Technical Paper
J. Astron. Space Sci. 30(4), 321-326 (2013)
http://dx.doi.org/10.5140/JASS.2013.30.4.321

JASS Journal of Astronomy and Space Sciences

A Modulation Transfer Function Compensation for the Geostationary Ocean Color Imager (GOCI) Based on the Wiener Filter

Eunsong Oh[1,2], Ki-Beom Ahn[1,2], Seongick Cho[1,2†], Joo-Hyung Ryu[1]

[1]Korea Ocean Satellite Center, Korea Institute of Ocean Science and Technology, Ansan 426-744, Korea
[2]Space Optics Laboratory, Dept. of Astronomy, Yonsei University, Seoul 120-749, Korea

The modulation transfer function (MTF) is a widely used indicator in assessments of remote-sensing image quality. This MTF method is also used to restore information to a standard value to compensate for image degradation caused by atmospheric or satellite jitter effects. In this study, we evaluated MTF values as an image quality indicator for the Geostationary Ocean Color Imager (GOCI). GOCI was launched in 2010 to monitor the ocean and coastal areas of the Korean peninsula. We evaluated in-orbit MTF value based on the GOCI image having a 500-m spatial resolution in the first time. The pulse method was selected to estimate a point spread function (PSF) with an optimal natural target such as a Seamangeum Seawall. Finally, image restoration was performed with a Wiener filter (WF) to calculate the PSF value required for the optimal regularization parameter. After application of the WF to the target image, MTF value is improved 35.06%, and the compensated image shows more sharpness comparing with the original image.

Keywords: modulation transfer function, MTF compensation, Wiener filter, geostationary ocean color imager (GOCI)

1. INTRODUCTION

The world's first geostationary ocean remote-sensing instrument, the Geostationary Ocean Color Imager (GOCI), was launched on 27 June 2010 to monitor the marine environment of the Korean peninsula. GOCI provides eight image acquisitions a day for the Northeast Asian region and can be applied to various research areas, such as suspended sediment and chlorophyll concentration monitoring, in addition to providing timely warning of marine dangers. GOCI images have a 500-m spatial resolution, consisting of 16 slot images for a 2500 × 2500 km area, centered at 130°E, 36°N (Table 1) (Ryu et al. 2012). Calibration and image quality control and enhancement are crucial to the successful operation of the GOCI system. The precise image quality assessment for increasing the applicability and scientific data accuracy uses a modulation transfer function (MTF) and signal-to-noise ratio (SNR) comparison.

In image-based MTF measurement methods, the knife-edge method, point source method, and pulse method are widely used to determine whether the targeted optical system performance has been achieved in real instrument operation. These methods also account for factors influencing the space environment which can change the resulting image quality (Helstrom 1967, Holst 2008, Hwang et al. 2008, Viallefont 2010, Yin et al. 1990). A common concept among the three methods is the characterization

Table 1. General specifications of the Geostationary Ocean Color Imager (GOCI).

Items	Specification
Volume (mm^3)	1,000 × 760 × 896
Weight (kg)	< 83.3
Spatial resolution (GSD)	500 m @ point of 130°E, 36°N
Observation period	1 hour (8 times per day)
MTF requirement	> 0.3 @ Nyquist frequency
SNR requirement	> 1,000

Received Sep 7, 2013 **Revised** Nov 13, 2013 **Accepted** Nov 26, 2013
[†]**Corresponding Author**
E-mail: sicho@kiost.ac
Tel: +82-31-400-7787, Fax: +82-31-400-7715

of the spatial quality of the remote-sensing systems with the Fourier transform of the point spread function (PSF) of the target image. First, the knife-edge method uses an edge spread function (ESF) created by a well-contrasted edge area in the target image. The line spread function (LSF) is then computed by a simple discrete differentiation of the ESF; the MTF value is obtained by the Fourier transform of the LSF in the last step (Choi 2002, Viallefont 2010, Viallefont & Leger 2010). The other two methods, the point source and pulse methods, are similar to the knife-edge method, but these methods obtain the PSF values directly from a particular point source and pulse. In this case, the MTF value is computed by Fourier transformation of the PSF (Choi 2002, Leger et al. 1994).

