Optical Engineering

SPIEDigitalLibrary.org/oe

Contrast enhancement and noise elimination using singular value decomposition for stereo imaging

Changwoo Ha
Gwanggil Jeon
Jechang Jeong

SPIE

Contrast enhancement and noise elimination using singular value decomposition for stereo imaging

Changwoo Ha,[a] Gwanggil Jeon,[b] and Jechang Jeong[a]
[a]Hanyang University, Department of Electronics and Computer Engineering, 222 Wangsimni-ro, Seongdong-gu, Seoul 133-791, Korea
[b]University of Incheon, Department of Embedded Systems Engineering, 12-1 Songdo-dong, Yeonsu-gu, Incheon 406-772, Korea
E-mail: jjeong@hanyang.ac.kr

Abstract. A new stereoscopic satellite image enhancement method based on singular value decomposition (SVD) is presented. The proposed stereoscopic image enhancement technique consists of four steps; SVD based on image analysis, image enhancement, noise reduction, and tone consistency. The goal of this work is to enhance low-contrast stereo satellite images with noise elimination, and obtain identical luminance levels from slightly different luminance in stereo images. Experimental results show the proposed method improves contrast performance while maintaining the luminance continuity. It also exhibits less noise than conventional methods. [DOI: 10.1117/1.OE.51.9.090504]

Subject terms: stereo satellite image; singular value decomposition; contrast enhancement; midway image equalization.

Paper 121040L received Jul. 18, 2012; revised manuscript received Aug. 19, 2012; accepted for publication Aug. 27, 2012; published online Sep. 18, 2012.

1 Introduction

Stereoscopic satellite image techniques have garnered much attention since innovative observation satellites were put into use. The view made possible by a stereo satellite has greatly improved our ability to analyze the phenomenon of severe space shift.[1] However, stereo satellite images frequently suffer from low contrast and inconsistent illumination problems because existing satellite images are obtained from several space weather satellites or other observational devices. Additionally, satellites often do not have the latest optics because their launches predate the development of such equipment, and they remain in orbit for an average of ten years. Consequently, post-processing techniques, such as image enhancement, are the last options for improving the perceptual quality of the content. A pair of images is used to maintain the tone consistency between each image, while enables a better three-dimensional effect for interpretability. They are generally used in the gray level and transform domains.

In this research, we specifically focus on the singular value decomposition (SVD) transform. The SVD is an important factorization technique in linear algebra for rectangular matrices and has many useful applications in signal processing and statistics; yet, two prominent issues exist when processing images based on SVD. The first important issue is image denoising.[2–5] The basic concept underlying noise reduction is the preservation of important small singular values and the removal of unimportant small singular value including noisy components. The second issue is image contrast enhancement.[6–8] The singular value matrix describes the illumination information of the image, and can be changed to reasonable values for contrast enhancement. SVD-based applications such as noise reduction and contrast enhancement have been developed independently; however, such applications to stereo images have not yet been proposed.

In this letter, we propose a new approach for adjustable stereoscopic satellite image enhancement based on SVD that is robust to noise. The rest of this letter is organized as follows: The SVD algorithm is described briefly in Sec. 2. In Sec. 3, we present the proposed algorithm. Experimental results are provided in Sec. 4. Finally, conclusions are given in Sec. 5.

2 Singular Value Decomposition

The SVD of a rectangular matrix $\mathbf{A}$ has many important properties and useful applications. Without loss of generality, for every $m \times n$ $(m \geq n)$ matrix $\mathbf{A}$, the SVD can be written as

$$A = U\Sigma V^T = \sum_{i=0}^{n} \vec{u}_i \alpha_i \vec{v}_i^T, \tag{1}$$

where $U = (\vec{u}_1, \vec{u}_2, \ldots, \vec{u}_m) \in R^{m\times n}$ and $V = (\vec{v}_1, \vec{v}_2, \ldots, \vec{v}_n) \in R^{n\times n}$ are two-column orthogonal matrices, and V^T denotes the transpose of V. Moreover, Σ is a diagonal matrix with elements α_i, $i = 1, 2, \ldots, n$. The diagonal elements can be arranged in a nonincreasing order and are called the singular values of A:

$$\Sigma = \begin{bmatrix} \alpha_1 & & \\ & \ddots & \\ & & \alpha_n \end{bmatrix} = \mathrm{diag}\{\alpha_1, \alpha_2, \ldots, \alpha_n\}. \tag{2}$$

The Σ matrix represents the intensity information of a given image. Since $\alpha_1 \geq \alpha_2 \geq \ldots \geq \alpha_n$, the first terms of this series will have the largest influence on the total sum, with the last few terms representing insignificant noise effects. Thus, we can approximate the matrix $\mathbf{A}$ by summing only a few terms of the series. Note that we can correct for a low-contrast image by using a new α with singular values obtained from the adjustable enhanced image.

