Auto-focusing Schemes for LAMOST Multipurpose Fiber-fed Spectrographs

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ABSTRACT

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) project is one of the National Major Scientific Projects undertaken by the Chinese Academy of Science. There are 16 low resolution multipurpose fiber-fed spectrographs in total, enabling it to obtain the spectrum of celestial objects as faint as down to 20.5. Building auto-focusing systems for the spectrographs is important due to the popularity of instruments. The system enables the optical system to automatically compensate changes in accordance to external variables, such as temperature, timidity, to ensure the spectrum collected more reliably. Image-based algorithm is utilized to calculate the departure of CCD plane from optical focal plane. The calculation also aids to regulation of the system. The defocus value is transformed to the controlling computer of each spectrograph. A driving step-motor performs refocusing function by moving the fiber slit unit to its right position.

Keywords: Low resolution spectrograph; Auto-focusing; resolution

1. INTRODUCTION

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) is a quasi-meridian reflecting Schmidt telescope. The aperture of LAMOST is 4m, enabling it to obtain the spectra of objects as faint as down to 20.5 with an exposure of 1.5 hour. Its focal plane is 1.75m in diameter, corresponding to a 5° field of view, may accommodate as many as 4000 optical fibers. So the light from 4000 celestial objects will be led into 16 spectrographs simultaneously.

Building auto-focusing systems for the spectrographs is important due to the popularity of the instruments. Preliminary results building the auto-focusing system is reported in the paper. The system enables the optical system to automatically compensate changes in accordance to external variables, such as temperature, timidity, to ensure the spectrum collected more reliable. Image based algorithms is utilized to calculate departure of the CCD plane from the optical focal plane. The calculation also aids to regulation of the system. The defocus value is transformed to the controlling computer of each spectrograph. A driving step-motor performs the refocusing function by moving the fiber slit unit to its right position.

2. AUTO-FOCUSING SYSTEM

2.1 Spectrograph introduction

The Low Resolution Spectrographs are of double beam full Schmidt design. Each spectrograph is fed with 250 optical fibers. The f/4 output beams are collimated by a spherical mirror, and the collimated beams are split into red (570–900nm) and blue (370-590nm) channels by a dichroic filter. The beams are dispersed by VPH gratings, and focused onto large format CCD using f/1.3 Schmidt cameras. Spectral resolution is 1000 for full wavelength coverage and 5000 for partial coverage. The resolution could be doubled by introducing a narrow slit. Fig.1 gives a schematic view of the spectrograph. The linear guide 9 and Hartmann shutter 2 are specialized for auto-focusing usage.

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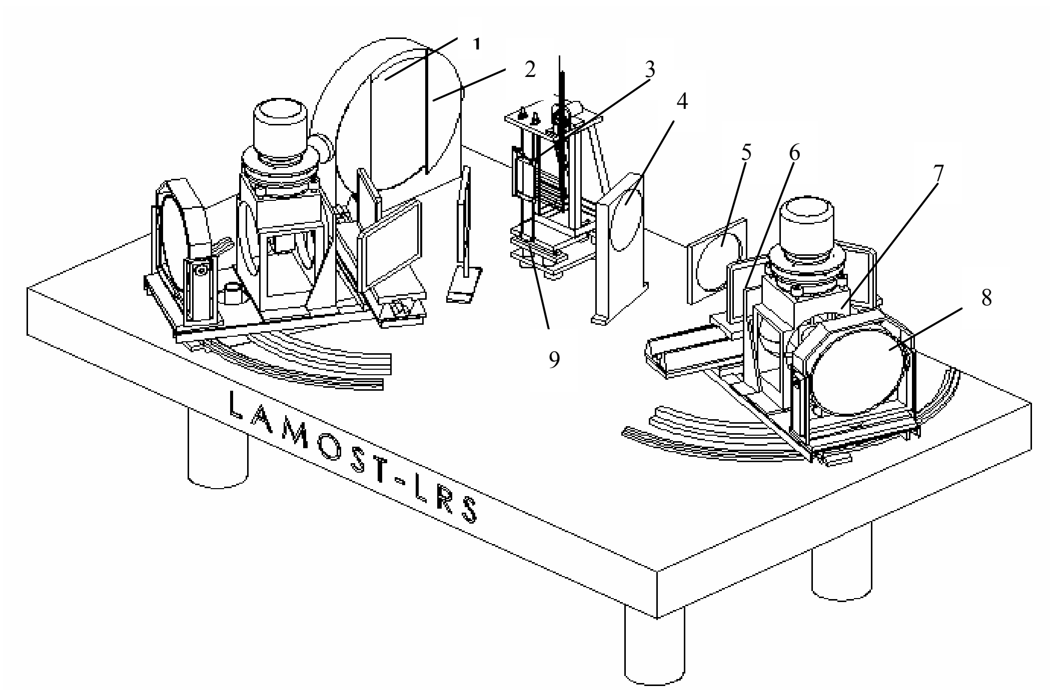