In this study, we focused on the proper MTF estimation method using the natural target and GOCI image enhancement with MTF compensation. If we assume that the remote-sensing PSF blurs the acquired image caused by atmospheric effects, satellite conditions, and other space environment effect, then MTF compensation methods are usually used to correct image degradation with estimating blurred PSF. These MTF compensation methods include the use of an inverse filter (IF), a pseudo-inverse filter (PIF), and a Wiener filter (WF) (Demoment 1989, Jeon et al. 2012). Despite the aforementioned techniques developed and used for various remote-sensing image investigations (Reichenbach et al. 1995, Rojas et al. 2002, Ruiz & Lopez 2002, Wu & Schowengerdt 1993), image enhancement for GOCI has never been studied with MTF compensation using the Wiener Filter.

This paper begins with a description of the GOCI system, MTF estimation, and compensation technique in Section 1. The methodology used to estimate MTF with the pulse method and image enhancement by Wiener filtering as compensation is described in Section 2. Section 3 presents the enhanced image results with MTF compensation for the Saemangeum area. Conclusions are presented in Section 4.

2. METHODS

2.1 Image-based MTF assessment method: pulse method

Fig. 1 shows the general process of MTF assessment, using the pulse method. First, a PSF value is obtained from the pulse target in an acquired image. The image is then Fourier transformed from a PSF to an MTF value (Helstrom 1967). The target area for the pulse input signal should be smaller than the spatial resolution of the remote sensor. The MTF result is more accurate when the Nyquist frequency is less than the first zero-crossing frequency in the Fourier transform step (Tzannes & Mooney 1995). Fig. 1 shows the blurring of an image of a rectangular-shaped input pulse, due to environmental effects, resulting in a PSF value that has a curve-shaped output. The pulse shape is determined by the size of the target pulse width. However, because noise is included in the pulse signal, a PSF curve-fitting model should be applied, such as the Gaussian function, polynomial curve, or Fermi function, which are commonly used for this purpose (Choi 2002, Jo et al. 2008, Smith 2006). For this study, we used a Gaussian function to fit the PSF curve, defined by

$$g(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \tag{1}$$

where σ and μ are the standard deviation and median value of the Gaussian curve, respectively. These two parameters will be used in the principle values of the WF.

2.2 Remote-sensing image compensation method: Wiener filter (WF) method

The purpose of image restoration is to remove noise from remote-sensing images and to approximate the original image via estimation with an ideal degradation model.

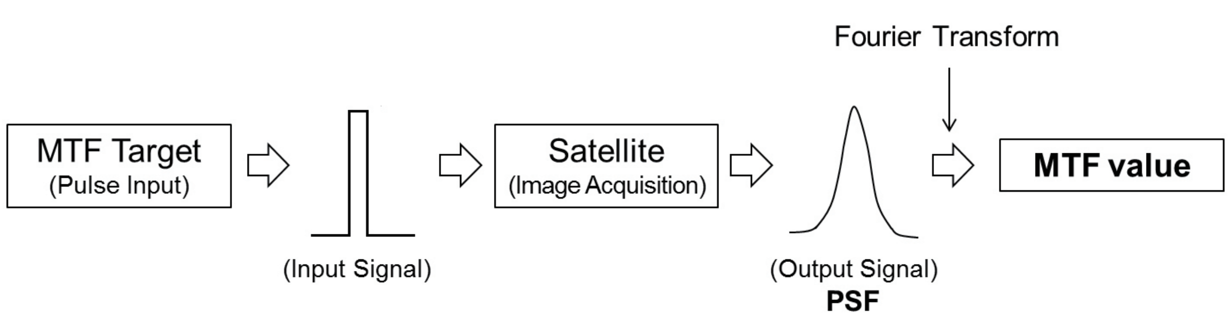


Fig. 1. Modulation transfer function (MTF) estimation process using the pulse method.

Among image restoration methods such as IF, PIF, and WF, we selected the WF method which minimizes the error in estimating the ideal image from the noisy image by linear filtering (Demoment 1989). The computational process for the WF method used in this paper is given in Eqs. (2-4):

$$g(x,y) = f(x,y) * s(x,y) + n(x,y) \tag{2}$$

$$G(u,v) = F(u,v)\,S(u,v) + N(u,v) \tag{3}$$

In Eq. (2), g(x,y) is the raw image generated from the satellite, $f(x,y)$ is the diffraction limited image, and $s(x,y)$ is the PSF. Convolution computation is denoted as *, and $n(x,y)$ is the noise. The Fourier transforms of Eq. (2) are given in Eq. (3), in which the transformed functions are represented by capital letters. Eq. (4) gives the WF value in the Fourier domain:

$$W(u,v) = \frac{S^*(u,v)}{|S(u,v)|^2 + \dfrac{c\Phi_N(u,v)}{\Phi_O(u,v)}} = \frac{S^*(u,v)}{|S(u,v)|^2 + \dfrac{1}{SNR}}, (c=1) \tag{4}$$

