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Effect of the Signal-to-Noise Power Spectra Ratio on MTF Compensated EOC Images

Chi-Ho Kang and Hae-Jin Choi

Satellite Mission Operation Department, Korea Aerospace Research Institute

Abstract : EOC (Electro-Optical Camera) of KOMPSAT-1 (Korea Multi-Purpose SATellite) has been producing land imageries of the world since January 2000. After image data are acquired by EOC, they are transmitted from satellite to ground via X-band RF signal. Then, EOC image data are retrieved and pass through radiometric and geometric corrections to generate standard products of EOC images. After radiometric correction on EOC image data, Modulation Transfer Function (MTF) compensation is applicable on EOC images with user's request for better image quality. MTF compensation is concerned with filtering EOC images to minimize the effect of degradations. For Image Receiving and Processing System (IRPE) at KOMPSAT Ground Station (KGS), Wiener filter is used for MTF compensation of EOC images. If the Pointing Spread Function (PSF) of EOC system is known, signal-to-noise (SNR) power spectra ratio is the only variable which determines the shape of Wiener filter. In this paper, MTF compensation in IRPE at KGS is briefly addressed, and MTF compensated EOC images are generated using Wiener filters with various SNR power spectra ratios. MTF compensated EOC images are compared with original EOC 1R images to observe correlations between them. As a result, the effect of SNR power spectra ratio on MTF compensated EOC images is shown.

Key Words : EOC, KOMPSAT-1, MTF Compensation, Wiener Filter, SNR Power Spectra Ratio.

1. Introduction

After the transmission from satellite to ground, EOC image data pass through the pre-processor that consists of radiometric and geometric correction. After pre-processes, standard EOC image products - Level 1R, Level 1GR, and Level 1GC - are generated. The object of pre-processing is to remove or minimize distortions, and compensate degradations in EOC image data.

Even the standard EOC image products, they still contain degradations. Any image acquired by optical, electro-optical, or electronic means is likely to be degraded by the sensing environment. The degradation may be in the form of noise, blur, and atmospheric turbulence and so on (Jain, 1989). The effect of degradations in observed image can be minimized with filtering and this process is defined as image restoration. Image restoration includes filtering techniques, which include inverse, pseudo-inverse, Wiener filters and so on. Some filters for image restoration are applicable to standard EOC image products for minimizing degradations.

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MTF compensation is based on the theory of image restoration. MTF compensation acts on EOC images as a high pass filter and it is expected that MTF compensated EOC images would show more discernible features for land's constitutions in high spatial frequencies. IRPE at KGS adopts Wiener filter for MTF compensation. If the PSF of EOC imaging system is known, SNR power spectra ratio determines Wiener filter.

In this study, MTF correction for EOC images in IRPE at KGS is addressed briefly. EOC images are compensated with various SNR power spectra ratios. In addition, MTF compensated EOC images are compared to observe correlations with the effect of SNR power spectra ratio.

2. MTF Compensation in EOC Image Processing

Fig. 1 shows EOC image processing step of level 1. After EOC image data of level 0 are generated through Data Acquisition System (DAS), standard EOC image products will be generated after radiometric and geometric corrections. Radiometric correction removes strips on EOC images, which are caused by the differences of spectral response between EOC's pixels. EOC 1R images are produced after radiometric correction. After then, MTF compensation is applied to EOC 1R images with user's request. Generally, MTF compensated EOC images are more discriminating than original EOC 1R images in high spatial frequencies. MTF compensation for EOC image is based on image restoration techniques. Now, Wiener filter is used in MTF compensation of EOC 1R images. EOC 1G processing follows EOC 1R processing with or without MTF compensation.

3. Image Restoration Using Wiener Filter

Image restoration refers to removal or minimization of known degradations in an image. Degradations consist of noise, blur, atmospheric turbulence and etc. Image restoration is concerned with filtering the observed image to remove or minimize the effect of degradations (Jain, 1989). Image restoration includes deblurring of images degraded by the limitations of the sensor or its environment, non-linearities due to sensors and etc. The visual quality of an image would be improved by various image restoration filter techniques.

