The research of the accurate measure of static transfer function for the TDI CCD camera

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Abstract. In the test course of static transfer function of TDI CCD camera, because of the influence that gets environmental and artificial etc. factor, the value of static transfer function measured at any time is between unceasing fluctuation, so, make accuracy reduce. To solve this problem, a kind of accurate measurement technique of static transfer function is put forward. First, before carrying out the measure of static quiet of transfer function, the best test point of transfer function of the TDI CCD camera must be determined, it is parallel to guarantee the rectangle target surface of parallel optical pipe and camera focal plane maintenance parallel, and again guarantee target strip in rectangle target and TDI CCD in camera focal plane maintenance vertical. TDI CCD catches rectangle target image, per 1000 lines of target mark image as a measures sample of static transfer function, exclude because of atmosphere tremble twisted, vague rectangle target mark image, retain 500 distinct and steady target mark image as measure sample set. Then, calculate the static transfer function of each measure sample respectively, take the average of all static quiet transfer function in measure sample set as the static transfer function of camera. Finally, the measure of the static transfer function for TDI CCD camera makes error analysis. Experimental results indicate that the value of the static transfer function of TDI CCD camera measured with this kind of method is 0.2923, with before measurement technique comparison, the value of static transfer function has raised 0.02, makes the accuracy of the measure of static transfer function have gotten raising.

1 Introduction
The modern remote sensing digital camera of high resolution capacity adopt TDI CCD push sweep image pattern\(^{[1-3]}\), MTF (Modulation Transfer Function) is to appraise a important index like image quality and application ability for this kind of camera, and it have reflected camera each space frequency weight in scenery respond property. The MTF of TDI CCD camera is including the static transfer function and the dynamic transfer function, after completing a series of works such as optical, mechanical and electronic installation and test in laboratory, the test of the static transfer function for TDI CCD camera must be carried out. In the test course of static transfer function of the TDI CCD camera, test environmental (atmosphere shake and environmental temperature), test method (target mark to carve line and transfer function calculation method), other aspects such as the space location of measure system can also affect as transfer function test produces. In which, major influencing factor is the space location of measure system and atmosphere tremble\(^{[4]}\).

Now, the method of testing static transfer function of the TDI CCD camera has a lot, including the point source method, the line source method, edge side method, sine input method and rectangle
input method, but in laboratory the method of major adopting is rectangle input method. This paper has put forward a new kind of method of accurate measure static transfer function on the foundation of rectangle input method, has raised accuracy and the test precision of static transfer function of the TDI CCD camera.

2 The form of the static transfer function measure system
The measure system of static transfer function of the TDI CCD camera forms as Figure 1 shows, including integrating sphere and rectangle target mark, parallel optical pipe, camera optical system, the TDI CCD focal plane, CCD signal handling, image collection card, computer, RS232 bus, the control system of revolving stage and target mark revolving stage. In which, parallel optical pipe includes spherical microscope mirror and plane microscope mirror, and integrating sphere includes silicon detector and illumination lamp group.

3 The accurate measure method of static transfer function
3.1 Initialize systematic location
Before measuring, the measure system of static transfer function of the TDI CCD camera must be initialized, the rectangle target mark is placed the entrance in parallel optical pipe, used for simulated infinite far scenery goal. The optical axis of parallel optical pipe and the optical axis of the TDI CCD camera are on same axle. TDI CCD camera has been put the export end in parallel optical pipe, and the image information gathered by camera is transmitted to computer through image collection card, computer communicated with the control system of revolving stage through RS232 bus. The control system of revolving stage controls the encoder and the motor of revolving stage, so realize target mark revolving stage turn with location information read.

3.2 The location relation that TDI CCD focal plane and rectangle target mark
The location relation that TDI CCD focal plane and rectangle target mark, and target mark revolving stage turn direction definition as Figure 2 show: the optical axis of parallel optical pipe and the optical axis of the TDI CCD camera are on same axle, it is Y direction to stipulate optical axis of parallel optical pipe, the positive Y direction points to camera optical system; X direction and Y direction are vertical and with ground parallel, the positive X direction points to left side visual field of parallel optical pipe; Z direction and Y direction are vertical and with ground also vertical, the positive Z direction points to the top of parallel optical pipe; \( \theta_x \) Direction, \( \theta_y \) direction and \( \theta_z \) direction spin respectively to be axle with X direction, Y direction and Z direction, stipulate to obey the direction of hour hand as positive direction. In the course of searching for the best transfer function test point, it is standard with this coordinate department\(^ {5-8} \).
3.3 Search for the test point of the best transfer function

