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AN AUTOGUIDER SYSTEM FOR THE 40 CM SCHMIDT TELESCOPE

By

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ABSTRACT

An autoguider system was constructed for the 40 cm Schmidt telescope at the Ouda Station. The sensor of the guider, a type ITT FW 130 image dissector, is attached to the guiding telescope. A microprocessor is introduced for processing the sensor output and for correcting the guiding error of the telescope. This enables the broadening of the objective prism spectra by a simple software.

The microprocessor is used also for other auxiliary functions for the telescope control.

1. Introduction

The 40 cm Schmidt telescope at the Ouda Station (Imagawa et al. 1977) is used extensively for infrared and narrow band observations, which often require long exposures. As a matter of course, observations with long exposures are apt to result in poor photographic image quality because of much accumulation of guiding errors. Further, in cases of spectral observations by using the objective prism, guiding errors in the direction of the spectral dispersion seriously degrades the quality of the plate material since spectral lines are smoothed out.

In order to realize better guiding in these observations, an autoguider system was designed and constructed. A microprocessor is used in this system. This processor controls the telescope not only for guiding but also for some other functions necessary for observations. The system has operated well for more than one year. A brief description is presented in the followings.

2. Provision of Guiding Stars

It is most desirable to sense the guide star position in the field of the main telescope to minimize flexural errors. However, this method was not chosen for the present system because of the following two reasons. One is that the main telescope is not so large that there is not enough space to install a guider sensor on the focal part assembly. The other reason is that any

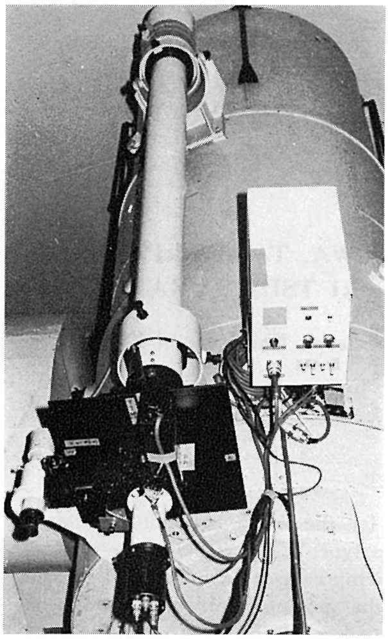


Fig. 1. The autoguider head attached to the 10 cm guiding telescope. An ITT FW130 image dissector is installed in a white tube mounted on a set of cross slides (the black part). The current to the deflection coil is supplied from the sweep generator (a white box).

well-established method to sence guide errors requires a point image of a guide star (see, e.g., Jelly 1980). However, when the objective prism is attached to the main telescope, the stellar images are linear.

Therefore, the existing guide telescope is used for sensing the guide star position. The aperture of objective lense is 10 cm, and its focal legth is 200 cm. At the end of the tube of this telescope, a set of cross slides is attached on which a field view optics and a guider sensor are mounted (Figure 1).

The guide stars are aquired manually; a suitable star is searched through an eye piece into which the star light is reflected by a sliding mirror inserted in front of the sensor. Once a star image is set on a cross wire in the eye piece field by movements of the cross slides, then the sliding mirror is removed off to introduce the star light onto the sensor.

The field area which is accessible by movements of the cross slides is 4 $(\text{deg})^2$. Although the field of the main telescope is as wide as 7.°1 in diameter, it is, of course, more desirable that a suitable guide star can be aquired without offset of the main telescope from a program field. The probablity that the offset of the main telescope is unnessesary depends on the magnitude of the faintest star which is usable as a guide star by the guider.

Star numbers for apparent magnitudes are tabulated by Allen (1973). We consider only stars with spectral types same as or earlier than F type, since the guider sensor (see later) is not so much sensitive for redder stars as for bluer stars. By assuming the random distribution of the stars on the celestial sphere, probabilities that more than one star brighter than 8, 9, and 10 mag can be aquired within an arbitrary 4 $(\text{deg})^2$ are found to be 44%, 78%, and 98%, respectively, if a program field is near the galactic pole.

