matrix of the output of the GHE. The new LL image is composed by

$$\begin{aligned}\overline{\Sigma}_{LL_A} &= \zeta \Sigma_{LL_A} \\ \overline{LL_A} &= U_{LL_A} \overline{\Sigma}_{LL_A} V_{LL_A}.\end{aligned} \tag{5}$$

Now, the $\overline{LL}_A$, LH_A, HL_A, and HH_A subband images of the original image are recombined by applying IDWT to generate the resultant equalized image $\overline{A}$

$$\overline{A} = \mathrm{IDWT}(\overline{LL}_A, LH_A, HL_A, HH_A). \tag{6}$$

In this letter, we have used the db.9/7 wavelet function as the mother function of the DWT. In the following section, the experimental results and the comparison of the aforementioned conventional and state-of-the-art techniques are discussed.

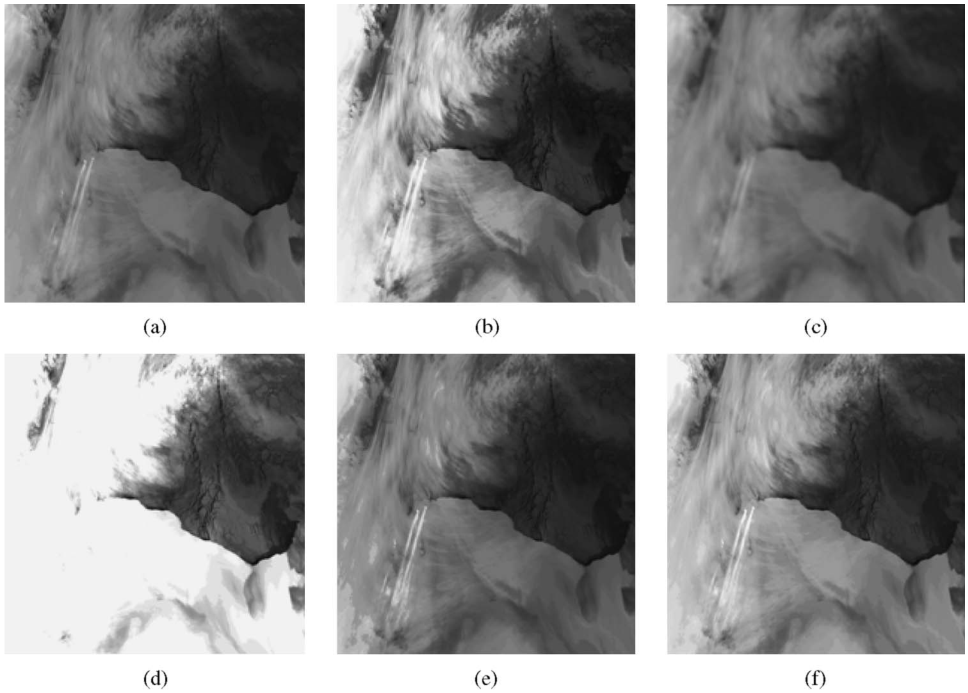

Fig. 2. (a) Original low-contrast images from the Antarctic Meteorological Research Centre. Equalized image by using (b) GHE, (c) LHE, (d) SVE, (e) BPDHE, and (f) the proposed technique.

