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Research paper

Image Enhancement by Unsharp Mask Filtering Based on Detrending Method

[1]Jeong-Hwan Kim, [2]Kang-Hwi Lee, [3]Jeong-Whan Lee, [*4]Kyeong-Seop Kim

Biomedical Engineering, School of ICT Convergence Engineering, College of Science and Technology, Konkuk University Chungju 27478, KOREA
**Corresponding author, Email: kyeong@kku.ac.kr*

Abstract

Background/Objectives: Unsharp Masking (UM) technique has been widely used to enhance high-frequency details such as edges by subtracting its local blurriness involved in pre-fixed low-pass filter mask operations and adding high-frequency weighting elements to original image. However, UM process has a major drawback: it estimates only local blurriness by performing convolution operation involved with the pixels in the limited spatial scope. With this aim, we present a new UM method by detrending analysis where overall blurriness in a given image is estimated in terms of a slow and non-stationary global tendency that is resultant of merging adjacent local trends.
Methods/Statistical analysis: In our study, global non-stationary trend was estimated by applying detrending method that was originally developed based on smoothness priors approach to estimate slow and non-stationary trend in Heart Rate Variability (HRV) analysis. In our study, non-stationary trend was resolved by merging subsequent local trends due to the limitations in inverse-matrix computations and this global tendency was interpreted as non-stationary part for applying detrending analysis.
Findings: Our test results reveal that the suggested UM approach can efficiently estimate the global trend of an image and subsequently it can be utilized to improve the sharpness and contrast of an image.
Improvements/Applications: In this study, zigzag-scanning algorithm was used to convert two-dimensional image data into one-dimensional vector form to estimate non-stationary trend of an image based on detrending analysis. In the future study, it might need to explore the role of specific scanning-order how this factor affects the performance of estimating local blurriness of an image.

Keywords: *Unsharp Mask (UM). Heart Rate Variability (HRV), Zigzag Scanning, Trend*

1. Introduction

Unsharp Masking (UM) model has been widely used to enhance the high-frequency components such as edges in an image by basically subtracting its local blurriness involved in the pre-fixed low-pass filter mask operations and adding the weighted fractions of high-pass filtered details to the given data to enrich sharpness. The variation of UM algorithm was introduced to emphasize the medium-contrast regions in a given image by employing the adaptive filter to control the gain of sharpening operations so as to avoid overshoot effects in abrupt edges and not to apply the operation to the smooth contrast areas [1]. The selective UM method was also proposed in which the advanced edge-preserving smoothing filter (bilateral filter) based on Laplacian intensity with saturation components of an image was applied to control sharpening effects [2].
To enhance the color tone and local depth contrast of color image, hue preserving UM method was applied to improve perceptual quality of color or depth information [3]. Concerning the improvement of diagnostic features in digital mammogram for breast cancer screening, nonlinear UM masking process based on the fusion process of different linear or nonlinear filtering operations applied to combine the enhanced components from the original data and nonlinear sigmoid function was suggested to implement a log-ratio based UM enhancement [4].
UM mask filter was also useful on screening brain disease by increasing the detection rate of detecting the mass lesions in the brain image acquired by Magnetic Resonance Imaging (MRI) [5] and the width of blood vessels on fundus image was estimated by the filter in order to determine the degree of blurriness on the image for rejection of low quality image [6]. The combination of UM scheme and the Parameterized Logarithmic Image Processing (PLIP) operation or anisotropic diffusion filtering was proposed to enhance the overall contrast and edges in chest radiography [7].
However, UM process has a major drawback: it estimates only local blurriness by performing convolution operation involved with the pixels in the limited spatial scope. To cope with this problem, we proposed a new UM algorithm by applying detrending method which was originally developed based on smoothness priors approach to estimate the slow and non-stationary signal trend in Heart Rate Variability (HRV) analysis [8]. In this research, overall tendency was resolved by nonstationary tendency with merging the subsequent local trends that is interpreted as the local blurriness.