For a program field near the galactic equator, the corresponding probabilities are as large as 89%, 100%, and 100%, respectively. From these values, the guider is of practical use if it operates for stars as faint as 9 mag.

3. The Star Sensor and the Method of Guiding

An image dissector of a type of ITT FW130 (S20-type photocathod) is

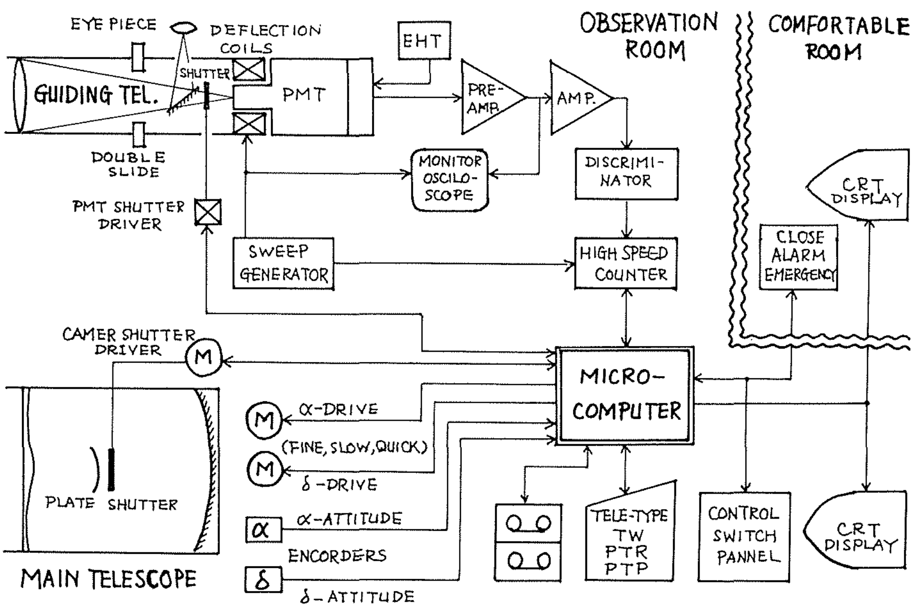


Fig. 2. The block diagram of the autoguider system.

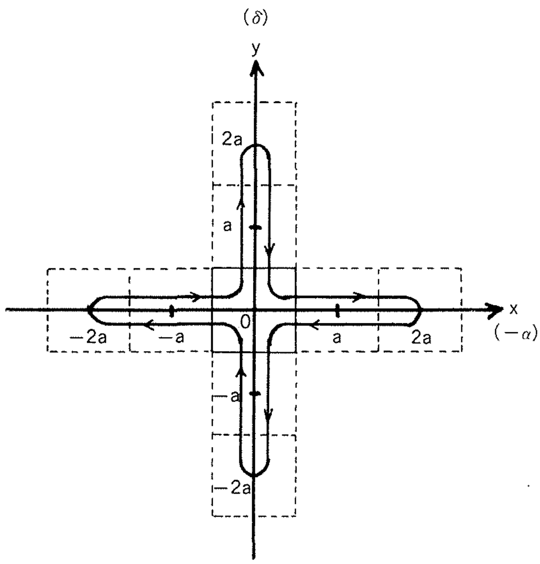


Fig. 3. The scan mode of the instantaneous effective photocathod aperture, which is a square with side of *a*.