We estimated the PSF of the target image using the WF method designed by Helstrom (1967). The WF value is denoted as $W(u,v)$ in the Fourier domain, and $\Phi_N/\Phi_{O(u,v)}$ is the ratio of the power spectrum of the noise to the object. The ratio constant, c, controls the weight of $\Phi_N/\Phi_{O(u,v)}$; we determined that c = 1 in the computational process. $\Phi_N/\Phi_{O(u,v)}$ can then be approximated by an inverse signal-to-noise ratio (SNR) (Fienup et al. 2002). In this paper, we assumed that $S(u,v)$ is PSF curve fitted by the Gaussian function constructed with σ and μ, and $\Phi_N/\Phi_{O(u,v)}$ was calculated with the image-based SNR value. Those control parameters used in Eq. (4) will be described in Section 3.

3. RESULTS

3.1 Data processing

Fig. 2 shows the regions of interest for MTF and PSF value computation (Target A) and image-based SNR (Target B). The Target A area corresponds to the Saemangeum seawall on the west coast. The MTF in this case (i.e., the complex coastline) was estimated using the pulse method. A constant signal from the East Coast area (Target B) was selected to estimate the SNR of the image and will be used as the major element of the WF. The detailed locations and sizes of the two target areas are listed in Table 2.

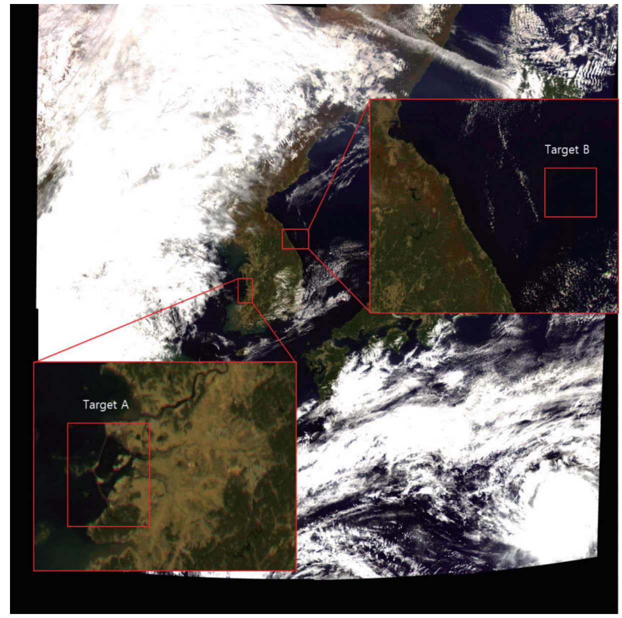


Fig. 2. Target areas. Target A and B are for calculating PSF value and SNR respectively.

Table 2. Target image areas for the modulation transfer function (MTF) and signal-to-noise (SNR) estimation.

	Target A	Target B
Latitude (°)	35.39~35.55 E	38.22°~39.20 E
Longitude (°)	126.25~126.41 N	129.93°~130.57 N

The Saemangeum seawall has an average width of 290 m, which was used to estimate the MTF value. The width of the image was estimated to be 312.02 m with a geometric slope of 67.16°. The target width as a pulse in the input signal fits the criterion of being smaller than the spatial resolution of a pixel (500 m) and is thus appropriate for our analysis. To obtain an image-based SNR, we selected an area in Target B with a chlorophyll value of less than 0.07 mg m−3. This SNR is based only on the image noise and excludes fluctuations that may exist due to ocean conditions (Hu et al. 2012).

To obtain the PSF and SNR values for the WF, the pulse signal for the target area was converted to a distribution function for each row. In Fig. 3, the radiance value for PSF for each row was ordered by the peak point at 0 pixel position (marked by 'black circular sign'). Then, the average values for the fitted curve were used to construct the PSF curve ('Red line' in Fig. 3). A Gaussian fitting curve was used to match the PSF curve as a normal distribution ('Blue line' in Fig. 3); from this, we computed σ and μ, which were 0.5645 and 0.0111, respectively. Additionally, the estimated full