1. Collimating mirror 2. Hartmann shutter 3. Fiber slit unit
4. Dichroic filter 5. Schmidt corrector 6.VPH grating
7. CCD 8. Camera mirror 9. Linear guide

Fig.1 Schematic view of LRS for LAMOST

2.2 Auto-focusing system

The actual auto-focusing system comprises following main units:

(1) Image-gathering unit obtains spectrum images of the blue and the red channels from CCD image acquisition computers located in local net by way of LAMOST OCS (observatory control system). Light source used is the same for wavelength calibration of LAMOST. CCD chips of 4096×4096 pixels are supplied by E2V. The controllers are made in China. An Apogee CCD is utilized for simulation in laboratory instead.

(2) Image-processing unit is designed for analyzing the spectrums. It calculates the resolution degradation and departure of CCD from the image plane. Details of the units will be described in the subsequent paragraph.

(3) Strategy decision unit evaluates results from image analysis. The best refocusing parameters will be worked out by the unit. When there are cases the CCD plane is found to be tilted or the two channels are defocused distinguishingly, and the resolution degradation information synthesis shows unacceptable, an alarm will be given instead of performing the action unit for focus compensation.

(4) The action unit which sends control information to drive the stepping motor for refocusing. Defocus is automatically compensated by moving the position of the fiber slit. A stepping motor is used to drive a screw to move fiber slit along the beam direction. The screw-pitch is 2 mm, and the stepping angle of motor is 1.8°. So a position resolution of 0.01 mm is available.

One industrial computer will be used to control two of the spectrographs. Together with Stepping motors, PCI -1240 motion cards (multi-axes), it is convenient to control the spectrographs. Fig2. shows the framework of the system.

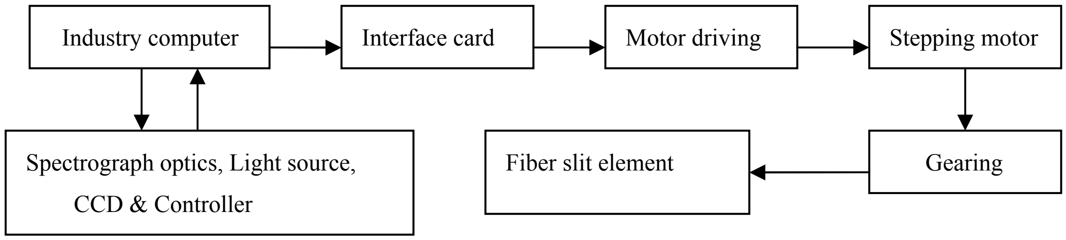

Fig.2 System framework

2.3 Software working flow

Software is developed with VC++6.0 under Windows environment. The working flow chart is simplified as in Fig.3. At current stage, interactive communication with OCS is not implemented.