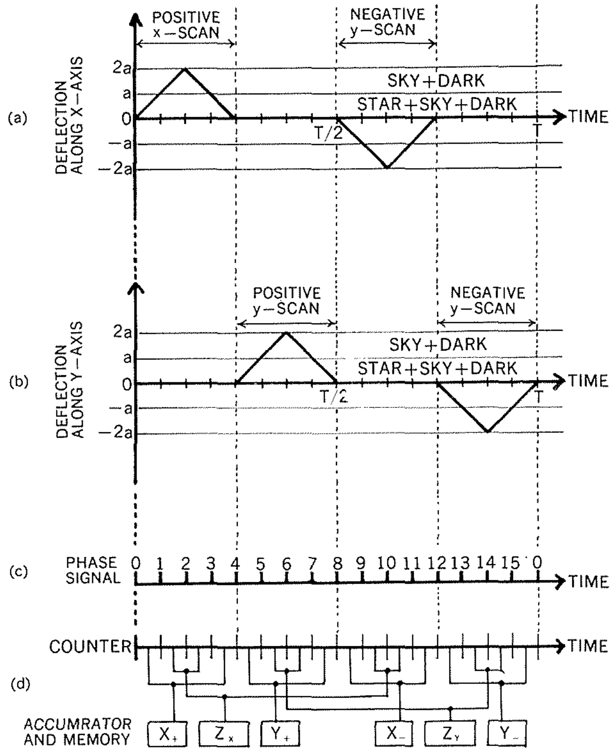


Fig. 4. (*a*) The time chart of the deflection of the center of the instantaneous effective photocathod aperture along x (the right ascension) direction.
(*b*) Same as (*a*) but for y (declination) direction.
(*c*) The timing chart of the phase signal generated by the sweep generator.
(*d*) The concept of the pluse counter assembly.

employed as the guider sensor. The image of a guiding star is focused on the photocathod of the dissector whose effective aperture is 0.014 inch square. The stellar image is scanned by the instantaneous effective photocathod in the manner so called as the Rossetta type or the Maltese-cross scan as well as in the systems of the KPNO (Ball and Hoag 1968), of Geneva (Poncet and Bartholdi 1972), and of the AAT (Kobler and Wallace 1976).

However, our system is different from these above systems in the point to measure the sky-background brightness around a guide star. The measurement of the background brightness is important when we are oblidged to use faint stars as guide stars (see section 5).

The scan mode of our system is illustrated in figures 3, 4*a* and 4*b*. The instantaneous photocathod area scans along four axes in order of positive x, positive y, negative x, and, finially, negative y. The x and y axes are taken to be parallel to the right ascension circle and the declination circle, respectively. The amplitude of the scan is two times of the side, a, of the effective photocathod aperture. The output from the sensor when the deflecttion of the center of the instantaneous effective photocathod aperture is less than a is due to contributions from the star, from the sky, and from the dark emissions. On the other hand, when there is no star near the guiding star, the output from the sensor when the deflection is between a and $2a$ is due to contributions from the sky and from the dark emissions.

The scan is realized by a special sweep generator (Figure 1) which supply a wave current to the deflection coil attached to the image dissector. A digital circuit generates a digital wave, which is converted into a wave current by a D/A converter. The scan frequency is selected from among 15, 30, and 60 Hz. In addition to the wave current, a parallel four-bit-signal by which the phase of the scan can be distinguished is generated by the sweep generator at each instance when a period of the scan is devided into 16ths, as illustrated in figure 4*c*. This generator was provided by Kobayashi Seisakusho Co. Ltd. together with the assembly of the sensor part.

The photon counting method is applied for the measurement of the output of the image dissector, which is followed by a preamplifier, a linear amplifier and a discriminator (Figure 2) which are widely provided for use in nuclear experiments.

A pulse counter assembly, custom-made for this guider by Kokusai Data Kiki Co., Ltd., counts, accumlates, and storages the imput pulses from the discriminator. According to the phase signal from the sweep generator, this counter assembly accumlates the pulse numbers separately for six kinds of the phase intervals of the deflection of the effective photocathod aperture.