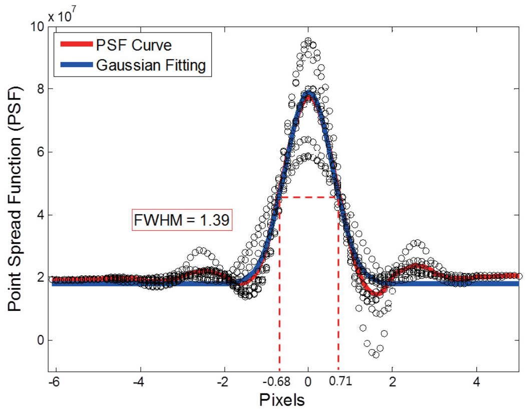
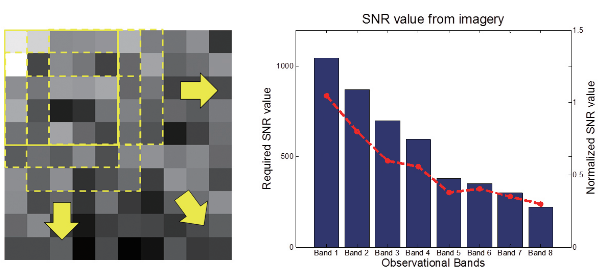


Fig. 3. Gaussian curve fitting for the estimated point spread function (PSF) from the original target image. A black circular sign means the PSF radiance value after interpolation in each pixel. Red and Blue lines are the average PSF curve and fitted Gaussian curve respectively.

Table 3. Control parameter for the MTF compensation with WF method.

Band (nm)	PSF σ	PSF μ	SNR
412			1045.77
443			870.36
490			698.11
555	0.5645	0.0111	595.48
660			379.85
680			350.87
745			299.99
865			222.14



(a) SNR estimation concept

(b) Estimated SNR based on the image signal at Target area 'B'

Fig. 4. The signal-to-noise (SNR) estimation concept (a) and calculated SNR value of the original image (b) for Target area 'B'.

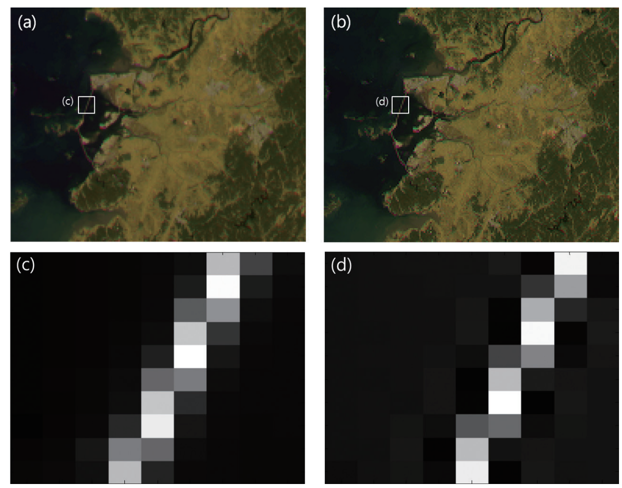


Fig. 5. (a) is the original image near Saemangum seawall, and (b) is the MTF compensated image after application of the WF. (c) and (d) image is the target area for estimating PSF value before and after application of the Wiener filter (WF) respectively.

width at half maximum (FWHM) of the fitted PSF curve was 1.3886 and did not exceed two pixels.

$$\sigma_{image}(counts) = \frac{\sum_{i=1}^{5}\sum_{j=1}^{5} DN_{ij}}{N} \tag{5}$$

$$\sigma_{image}(counts) = \frac{\sum_{i=1}^{5}\sum_{j=1}^{5} DN_{ij}}{N} \tag{6}$$

$$\sigma_{noise}(counts) = \sqrt{\frac{\sum_{i=1}^{5}\sum_{j=1}^{5} (DN_{ij} - \sigma_{image})^2}{N}} \tag{7}$$

The SNR values used in the WF for the target area (Target B) were calculated using Eq. (5) (Fig. 4). To achieve the SNR from the nearly homogeneous area in the imagery, a small square (n × n) window of pixels (in this paper, 5 × 5 pixels) was moved within the target area (100 × 100 pixels for GOCI) by one-pixel steps to obtain the average value of σ_{image} (counts) and the standard deviation value of σ_{noise} (counts), as shown in Fig. 4b.

Table 3 summarized the image restoration parameter of PSF and SNR that we calculated σ and μ value of a Gaussian fitting curve at the Target area 'A', and SNR values are estimated from each band image signal of the Target area 'B'. With those parameters, we applied WF to compensate the image, and discussed the results in the Section 3.3.