In addition, histogram equalization (HE) is a widely used image contrast enhancement method,[9] but it tends to excessively enhance the contrast in some images and generate additional noise. Hence, we introduce a method based on SVD that controls the level of contrast enhancement while reducing the noise.

3 Proposed Method

The main concept underlying our approach is to decompose stereoscopic satellite images through SVD, and then calculate the adjustable image enhancement ratio by controlling the

0091-3286/2012/$25.00 © 2012 SPIE

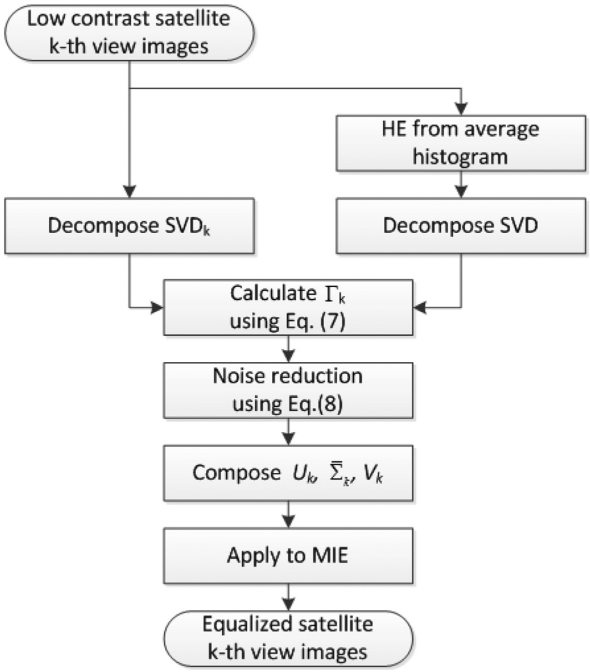

Fig. 1 Flowchart of proposed method. HE =; histograph equalization SVD = singular value decomposition; MIE = midway image equalization.

contrast level. The noise components can be subsequently eliminated by the threshold bound through the rank approximation. Finally, each enhanced stereo satellite images can be equalized by midway image equalization (MIE). The overall structure of the proposed method is shown in Fig. 1.

The adjustable singular value with noise reduction can be seen as a solution to a three-criterion optimization problem. The object functions are to find the adjustable singular value α_{AI} that is close to α_{AH} in the first two terms and to find the optimal singular value $\widetilde{\alpha}_k$ that has a small bin values for noise reduction in the last term. Here, α_{AI} and α_{AH} represent the average image between the original images and the average histogram equalized images, respectively. Then, the adjustable singular value with a decrease in noise can be formulated as a weighted sum of the first two objectives with an additional term for noise cancelling such that

$$\widetilde{\alpha}_k = \arg\min_{\alpha_k}\{\|\alpha_k - \alpha_{AI}\| + \lambda\|\alpha_k - \alpha_{AH}\| + \|D^{\varepsilon_k}\alpha_k\|\}, \quad (3)$$

where k denotes the view (left or right), and α_k, α_{AI}, and α_{AH} signify the singular values of the k^{th} image, the average image between the original images, and the average histogram equalized images, respectively. The diagonal matrix $D^{\varepsilon_k}(i_k, i_k) = 1$ for $i_k = [0, \varepsilon_k]$ and the remaining diagonal elements are zero.

An analytical solution of Eq. (3) can be obtained when the squared sum of the Euclidean norm is used,

$$\widetilde{\alpha}_k = \arg\min_{\alpha_k}\{\|\alpha_k - \alpha_{AI}\|_2^2 + \lambda\|\alpha_k - \alpha_{AH}\|_2^2 + \|D^{\varepsilon_k}\alpha_k\|_2^2\}, \quad (4)$$

which results in a quadratic optimization problem.

$$\widetilde{\alpha}_k = \arg\min_{\alpha_k}\left\{\begin{array}{c}(\alpha_k - \alpha_{AI})^T(\alpha_k - \alpha_{AI}) \\ +\lambda(\alpha_k - \alpha_{AH})^T(\alpha_k - \alpha_{AH}) \\ +(\alpha_k)^T D^{\varepsilon_k}(\alpha_k)\end{array}\right\}. \quad (5)$$