1) Wiener Filter

Wiener filtering is a method of restoring images in the presence of blur as well as noise. Wiener filtering is

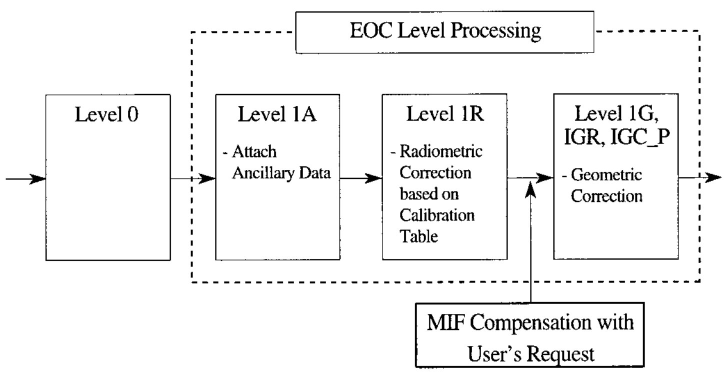

Fig. 1. EOC Image Processing - Level 1.

optimal in terms of the Mean Square Error (MSE). In other words, it minimizes the overall MSE in the process of filtering.

In Fourier space the Wiener filter assumes the form (Busko, 1994).

$$F(u,v) = \frac{D^*(u,v)}{|D(u,v)|^2 + \frac{P_n(u,v)}{P_f(u,v)}} G(u,v) \qquad (1)$$

where $F(u, v)$ is the restored signal, $D(u, v)$ is the Optical Transfer Function (OTF) of the system, $D^*(u, v)$ its complex conjugate. ***OTF is the Fourier transform of the PSF, and MTF is the modulus of the OTF***. If OTF of a system is real-valued and positive, MTF is equal to OTF (Holst, 1995). $G(u, v)$ is the Fourier transform of the observed image. And $P_f(u, v)$ and $P_n(u, v)$ are respectively power spectra of EOC image signal and the additive noise. The symbol * means the complex conjugate. So, if the PSF of a system is known, SNR power spectra ratio determines optimized Wiener filter completely.

4. MTF Compensation Algorithm

Fig. 2 shows MTF compensation in EOC image processing. The OTF is the measure of how the optic system responds to the incident light in frequency domain and is derived from PSF of EOC system. MTF can be calculated as the magnitude of OTF.

Wiener filter is embedded in the calculation of inverse MTF, and it can be determined with applying SNR power spectra ratio to the formula (1). Currently, SNR power spectra ratio value of 9 is assigned for Wiener filter in IRPE at KGS.

After Wiener filter is inversely transformed to spatial domain, MTF compensation filter in spatial domain is generated. In Fig.2, ⊗ means convolution. MTF compensation filter in spatial domain is convolved with EOC 1R image to generate MTF compensated EOC image. Finally, MTF compensated EOC images of which blurring and noise are minimized can be generated.

5. MTF Compensation with SNR Power Spectra Ratio

When the PSF of EOC system is known, SNR power spectra ratio determines the shape of Wiener filter. So features of MTF compensated EOC images are dependent only on SNR power spectra ratio. Generally, MTF compensation acts on original EOC 1R images as a high-pass filter. So it is expected that original EOC 1R images undergo some changes of pixel values to

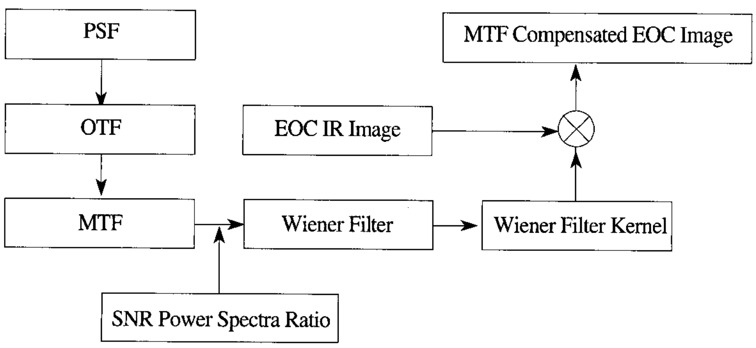

Fig. 2. MTF compensation in EOC image processing.

increase sharpness of them.