Make certain the relatively location relation of TDI CCD camera and parallel optical pipe\(^{[9-10]}\), find out the best transfer function test point of TDI CCD camera, it can raise test precision of static transfer function, specific method is as follows:

a) The course of search is to adjust the location relation of target mark and TDI CCD focal plane. Guarantee target mark carve line and the horizontal direction of TDI CCD vertical, at the same time, it is parallel to again guarantee rectangle target mark surface and the TDI CCD focal plane;

b) Target mark revolving stage along X direction level to move, make the first image pixel of TDI CCD catch initial carve line of target marks image in X direction, in the course of moving along X direction, computer real time calculates and draws the transfer function change curve, the ideal transfer function change curve as Figure 3 shows, abscissa express the location of revolving stage, ordinate express the value of transfer function. Corresponding abscissa value of the curve highest point is the test point of the best transfer function on this direction. After testing, level revolving stage to move the test point of the best transfer function on X direction;

c) Revolving stage is flat along Z direction to move, make TDI CCD in Z direction accurate alignment rectangle target mark, in the course of flat moving, computer real time calculates and draws...
the transfer function change curve of Z direction, after testing, level revolving stage to move the test
point of the best transfer function on Z direction;

d) Revolving stage spins along $\theta_y$ direction, make rectangle target mark curve line and the
horizontal direction of TDI CCD vertical, in revolving course, computer real time calculates and draws
the transfer function change curve, after testing revolving stage revolves to the test point of the best
transfer function on $\theta_y$ direction;

e) Revolving stage spins along $\theta_x$ direction and $\theta_z$ direction, it is parallel to make camera focal
plane and rectangle target mark surface, in revolving course, computer real time calculates and draws
the transfer function change curve, after testing, revolving stage revolves to the test point of the best
transfer function on $\theta_x$ direction and $\theta_z$ direction;

f) The test point of the best transfer function of X direction, Z direction, $\theta_x$ direction,
$\theta_y$ direction, $\theta_z$ direction are stored to the location information area. After establishing location
information area, the test of static transfer function of TDI CCD camera can be carried out.

3.4 Calculate the static transfer function

Computer takes out the location information of revolving stage (the test point of the best transfer
function) from location information area, and sends them to the control system of revolving stage.
Revolving stage reaches the location intended, after confirmation, computer begins to calculate static
transfer function. Revolving stage is beginning from the first pixel of TDI CCD, moves with regular
step length along X direction. Computer calculates one time transfer function per move once. Fix step
length is target mark image that occupies pixel number, and it is probably hundreds of pixel width.

The original target image that the collection of TDI CCD and the effective transfer function test
area as Figure 4 show, image data in the frame of dotted line is effective transfer function test area. In
Figure 4, per 1000 lines of target mark image as a measure sample, exclude because of atmosphere
tremble twisted, vague rectangle target mark image (the image with low transfer function value ),
remain 500 no vague target mark images as measure sample set. Then, that calculates respectively
static transfer function of each measure sample, takes the average of all measure samples in measure
sample set as static transfer function of camera.

\[\text{Figure 4. The original target image and the effective transfer function test area}\]

The target mark image enlarged in effective transfer function test area as Figure 5 show, in the
frame of dotted line to be adjacent target mark image, the first value of gray scale is low (dark stripe ),
the next value of gray scale is high (white stripe ), through this two values of gray scale, transfer
function can be calculated\[11\].
The calculation formula of the average static transfer function for a marks image as Equation (1) show.

$$MTF_{avg} = \frac{\pi}{4} \times \frac{1}{mn} \times \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} \frac{|I_{i,j} - I_{i+1,j}|}{I_{i,j} + I_{i+1,j} - 2I_{bg}}, \tag{1}$$

In Equation (1), $MTF_{avg}$ expresses average static transfer function in effective transfer function test area in a target mark image. $m$ and $n$ express the row number and column number of target mark image in effective transfer function test area. $I_{i,j}$ expresses the gray value of target mark image in $i$ row, $j$ column, $I_{bg}$ expresses the dark field value of target mark image.

According to average static transfer function $MTF_{avg}$ calculated, exclude because of atmosphere tremble twisted, vague rectangle target mark image$^{[12-13]}$ (the $MTF_{avg}$ is smaller than 0.1), select 500 no shaken mark image as measure sample set$^{[14]}$.

After measuring the static transfer function of the first step long, along X direction, move a step length, begin to test second step long and test method of static transfer function is identical, up to the final step length. After testing, the static transfer function test of entire visual field is completed. This kind of method has raised test accuracy and working efficiency.

4 Test result

In the course of searching for the test point of the best transfer function, revolving stage turns respectively along X direction, Z direction, $\theta_x$ direction, $\theta_y$ direction, $\theta_z$ direction, at the same time, computer real time records the value of static transfer function and draws the transfer function change curve. The highest point of the transfer function change curve is the test point of the best transfer function. After that, revolving stage is beginning from the first pixel of TDI CCD, moves with regular step length along X direction. Computer calculates one time transfer function per move once. Fix step length is target mark image that occupies pixel number, and it is six hundreds of pixel width. Because of each slice of TDI CCD effective pixel number is 2048, therefore the static transfer function that measures each slice of TDI CCD need to move 4 step lengths. In adjacent step the target mark image should have certain overlapping rate, so then can guarantee the continuity of the static transfer function in visual field of camera.

