The modulation transfer function measurement method via using kernel estimation from satellite image

Yu-Lin Tsai (1), Kuo-Hsien Hsu (1), Yun-Shan Lee (1), Shiau-Jing Liu (1)

[1]National Space Organization, 8F, 9 Prosperity 1st Road, HsinChu, Taiwan
Email: morphling@nspo.narl.org.tw ; khhsu@nspo.narl.org.tw ; sunnylee@nspo.narl.org.tw ; cynthia@nspo.narl.org.tw

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ABSTRACT: The modulation transfer function (MTF) is to evaluate the resolution and contrast information of the optical systems and remote sensing satellites. The MTF of remote sensing system is measured by edge method or pulse method on the ground. However, remote sensing satellite is also required to evaluate and monitor the performance on orbit. On orbit, the MTF evaluation is constrained by location of calibration targets. Therefore, this paper presents the MTF measurement method via using image-based kernel estimation method for nonexistent calibration targets in satellite image. The MTF is the expression of the two-dimensional point spread function (PSF), which can be predicted by image-based kernel estimation method, in frequency domain.

$$\mathrm{MTF} = |\mathcal{F}\{PSF\}| \tag{1}$$

The PSF is generated by integrating multiple PSFs which are estimated by the different piece of the satellite image for eliminating the noise of PSF. The kernel estimation method, which is to select the usefulness of image edges, uses total variation method under L^0 norm for generating a sparse kernel and edge blurring model

$$\nabla \mathrm{B} = \nabla \mathrm{I} \otimes PSF \tag{2}$$

Where B and I are observed image and clear image, respectively. The MTF is finally calculated as a function in two-dimensional frequency domain. The result shows that the MTF of remote sensing image can be observed without particular calibration targets.

1. Introduction

The modulation transfer function, which describes the ability of optical system to transfer detail information from object space to image space (Goodman, 2005), is a convenient measurement index for evaluating the performance of the optical systems and remote sensing satellites. On the ground, the MTF measurement method can be classified into two algorithms: (1) knife edge method and (2) pulse method. The knife edge method is to extract MTF from the image of slanted edge test target (Tzannes et al., 1995, Li et al., 2016). The line spread function (LSF) can be considered as integral of PSF along one direction $n^{\perp}$. The MTF along direction n can be derived by

$$\mathrm{MTF}(f_n) = |\mathcal{F}\{LSF(n \cdot s)\}| \tag{3}$$

The LSF can be computed by the derivative of the edge spread function (ESF) which is the image of slanted edge test target. In the other way, the pulse method is to create a target which consists of a slightly slit surrounded by dark regions. The LSF can be directly measured by image of target (Fujita et al., 1992). On orbit, the MTF of remote sensing satellite must be measured during a period of time for checking the performance of spatial resolution. The Edge calibration targets are built for MTF measurement by the requirement of knife edge method (Kohm, 2004). There are limitations for acquiring the images of calibration targets. In the urban area, suitable edges can be used for measuring MTF (Wang et al., 2009). In the other way, the pulse method is to watch stars which can be treated as a perfect pulse function for measuring the points spread function (Kang et al., 2015).

In digital image processing techniques, image deblurring technique is used to enhance image sharpness and signal-to-noise ratio. One of major image deblurring processing is to estimate kernel function of image, which is also called PSF. The estimated PSF of remote sensing imaging system is combination of PSF of remote sensing optical system and atmospheric interference. The PSF estimation methods are formulated by statistical model or total variation model. The image blurred model is formulated

$$\mathrm{B} = \mathrm{I} \otimes PSF + n \tag{4}$$

The maximum a posteriori method is to maximize conditional probability $\mathrm{p}(I, PSF|B)$ for estimating PSF via approximated pair (I, PSF) (Levin et al., 2009). A different maximum a posteriori method is to consider the PSF which is a finite impulse response (Fergus at al., 2009). Xu and Jia (Xu, L. et al., 2010; Xu, L. et al., 2013) are proposed two phase kernel estimation based on Equation (1) by selecting sharp image edge and refining kernel though iterative support detection (Wang, Y., & Yin, W., 2010). The objective function is modeled by total variation method under L^0 norm for generating a sparse kernel, as shown in below

$$\mathrm{E}(PSF) = \|\nabla \mathrm{I} \otimes PSF - \nabla \mathrm{B}\|^2 + \gamma \|PSF\|_0 \tag{5}$$

In this paper, we propose an on orbit MTF measurement method without particular calibration targets based on kernel estimation method.