The solution to this minimization problem of Eq. (5) is

$$\widetilde{\alpha}_k = \{(1+\lambda)I + D^{\varepsilon_k}\}^{-1}(\alpha_{AI} - \lambda\alpha_{AH}). \quad (6)$$

The controllable singular value $\widetilde{\alpha}_k$ is a weighted average of α_{AI} and α_{AH} with noise reduction. In the first and the second terms in Eq. (3), the parameter λ varies over $[0, \infty)$, and the solution of Eq. (3) gives the optimal trade-off curve between the first and second objectives. If λ is zero, $\widetilde{\alpha}_k$ is the singular value that includes the average values of the two images, and as λ approaches infinity, $\widetilde{\alpha}_k$ approaches the maximum singular value of the histogram equalized image. Consequently, many enhancement levels can be easily tuned by changing the parameter λ. In fact, the adjustable contrast enhancement ratio is defined as

$$\Gamma_k = \frac{\sup(\widetilde{\alpha}_k)}{\sup(\alpha_k)}, \quad (7)$$

where $\sup(\alpha_k)$ and $\sup(\widetilde{\alpha}_k)$ are maximum singular values of α_k and $\widetilde{\alpha}_k$, respectively.

To reduce the noise, the last term in Eq. (3) introduces a low rank matrix approximation for a noise estimator that effectively removes the high noise frequency elements. The threshold is

$$\varepsilon_k = \gamma_k\sqrt{m_k n_k \sigma_k}, \quad (8)$$

where m and n are the numbers of rows and columns, respectively. The $\sigma_k = \text{median}(|Y_k^{HH}|)/0.6745$ is the global noise variance that can be estimated from the detailed wavelet coefficients (Y_k^{HH}), and γ_k is an empirical constant that determines the filter strength.

Finally, the enhanced image A_k with noise reduction is composed by

$$A_k = (U_k)(\bar{\Sigma}_k)(V_k)^T, \qquad \bar{\Sigma}_k = \Gamma_k\alpha_k, \quad (9)$$

where $\bar{\Sigma}_k$ represents new singular values, which is obtained from Eq. (7) and singular values of input image α_k.

We can obtain nearly identical equalized stereo images from Eq. (9); however, they do not have the exact same histograms because U and V contain important information for the recognition of each image.[10] Thus, after employing the proposed stereo satellite equalized method, we apply a tune continuity between the equalized images. More specifically, we use MIE, which creates intermediate histogram between the left and right histograms while remaining coherent with their previous gray level dynamics.[11] The intermediate midway cumulative histogram (CH) can be constructed as follows

$$H_{MIE} = \left(\frac{H_L^{-1} + H_R^{-1}}{2}\right)^{-1}, \quad (10)$$

where H_L, H_R, and H_{MIE} are two CHs of the original images and a midway CH, respectively.