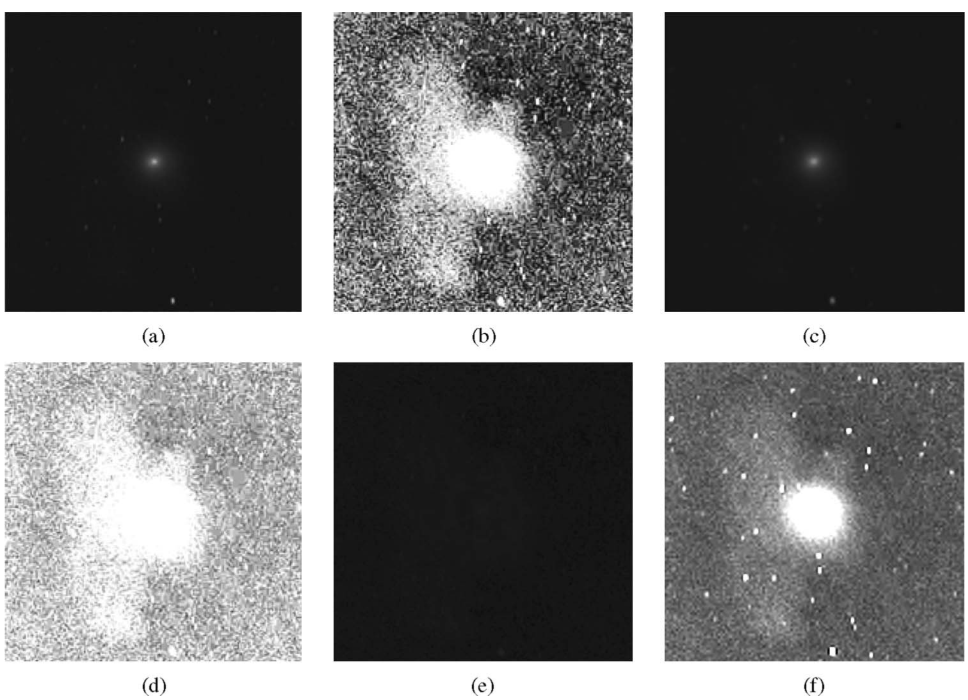

Fig. 3. (a) Original low-contrast image from Satellite Imaging Corporation. Equalized image by using (b) GHE, (c) LHE, (d) SVE, (e) BPDHE, and (f) the proposed technique.

Fig. 1 shows all the steps of the proposed image equalization technique.

III. Experimental Results and Discussions

Figs. 2(a), 3(a), and 4(a) show the low-contrast images taken from several aerospace and geosciences resources mentioned in the acknowledgment section. These images have been equalized by using GHE [Figs. 2(b), 3(b), and 4(b)], SVE [Figs. 2(c), 3(c), and 4(c)], BPDHE [Figs. 2(d), 3(d), and 4(d)], LHE [Figs. 2(e), 3(e), and 4(e)], and the proposed equalization technique [Figs. 2(f), 3(f), and 4(f)]. The quality of the visual results indicates that the proposed equalization technique is sharper and brighter than the one achieved by BPDHE, SVE, GHE, and LHE. The resultant image generated by BPDHE is comparable with the image achieved by the proposed method. Experiments

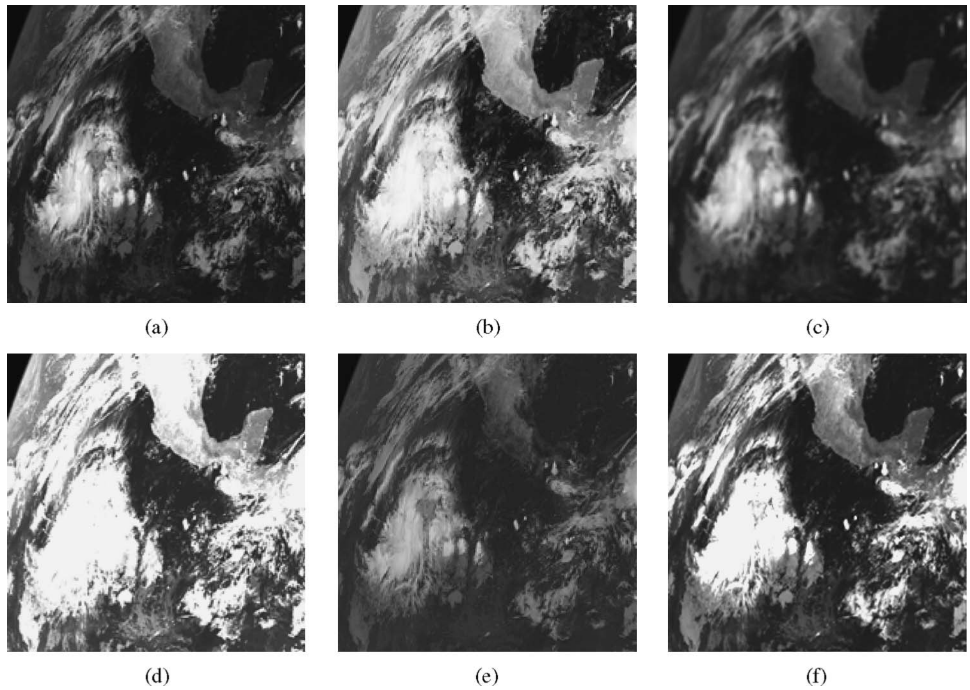

Fig. 4. (a) Original low-contrast images from the Antarctic Meteorological Research Centre. Equalized image by using (b) GHE, (c) LHE, (d) SVE, (e) BPDHE, and (f) the proposed technique.