3.2 Image restoration results

In Fig. 5a and b, two red-green-blue (RGB) composite image (R: 680 nm, G: 555 nm, B: 412 nm) obtained at UTC 03 on 16 October 2012 are compared that the MTF compensated image illustrates the improved image quality in aspect of sharpness and contrast in the coastal area near the Saemangeum seawall and inland river boundary. We compared the MTF results between the original and enhanced images after estimating the PSF with the WF method to confirm this difference quantitatively with using the target areas as shown in Fig. 5c and d.

The FWHM and PSF values of the reconstructed image using the WF were improved significantly compared with the original image. In Fig. 6, the FWHM and the σ

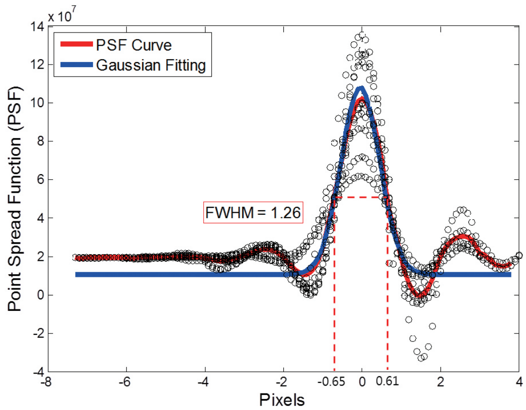


Fig. 6. Gaussian curve fitting for the estimated PSF from the enhanced target image with the WF.

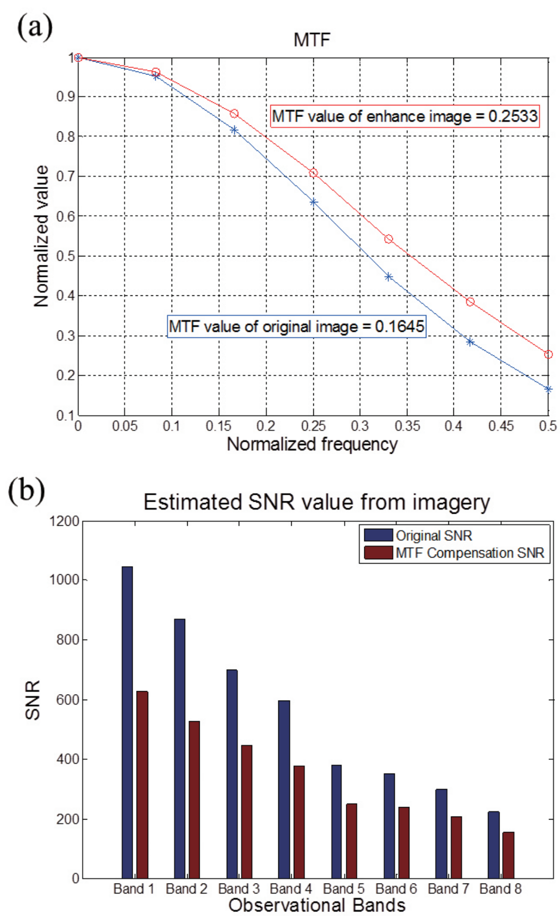


Fig. 7. (a) Comparison of MTF results between the original (blue line) and enhanced (red line) images, (b) The SNR value variation for all bands after applied WF MTF compensation.

value of the standard deviation of the Gaussian function improved from 1.3886 to 1.2600 and from 0.5645 to 0.4924, respectively. Finally, the MTF value at the Nyquist frequency increased by 35.06% (0.2533) compared with the source image as shown in Fig. 7a. On the other hand, SNR values estimated in the Target 'B' are decreased for all bands. In case of band-8, the estimated SNR value based on the image is changed from 222.14 to 155.62.

4. CONCLUDING REMARKS

This study was performed to evaluate the image quality of the GOCI system with the first suggested technique using the natural target, as well as to improve its quality with MTF compensation based on the WF method. We measured the MTF for a natural target, the Saemangeum seawall, at UTC 03 on 16 October 2012 and designed a WF with a PSF value, on the basis of MTF processing and SNR values obtained for seawater. After application of the WF to the target image, the enhanced image was generated with a 35.06% improved MTF value compared with the original image.

Despite the 500-m spatial resolution of the GOCI satellite image, it is difficult to estimate the exact PSF value. In addition, the SNR values are also relatively estimated based on the image, and that is reason why the SNR value is underestimated comparison with requirement. Although SNR value is decreased from applying MTF compensation, the enhanced image having high MTF value can be practically used in monitoring works and researches in coastal area. Furthermore, the relationship between ocean color product accuracy and MTF enhanced image will be discussed with further investigation in the near future.