In the test, MTF compensation to original EOC 1R images is applied with the value of signal to noise power spectra ratio 9. Visual inspections are applied to see the characteristic of MTF compensation as a high pass filter,. After then, SNR power spectra ratio has been changed to generate other Wiener filters. After then, those filters are applied to MTF compensation for EOC 1R images. Each line of the MTF compensated EOC images are compared with that of original EOC 1R images horizontally and vertically. Correlation would indicates how MTF compensation with different Wiener filters changes the distribution patterns of pixel values. To investigate the effect of MTF compensation according to spatial frequecies, sample images which would show different spatial frequencies on lands are extracted from EOC 1R images of Jeonju city. Building, rice field, mountain area from EOC 1R images have been selected in view of spatial frequencies. Fig. 3 shows EOC 1R image samples. Each EOC 1R image sample has the size of about 1.7 km × 1.7 km. All EOC images viewed in this paragraph are linearly stretched for better visibility.

Fig. 3. EOC image samples in the test.

1) Building Area

Building area mainly consists of sharp-edged buildings and roads. There are a lot of changes in values between adjacent pixels and high spatial frequencies dominate building area. Fig. 4 shows EOC 1R image sample and Fig. 5 shows MTF compensated EOC image sample of building area. Fig. 5 shows more discernible features than Fig. 4. So it is expected that MTF compensated EOC image have many changes of pixel values in high spatial frequencies area in comparison with original EOC 1R image.

2) Rice Field Area

Rice field area also consists of sharp-edged rice field and roads and so on. Middle spatial frequencies are dominant over the rice field area relatively to building area. Fig. 6 shows EOC 1R image sample and Fig. 7 shows MTF compensated EOC image sample of rice field area. Fig. 7 also shows more discernible features than Fig. 6.

Fig. 4. EOC 1R image: building area.

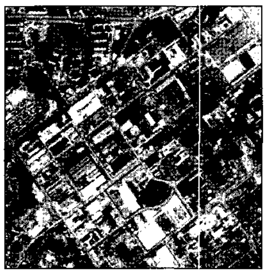

Fig. 5. MTF compensated image: building area.

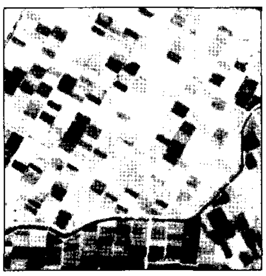

Fig. 6. EOC 1R image: rice field area.

Fig. 7. MTF compensated image: rice field area.

3) Mountain Area

Mountain area has small changes in values between successive pixels relatively to building and rice field area. Relatively, low spatial frequencies are dominant over the mountain except small town area. It is expected that there are small changes of pixel values after MTF compensation because MTF compensation generally emphasizes high spatial frequencies in the image. Fig. 8 shows EOC 1R image sample and Fig. 9 shows MTF compensated EOC image sample of mountain area. Although it is small changes, Fig. 9 shows discernible features compared to Fig.8.

As a result, it is shown that MTF compensation on the EOC 1R image changes original EOC 1R image to new image that has more sharpened and discernible features.

4) Application of various SNR Power Spectra Ratio

Currently, the value 9 is assigned as SNR power spectra ratio in the generation of Wiener filter in IRPE at KGS. Changes of pixel values have been inspected in MTF compensated EOC image samples. In the test, Wiener filters of which SNR power spectra ratio have values from 1 to 100 were generated and each Wiener filter is applied to MTF compensation on EOC 1R image samples.

At the first, visual inspections are applied to EOC 1R images and MTF compensated EOC images for the observation of sharpness enhancement. And the next, correlation coefficients in horizontal and vertical lines are calculated. As a result, it is observed that how SNR power spectra ratio affects sharpness of MTF compensated EOC images and changes correlations between them in horizontal and vertical lines.

Fig. 8. EOC 1R image: mountain area.

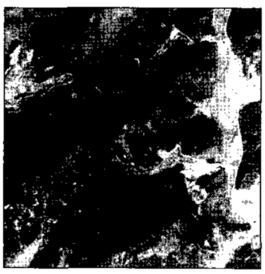

Fig. 9. MTF compensated image: mountain area.