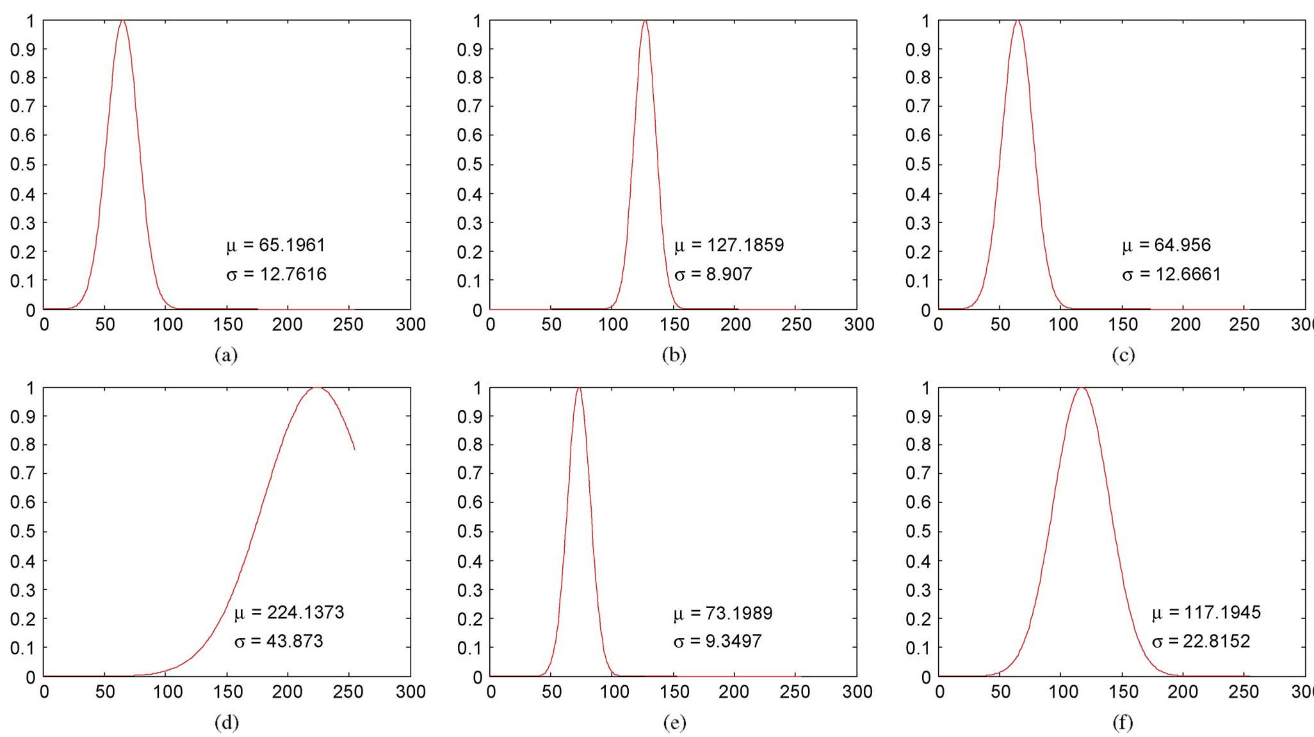

Fig. 5. Estimated Gaussian distribution for Fig. 4(a)–(e), respectively.

have been performed on over 100 randomly selected images from various sources which confirmed the qualitative results.

In order to support the qualitative conclusions on the superiority of the proposed method, a quantitative analysis is required. However, when the ground truth that represents the original image is missing, a quantitative error analysis on the enhanced image is not possible. In an attempt to estimate the quantitative performance, we propose to analyze the estimated Gaussian distribution of the enhanced images which are modeled by using the calculated mean (μ) and standard deviation (σ) of the output images. Any pixel of an image can be considered as a random variable with a distribution function. According to the central limit theorem, the sum of a sequence of random variables tends to have a Gaussian distribution [18]. In line of this assumption, Fig. 5 shows the Gaussian distributions of the images used in Fig. 4. It is clear from these distributions that the estimated Gaussian functions of the GHE and the proposed method have means which are close to the ideal mean for the gray level range [Fig. 5(b) and (f) with $\mu = 127.19$ and 117.19, respectively]. However, the estimated Gaussian distribution of the proposed method covers a wider gray level range [Fig. 5(f)]; that is why it has better illumination. Thus, this analysis supports the qualitative observation that the proposed method overperforms the conventional and state-of-the-art techniques.

IV. Conclusion

In this letter, a new satellite image contrast enhancement technique based on DWT and SVD was proposed. The proposed technique decomposed the input image into the DWT subbands, and, after updating the singular value matrix of the LL subband, it reconstructed the image by using IDWT. The technique was compared with the GHE, LHE, BPDHE, and SVE techniques. The visual results on the final image quality show the superiority of the proposed method over the conventional and the state-of-the-art techniques. The authors would like to thank H. Ibrahim and N. S. P. Kong from the School of Electrical and Electronic Engineering, University Sains Malaysia, for providing the equalized output images of the BPDHE technique and also Satellite Imaging Corporation, Automatic Weather Stations Project, and Antarctic Meteorological Research Centre for providing the satellite images for research purposes.