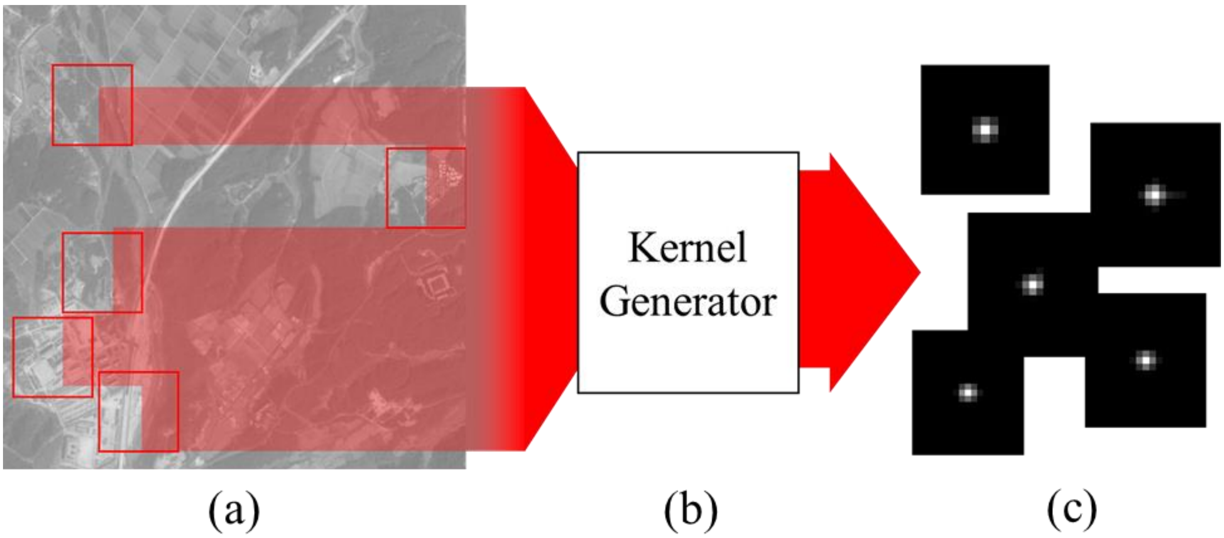

Figure 1. (a) Select region which contain enough edge information. (b) The kernel generator can use Levin's method, Fergus's method, two phase kernel estimation, and etc. (c) estimated PSFs.

2. Methodology

2.1 Point Spread Function pre-processing

We base on the PSF satisfies independent of position in the object plane, which is called shift-invariant. We first select several regions, which contain enough edge information, in the image, as shown in Figure 1(a). The kernel generator can use Levin's method, Fergus's method, two phase kernel estimation, and etc., as shown in Figure 1(b). Figure 1(c) shows the estimated PSFs from different region. A PSF set K can be defined by

$$K = \{PSF \mid the\ PSF\ is\ estimated\ from\ different\ region\} \tag{6}$$

The kernel estimation process introduce a small perturbation, which can be considered as random noise, into the PSF. To eliminate the random noise, we take the average of the estimated PSFs in Equation (7).

$$\overline{PSF} = \frac{1}{n}\sum_{i=1}^{n} PSF_i \quad where\ PSF_i \in K \tag{7}$$

2.2 Point spread function modeling

The two-dimensional Gaussian distribution function fitting in Equation (8) is applied to the $\overline{PSF}$ for the sub-pixel interpolation.

$$\widehat{PSF}(x,y) = \mathrm{A}e^{-\frac{1}{2}\left(\frac{x^2}{\sigma_x^2}+\frac{y^2}{\sigma_y^2}\right)} \tag{8}$$

Where A is amplitude of the Gaussian distribution, σ_x and σ_y are the stand derivation of the Gaussian distribution along x and y direction, respectively. Taking the natural logarithm of the Gaussian distribution in Equation (8) yields

$$\begin{aligned} \ln \widehat{PSF}(x,y) &= -\frac{1}{2\sigma_x^2}x^2 - \frac{1}{2\sigma_y^2}y^2 + \ln A \\ &= a_1x^2 + a_2y^2 + a_3 \end{aligned} \tag{9}$$

