Effect of the Signal-to-Noise Power Spectra Ratio On MTF compensated EOC images

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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 generated 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 in MTF compensation for EOC images. If the Pointing Spread Function (PSF) of EOC system is known, signal-to-noise power spectra ratio is the only factor in the determination of Wiener filter. In this paper, MTF compensation in IRPE at KGS is introduced and MTF compensated EOC 1R images are generated using Wiener filters with various signal-to-noise power spectra ratios. MTF compensated EOC 1R images are correlated with EOC 1R images for observing linearities between them. As a result, the effect of signal-to-noise power spectra ratio is shown on MTF compensated EOC 1R images.

Key words ; MTF compensation, Wiener filter, Signal-to-Noise Power Spectra Ratio

1. Introduction

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

Although 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, atmospheric turbulence and so on (Jain 1989). The effect of degradations for observed image can be minimized with filtering and this process is defined as image restoration. Image restoration contains filtering techniques including inverse, pseudo-inverse, Wiener filters and so on. Some filters for image restoration are applicable to standard EOC image products for minimizing degradations.

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 1R images would show more discernible features for land's constitutions in high spatial frequencies. MTF compensation in IRPE at KGS adopts Wiener filter. If PSF of imaging system is known, signal-to-noise power spectra ratio determines Wiener filter.

In this study, MTF correction for EOC images in IRPE at KGS is addressed and MTF corrected EOC images are generated with various signal-to-noise power spectra ratios. In addition, MTF compensated EOC 1R images are correlated with EOC 1R images. Correlations between them are measured for finding linearities between them and the result shows us the effect of signal-to-noise power spectra ratio on MTF compensated EOC 1R images.

2. MTF Compensation in EOC Image Processing

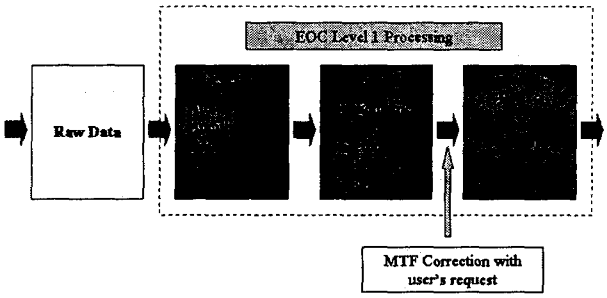


Fig.1 EOC Image Processing – Level 1

Fig.1 shows level 1 process in EOC image processing. After EOC image data of level 0 are generated through Data Acquisition System (DAS), they pass through pre-process including radiometric and geometric corrections to generate standard EOC image products. Radiometric correction includes removing strips on EOC images with sensor calibration look-up tables. After radiometric correction, EOC 1R image products are produced. After EOC 1R images are produced, MTF compensation is applied to EOC 1R products with user's request. Generally, MTF compensated EOC 1R images show more discriminating features than EOC 1R images in high spatial frequencies. MTF compensation for EOC image is based on image restoration techniques and Wiener filter is used in MTF compensation of EOC 1R images. EOC 1G products are following EOC 1R products 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 so on. Image restoration is concerned with filtering the observed image to remove or minimize the effect of degradations (Jain, 1989). Image restoration includes de-blurring of images degraded by the limitations of a sensor or its environment, noise filtering, and correction of geometric distortion or non-linearities due to sensors. The visual quality of an image would be improved by various image restoration filter techniques.

3.1 Wiener Filter

Wiener filtering is a method of restoring images in the presence of blur as well as noise. Wiener filtering is optimal in terms of the Mean Square Error (MSE). In other words, it minimizes the overall MSE in the process of inverse filtering and noise smoothing.

Wiener filter in frequency domain can be expressed as follows (Jain 1989).

$$W(v_1,v_2)=\frac{H^*(v_1,v_2)}{|H(v_1,v_2)|^2+\dfrac{S_{nn}(v_1,v_2)}{S_{uu}(v_1,v_2)}}$$

Where $H(v_1,v_2)$ is the OTF of optic system. If OTF of optic system is real-valued and positive, OTF and MTF are equal (Holst 1995). $S_{uu}(v_1,v_2)$ and $S_{nn}(v_1,v_2)$ are respectively power spectra of EOC image signal and the additive noise. The symbol * means the conjugate of a complex number. So, if the PSF of a system is known, signal-to-noise power spectra ratio determines optimized Wiener filter completely.