5) Visual Inspections

EOC 1R image and MTF compensated EOC images were compared by visual inspection for the judgment of sharpness enhancement. As a result, sharpness in high spatial frequencies was generally enhanced with the increase of SNR power spectra ratio except value of 1. Fig.10, Fig.11, Fig.12, Fig.13 show MTF compensated EOC images resulted from various SNR power spectra ratios. When SNR power spectra ratio has the value of 1(Fig. 10), MTF compensated EOC images shows rather smoothed features compared to original EOC 1R images (Fig. 4). So, it can be deduced that noise is over-estimated when SNR power spectra ratio is assigned to

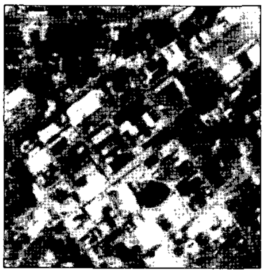

Fig. 10. EOC 1R image when SNR = 1.

Fig. 11. EOC 1R image when SNR = 4.

Fig. 12. EOC 1R image when SNR = 25.

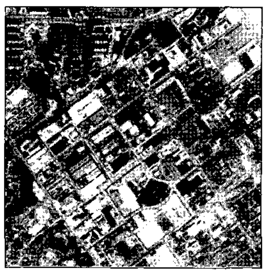

Fig. 13. EOC 1R image when SNR = 100.

the value of 1 and this caused the smoothing on MTF compensated EOC images. As a result, SNR power spectra ratio bigger than 1 should be applied to MTF compensation for more sharpened features in high spatial frequencies.

6) Analysis on Correlation Coefficients Distributions

MTF compensated EOC images have been compared to EOC 1R images to observe correlations of pixel values. Correlations between two images in horizontal and vertical directions are derived. Vertical correlation distribution is the sum of correlation coefficients of all horizontal lines between two images. Horizontal correlation distribution is the sum of correlation coefficients of all vertical lines between two images. These two coefficients show how SNR power spectra ratio changes EOC 1R images in view of correlation. Distributions of Horizontal and Vertical Correlation Coefficients are shown from Fig. 13 to Fig. 18.

In all cases, horizontal and vertical correlation coefficients decrease with the increase of SNR power spectra ratio. It means that the increase of SNR power spectra ratio derives the increase of changes of pixel values when MTF compensation is applied. It is shown that rice field area responds most sensitively to the increase of SNR power spectra ratio. It means that high spatial frequencies of the rice field area were more emphasized than those of other two images. It is assumed that differences of adjacent pixels around high frequencies are larger in rice field area than in other areas even high frequencies are dominant in building area, which follow more decrease of correlation than other areas.

From the test, when SNR power spectra ratio has the value of 4, there are maximum correlations between original EOC 1R images and MTF compensated EOC images. However, maximum correlation does not mean the best quality of MTF compensated EOC images. Correlation tells us how much changes of pixel values to enhance sharpness in the process of MTF compensation happened. It means that higher sharpened MTF

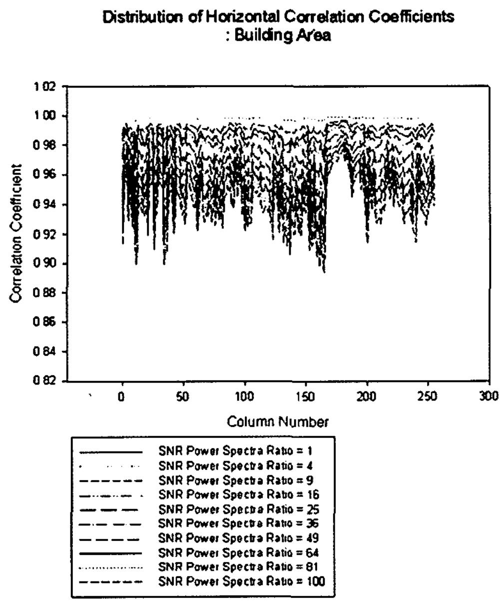

Fig. 13. Horizontal correlation distribution in building area test.