These parameters can be estimated by weighted least squares Gaussian curve fitting algorithm (Guo, 2011, Kang et al., 2015).

$$\begin{bmatrix} \iint x^4p_{k-1}^2dA & \iint x^2y^2p_{k-1}^2dA & \iint x^2p_{k-1}^2dA \\ \iint x^2y^2p_{k-1}^2dA & \iint y^4p_{k-1}^2dA & \iint y^2p_{k-1}^2dA \\ \iint x^2p_{k-1}^2dA & \iint y^2p_{k-1}^2dA & \iint p_{k-1}^2dA \end{bmatrix} \begin{bmatrix} a_1^k \\ a_2^k \\ a_3^k \end{bmatrix} = \begin{bmatrix} \iint x^2p_{k-1}^2 \ln \widehat{PSF}\, dA \\ \iint y^2p_{k-1}^2 \ln \widehat{PSF}\, dA \\ \iint p_{k-1}^2 \ln \widehat{PSF}\, dA \end{bmatrix} \tag{10}$$

Where

$$p_k = \begin{cases} \widehat{PSF} & for\ k = 0 \\ e^{a_1^kx^2+a_2^ky^2+a_3^k} & for\ k > 0 \end{cases} \tag{11}$$

The two-dimensional MTF can be computed by taking the fitted Gaussian curve function into Equation (1).

3. Result

In this study, we use the Formosat-2 image as the test data for kernel estimation based MTF measurement. In the Formosat-2 image, we select twenty sub-images at 800 x 800 pixels. Those selected sub-images should contain enough edge information. In our experience, the urban area and clear road image can generate a suitable kernel function.

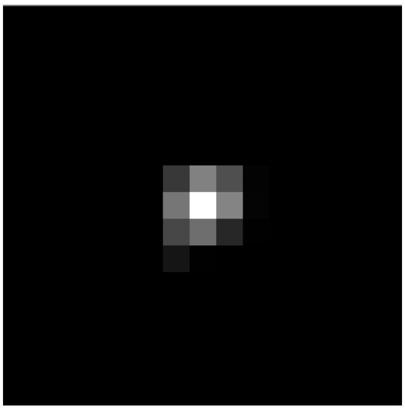

Figure 2. Estimated PSF

Figure 2 shows the estimated PSF with random noise. The average of the estimated PSFs for eliminating random noise, as shown in Figure 3.

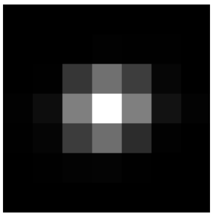

Figure 3. Average of Estimated PSFs

Figure 4 shows the average PSF is modeled by using Gaussian function with A $= 1.001$, $\sigma_x = 0.6464$, and $\sigma_y = 0.6168$.

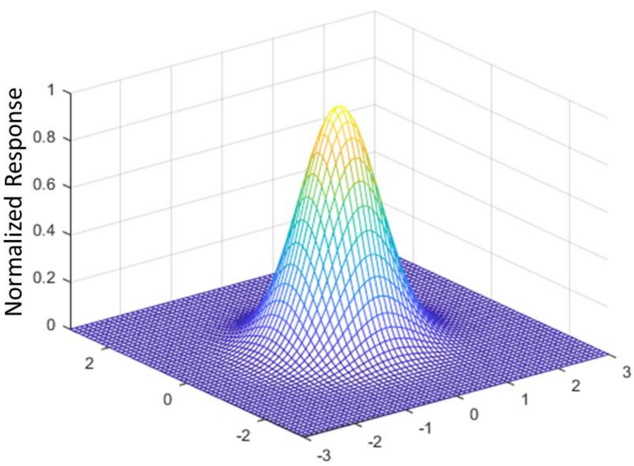

Figure 4. The average PSF is modeled by using Gaussian function

Figure 5 shows the MTF curve along the cross-track direction and along-track direction. The

MTF values at the Nyquist frequency are 0.1275 and 0.1533 in the cross-track direction and along-track direction, respectively. This result shows the consistency between proposed method and Formosat-2 performance.