Thus, the significance of this paper lies in the improvement of the image quality using the well-constructed WF method with Gaussian curve fitting. With the restoration results, the complexities of the west coast area and its islands were clearly distinguished with the naked eye as a result of the improved image quality. Additionally, this work is firstly suggested to estimate in-orbit MTF and SNR value, and generate the MTF compensated image of geostationary orbit satellite for ocean monitoring. We believe that the results of this study are expected to provide a more accurate description of the coastal regions for improvement in image processing such as cloud detection for atmospheric correction and ocean color data in coastal area.

ACKNOWLEDGMENTS

This research was a part of the project titled "Geostationary earth orbit Korea Multi-Purpose Satellite Ocean Monitoring Payload Development" funded by the Ministry of Land, Transport and Maritime Affairs, Korea, and as Basic Research Projects (PE98985) of the Korean Institute of Ocean Science and Technology.

REFERENCES

Choi T, IKONOS Satellite on Orbit Modulation Transfer Function (MTF) Measurement using Edge and Pulse Method, MSc Thesis, South Dakota State University (2002).

Demoment G, Image reconstruction and restoration: Overview of common estimation structures and problems, Acoustics, Speech and Signal Processing, IEEE Transactions on 37, 2024-2036 (1989).

Fienup JR, Griffith DK, Harrington L, Kowalczyk A, Miller JJ, et al., Comparison of reconstruction algorithms for images from sparse-aperture systems, Proc. SPIE, 4792, 1-8 (2002).

Helstrom CW, Image restoration by the method of least squares, JOSA, 57, 297-303 (1967).

Holst GC, Electro-optical imaging system performance (SPIE press, Bellingham, Washington, 2008).

Hu C, Feng L, Lee Z, Davis CO, Mannino A, et al., Dynamic range and sensitivity requirements of satellite ocean color sensors: Learning from the past, Applied Optics, 51, 6045-6062 (2012).

Hwang H, Choi YW, Kwak S, Kim M, Park W, et al., MTF assessment of high resolution satellite images using ISO 12233 slanted-edge method, in Proc. SPIE, 7109, 710905-1-9 (2008).

Jeon B-I, Kim H, Chang YK, A MTF compensation for satellite image using L-curve-based modified Wiener filter, Korean Journal of Remote Sensing, 28, 561-571 (2012).

Jo HG, Kim JH, Choi SC, Lee SK, Kim J-M, et al., A study on the simulation method of satellite image quality considered design, manufacturing and operation, Korean Journal of Remote Sensing, 24, 591-603 (2008).

Leger D, Duffaut J, Robinet F, MTF Measurement Using Spotlight, Proc. IGARSS, 7803, 2010-2012 (1994).

Reichenbach SE, Koehler DE, Strelow DW, Restoration and reconstruction of AVHRR images, Geoscience and Remote Sensing, IEEE Transactions on 33, 997-1007 (1995).

Rojas F, Schowengerdt RA, Biggar SF, Error and correction for MODIS-AM's spatial response on the NDVI and EVI science products, Proc. SPIE, 4814, 447-456 (2002).

Ruiz CP, Lopez FJA, Restoring SPOT images using PSF-derived deconvolution filters, International Journal of Remote Sensing, 23, 2379-2391 (2002).

Ryu JH, Han HJ, Cho S, Park YJ, Ahn YH, et al., Overview of geostationary ocean color imager (GOCI) and GOCI data processing system (GDPS), Ocean Science Journal, 47, 223-233 (2012).

Smith EHB, PSF estimation by gradient descent fit to the ESF, Proc. SPIE, 6059, 60590E-1-9 (2006).

Tzannes AP, Mooney JM, Measurement of the modulation transfer function of infrared cameras, Optical Engineering, 34, 1808-1817 (1995).

Viallefont F, Edge method for on-orbit defocus assessment, Optics Express, 18, 20, 20845-20851 (2010).

Viallefont F, Leger D, Improvement of the edge method for on-orbit MTF measurement, Optics Express, 18, 4, 3531-3545 (2010).

Wu HHP, Schowengerdt RA, Improved estimation of fraction images using partial image restoration, Geoscience and Remote Sensing, IEEE Transactions on 31, 771-778 (1993).

Yin FF, Giger ML, Doi K, Measurement of the presampling modulation transfer function of film digitizers using a curve fitting technique, Medical Physics, 17, 962 (1990). http://dx.doi.org/10.1118/1.596463