These six kinds of the phase intervals correspond to the ranges of $0 \leqq x \leqq a$, $-a \leqq x \leqq 0$, $a \leqq |x| \leqq 2a$, $0 \leqq y \leqq a$, $-a \leqq y \leqq 0$, and $a \leqq |y| \leqq 2a$, respectively, where x and y are the deflection of the center of the effective photocathod aperture. The numbers of pulses accumulated and stored in the corresponding six memories within a certain integration time are expressed as X_+, X_-, Z_X, Y_-, and Z_Y, respectively. Then, the error signals ε_x and ε_y are computed as

$$\varepsilon_x \equiv \frac{x_*}{(a/2)} = \frac{X_+ - X_-}{X_+ + X_- - Z_X}, \tag{1}$$

and

$$\varepsilon_y \equiv \frac{y_*}{(a/2)} = \frac{Y_+ - Y_-}{Y_+ + Y_- - Z_Y}, \tag{2}$$

where (x_*, y_*) is the coordinate of the position of the guide star, or the average guide errors during the integration time. These guide errors are transformed into the time intervals during which the telescope motors of fine motion should be drived in order to make ε_x and ε_y zero.

The control of the counter assembly, the computation of the error signals, and the control of the telescope motors are conducted by a microcomputer system supplied by Kokusai Data Kiki Co. Ltd.. The microprocessor used as the CPU in this system is of a type TI 8080A.

4. Broadening of Objective Prism Spectra

As is well known, the broadening of objective prism spectra demands skillful technique to an observer because of absence of a slit with which trace of poor guiding is covered in case of the observation with a spectrograph. Therefore, it is much advantageous to equip an autoguider for a Schmidt telescope with ability to broaden the objective prism spectra.

In principle, two kinds of methods for broadening may exist. One is to provide a guide-star image which moves linearly in the direction perpendicular to the dispersion of spectra. Usual autoguide with this moving guide-star will resultantly broaden the spectra. The movement might be realized by some preoptics and/or mechanics. The other method is to move linearly the sensor of an autoguider by some mechanical means. Autoguiders with the moving sensor produce broadening as well as above method.

A method which may belong to the former method has been successfully deviced for the Vatican Schmidt (Otten et al. 1978). In this system, the autoguide in the right assension is disabled for the first, and, then an offset of the telescope in the direction of the right ascension is caused by changing the rate of the sidereal drive for a short time interval. Thereafter, the sidereal drive rate is restored to the normal one, and, simultaneously, the autoguide is reactivated. By this method, spectra can be broaden when the dispersion is in the direction of the declination.

As for the latter method in case of the electronic scan by an image dissector, the mechanical movement of the sensor could be replaced by offset of the coordinate system of the scan by supplying a bias current which changes linearly with time to the deflection coil in addition to the current for the usual scan. In such a system, keeping the error signals zero broadens the spectra.

In our system, the offset of the coordinate system is realized by a software. The observer can take an optional routine which modifies the error signal as

$$\varepsilon_{x'} = \varepsilon_x + f(t)\cos\theta\,, \tag{3}$$

and

$$\varepsilon_{y'} = \varepsilon_y + f(t)\sin\theta\,, \tag{4}$$

where ε_x and ε_y are defined by (1) and (2), θ is the angle between x axis and the direction of the spectral broadening (Figure 5). The function $f(t)$ changes as a triangular wave with time t, and the peak-to-peak amplitude of the wave relates to the broadness of the spectra. Control of the telescope so as to keep the modified error signals zero causes a motion of the guide star along a line segment shown in figure 5. From this figure, one can easily

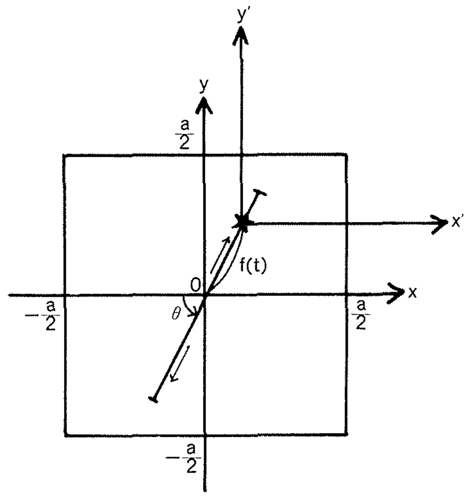


Fig. 5. The movement of the image of a guide star on the photocathod of the image dissector in case of broadening the objective prism spectra. The square shows the effective photocathod aperture at its neutral position.

find that the amplitude of the movement is limited within the size of the effective photocathod aperture.