The test point of the best transfer function of revolving stage as table 1 shows.
Table 1. The test point of the best transfer function of revolving stage

| Direction of target mark revolving stage | Y direction | Z direction | $\theta_x$ direction | $\theta_y$ direction | $\theta_z$ direction |
|----------------------------------------|-------------|-------------|----------------------|----------------------|----------------------|
| The 1st step                           | -179.75     | -32.6       | 1.04                 | 0.78                 | 0.612                |
| The 2nd step                           | -149.75     | -22.1       | 1.076                | 0.78                 | 0.576                |
| The 3rd step                           | -119.75     | -32.6       | 1.112                | 0.78                 | 0.54                 |
| The 4th step                           | -89.75      | -22.1       | 1.148                | 0.78                 | 0.504                |

With same method, measure the static transfer function value of other step long of TDI CCD, and eventually draw the static transfer function curve of entire visual field of TDI CCD camera. The static transfer function curve of entire visual field tested using the before test method and test method of this paper as Figure 6 show, abscissa is expressed so as the visual field of TDI CCD camera with pixel partition, and ordinate expresses the static transfer function value. Dotted line expresses the static transfer function curve (drafted with discrete test points rear) tested using before method, the average of static transfer function is 0.2703. Solid line expresses the curve using test method of this paper, the average of static transfer function is 0.2923, and raised 0.02 compared with before test method.

Figure 6. Static transfer function curve of the entire visual field tested using the method of the former and this paper

5 Conclusions
This paper has put forward a kind of accurate measurement technique of static transfer function, which applies to the TDI CCD camera. Computer real time analyzes the feature of target mark image, and draws the change curve of static transfer function, control revolving stage voluntarily to drive target mark to turn, search for the test point of the best transfer function. This measurement method solves the test error problem aroused by measure systematic space location and atmosphere shake in the course of testing static transfer function[15], raises the measure precision of static transfer function of TDI CCD camera. At the same time, this method has solved the test difficult, workload etc. problem of static transfer function, and has raised working efficiency. The average of static transfer function tested is 0.2923, and raised 0.02 compared with before test method.

References
[1] Li C H, Wang Z X, Wu K Y. Optical assembly of CCD focal plane for space camera[J]. Opt. Precision Eng, 2000, 8 (3): 213-216
[2] Xu Q Y, Ye D, Che R S. On-line calibration of stereo vision measurement system based on optical reference bar[J]. Acta Optica Sinica, 2008, 28(1):81-86
[3] Zhou W. Study on Enhancing Dynamic Range of CCD Image Based on Digital Micro-Mirror Device[J]. Acta Optica Sinica, 2009, 29(3): 638-642
[4] Li H Z, Han C Y, Ma D M. Assessment Method of Modulation Transfer Function of On-Orbit Space Optical Remote Sensor Using Neural Network [J]. Acta Optica Sinica, 2007, 27 (4): 631- 637
[5] Qian Y X, Liang W, Gao X D. Numerical Analysis of Dynamic Modulation Transfer Function for High-Resolution Aerial Camera[J]. Acta Optica Sinica, 2009, 29(1): 192-196
[6] Feng Z W, Cheng H B, Song Q, Shang Y Y. Modulation Transfer Function Measurement of Electron Multiplying CCD[J]. Acta Optica Sinica, 2008, 28(9): 1710-1716
[7] Guo Y, Liu X P, Yang H. MTF Analysis for CCD. Spacecraft Recovery & Remote Sensing, 2004, 25(3):25-28
[8] LAMBERT B M, HARBOLD J M. Experimental methods for measurement of the modulation transfer function (MTF) for time-delay-and-integrate (TDI) charge coupled device (CCD) image sensors. SPIE, 2009, 7405: 75-83
[9] Lu J, Chen W M, Cen J B. Effect of distance on modulation transfer function of imaging sensor using rectangle template contact method[J]. Acta Optica Sinica, 2006, 26(7): 1021-1026
[10] Mao X F, Su X Y, Liu Y K, Chen W J. Analysis on Optical Coordinate Measurement Based on Phase Target[J]. Acta Optica Sinica, 2009, 29(9): 2452-2457
[11] Xue M Q, Shen W M. Optical Design of Light Weight and Compact High Resolution TDI CCD camera[M]. Beijing: Science Publishing Company, 2005 :158-163
[12] MAGNAN P, ESTRIBEAU M, ROLLAND G, et al.. Theoretical evaluation of MTF and charge collection efficiency in CCD and CMOS image sensors. SPIE, 2009, 7427: 23-34
[13] LI W J, QI C, ZHANG Y, et al.. Review on the theory and method of measuring MTF of CCD cameras. SPIE, 2005, 31:130-138
[14] Fei Y T. Error Theory and Data Processing[M]. Beijing: China Machine Press, 2007 :68-70.
[15] Han C Y. Study on optical system of high resolution space camera [J]. Optics and Precision Engineering, 2008, 16(11):2164-2172