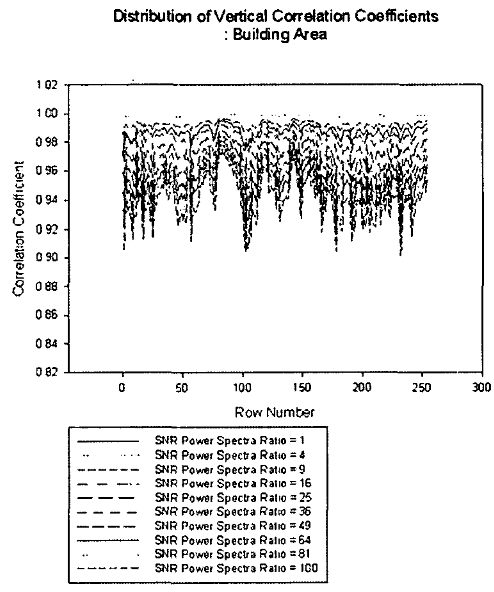

Fig. 14. Vertical correlation distribution in building area test.

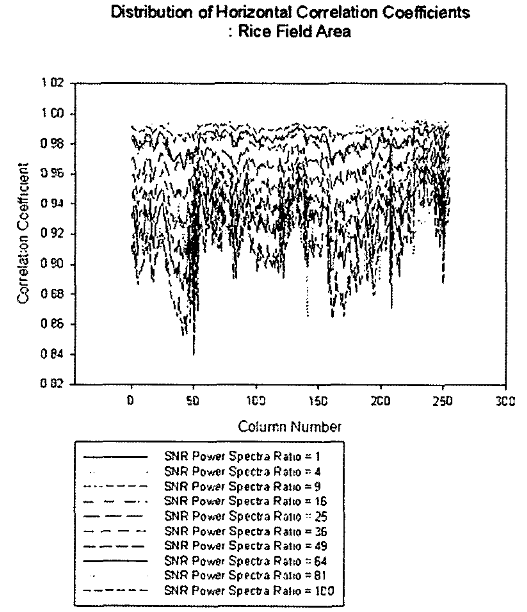

Fig. 15. Horizontal correlation distribution in rice field area test.

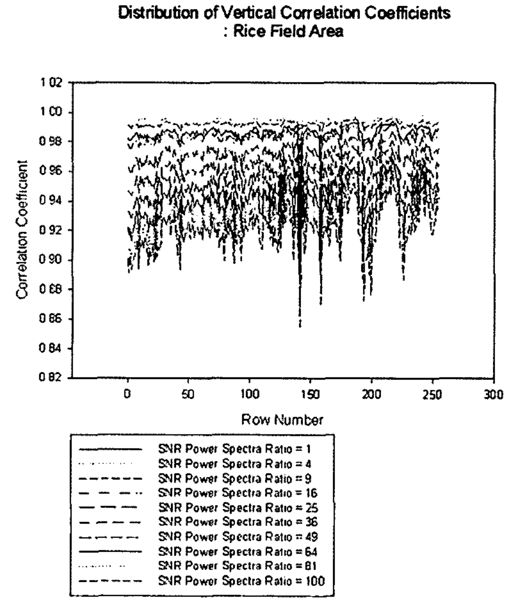

Fig. 16. Vertical correlation distribution in rice field area test.

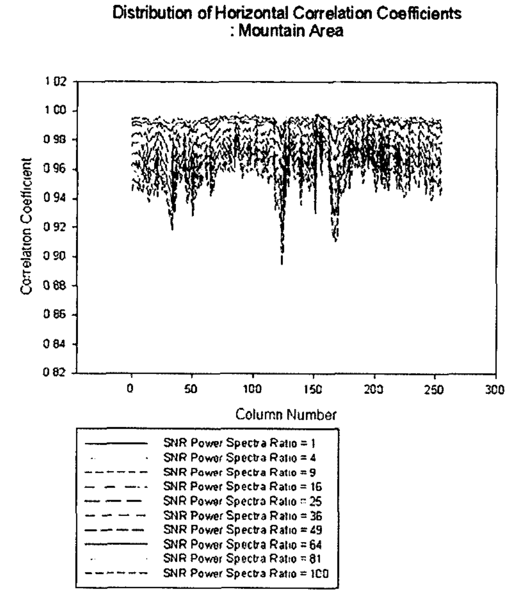

Fig. 17. Horizontal correlation distribution in mountain area test.