The amplitude and the angle θ are set as parameters which should be input into the system by the observer. In practice, the broadness of the spectra on the plate are selectable among several steps from zero (no trail) to 0.2 mm. The angle θ can be taken an arbitrary value at 30° interval according to the position angle of the apex of the objective prism.

5. The Guider Performance

As discussed in section 2, the present guider is expected to operate with a guide star as faint as 9 mag in oder to avoid offset of the main telescope from a program field.

However, since the aperture of the objective lense of the guide telescope to which the guider sensor is attached is only 10 cm in diameter, the statistical fluctuation of the photon number is serious in measuring the guide error by using a faint star.

The inaccuracy of the error signal due to the photon statistics is estimated from equation (1) and (2). Let $S_\pm$ be the contributions from the guid star in $X_\pm$ (or $Y_\pm$) and D be that from the sky plus dark. Then, considering that the fluctuations of S and D are equal to $\sqrt{S}$ and $\sqrt{D}$, respectively, the theory of the propagation of error gives the standard deviation σ of ε in case that ε is nearly equal to zero, i.e., $S_+ = S_- = S$, as

$$\sigma^2 = \frac{S+D}{2S^2} . \tag{5}$$

In our system, the size of the effective photocathod aperture corresponds to 37″, while the most frequent image diameter at the Ouda Station seems 3″. Therefore, if the guiding is intended to be as accurate as one tenth of the image diameter, σ should be kept less than $0''.15/(37''/2)=0.008$. From this value, our system is so designed as $\sigma=0.01$.

Once the accuracy σ is set, the integration time required to smooth out the fluctuation of the photon number is estimated for a given magnitude of a guide star. Let s and d be pulse counts per unit time due to the star light and to the sky brightness plus the dark emission, respectively. Then, the integration time is related to these quantities as $S=s(\tau/8)$ and $D=d(\tau/8)$, since the phase intervals when the star and the sky are observed are one eighth of a period for one direction of the coordinate axis (see figure 4*a* and 4*b*). By introducing the above expressions of S and D into equation (5), we obtain

$$\tau=\frac{4(s+d)}{\sigma^2 s^2}\,. \tag{6}$$

The counting rate s is evaluated by the following equation:

$$s=k\pi\left(\frac{\phi}{2}\right)^2 10^{-0.4m_V} f(z)\int_0^\infty P(\lambda)Q(\lambda)d\lambda, \tag{7}$$

where ϕ is the diameter of the objective lense, m_V the visual magnitude of a guide star, $f(z)$ the air mass function. $P(\lambda)$ denotes the photon flux from a 0th mag star at wavelength λ through a clear unit air mass, and $Q(\lambda)$ is the quantum efficiency of the photocathod to produce a photoelectron by a single photon. The effect of various light loss due to the optical elements, the air polution and etc. is represented by a single numerical factor k.

Hereafter, we consider an A0 star as a representative since A type is the most frequent type among spectral types earlier than or equal to F (Allen 1973). Introducing $P(\lambda)$ for A0 type and $Q(\lambda)$ for S20 type, we obtain that

$$s\simeq k\cdot 3\times 10^{7-0.4m_V} f(z) \quad (\text{count}\cdot\text{sec}^{-1}). \tag{8}$$

The numerical factor k has been estimated to be equal to 0.2 or less by experiments in excellently transparent nights.

In the next place, the counting rate d should be estimated. As for the sky background brightness, we assume 10 times of the natural brightness (Allen 1973) since the city light from the Osaka Megalopolice affects seriously in the north west part of the sky at the Ouda Station. Thus, the pulse count rate is found to be $10^3 k$ or so over the effective photocathod aperture. As to the dark emissions, the rate is as small as 100 count·sec^{-1} according to the data sheet by the manufacturer. Therefore, d seems to be around 300 count·sec^{-1}.

