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An automatic MTF measurement method for remote sensing cameras

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The modulation transfer function (MTF) for remote sensing imaging sensors sometimes need be automatically measured both in order to fast calibrate them for best performance while working on board and to do (near) real-time digital compensation for inevitable degradation. In this paper, we presented such an automatic MTF measurement approach. It is based on the detection of straight lines with Hough transforms. Once qualified lines are determined, the MTF is estimated by a step edge method. Experiments with IKONOS images showed the proposed technique has a high success rate for automatically measuring the MTF with an acceptable accuracy.

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1. Introduction

The modulation transfer function (MTF) of an optical imaging system [1] is a fundamental specification with regard to imaging quality. Images acquired by space-borne or air-borne cameras undergo a certain degree of degradation caused by lens out-of-focus, atmospheric turbulence, platform shake or relative movement and so forth. The MTF is a measure to the degradation of an imaging system. On-board (on-orbit) MTF measurement methods in practical use are exclusively implemented by examining step edges or pulse lines in acquired images [2-4]. All the known work, to the authors' knowledge, needs experts to choose proper edges or lines to make an estimation of MTF. However, sometimes the MTF needs to be estimated automatically in a (near) real time basis while the sensor is working on board in order to calibrate the sensor for best performance with imaging environments changed, and also to make immediate compensation for inevitable degradation, which enables fast supply of image products.

In this paper, we present an automatic on-board MTF measurement approach based on the detection of straight lines with Hough transforms. Once qualified lines are determined, the MTF is estimated by a step edge method.

2. The proposed method

2.1 Overall scheme

Since the MTF is measured by a step edge method, we first use Hough transform to detect straight lines, then we give a set of conditions to choose the qualified lines that can be used for MTF estimation, and following that, the estimation of MTF can be conducted. The overall scheme is shown in a diagram in Fig. 1. The main phases will be explained in the following subsections.

2.2 Straight line detection

Straight line detection is a most investigated problem in machine vision. Among its variety of algorithms, the classical ones are Hough transform [5] and its many variations, such as randomized [6], constrained [7] and regularized [8] and so on.

In the straight line detection phase, classical Hough transform is employed. The Hough transform maps a line in the image space to a point in a parameter space. Now suppose we have a straight line in an image. All the points on it, denoted by (x_i, y_i), satisfy

$$y_i = m_0 \cdot x_i + c_0 \qquad (1)$$

in (*x*, *y*)-plain. So the line can be mapped to point (m_0, c_0) in slope-intercept (*m*, *c*)-plain.

Reversely, a point (x_0, y_0) in (*x*, *y*)-plain takes the form

$$y_0 = m \cdot x_0 + c \tag{2}$$

with (*m*, *c*) being arbitrary numbers that satisfy

$$c = -x_0 \cdot m + y_0 \tag{3}$$

which is clearly a line in (*m*, *c*)-plain.

Collinear points (x_i, y_i) in (*x*, *y*)-plain share the same values of *c* and *m*, so the lines in (*m*, *c*)-plain that they correspond to intersect at one point. In other words, if a point (m_0, c_0) in (*m*, *c*)-plain have many lines intersected at it, there must be as many collinear points in (*x*, *y*)-plain. Based on this inspiration, a straight line detection algorithm can be described as follows:

1) Edge detection. Find the edges with any suitable edge detection method;

2) Quantization. Quantize the (*m*, *c*)-plain into cells with suitable quantization levels;

3) Voting. For each cell, set its value to be the number of edge pixels whose correspondent line in (*m*, *c*)-plain passes the cell;

4) Thresholding. Only those cells with suitable large values are considered to correspond to a line in (*x*, *y*)-plain;

5) Line ending. Incorporate line detection and edge detection results and can decide the ends of lines without difficulty.

2.3 Conditions for qualified lines

Automatic measurement of MTF depends on the acquisition of straight lines that can be modelled as step edges. A qualified candidate line must satisfy the following conditions:

1) The neighbouring areas (width = n) on both sides of the line have similar (difference < s) radiometric values (or digital number, DN), respectively;

2) The two areas mentioned above have a large difference (> d) in radiometric values (or DN).