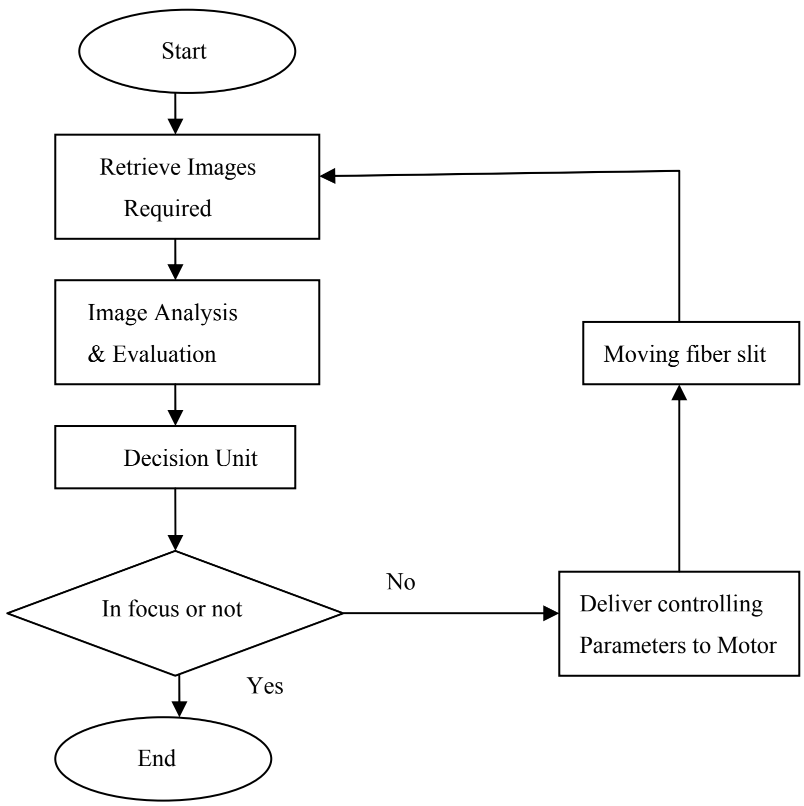

Fig.3 Work flow of the software for auto focusing system

The process of computing is described as follows:

1. Expose one picture with Hartmann shutter fully opened. Calculate resolution degradation and decide if adjustment is necessary.

2. If necessary, obtain two exposures with either of the Hartmann shutter opened and the other closed.

3. Calculate CCD plane deviation from image plane by using the two exposed images.

4. Determine whether automatic procedure is sufficient to compensate the errors.

5. Send controlling parameters to stepping motor, and change the position of the fiber slit.

6. Expose one picture with Hartmann shutter fully opened. Determine whether further automatic adjustment is necessary.

3. PRINCIPLES AND ALGORITHMS

There are many image-based algorithms for auto-focusing such as frequency domain function, grey function, informatics function and statistic function. Many well-known algorithm has their own characteristics. The sum of grad-change function is typically used to large-scale cursory focusing . The Laplacian function and the Tenengrad function are used to detect sharp peaks near the focused regions and appropriate to small-scale accurate focusing. The Roberts gradient function seems good for moderate-scale auto-focusing . Stability and calculation speed are considered for choosing or designing an appropriate algorithm. In our system, we have a large field of view and expect the system is in focus in only a few steps. As there are 16 spectrographs, more attention should be paid on reliability.

Two schemes specialized for spectrographs to obtain the best focus position are considered. The one is a spectrograph resolution based method. In this case we obtain a sequence of image for different fiber slit position. A statistically weighted resolution criterion across the full image plane is utilized as the merit function for each image. The other is a traditionally used Hartmann shutter method. Quantities of the deviation of CCD plane (defocus, pitch and tilt) from image plane could be obtained by only two image frames.

Two schemes are physically significant thus providing principally very robust methods. Yet the stability still depends on how we implement the algorithm. Some of the key elements are described below in the following image processing procedures.

3.1 Pre-processing of images

Image we obtained is of 4096×4096. Here, abscissa x illustrates space direction, y indicates dispersion direction. Suppose bias is already subtracted and singularities are eliminated from each image. We normalize the image value of each pixel to 0~1 by using formula (1).

$$s'_i = \frac{s_i - s_{\min}}{s_{\max} - s_{\min}} \tag{1}$$

Let The image is represented by an array s(n,m). The s(n,m) usually contains some noise described by formula (2):

$$s(n,m)=f(n,m)+\sigma e(n,m) \tag{2}$$

where, f(n,m) is the real signal to be recovered. e(n) is noise, and σ shows its intensity.

A wavelet de-noising method is utilized to obtain the reconstructed signal.