Using the above data for equation (6), the integration time required to measure the guiding error with accuracy of 0.″3 for a 9th mag star at the zenith is found to be about 30 sec or longer when the atmosphere is clear. In practice, 60 sec or more is required to guide with a 9th mag star at an intermediate zenith distance where the atmospheric transparency is intermediate.

Unfortunately, however, there is a periodic tracking error in the sidereal drive of our telescope driving mechanics. This error is attributed to the worm gear. The amplitude is about 2″ and the period is 2 min. Therefore when a 9th mag star is used as a guide star, the guider system cannot completely compensate this periodic tracking error. In cases of practical observations, 7th or brighter stars are used at the present stage. The refinement of the driving mechanism is desired.

The performance of the autoguider is seen in figure 6, which shows two stellar images of a same star on a plate; one image was taken by operating the autoguider and the other by no guiding. The exposures of both images are 10 min. Figure 7 also illustrates the performance by representing the changes of the error signals with time on a chart recorder. In the case of this experiment, the guid star used was so bright that the integration time was taken as 1 sec. From this figure, the guide error is found to be about 0.″2, which is consistent to the accuracy originally intended.

Further, figure 8(a) demonstrates the stellar images trailed by the auto-

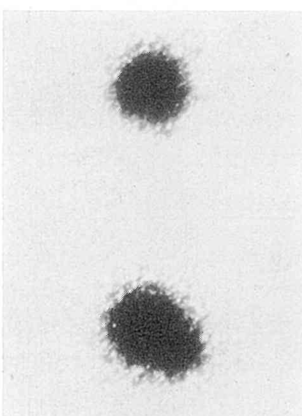


Fig. 6. The stellar images on a plate with the autoguide (the upper) and with no guide (the lower). The exposure times are 10 min for both.

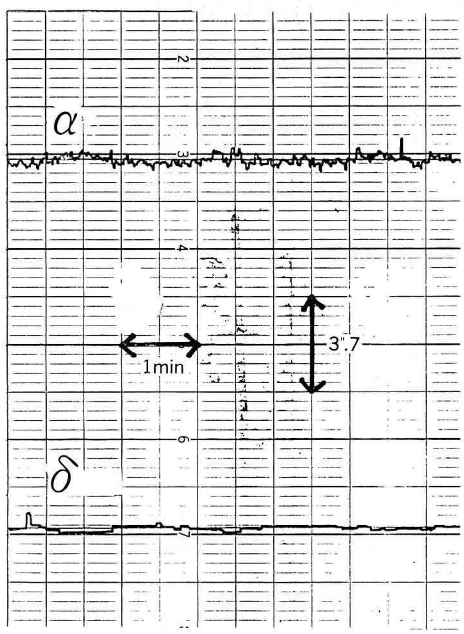
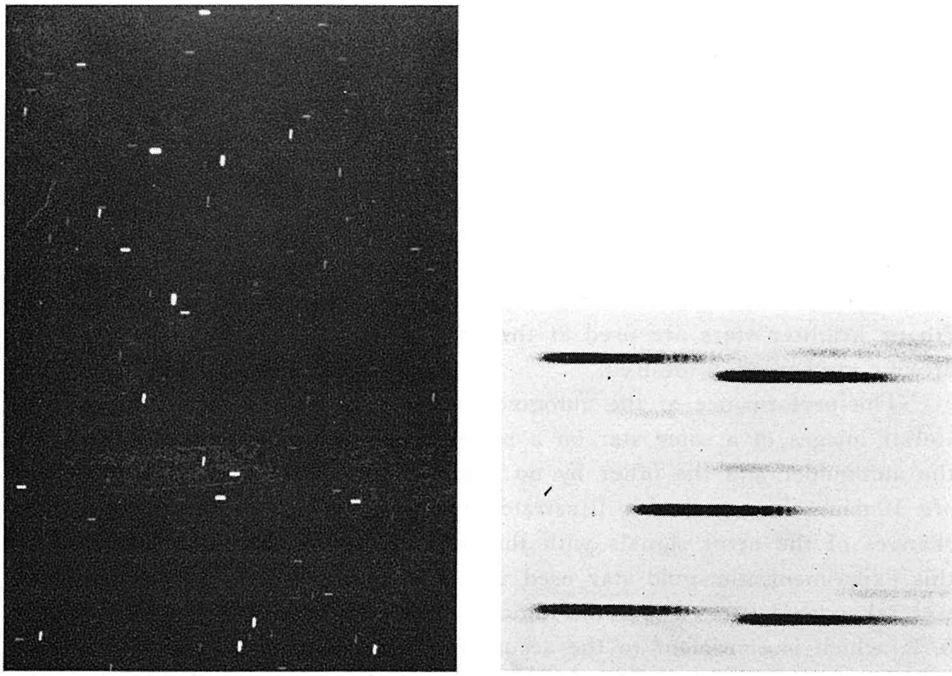