2. Unsharp Mask (UM) Filtering by Detrending Method

2.1. UM Filtering

Effect of UM filtering was the resultants of adding a scaled fraction of high-frequency details to an original image and this process can be expressed by equation (1)

$$g[m,n] = f[m,n] + \mu \cdot (f[m,n] - s(f[m,n])) \quad (1)$$

where $g[m,n]$ denotes an enhanced image, $s(f[m,n])$ is a low-pass filtered image on original data by convolving the surrounded pixels at $[m,n]$ location with a low-pass mask, and μ denotes a scale factor used to adjust the sharpening strengths. However, this conventional UM operation has a major shortcoming: the size of a convolution mask is rather small (usually a 3 x 3 window) with the fixed kernel values, and consequently UM operation cannot take into account of global trend of a given image because it performs a low-pass mask operation with the limited spatial scope based on kernel size. For this reason, traditional UM operation is vulnerable to occurrence of halo effects especially at the edges and it is extremely to noise. To cope with these problems, we propose a way of estimating $s(f[m,n])$ by using detrending method that was used for suppressing non-stationary tendency in HRV [8].

2.2. Zigzag Scanning

In our research, the pixel-data of a target image are rearranged by the zigzag scanning order covering the entire scope of the data to apply detrending method for the estimation of global non-stationary trend of a given image. The zigzag scanning algorithm had been applied for image compression based Walsh-Hadamard Transform, Discrete-Cosine Transform (DCT) and Low-density-parity-check (LPC) coding [9]. The transform coefficients are computed in zigzag order by dividing the input data into non-overlapping eight by eight partitions. In contrast with the conventional zigzag scanning algorithm, input pixels are grouped with forming non-square blocks covering triangular or trapezoid regions to achieve better image compression efficiency [10]. In this study, the scanning algorithm was proposed by deploying a triangular blocks with covering the entire image data as shown in Figure 1.

Figure 1: Illustrations of zigzag scanning order covering entire scope of an image data

The detrending method postulates that $f[m,n]$ is the additive components representing the stationary data, $f[m,n]^{stat}$ and the low frequency aperiodic trend, $f[m,n]^{trend}$. This trend can be estimated with a linear operator, H by solving the regularized least-squares expressions [8]:

$$\hat{f}[m,n] = H\hat{\theta}_\lambda \quad (2)$$

$$\hat{\theta}_\lambda = (H^T H + \lambda^2 H^T D_2^T D_2 H)^{-1} H^T \cdot f[m,n] \quad (3)$$

$$D_2 = \begin{pmatrix} 1 & -2 & 1 & 0 & \cdots & 0 \\ 0 & 1 & -2 & 1 & \ddots & \vdots \\ \vdots & \ddots & \ddots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & 1 & -2 & 1 \end{pmatrix} \quad (4)$$

$$f[m,n] - H\hat{\theta}_\lambda = \left(I - (I + \lambda^2 D_2^T D_2)^{-1}\right) \cdot f[m,n] \quad (5)$$

, where θ is a regression coefficient for predicting $\hat{\theta}_\lambda$ in least square regression, D_2 is the 2nd derivative operator and λ is a regularization parameter. Hence the nonstationary trend of an image can be estimated by $H\hat{\theta}_\lambda$. Zigzag scan-ordered image data is divided into one-dimensional N segments and each segment is overlapped with 50% of the previous section because the estimation of global trend requires the computations of inverse matrix as stated in equation (5). The overall trend of an image data, $f[m,n]^{trend}$ can be resolved by arranging the computed trend in each section order and calculating the difference between two sequential trends to find the connecting point that guarantees the smooth transition between the adjacent trends [11].

2.3. Formulation of Detrending Smoothness Priors

To formulate detrending smoothness priors, a regularization parameter, λcan be determined by applying curve-fitting analysis on the design specifications of frequency response as listed in Table 1 [11].