3.2 Spots recognition within an image and spots matching between images

In fiber fed spectrographs, emission lines of different arc lamps are utilized for wavelength calibration. The emission lines in CCD image are a series of circular area spots. Fig.4 is a typical image sampled of

Fe-Ar lamp on a 4K×4K CCD.

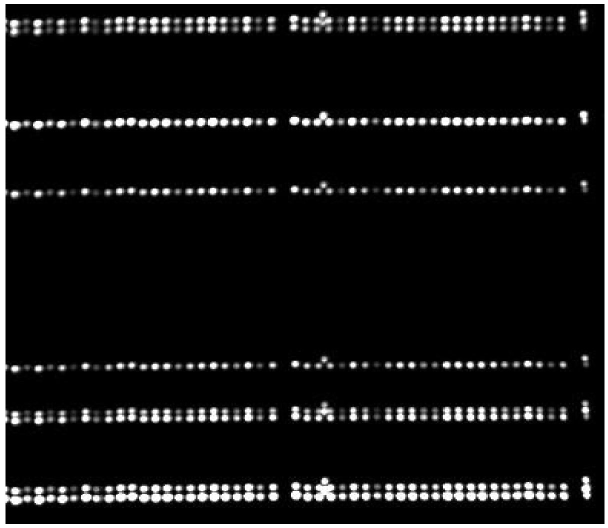

Fig.4 Typical image sampled of Fe-Ar lamp

For one image frame, there may be thousands of spots. Each spot should be recognized and distinguished from background. We could do calculations on the distinguished spots and make statistics. For example, the center coordinate of each spot could be calculated by:

$$X_g = \frac{\sum_{i=1}^{13} i \cdot x_{ij}}{\sum_{i=1}^{13}\sum_{j=1}^{13} x_{ij}}, \qquad Y_g = \frac{\sum_{j=1}^{13} j \cdot x_{ij}}{\sum_{i=1}^{13}\sum_{j=1}^{13} x_{ij}} \tag{3}$$

where, x_{ij} is the value of pixel position (i, j). X_g is center coordinate of the spot in space direction, and Y_g in dispersion direction.

When there are more than one image frames, each spot of different emission lines from different fibers may occur in slightly different position. There is a matching algorithm to find the corresponding spots. Formula (3) and a distance measure are utilized for spot matching between images.

The technique is not merely designed for refocusing. We can monitor the variation of the spectrums caused by temperature variation. Two images were obtained separately at temperature 10°C and 20°C. By matching spots in different area, we can know how the system drifts in space and dispersion directions due to temperature change. The results are shown by table1.

From the table 1, we can draw a conclusion that the value of centroid deviation indicates the defocus value, while the sign of deviation illustrates the orientation of adjusting strategy.

coordinates of spot	Drift of point	
	x	y
1 (976,3296)	0.6228	-0.2354
2 (2734,3295)	0.8382	-0.2830
3 (3312,3309)	0.6068	-0.2266
4 (1076,2927)	0.7634	-0.1826
5 (2765,2932)	0.3890	-0.1748
6 (3324,2950)	0.3952	-0.2518
7 (678,975)	0.4076	-0.3740
8 (2472,979)	0.3108	-0.0396
9 (3267,982)	0.4210	-0.2306
10(514,491)	0.5238	-0.4392
11(1867,495)	0.5360	-0.1622
12(3542,497)	0.6630	-0.4370

Table1: FWHM and centroid deviation of matching spots in different areas

3.3 Gaussian fitting

We have thousands of spots to be analyzed in one image. Analysis area of each spot is definitely given 13x13 pixels or more. Cross sections of each spot in an image are fitted by a Gaussian function to obtain sub pixel accuracy.

$$f(x) = A \cdot \exp\left[-\frac{(x-x_0)^2}{2\sigma^2}\right] + B \tag{4}$$

Use of the constant term B makes the fitting procedure more robust. After two nonlinear fitting of the spot in space and in dispersion direction, FWHM (Full Width Half Maximum) and accurate center point coordinates are retrieved. Fig.5 shows a fitted spot cross section in dispersion direction. Typical FWHM of LRS is not more than 9 pixels.