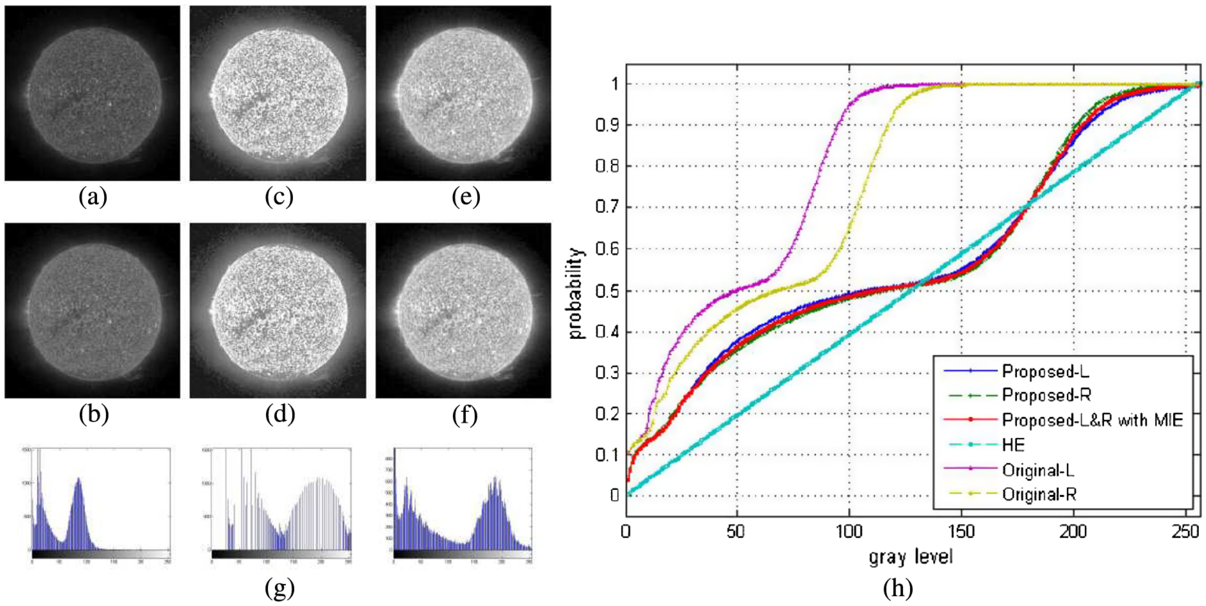

Fig. 2 Comparison of stereoscopic satellite images: (a) Original (left); (b) Original (right); (c) histogram equalization (HE, left); (d) HE (right); (e) Proposed (left); (f) Proposed (right); (g) Histograms of left (a), middle (c), and right (e); (h) Cumulative histograms (CH).

4 Experimental Results

This letter presents a novel method for enhancing stereoscopic satellite image. In this experiment, the enhancement parameter λ was set to 9, and γ was set to 0.08. These values were obtained empirically. The experimental results are shown in Fig. 2. Figure 2(a) and 2(b) are the original left and right images, respectively. Figure 2(c) and 2(d) were obtained by HE, and Fig. 2(e) and 2(f) were obtained by the proposed method. Figure 2(g) is the histogram of the left image in each method, and 2(h) is the CH of the original left and right images, the HE images, the proposed method left and right images, and proposed method with MIE image.

Figure 2(c) and 2(d) shows the equalized results by HE; noise and over-enhancement is clearly evident. On the other hand, Fig. 2(e) and 2(f) presents images that appear more natural looking than the others. Figure 2(g) shows that the histogram of the proposed algorithm has good extension while maintaining the original histogram shape. Figure 2(h) shows that the CH of the proposed method has simultaneous similar tendencies between HE and the original CH.

5 Conclusions

An important issue in stereoscopic satellite image enhancement based on SVD is how to control the enhancement in order to obtain a natural-looking image. This goal is to reduce the noise resulting from its enhancement and luminance continuity for a natural looking, three-dimensional effect. Hence, we used an adjustable enhancement, as well as noise estimation techniques developed via three-criterion optimization. The proposed method effectively enhanced the satellite images. The experimental results verified that the proposed algorithm not only reduced noise, but also enhanced the stereo image contrast. In the future work, we will study on speedup of SVD and the optimization by adaptive parameter.

Acknowledgments

This research was supported by the MKE (Ministry of Knowledge Economy), Korea, under the ITRC (Information Technology Research Center) support program supervised by the NIPA (National IT Industry Promotion Agency (NIPA-2012-C1090-1200-0010).

References

1. R. A. Howard et al., "Sun earth connection coronal and heliospheric investigation (SECCHI)," *Adv. Space Res.* **29**(12), 2017–2026 (2002).
2. K. Konstantinides and K. Yao, "Statistical analysis of effective singular values in matrix rand determination," *IEEE Trans. Acoustics, Speech, Signal Process.* **36**(5), 757–763 (1988).
3. D. Kalman, "A singularly valuable decomposition: the SVD of a matrix," *College Math J.* **27**(1), 2–23 (1996).
4. Z. Hou, "Adaptive singular value decomposition in wavelet domain for image denoising," *Pattern Recogn.* **36**(8), 1747–1763 (2003).
5. Y. He et al., "Adaptive denoising by singular value decomposition," *IEEE Sign. Process. Lett.* **18**(4), 215–218 (2011).
6. H. Demirel, G. Anbarjafari, and M. N. S. Jahromi, "Image equalization based on singular value decomposition," in *Proc. ISCIS 23rd Int. Symp.*, pp. 1–5, IEEE, Istanbul, Turkey (2008).
7. H. Demirel, C. Ozcinar, and G. Anbarjafari, "Satellite image contrast enhancement using discrete wavelet transform and singular value decomposition," *IEEE Geosci. Remote Sens. Lett.* **7**(2), 333–337 (2010).
8. W. Lin, J. Wang, and S. Lin, "Contrast enhancement of x-ray image based on singular value selection," *Opt. Eng.* **49**(4), 047005 (2010).
9. R. C. Gonzalez and R. E. Wood, *Digital Image Processing*, 3rd ed., Prentice Hall, Upper Saddle River, NJ (2008).
10. Y. Tian et al., "Do singular values contain adequate information for face recognition?" *Pattern Recogn.* **36**(3), 649–655 (2003).
11. J. Delon, "Midway image equalization," *J. Math. Imag. Vis.* **21**(2), 119–134 (2004).