Table 1: Regularization parameter, λ and the corresponding cut-off frequency, F_c

λ	F_c
1	$0.189 \times F_s$
2	$0.132 \times F_s$
3	$0.093 \times F_s$
10	$0.059 \times F_s$
20	$0.041 \times F_s$
50	$0.025 \times F_s$
300	$0.011 \times F_s$

note: F_s *is the sampling frequency*

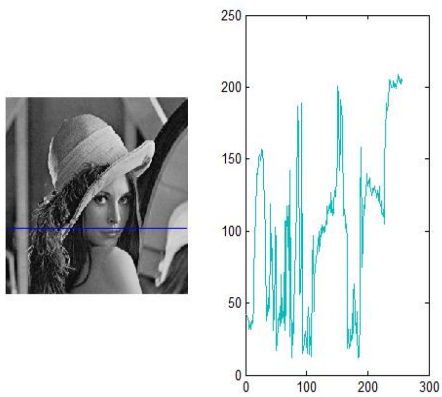
Here λ is resolved by applying logarithmic transform to linearize an exponential curve.

$$F_c = 0.1865\, \lambda^{-0.5022} \cdot F_s \quad (6)$$

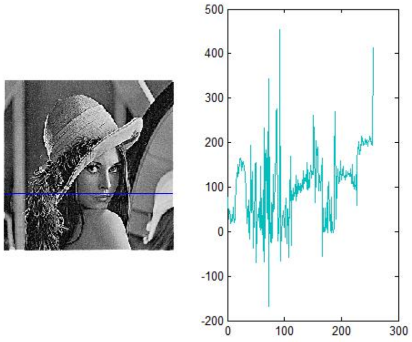
3. Experimental Simulations

For the experimental comparisons of the filtered image by UM process using a 3 x 3 convolution kernel in equation (7) and detrending method, the "Lenna" image was considered. Figure 2 shows the UM filtered images with line-profile gray-levels along the horizontal line superimposed on the original image. Here, UM filtered image by detrending method appears much sharper than the filtered image processed by conventional UM process.

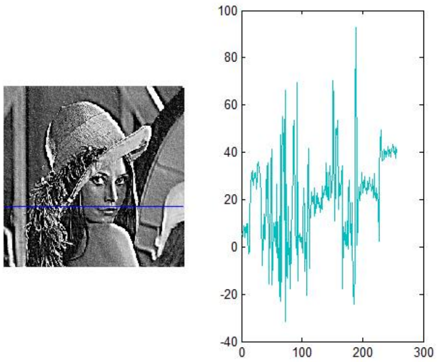
$$\begin{bmatrix} -0.17 & -0.67 & -0.17 \\ -0.67 & 0.58 & -0.67 \\ -0.17 & -0.67 & -0.17 \end{bmatrix} \quad (7)$$



(a)



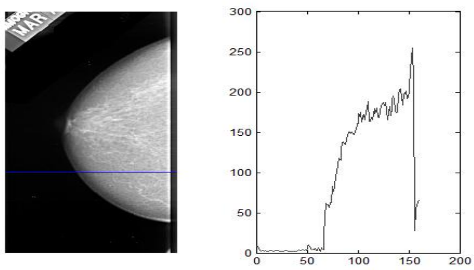
(b)



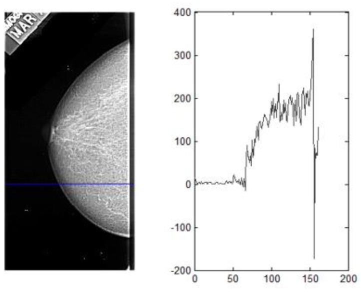
(c)

Figure 2: (a) “Lenna” (b) enhanced image by the conventional UM sharpening by comprising local trends (c) UM filtered image by detrending method (F_c = 0.1Hz, F_s = 1Hz, λ =3.4592 and μ = 0.8)