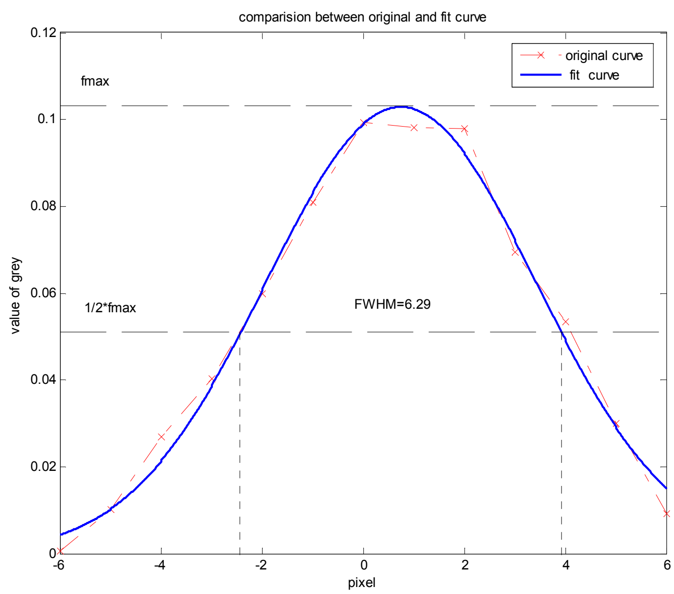

Fig.5 Fitted spot cross section in dispersion direction

3.3 Refocus mechanism

Using of FWHM criterion could sufficient use for resolution based scheme. A sequence of images for different fiber slit positions is obtained first. Then we observe the trend of FWHM variation for a dozens of spots through the sequence of images. A statistically weighted resolution criterion across the full image plane is utilized as the merit function for each image. The one with minimum merit function means that of the best focus position. For actual use, resolution criterion is only used to determine if compensation is necessary. This means only images before and after regulation are sampled.

The Hartmann shutter based scheme is used to determine how to compensate the deviation of CCD plane. Two image frames are obtained by alternatively switch to either of the Hartmann shutters. Deviation of CCD plane from image plane is described by position differences of the thousands of the spots. The difference value is the center point deviation in dispersion direction obtained by Spots recognizing within a image, spots matching between images and the Gaussian fitting procedure.

4. DISCUSSION

Through analyzing centroid deviation of matching spots in dispersion direction, we can get actual CCD defocus values across image plane. The defocus of CCD could be treated as average value of the spots. Tilt of CCD plane to image plane could also be retrieved since defocus variation is due to CCD plane declination. The relationship of the deviation and defocus could be calibrated for small scale defocus. Each spot area is likely to be of donut shape (due to vignetting of CCD) for large scale defocus. Gaussian fit would not be appropriate in the case. Yet the Hartmann shutter based scheme could still work well.

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REFRENCES

1. Rui Ling Duan, Hui Bo Duan, Qing Xiang Li, Yu He Li , Zai Hua Yang. Mcro-asembly auto-focusing system based on image processing [J]. *Optics and precision Engineering*, Vol.14, No.3, pp.468-472,Jun.2006.
2. Qing Xiang Li , Dong Sheng Wang, Yu He Li. *The design of modern precise instruments* [M]. Beijing: Tsinghua University Press, pp. 112-140, 2004.
3. ASHOK A, NEIFELD M A. Information-based analysis of simple incoherent imaging systems[J]. *Opt. Express*, 2003(11), 2153-2162
4. Tao Men, Jian An Chen. Wavelet denoise image based on smoothing threshold function[J]. *Computer Engineering and Scientifics*, 2004, 26(8): 50-52.
5. Hughlett E, Kaiser P. An autofocus technique for imaging microscopy[C]. *IEEE Int Conf on Acoustics*, *Speech and Signal Processing*, 1992: 93-96
6. Ding-qiang Su, Xiangqun Cui, Ya-nan Wang and Zhengqiu Yao, "Large Sky Area Multi-object Fiber Spectroscopic Telescope (LAMOST) and its key technology", *Advanced Technology Optical/IR Telescopes VI, ed. by L. M. Stepp*, SPIE Vol. 3352, pp. 76-90, 1998.