4. MTF Compensation Algorithm

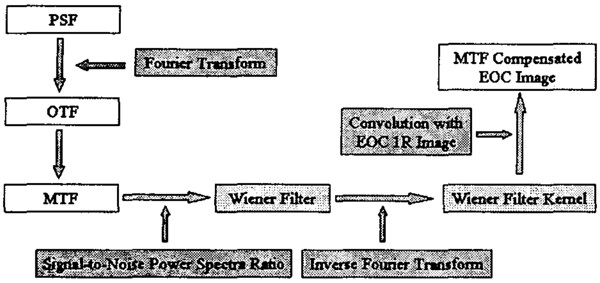


Fig.2 MTF Compensation Algorithm in EOC image processing

Fig.2 shows MTF compensation algorithm in EOC image processing. The OTF is the measure of how the optic system responds to spatial frequencies and is derived from PSF of EOC system. After OTF is acquired, MTF is calculated as the magnitude of OTF. Wiener filter is embodied in the calculation of inverse MTF. In IRPE at KGS, signal-to-noise power spectra ratio value of 3 is assigned in generating Wiener filter. After Wiener filter is inversely transformed to spatial domain, a de-convolution filter for MTF compensation in spatial domain is generated. It is convolved with EOC 1R image to generate MTF compensated EOC 1R image. Finally, MTF compensated EOC 1R images of which blurring and noise are minimized are generated. Generally, MTF compensated EOC 1R images have more sharpened features than EOC 1R images.

5. MTF Compensation with signal-to-noise Power Spectra ratio

When the PSF of EOC system is known, Wiener filter for MTF compensation of EOC images is only determined by signal-to-noise power spectra ratio. So the quality of MTF compensated EOC 1R images are dependent on signal-to-noise power spectra ratio. As MTF compensation acts on EOC 1R images as a high-pass filter, it is expected that there are some changes in the pixel value distribution patterns of horizonal and vertical lines.

In the test, we have generated Wiener filters of various signal-to-noise power spectra ratio and applied them to EOC 1R images for MTF compensation. After MTF compensated EOC 1R images are generated, they were compared with EOC 1R images. In comparison, horizontal and vertical line of MTF compensated EOC 1R images are correlated to those of EOC 1R images. Correlation would tell us how pixel value distribution patterns of horizontal and vertical lines are changed through MTF compensation and the order of linearities between them. To investigate the effect of MTF compensation according to spatial frequecies, sample images are extracted from EOC images of Jeonju city. Fig. 3 shows EOC image samples. Each EOC 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.

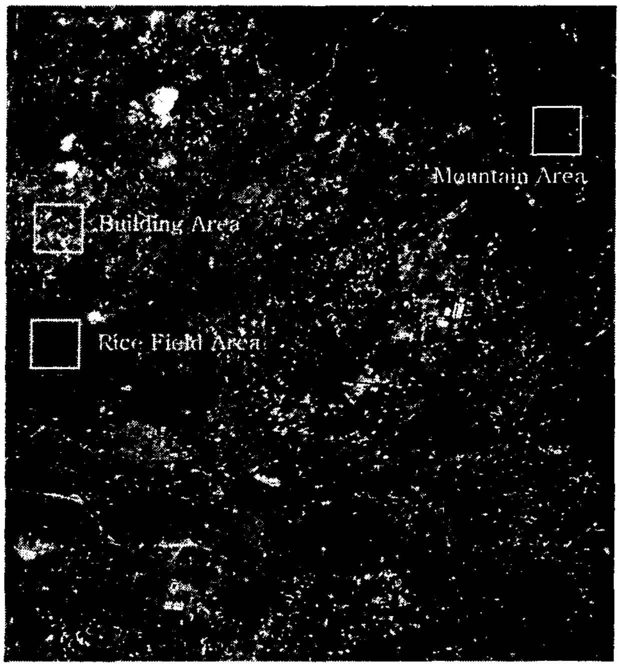


Fig. 3 EOC image samples in the test

Building Area

Building area is mainly made up of sharp-edged buildings and roads and so on. 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 1R image sample of building area. It is expected that after MTF compensation there are many changes of pixel values in high spatial frequencies area.

Fig. 4. EOC 1R Building Area Image

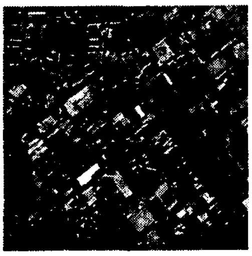


Fig.5. MTF Compensated Building Area Image

Rice Field Area

Rice field area is made up of sharp-edged rice field and roads and so on. Middle spatial frequencies are dominant over the rice field area compared to building area. Fig. 6 shows EOC 1R image sample and Fig. 7 shows MTF compensated EOC 1R image sample of rice field area.