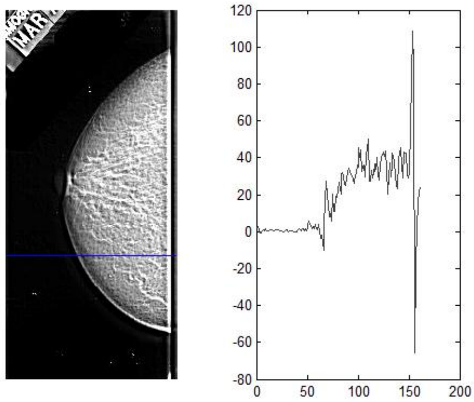
For experimental tests for suggested UM method, we consider open database, DDSM for screening mammography. Figure 3(a) shows normal breast image in which no lesion is annotated. The enhanced image by the conventional UM sharpening is shown in Figure 3(b) with applying a 3× 3 mask filter whereas the effect of detrending-based UM sharpening is illustrated in Figure 3(c) with plotting the grey-levels of image pixels along the horizontal line. Here, UM filtered image by detrending method reveals much high-frequency details than the filtered image by traditional UM approach.



(a)



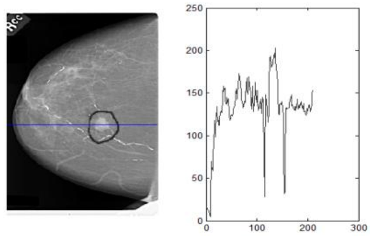
(b)



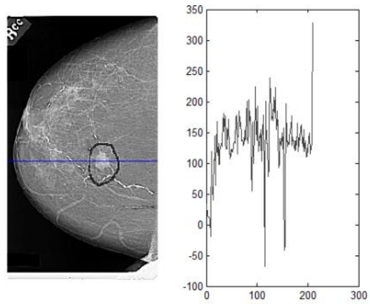
(c)

Figure 3: (a) Normal mammograms (file name: A-0003-1.LEFT_CC) (b) enhanced image by the conventional UM sharpening with 3 x 3 convolution mask (c) UM filtered image by detrending method (F_c = 0.1Hz, F_s = 1Hz, λ =3.4592 and μ = 0.8)

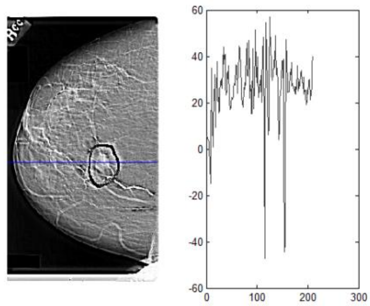
Likewise, Figure 4(a) shows a mammographic image in which a breast-cancer lesion is marked as a circle with plotting the grey-levels of image pixels along a horizontal row of data. The enhanced image by the conventional UM sharpening is depicted in Figure 4(b) with applying a 3 x 3 kernel to emphasize edges whereas the effect of detrending-based UM sharpening is illustrated in Figure 4(c).



(a)



(b)



(c)

Figure 4: (a) Mammographic image with annotated lesion(file name: C-0031-1.RIGHT_CC) (b) enhanced image by the conventional UM sharpening with considering 3 x 3 mask (c) an emphasized image by detrending-based UM (F_c = 0.1Hz, F_s = 1Hz, λ =3.4592 and μ = 0.8).

4. Conclusions

To cope with a problem of estimating local blurriness by conventional UM filter, detrending-based UM approach was proposed to estimate low-frequency components in an image in terms of the global non-stationary trend by formulating smoothness priors with solving a regularization parameter, λ. In our approach, overall blurriness in a given image can be estimated in terms of a slow and non-stationary global trend followed by merging the adjacent local trends extracted by zigzag scanning order. Our experimental tests illustrate that suggested UM approach can efficiently estimate the global trend of an image and subsequently it can be utilized to emphasize the sharpness of the given data by augmenting the high-frequency details derived from an overall tendency.

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