Design of a novel high precision opto-electronic levelmeter

Guoping Li*[a], Qiuhui He[b], Xinnan Li[a]
[a]National Astronomical Observatories/Nanjing Institute of Astronomical Optics & Technology, Chinese Academy of Sciences Nanjing, 210042, China;
[b]Department of Astronomy, Nanjing University, Nanjing 210093, China

ABSTRACT

For currently market available levelmeter can not meet the requirement for measuring the azimuth mounting of the LAMOST, this paper presents a novel design scheme of an opto-electronic levelmeter with needed high precision. The levelmeter is essentially a combination of an optical front end and a computer aided measuring back end. The light from a point source is firstly turned to be parallel and reflected by a tip-tilt mirror which keeps pointing to the zenith and then imaged onto a CCD target through optical system, afterwards, the position of the image spot is processed by computer software to give measurement results. By rotating the LAMOST mounting about azimuth axis with the levelmeter on it, the axis system is measured, and if the measured azimuth axis is not perpendicular enough, the image spot on CCD target is to offset some distance by which the tilt angle of the axis can be evaluated. The design principle and data processing of the levelmeter are detailed systematically in this paper. Experiment results confirmed that the accuracy of the levermeter is up to 0.043" beyond that required by the technical specification of the LAMOST. Also, the novel levermeter is applicable to measuring azimuth axes of other telescopes.1

Keywords: Astronomical telescopes, Alt-azimuth mounting, Levelmeter, Data processing

1. INTRODUCTION

Levelmeter is designed for measuring obliquity, including generic telemeter and electronic levelmeter. It is updated many times from bubble levelmeter to electronic levelmeter. Traditional levelmeter are based on physical principle of strain from electronic induction, capacitance or thermal balance. With the development of modern instrument, the output of the levelmeter is the digital signal in order to connect with computer. Now, levelmeter usually outputs the analog signals of the obliquity and converts them to digital signals by the A/D. Because the time of A/D shift limit the resolution and the precision of the simulative circuit and the A/D parts of an apparatus is low, so the high precision data is not obtained. The precision of modern levelmeter is usually under 0.001mm/m. The high precision levelmeter is required with the development of the nice manufacture.

This paper discusses a high precision optoelectronic levelmeter with CCD. The light from a point source image onto the CCD target through optical system, the image on the CCD target is obtained by picture card, then obliquity is evaluated by computer processing. The precision of it is high.

* Correspondence: Email: gpli@nairc.ac.cn; Telephone: +86-25-5482-208; Fax: +86-25-5405562; http://www.nairc.ac.cn;
Nanjing Institute of Astronomical Optics & Technology (NIAOT), Bancang Str. 188 210042 Nanjing P. R. China

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2. STRUCTURE AND PRINCIPLE

2.1 Principle

This optoelectronic levelmeter adopts the technique which combines the optical way with electric one. Fig. 1 and Fig. 2 show the principle of the levelmeter. It consists of point source, primary mirror, sub-mirror, beam spliter, pendulum and CCD. The light, from a point source, which is reflected by the beam splitter is turned to be parallel through primary mirror and sub-mirror onto the pendulum, then the parallel light is reflected again through primary mirror and sub-mirror onto CCD target. The normal of the pendulum is always vertical. When the tested plane is tilted, the angle between the incidence light and the reflected light on the pendulum is two times obliquity of the tested plane, the spot which is focused on CCD target is to offset some distance. Tilt direction and obliquity of the tested plane are evaluated based on two-dimensional offset vector on the CCD target. When the focus is f, the light is axial, the initialposition of the image is the origin of the coordinate, if the obliquity of the tested plane is θ, the offset distance of the image is $R1$, so the offset vector is:

$$\vec{R}1 = X\vec{i} + Y\vec{j} \tag{1}$$

whose module is:

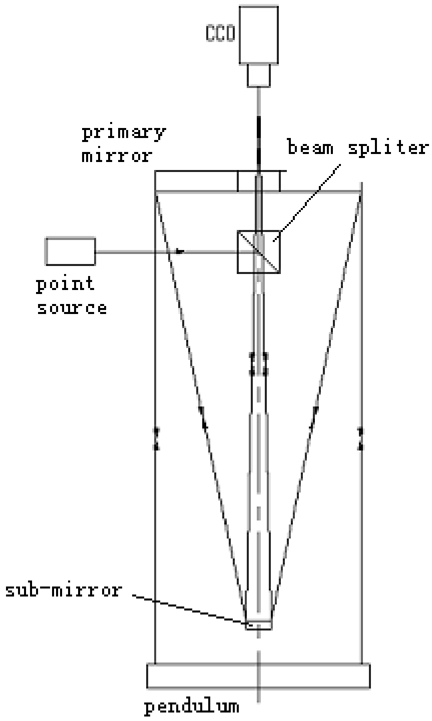


Fig. 1. optical principle

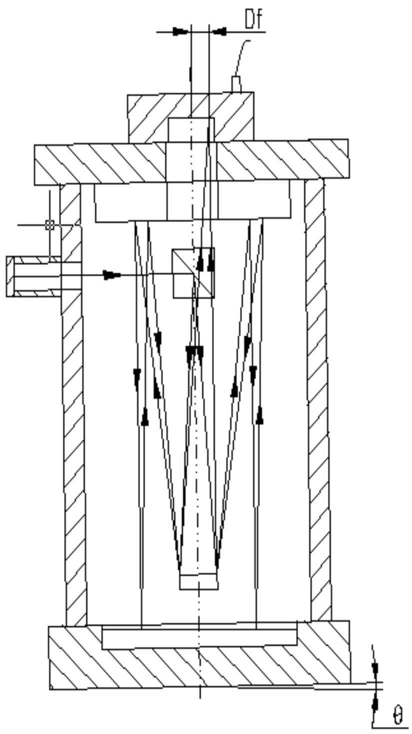


Fig. 2. measuring principle

$$|D_f| = X^2 + Y^2 = 2f\theta \tag{2}$$

In order to obtain high resolution and precision, multi-pixel on the CCD target are covered by the spot that is defocused, the center of the spot (Xc, Yc) can be evaluated,

$$X_c = \frac{\sum_{i,j} iI_{i,j}}{\sum_{i,j} I_{i,j}}, \qquad Y_c = \frac{\sum_{i,j} jI_{i,j}}{\sum_{i,j} I_{i,j}}$$

where i represents the ith pixel on X direction of the arbitrary point (i, j) on CCD target, j represents the jth pixel on Y direction of the arbitrary point (i, j) on CCD target, I_{ij} represents gray value of the arbitrary point (i, j) on CCD target.

(1) Range

Based on equation (1), the max range is:

$$\beta = \pm \frac{l}{4f}$$

where l is the width, f is the focus of the optical system.

(2) Resolution

Based on relative experiment in which the orientation precision of CCD is up to 1/30 pixel, the orientation precision of CCD is usually up to 1/10 pixel. When the focus of the levelmeter is 20m, the number of CCD pixel is 795(H) x 596(V), the size of the pixel is 8.6(H) x 8.3(V), the resolution is up $0.0014'' \sim 0.0042''$.

2.2 Error

The spot on CCD twitter during this levelmeter measuring. So this paper discusses the possibility that bring on error and the methods that remove the twitter based on principle and structure.

(1) Temperature

There is difference in temperature during measuring. The change of the temperature makes the size of the apart of the apparatus change. Because the expand coefficient is different each other, the variational size of each part is different each other, so the error is brought out. In order to reduce the influence of the temperature, the relative parts should be parts, which have same expand coefficient.

(2) Position error of CCD

The position of CCD that is fitted may affect the measuring precision. The relation between ideal position and actual position which is fitted is showed on Figure 3. δ is the angle between x”-y” plane and x-y plane, ϕ is the angle between the projection of x” on the x-y plane and x. So the fitting CCD possibly results in tilt error, level error and vertical error. In this paper, the level error and vertical error do not affect measuring precision. Tilt error is showed on the figure 4. Because there is no fitting datum plane, the fitting error d is up to 0.5mm. If h is the length of CCD, so fitting obliquity is α ($tg\alpha = d/h$), the max offset $\Delta = (1-\cos\alpha)h$. Based on CCD, which is used in the experiment, the max offset is 0.0077um, so we may think this error do not effect the result.