Fig. 6. EOC 1R Rice Field Area Image

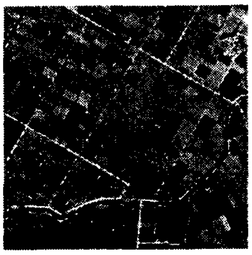


Fig.7. MTF Compensated Rice Field Area Image

Mountain Area

Mountain area has lower pixel values than building and rice field areas. There are small changes in values between successive pixels in the sample. Low spatial frequencies are dominant over the mountain area compared to building and rice field area except small town area. It is expected that there are small changes in pixel values after MTF compensation because MTF compensation emphasizes high spatial frequencies. Fig. 8 shows EOC 1R image sample and Fig. 9 shows MTF compensated EOC 1R image sample of mountain area.

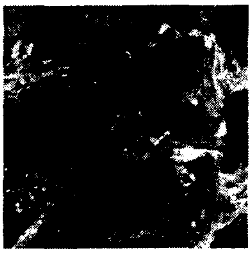


Fig. 8 EOC 1R Mountain Area Image

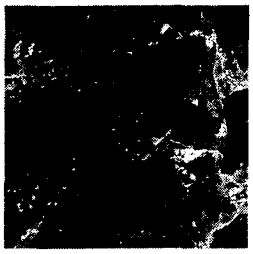


Fig.9. MTF Compensated Mountain Area Image

Test

Now, the value 3 is assigned as signal-to-noise power spectra ratio in the generation of Wiener filter in IRPE at KGS. We have inspected pixel value changes of MTF compensated EOC 1R image samples in comparison with EOC 1R image samples. In the test, Wiener filters of which signal-to-noise power spectra ratio have values from 1 to 10 were generated and each Wiener filter is convolved with EOC 1R image sample. At first, Visual inspections are executed on EOC 1R image and MTF compensated EOC images for observation of quality enhancement. At second, we have calculated correlation coefficients between them in horizontal and vertical lines for analysis after MTF compensation and get statistical informations.

Visual Inspections

Visual inspections on EOC 1R image and MTF compensated EOC images were executed for the judgment of image quality. As a result, resolutions for high spatial frequencies were enhanced with the increase of signal-to-noise power spectra ratio except value of 1. When signal-to-noise power spectra ratio has the value of 1, all sample images show more smoothed features in high spatial frequencies than EOC 1R image samples. It means that signal-to-noise power spectra ratio bigger than 1 should be applied to MTF compensation for better resolutions in high spatial frequencies.

Distributions of Correlation Coefficients

We have MTF compensated EOC 1R image samples correlated with EOC 1R image samples to observe pixel value distribution changes after MTF compensations with various signal-to-noise power spectra ratio. We have derived vertical and horizontal correlation distributions from each test. Vertical correlation distribution is the sum of correlation coefficients of all horizontal lines between EOC 1R image sample and MTF compensation EOC 1R image sample. Horizontal correlation distribution is the sum of correlation coefficients of all vertical lines. Distributions of Horizontal and Vertical Correlation Coefficients are shown from Fig. 13 to Fig. 18. In all figures, SNR means signal-to-noise power spectra ratio.