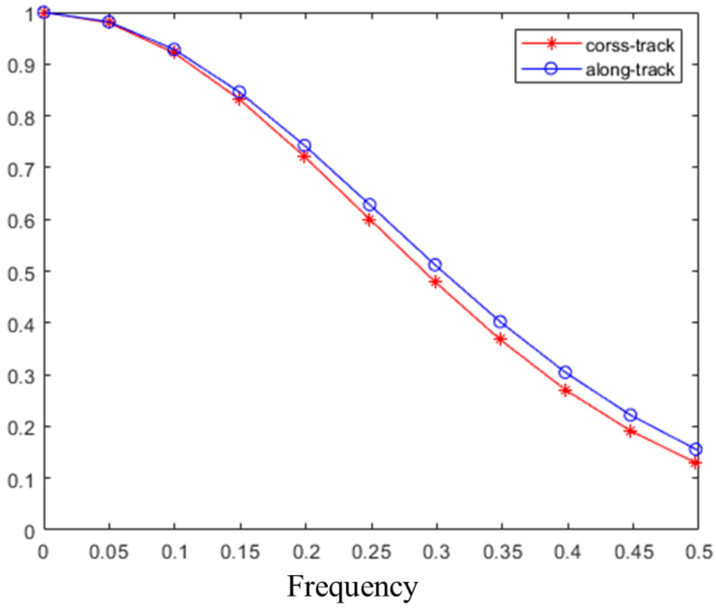

Figure 4. The average PSF is modeled by using Gaussian function

4. Conclusion

In this paper, we propose an MTF measurement method which is based on kernel estimation technique in digital image processing. This MTF measurement method can diminish for observing the particular calibration targets. The result shows the MTF values at the Nyquist frequency have consistency between proposed method and Formosat-2 performance.

5. References

Fergus, R., Singh, B., Hertzmann, A. Roweis, S. T., and Freeman, W. T., 2006. Removing camera shake from a single photograph. In: ACM Transactions on Graphics, Vol. 25

Fujita, H, Tsai, D. Y., Itoh, T., Doi, K., Morishita, J., Ueda, K., and Ohtsuka, A., 1992. A simple method for determining the modulation transfer function in digital radiography. IEEE Transactions on Medical Imaging, 11 (1), pp. 34-39.

Goodman, J.W., 2005. Introduction to Fourier Optics. Roberts and Company, Colorado, pp. 127-172

Guo, H., 2011. A simple algorithm for fitting a Gaussian function. IEEE Signal Processing Magazine, 28 (5), pp. 134-137.

Kang, C. H., Chung, J. H., and Kim Y. H., 2015. On-orbit MTF estimation for the KOMPSAT-3 satellite using star images. Remote Sensing Letters, 6 (12), pp. 1002-1011.

Kohm, K. 2004. Modulation transfer function measurement method and results for the Orbview-3 high resolution imaging satellite. In: Proceedings of ISPRS, pp. 12-23

Levin, A., Weiss, Y., Durand, F., and Freeman, W. T., 2009. Understanding and evaluating blind deconvolution algorithms. In: Computer Vision and Pattern Recognition, Miami, pp. 1964-1971.

Li, H., Yau, C., and Shao, J. 2016. Measurement of the Modulation Transfer Function of Infrared Imaging System by Modified Slant Edge Method. Journal of the Optical Society of Koream, 20 (3), pp. 381-388.

Tzannes, A. P., and Mooney, J. M., 1995. Measurement of the modulation transfer function of infrared cameras. Optical Engineering, 34 (6), pp. 1808-1817.

Wang, T., Li, S., and Li, X., 2009. An automatic MTF measurement method for remote sensing cameras. In: The 2nd IEEE International Conference on Computer Science and Information Technology 2009, pp. 245-248.

Wang, Y., & Yin, W. (2010) Sparse signal reconstruction via iterative support detection. SIAM Journal on Imaging Sciences, 3 (3), pp. 462-491.

Xu, L., Zheng, S., and Jia, J. (2013). Unnatural l0 sparse representation for natural image deblurring. In: Computer Vision and Pattern Recognition, pp. 1107-1114

Xu, L., and Jia, J., 2010. Two-phase kernel estimation for robust motion deblurring. In: European conference on computer vision, Berlin, pp. 157-170.