Fig. 7. Display of guiding errors on a chart recorder. The upper trace shows the errors in right assension and the lower is for the declination. The integration time is 1 sec.



(*a*) (*b*)

Fig. 8. (*a*) A photograph of stellar images trailed for spectral observation but without the objective prism. Two exposures with trails perpendicular each other are given on a plate.
(*b*) Spectra taken by autoguide. The width is 0.2 mm on the original plate.

guider but without the objective prism. On this plate, two experimental exposures were given which are orthogonal each other. In cases of spectral observations, the spectra with their dispersion perpendicular to the trails of the stellar images are broadened. Spectra taken by the autoguide are shown in figure 8(b).

6. The Operation of the System and its Auxiliary Functions

Except the acquisition of guide stars described in section 2, the guider is operated from the control switch pannel shown in figure 9. Numerical parameters necessary for individual observations, for example, the integration time and etc. are input from wheel switches. The start and stop of autoguide is controled by push switches.

The microprocessor introduced for this guider is used not only for autoguiding but also for other various auxiliary functions of the system (figure 2). Major functions of these are described in the followings.

(1) Keeping Times

A clock of Japan Standard Time generates a pulse at one second interval. The pulse interrupts the CPU to calculate the local sidereal time at the instance.

(2) Pointing the Telescope

The attitude of the telescope is sensed by two absolute encoders attached on the telescope axes. The one digit of the encorder corresponds to 6′. The telescope is pointed to a field whose central coordinate is input from the control pannel. The coordinates of program fields up to 99 can be registered prior to the observation of a night.

Pointing the telescope to the rest attitude at which the plate holder is loaded on or unloaded from the telescope is so programmed that the observer can drive the telescope without inputting the coordinate.

When the objective prism is attached to the telescope, the deflection of the direction of the telescope from the program field is automatically corrected according to the direction of the vertex of the prism.

Driving the telescope for pointing or resting can be made by pushing only one button on the control pannel.

(3) Monitering the Exposure

The CPU counts the exposure time and closes the camera shutter when the integrated exposure time becomes equal to the preset value which was input from the control pannel.

The camera shutter is also closed when the guide star becomes too faint by clouds for its position to be measured with the accuracy described in section 5. Further, the exposure is interrupted when the guide error becomes larger than a value which was input from the control pannel by the observer.

The observer has option to integrate the sky background brightness. In the case of this option, the dark emission is measured at every four integration time intervals by closing a shutter in front of the image dissector. When the integraded sky barkground brightness exceeds a preset value, the camera shutter is closed.