References

[1] W. G. Shadeed, D. I. Abu-Al-Nadi, and M. J. Mismar, "Road traffic sign detection in color images," in *Proc. 10th IEEE Int. Conf. Electron., Circuits Syst.*, Dec. 2003, vol. 2, pp. 890–893.

[2] R. C. Gonzalez and R. E. Woods, *Digital Image Processing*. Englewood Cliffs, NJ: Prentice-Hall, 2007.

[3] T. K. Kim, J. K. Paik, and B. S. Kang, "Contrast enhancement system using spatially adaptive histogram equalization with temporal filtering," *IEEE Trans. Consum. Electron.*, vol. 44, no. 1, pp. 82–87, Feb. 1998.

[4] S. Chitwong, T. Boonmee, and F. Cheevasuvit, "Enhancement of color image obtained from PCA-FCM technique using local area histogram equalization," *Proc. SPIE*, vol. 4787, pp. 98–106, 2002.

[5] H. Ibrahim and N. S. P. Kong, "Brightness preserving dynamic histogram equalization for image contrast enhancement," *IEEE Trans. Consum. Electron.*, vol. 53, no. 4, pp. 1752–1758, Nov. 2007.

[6] H. Demirel, G. Anbarjafari, and M. N. S. Jahromi, "Image equalization based on singular value decomposition," in *Proc. 23rd IEEE Int. Symp. Comput. Inf. Sci.*, Istanbul, Turkey, Oct. 2008, pp. 1–5.

[7] T. Kim and H. S. Yang, "A multidimensional histogram equalization by fitting an isotropic Gaussian mixture to a uniform distribution," in *Proc. IEEE Int. Conf. Image Process.*, Oct. 8–11, 2006, pp. 2865–2868.

[8] A. R. Weeks, L. J. Sartor, and H. R. Myler, "Histogram specification of 24-bit color images in the color difference (C-Y) color space," *Proc. SPIE*, vol. 3646, pp. 319–329, 1999.

[9] H. Demirel and G. Anbarjafari, "Pose invariant face recognition using probability distribution function in different color channels," *IEEE Signal Process. Lett.*, vol. 15, pp. 537–540, May 2008.

[10] C. C. Sun, S. J. Ruan, M. C. Shie, and T. W. Pai, "Dynamic contrast enhancement based on histogram specification," *IEEE Trans. Consum. Electron.*, vol. 51, no. 4, pp. 1300–1305, Nov. 2005.

[11] Y. Tian, T. Tan, Y. Wang, and Y. Fang, "Do singular values contain adequate information for face recognition?" *Pattern Recognit.*, vol. 36, no. 3, pp. 649–655, Mar. 2003.

[12] J. W. Wang and W. Y. Chen, "Eye detection based on head contour geometry and wavelet subband projection," *Opt. Eng.*, vol. 45, no. 5, pp. 057001-1–057001-12, May 2006.

[13] J. L. Starck, E. J. Candes, and D. L. Donoho, "The curvelet transform for image denoising," *IEEE Trans. Image Process.*, vol. 11, no. 6, pp. 670–684, Jun. 2002.

[14] M. Lamard, W. Daccache, G. Cazuguel, C. Roux, and B. Cochener, "Use of a JPEG-2000 wavelet compression scheme for content-based ophthalmologic retinal images retrieval," in *Proc. 27th IEEE EMBS*, 2005, pp. 4010–4013.

[15] C. C. Liu, D. Q. Dai, and H. Yan, "Local discriminant wavelet packet coordinates for face recognition," *J. Mach. Learn. Res.*, vol. 8, pp. 1165–1195, 2007.

[16] H. Demirel and G. Anbarjafari, "Satellite image super resolution using complex wavelet transform," *IEEE Geosci. Remote Sens. Lett.*, vol. 7, no. 1, Jan. 2010, to be published. [Online]. Available: http://ieeexplore.ieee.org/xpl/freepre_abs_all.jsp?isnumber=4357975&arnumber=5235113

[17] D. Q. Dai and H. Yan, "Wavelet and face recognition," in *Face Recognition*, K. Delac and M. Grgic, Eds. Vienna, Austria: I-Tech Edu. Publ., 2007, ch. 4, pp. 59–74.

[18] K. S. Shanmugan and A. M. Breipohl, *Random Signals: Detection, Estimation and Data Analysis*. Hoboken, NJ: Wiley, 1988.