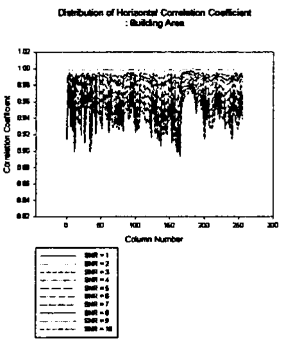


Fig. 13 Horizontal Correlation Distribution in Building Area Test

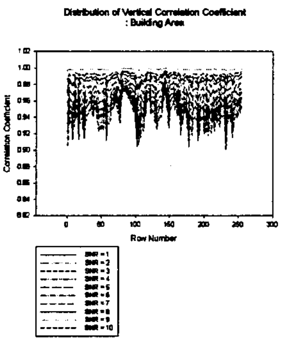


Fig. 14 Vertical Correlation Distribution in Building Area Test

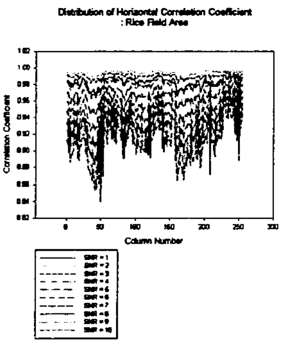


Fig. 15 Horizontal Correlation Distribution in Rice Field Area Test

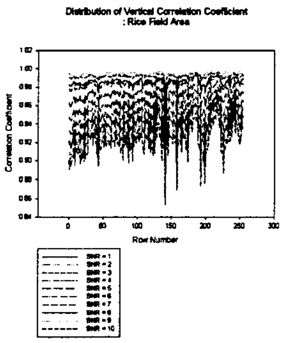


Fig. 16 Vertical Correlation Distribution in Rice Field Area Test

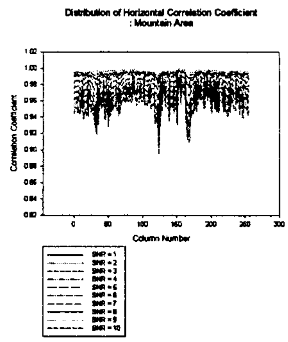


Fig. 17 Horizontal Correlation Distribution in Mountain Area Test

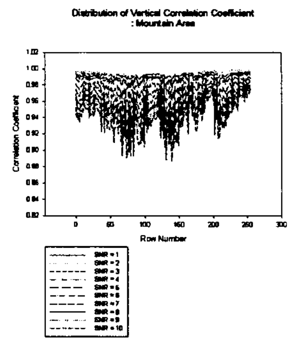
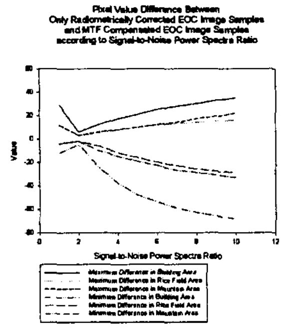


Fig. 18 Vertical Correlation Distribution in Mountain Area Test

In all cases, horizontal and vertical correlation coefficients decrease with the increase of signal-to-noise power spectra ratio. It means that the increase of signal-to-noise power spectra ratio derives more changes in MTF compensated EOC 1R images compared to EOC 1R images. It is shown that rice field area responds most sensitively to the increase of signal-to-noise power spectra ratio. It is expected that after high spatial frequencies of the rice field area be emphasized, pixel value distribution patterns has mostly changed than those of other areas. But all correlation coefficients are more than 0.8 in all above figures and it means that MTF compensation effectively enhance the sharpness of an image regardless of land features. When signal-to-noise power spectra ratio has the value of 2, there are maximum linearities between EOC 1R images and MTF compensated EOC 1R images. It is observed that there are strong linearities between EOC 1R images and MTF compensated EOC 1R images regardless of the increase of signal-to-noise power spectra ratio.

Statistics

We have calculated differences of pixel values and its standard deviations between EOC 1R images and MTF compensated EOC 1R images. Statistical informations tell us how much pixel values of EOC 1R image have been changed after MTF compensation.



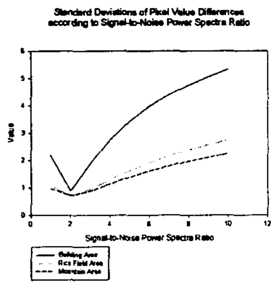


Fig. 19 Differences between EOC 1R Images and MTF Compensated 1R Images

Fig.20 Standard Deviations of Differences

Fig. 19 shows differences between EOC 1R images and MTF compensated 1R images and Fig. 20 shows standard deviations of differences. As you see in Fig. 19, maximum and minimum changes in pixel values happened in the MTF compensation EOC 1R images of building area. High spatial frequencies are dominant in MTF compensated EOC1R images of building area and characteristics of Wiener filter as a high pass filter result in much changes of pixel values in MTF compensated EOC images of building area. Relatively, MTF compensated EOC 1R images of rice field area and mountain area shows less changed features than that of building area. And maximum and minimum changes in pixel values increase with signal-to-noise power spectra ratio. In Fig. 20, standard deviations of differences are increasing with signal-to-noise power spectra ratio, too.

As a result, it is thought that increases of signal-to-noise power spectra ratio in MTF compensation result in better resolution of high spatial frequencies.

6. Conclusions

In this paper, MTF compensation in IRPE at KGS is addressed. MTF compensation includes the image restoration of EOC 1R image data with Wiener filter and MTF compensation in IRPE at KGS is processed with user's request. MTF compensated EOC 1R images shows more sharpened features that EOC 1R images.

The signal-to-noise power spectra ratio is the only variable of Wiener filter with known PSF. Signal-to-noise power spectra ratio has the value of 3 in IRPE for KOMPSAT-1 EOC images. The quality of MTF compensated EOC images changes with selecting signal-to-noise power spectra ratio.

We have tested how signal-to-noise power spectra ratio effects on MTF compensation of EOC images. Generally, EOC land imageries contain spatial frequencies of wide range. Three samples of an EOC image are selected to observe relations between signal-to-noise power spectra ratio and deformations of distribution patterns in MTF compensated EOC images. For this, we have compared MTF compensated EOC images with EOC 1R images by means of visual inspection, correlation and pixel value difference.

As a result, MTF compensation enhances qualities of EOC 1R image in view of spatial frequency and is applicable to EOC 1R image for better spatial resolutions. Although MTF compensation of EOC 1R image, linearities with EOC 1R image are maintained. It is concluded that the increase of signal-to-noise power spectra ratio results in better image qualities in high spatial frequencies of MTF compensated EOC images.

References

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