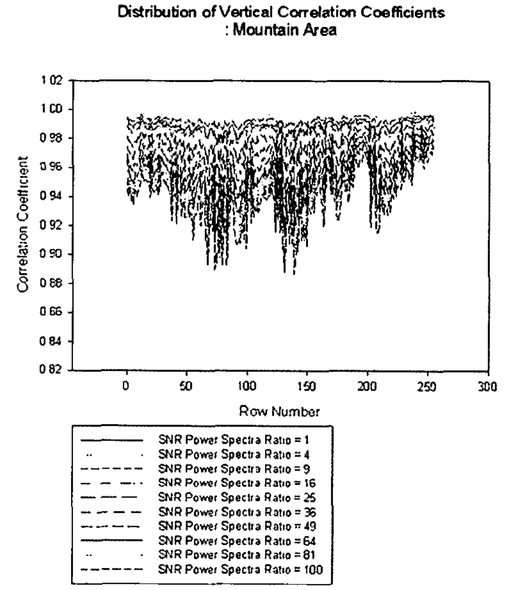

Fig. 18. Vertical correlation distribution in mountain area test.

compensated EOC images have less correlation with EOC 1R images. As a result, MTF compensated EOC images with maximum correlation has most similar features compared to EOC 1R images. As a result, it can be deduced that MTF compensated EOC images with SNR value 4 are most similar to EOC 1R images.

Fig. 19 to Fig. 24 show features of correlation distributions with fixed SNR values. When SNR has the

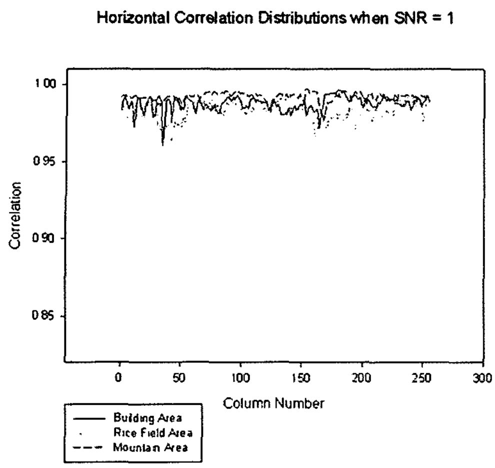

Fig. 19. Horizontal correlation distribution when SNR = 1.

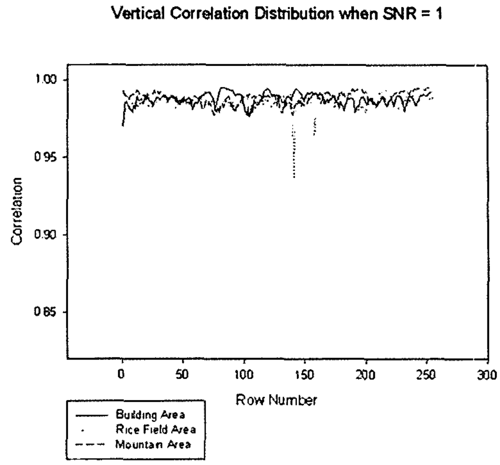

Fig. 20. Vertical correlation distribution when SNR = 1.

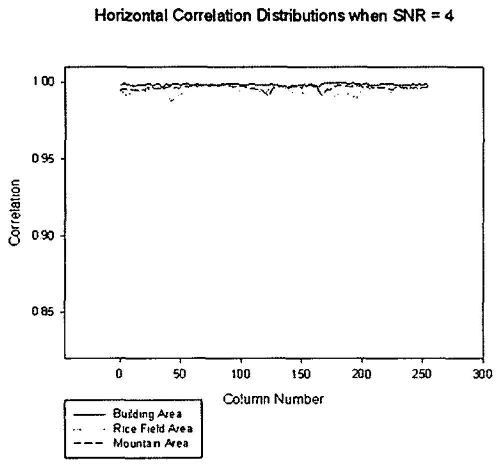

Fig. 21. Horizontal correlation distribution when SNR = 4.