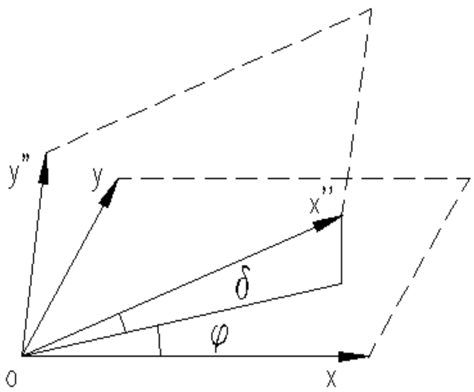


Fig. 3. relation between coordinates

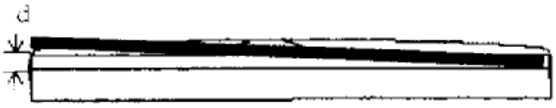


Fig. 4. Fitting aslant error

(3) Background and CCD flat

Because of the influence of the background, data from CCD should get rid of noise signal. With valve filter method, the grey value I_0 is the grey gate value.

$$I_{i,j} = \begin{cases} I''_{i,j} - I_o & I''_{i,j} > I_o \\ 0 & I''_{i,j} < I_o \end{cases}$$

If we choose likely valve value I_0, the image obtained by computer should be spot focused on CCD target, the other grey value is zero.Because of the influence of CCD flat, the spot is distortion and aberrant. In order to get rid of the influence, the flat should be obtained. By correcting the CCD bias, dark and background, the final intensity of the spot should is:

$$final\, intensity = \frac{total\, intensity - bias - dark}{flat - bias - dark}$$

(4) Remove the twitter

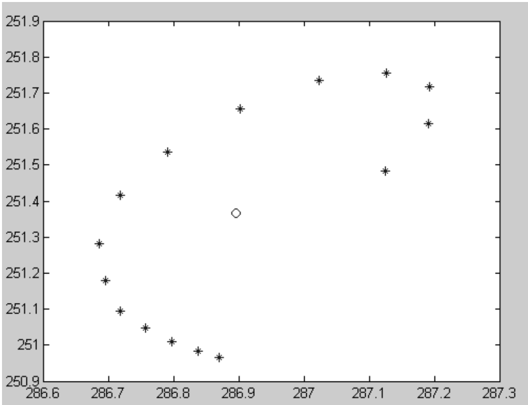
The air disorder and the twitter of the tested plane both make the spot twitter. If image obtained from CCD is pre-processed with smoothness method, the twitter is got rid of.

$$X = \frac{\sum_k \sum_{i,j} i I_{i,j}^k}{\sum_k \sum_{i,j} I_{i,j}^k} \quad , \quad Y = \frac{\sum_k \sum_{i,j} j I_{i,j}^k}{\sum_k \sum_{i,j} I_{i,j}^k}$$

where (X,Y) is the even center of the image, $I_{i,j}^k$ is the grey of the point（I，j）^{k} (k=1,…,n).

2.3 Data

By a series of experiments, the levelmeter discussed is analyzed. We select several sets data as measuring result for keeping data integrality based on telemeter status. The precision of the telemeter is different from frame repeated and intensity with the same others parameter. With the same others condition, we change number of frame repeated to gain the different precision. When ten frames are repeated, the distributing of the center of gravity is showed in Fig. 4, the error curve is showed in Fig. 5. The repeat position precision is 0.34 pixels(0.03″)



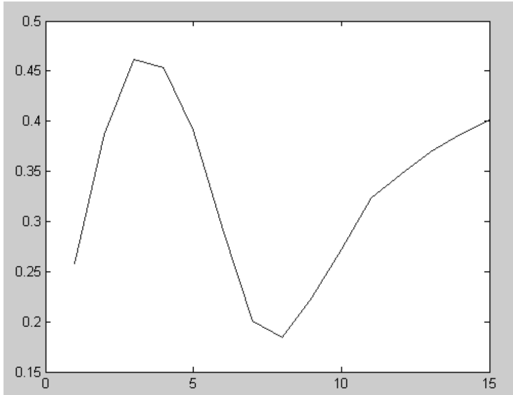


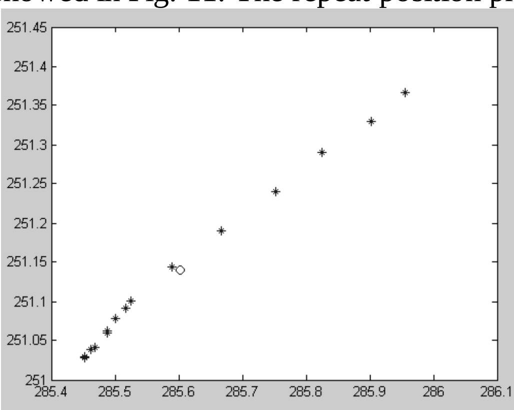
Fig. 4. Distribution of the center of gravity when ten frames are repeated

Fi. 5. Error curve when ten frames are repeated

When twenty frames are repeated, the distributing of the center of gravity is showed in Figure 6, the error curve is showed in Fig. 7. The repeat position precision is 0.20 pixels(0.017″. When fifty frames are repeated, the distributing of the center of gravity is showed in Fig. 8, the error curve is showed in Figure 9. The repeat position precision is 0. 12 pixels(0.01″).