Figure 2(a) gives an illustration of such a line. If we visit the line orthogonally from the left neighbouring area to the right, as along the *x* (arrow) direction, an ideal step form of DN will be obtained, as shown in figure 2(b).

After straight lines are detected, the conditions are tested and only those qualified lines may enter the estimation phase. A confidence is given to each qualified line, according to how well they satisfy the conditions. The confidence, together with estimated MTF, will be saved for later use.

2.4 MTF estimation with step edges

After straight lines are detected and conditions test is done, the MTF is estimated with step edge method [4]. As illustrated in Fig. 2, an ideal step edge is obtained when we visit the detected line orthogonally from the left neighbouring area to the right, as along the x (arrow) direction.

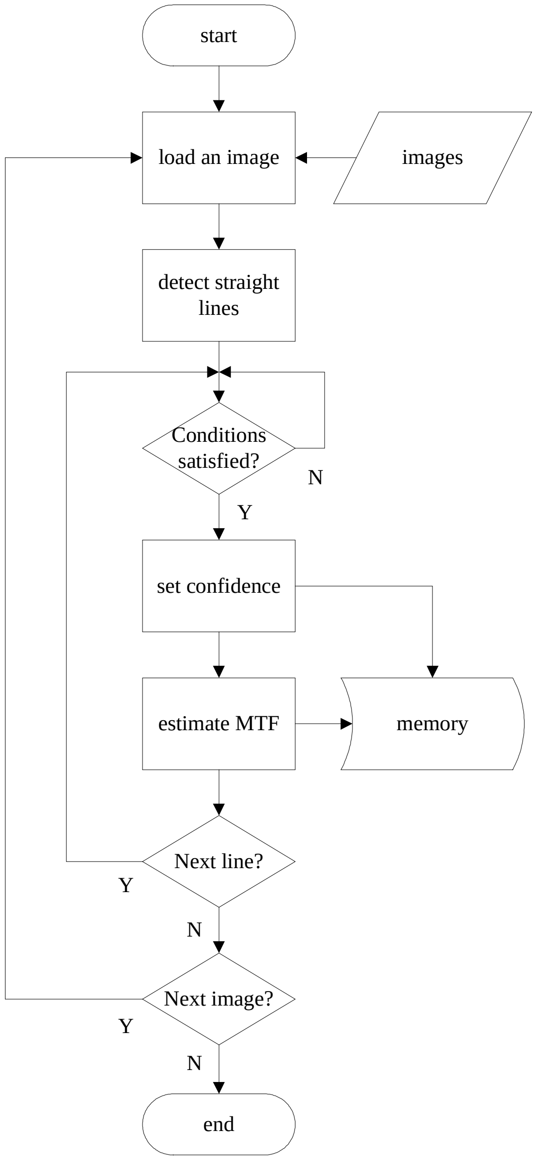
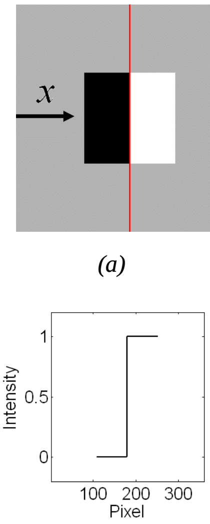


Fig. 1. Overall scheme diagram.



(a)

(b)

Fig. 2. An ideal step edge model.

For a real imaging system, the ideal step edge will be spread or degraded to a gradually changing band, as shown in Fig. 3(a, b). Let *u*, *y* and *h* denote the ideal step function, real observed edge spread function (ESF) and the line spread function (LSF), then

$$y(n) = u * l(n) = \sum_{k \le n} l(k) \tag{4}$$

So the LSF *l* can be simply obtained by differentiating *y*, that is,

$$l(n) = y(n) - y(n-1) \tag{5}$$

as shown in Fig. 3(c).