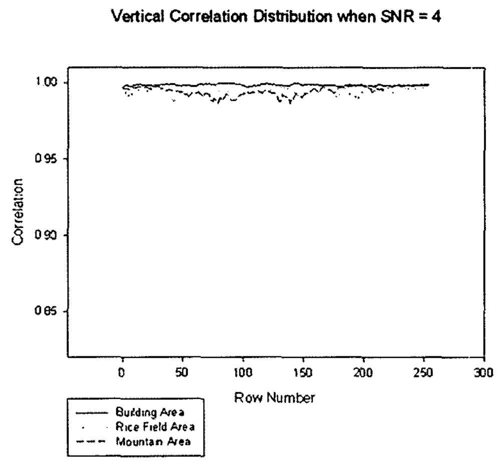

Fig. 22. Vertical correlation distribution when SNR = 4.

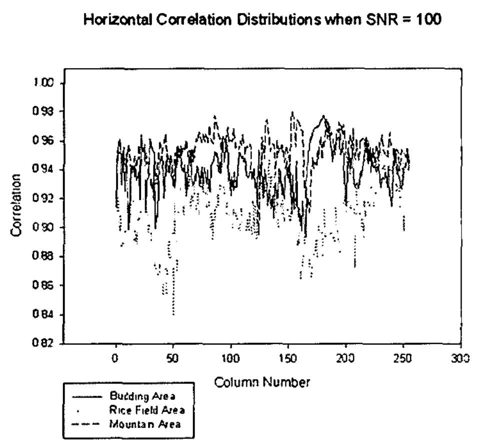

Fig. 23. Horizontal correlation distribution when SNR = 100.

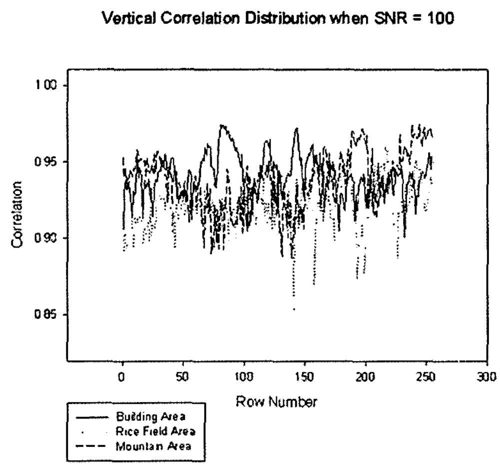

Fig. 24. Vertical correlation distribution when SNR = 100.

value of 4, MTF compensated EOC images have maximum correlations regardless of the land features. Other tests show decreases of correlation as SNR value increases. From above figures, it is shown that rice field area image undergoes more decrease of correlation by MTF compensation compared to other areas. Considering characteristics of MTF compensation as a filter for enhancing high frequency components, high frequency components of rice field area image has been enhanced much more than those of other areas.

Meanwhile, all correlation coefficients are more than 0.8 in all above figures and it means that MTF compensation effectively enhance the sharpness of an EOC 1R image regardless of various land features with proper loss of correlation.

7) Statistical Analysis

Differences of pixel values and its standard deviations between EOC 1R images and MTF compensated EOC images were inspected. Statistical information shows how much pixel values of original EOC 1R image have been changed after MTF compensation.

Fig. 25 shows pixel value differences between EOC 1R images and MTF compensated EOC images and Fig. 26 shows standard deviations of pixel value differences. As you see in Fig. 25, maximum and minimum changes of pixel values happened after the MTF compensation on the EOC 1R image of building area. High spatial frequencies are dominant in original EOC 1R images of building area this leads Wiener filter to act on original EOC 1R image as a high pass filter. It result in many changes of pixel values in the MTF compensated EOC image of building area. Relatively, MTF compensated EOC images of rice field area and mountain area show less changed features than that of building area.

Meanwhile, it is shown that maximum and minimum changes in pixel values simply proportional to the increase of SNR power spectra ratio. In Fig. 26, standard deviations of differences are proportional to the increase of SNR power spectra ratio, too.