With the same others condition, we change the intensity of the point source to gain the different precision.

When the max grey is 226, the distributing of the center of gravity is showed in Fig. 10, the error curve is showed in Fig. 11. The repeat position precision is 0.1 pixels(0.09″).



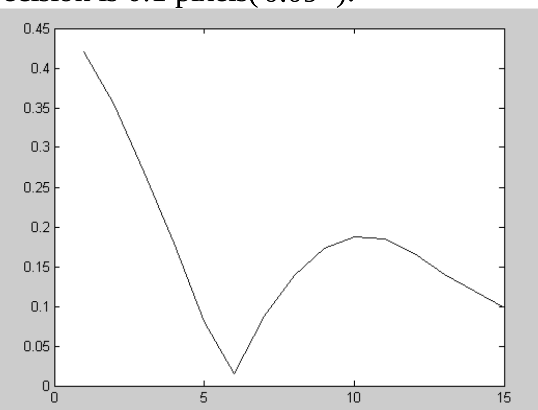
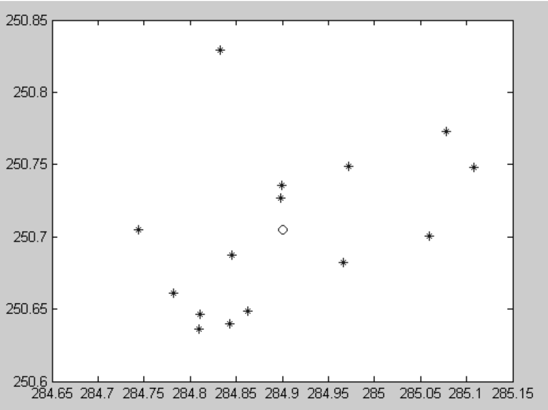


Fig. 6. Distributing of the center of gravity when twenty frames are repeated

Fig. 7. Error curve when twenty frames are repeated



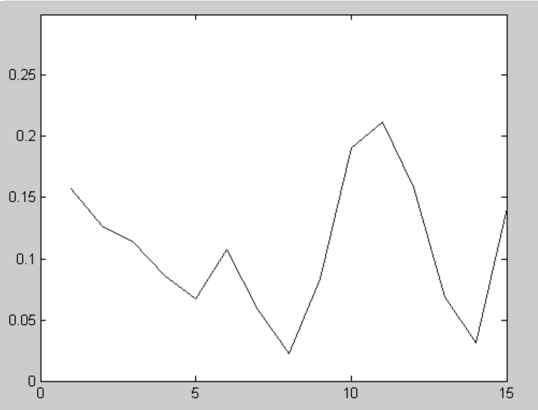
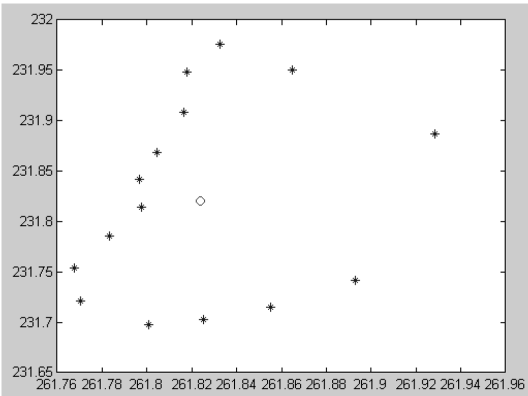