Under the assumption that the point spread function (PSF) H is homogenous, it in the matrix form can be calculated from the LSF in the vector form,

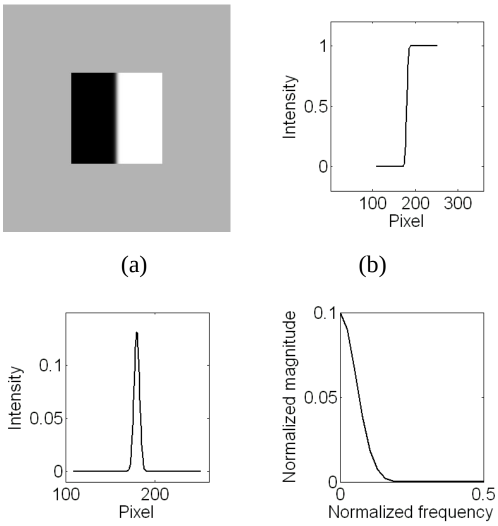
$$H = h \cdot h^T / \sum (h \cdot h^T) \tag{6}$$

where the denominator is only for the purpose of normalization.

Finally, the MTF is the magnitude of the Fourier transform of PSF by definition,

$$MTF = \left| \mathrm{DFT}(H) \right| \tag{7}$$

which is shown in Fig. 3(d).



(a) (b)

(c) (d)

Fig. 3. Step edge method (a)degraded edge; (b)ESF; (c)LSF; (d)MTF.

If more than one qualified line is detected for an image, the estimated MTFs are to be averaged to obtain the final MTF that corresponds to the imaging situations when the image is taken.

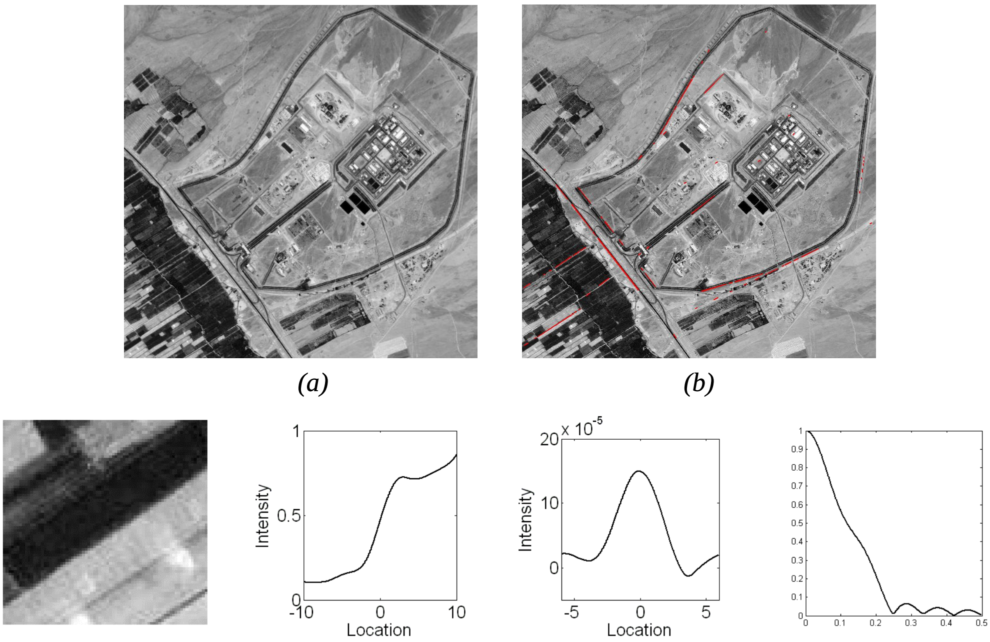
3. Results and discussion

An image set of 42 IKONOS remote sensing images was used in our experiments to verify the proposed approach. A comparison of results of the proposed automatic MTF estimation with those of expert-conducted measurement for the same set of images is listed in Table 1. The first field of the table, No, is the image number. The second field, nL, is the number of qualified lines that were detected for the image. The last field, rmse, is the relative mean square error between the results of the proposed approach and expert-conducted one. We can see from the table that 76% images from the set can be successfully detected at least one qualified straight line, and that, for images with qualified lines detected, the difference (measured by rmse) between the results of the proposed automatic estimation and the expert-conducted measurement is no more than 12%.