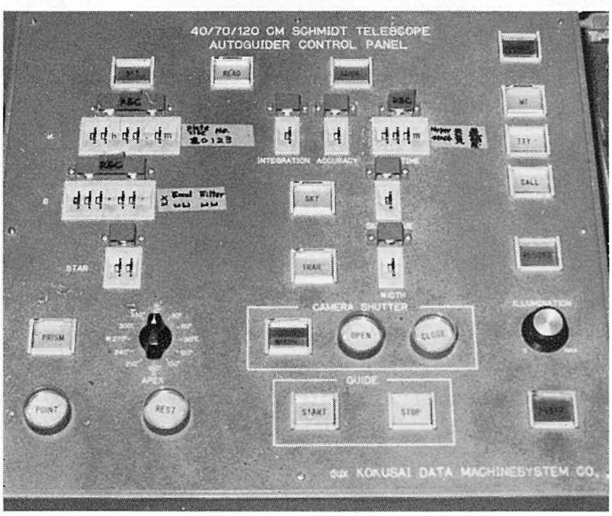


Fig. 9. The control switch pannel.

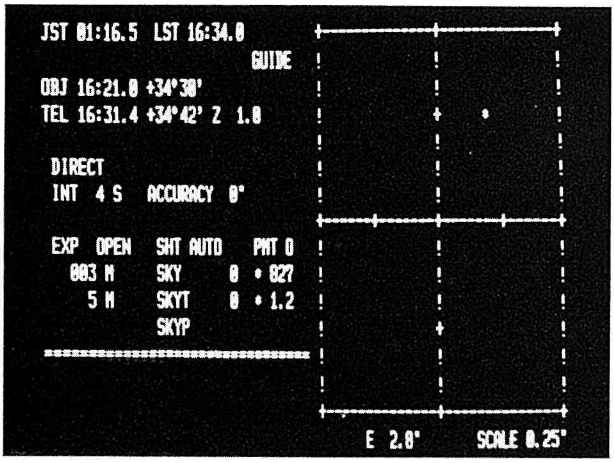


Fig. 10. The display on the CRT. Massages are shown in the lower left part below the double dashed lines.

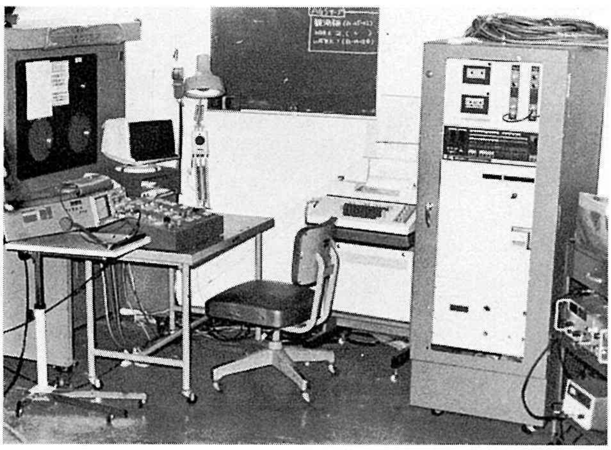


Fig. 11. The system components except for the guider head part.

(4) Display and Alarms

On two CRTs, various parameters of the observation are displayed (figure 10). On the left half areas of the CRTs are displayed the times, the attitude of the telescope, the exposure time, the status of the camera shutter and so on. The guide error is shown on a $\alpha\delta$-coordinate plane on the right halves of the CRTs. Tens messages to the observer are given on the CRTs to assist the operation of the system.

The CPU calls the observer's attention by a buzzer to a few affairs, i.e., finish of an exposure, unexpected interruption of an exposure, and dangerous attitudes of the telescope.

One CRT is set in the observing room together with other components of the system (figure 11). The other CRT is set in a neighbouring room, where the observer can monitor the status of the automatic observation. In this room, extensions of the buzzer and of the switches for closing the camera shutter and for the emergency stop of the telescope motion are also set.

(5) Recording the Observation Log

The log of the observation is recorded on a type writer and on a paper tape. Before the output, observational parameters which cannot be automatically sensed, i.e., the emulusion type, the filter name, the weather condition and etc., are input by the observer from the control pannel befor the output of the record.

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