Fig. 8. Distributing of the center of gravity when fifty frames are repeated

Fig. 9. Error curve when fifty frames are repeated



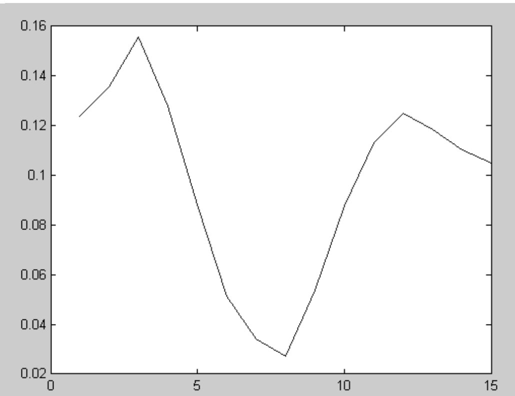
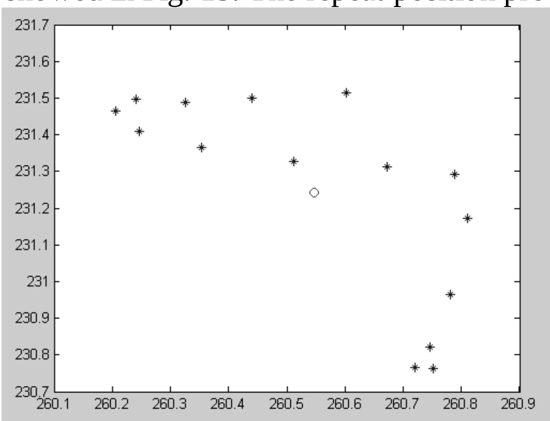


Fig. 10. Distributing of the center of gravity when the max grey is 226

Fig.11. Error curve when the max grey is 226

When the max grey is 193, the distributing of the center of gravity is showed in Figure 12, the error curve is showed in Fig. 13. The repeat position precision is 0.31 pixels(0.027″).



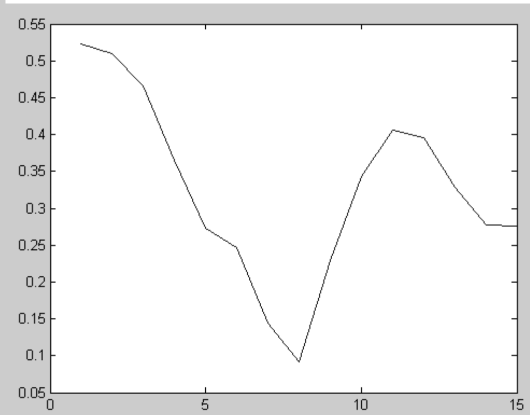
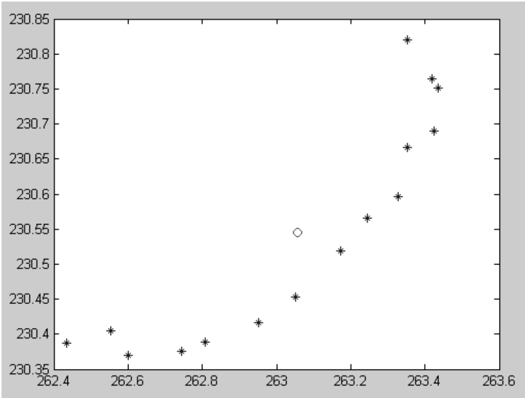


Fig. 12. Distributing of the center of gravity when the max grey is 193

Fig. 13. Error curve when the max grey is 193

When the max grey is 100, the distributing of the center of gravity is showed in Figure 14, the error curve is showed in Fig. 15. The repeat position precision is 0.37 pixels(0.032″).



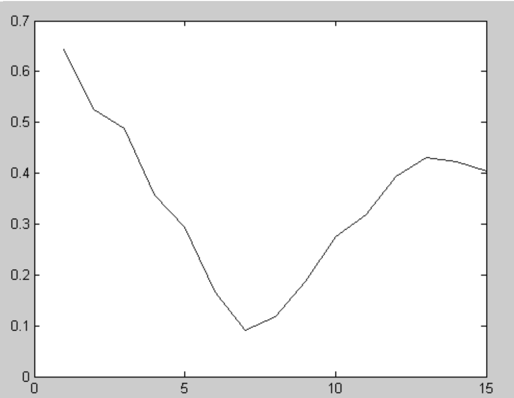


Fig. 14. Distributing of the center of gravity when the max grey is 100

Fig. 15. Error curve when the max grey is 100

2.4 Conclusion

When the temperature is invariableness and there is few vibration, the continuous data is obtained:

number	resolution
0	0.0057″
1	0.0079″
2	0.0069″
3	0.0058″
	0.0015″

So, when the temperature is invariableness, the resolution of the levelmeter designed this paper is up to 0.0086″. The resolution is usually up to 0.043″.

The high precision optoelectronic tiltmetr with CCD discussed in this paper, which combine the optical way with electrical way and correct the error can measure tiny obliquity correctly. The outstanding virtue of this levelmeter is high resolution and resolution.

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