Table 1. Comparison of experiment results.

No.	nL	rmse	No.	nL	rmse
1	2	11.83	22	3	2.01
2	5	0.15	23	2	10.58
3	1	5.36	24	2	6.21
4	0	-	25	0	-
5	0	-	26	1	6.97
6	1	7.16	27	1	8.11
7	3	6.55	28	4	0.20
8	2	3.14	29	3	2.78
9	2	2.75	30	3	6.36
10	3	5.73	31	3	3.27
11	0	-	32	1	6.72
12	0	-	33	0	-
13	5	1.06	34	1	1.49
14	2	1.85	35	1	4.73
15	2	8.36	36	5	1.16
16	4	0.09	37	3	5.91
17	4	7.22	38	3	6.54
18	0	-	39	1	10.80
19	1	7.21	40	0	-
20	1	3.79	41	2	4.99
21	0	-	42	0	-

The main intermediate and final results are also illustrated for one of the images, as displayed in Fig. 4 (a) and (b) are the original image and the resulting image with straight lines detected, respectively. (c) is a zoomed qualified straight line in the image. (d)-(f) are the ESF, LSF and MSF estimation out of the zoomed line.



(c) (d) (e) (f)

Fig. 4. Automatic MTF measurement (image source: ©GeoEye)(a)original image; (b)lines detected; (c)a qualified line, zoomed; (d)ESF□(e)LSF; (f)MTF.

The Hough transform is somewhat slow and sensitive to quantization of parameters, but it is robust to noise and can well and concisely convey the main idea of this paper, without entering into minor details. In real implementation of the proposed approach, a more efficient and accurate variation may be used instead, such as the constrained Hough transform [7], which can solve the detection problem in O(*n*) complexity, where *n* is the pixel numbers.

When implementing the MTF estimation, the following concerns should be noted.

1) For each detected line, several orthogonal visits in equal intervals along the line should be done to reduce the error of observed ESF;

2) The coarse observed ESF should be interpolated by a suitable interpolation method to obtain a smooth ESF;

3) Before the calculation of PSF with LSF, the LSF should be trimmed to reduce the noise present in the small-value ending points on both sides.

4. Conclusions

In this paper, we presented an automatic approach to measure MTF for airborne or satellite remote sensing imaging sensors. It is based on the detection of straight lines with Hough transform. A set of conditions are formulated to choose qualified lines. Once qualified lines are obtained, a step edge method is taken to measure the MTF. Experiments with real remote sensing images showed that the proposed approach can automatically measure the MTF with a high success rate and an acceptable accuracy.

The classical Hough transform is employed in order to concisely describe the basic idea. More efficient variations may be used instead, to reduce computational complexity and increase line detection accuracy.

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References

[1] R. A. Schowengerdt, Remote sensing: models and methods for image processing, Academic Press, San Diego, 1997.

[2] K. Kohm, in ISPRS Congress, Istanbul, 12, 2004.

[3] U. M. Leloglu, E. Tunali, in ISPRS Commission 1 Symposium, 4, 2006.

[4] T. Choi, M. S. thesis, South Dakota State University, Brookings, SD, USA, 2002.

[5] J. Illingworth, J. Kittler, Computer Vision, Graphs, & Image Process **44**, 87 (1998).

[0] [6] L. Xu, E. Oja, P. Kultanen, Pattern Recognition Letter **11**, 331 (1990).

[0] [7] C. F. Olson, Computer Vision and Image Understanding **73**(3), 329 (1999).

[8] N. Aggarwal, W. C. Karl, IEEE Trans. on Image Processing **15**(3), 582 (2006).

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