As a result, it is concluded that the increases of SNR power spectra ratio in MTF compensation result in more sharpened features compared to original EOC 1R images in high spatial frequencies.

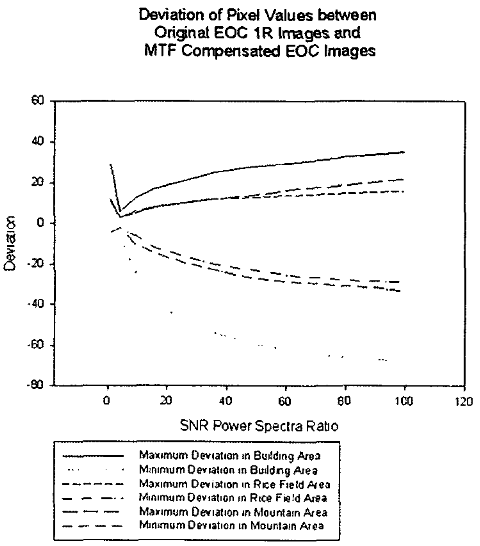

Fig. 25. Deviations between EOC 1R Images and MTF compensated 1R Images

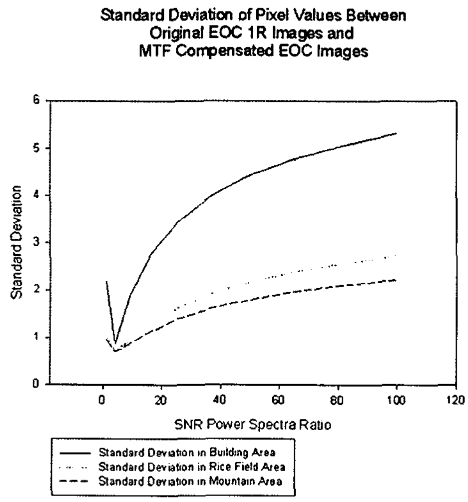

Fig. 26. Standard deviations of differences

6. Conclusions

In this paper, MTF compensation in IRPE at KGS is addressed in brief. MTF compensation is accomplished by the image restoration of EOC 1R image data with Wiener filter. MTF compensated EOC images shows more sharpened features than original EOC 1R images.

The SNR power spectra ratio is the only variable of Wiener filter with known PSF. Current SNR power spectra ratio is assigned to 9 in IRPE of KGS. The sharpness of MTF compensated EOC images can vary according to SNR power spectra ratio.

At the first, it is shown that how SNR power spectra ratio affects on MTF compensation of original EOC 1R images. Generally, EOC land imageries contain spatial frequencies of wide range and three samples of an EOC image are extracted to observe correlations between SNR power spectra ratio and the quality of MTF compensated EOC images in view of the sharpness. Tests shows that the sharpness of MTF compensated EOC image is enhanced as the increase of SNR power spectra ratio.

And the next, MTF compensations with various SNR power spectra ratios that range from 1 to 100 have applied to see changes of pixel values as the result of applications of higher SNR power spectra ratios. After those applications, two images before and after are compared by means of visual inspection, correlation and statistics. From the test, there is maximum correlation between two images when SNR has the value of 4. In IRPE of KGS, SNR has been set as 9 to get more sharpened images in spite of the decrease of correlation. Visual inspection has shown that MTF compensated EOC images in the case of SNR value of 9 shows more sharpened features without any loss of image quality. So, SNR value of 9 has been selected for MTF compensation of EOC 1R images.

Meanwhile, although correlation between two images undergoes some decrease as the increase of SNR power spectra ratio, MTF compensation enhances the sharpness of EOC 1R image without any remarkable noise or degradation of quality. The result shows that MTF compensated EOC images with better quality can compensate for the decrease of correlation compared to original EOC 1R images.

Finally, it is concluded that higher SNR power spectra ratios than currently used are applicable to EOC 1R images and those guarantees better image qualities in high spatial frequencies than original EOC 1R images. In the future study, SNR power spectra ratio which includes infinite number shall be applied to MTF compensation and the result shall be analyzed.

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